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NEOM Regional Baseline & Monitoring Program

**Soil and Groundwater Survey Procedure**

Amec Foster Wheeler Energy and Partners Engineering Company – April 2021

Report for

NEOM

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# Introduction

## Preamble

Amec Foster Wheeler Energy and Partners Engineering Company (hereafter referred to as “Wood”) is pleased to provide this technical methodology to NEOM. This technical methodology outlines the proposed approach to the conduct of Soil and Groundwater survey within the NEOM development area, the scope of works to be performed including detailed information of the equipment to be used, references to international standards and best practices in the air quality sectors, a description of the equipment and deliverables.

## Project Background

Located in the northwest of Saudi Arabia on the Red Sea and Gulf of Aqaba coasts, NEOM spreads over an area of 26,500 km2 and encloses areas with a wide variety of activities and receptors. Very little information is currently available to characterize air quality condition in the region making necessary to collect primary data to support permit application for future developments.

As part of the NEOM Regional Baseline & Monitoring Program, NEOM required the development of a standard approach to the performance of soil and groundwater surveys ensuring that evaluations for different NEOM developments will be undertaken in a consistent manner and to a level that meets or exceeds international best practice.

This document has been developed to describe how the soil and groundwater survey should be executed, including:

* **Reference Standards** to ensure the proposed approach is robust and based on internationally accepted guidance.
* **Survey and Monitoring Methods** to provide a detail description of method to be adopted to deliver this task
* **Monitoring Equipment** description (AQMS, portable monitors and weather stations), including details of installation procedures, use and maintenance.

## Objectives of Soil and Groundwater Surveys

### Soil Quality Survey

Soil quality is the capacity to function within the ecosystem and land-use boundary to sustain biological productivity and maintain environmental quality. Furthermore, it plays a major role in any construction development plan.

The definition of soil quality aims to investigate in detail the quantitative and qualitative characteristics of the soil surface.

In the onshore and land sites, soil samples will be collected from the most representative stations and from different depths to detect the potential soil contamination.

The main purpose of collecting the soil samples is to establish the baseline conditions of the existing and planned construction sites as well as the variation in the physical landforms.

### Groundwater Conditions Survey

The main objective of the groundwater condition study is to develop a hydrogeological conceptualization understanding of the NEOM area. It will cover the characterization of the aquifer, the geometrical (area covered and thickness) characteristics of the aquifer, the qualitative and partially the quantitative characteristics by applying different (geological, geophysical, geochemical, geostatistical) methods, as follows:

**Geochemical analysis**: Statistical analysis will be applied to produce maps of the spatial distribution of the qualitative characteristics of the groundwater.

**Geophysical measurements**: Based on the geological maps, Electrical and Electromagnetic data will be collected to provide a detailed mapping and characterization (lithology, water level, water flow, tectonic and karstic zones, water saturation, transmissivity, hydraulic conductivity, indirectly qualitative information, etc.) of the groundwater.

**Geological, hydrogeological and tectonic study of the area under investigation**: The analysis will be performed using topographic maps, satellite images, and available literature. During the mapping, all possible point source contamination sites from the broader area will be traced (using mainly satellite images). All of the above will be imported to GIS and the correlation between the available data (water supply, water level, chemical analysis, hydrowell location, tectonic/geological structures) will be applied.

In addition, this document identifies Saudi Legislation, national / international standards and guidelines, and best practices applicable to the Soil quality and Groundwater conditions surveys activities.

# Reference Standards and Guideline

The Soil Quality and Groundwater Conditions Survey procedure has been prepared in accordance with provisions set by the applicable Saudi Legislation, national / international standards and guidelines, and best practices.

Until NEOM develops its regulations, laws, procedures and policies, the following national and international regulations will be applicable.

## National Governmental bodies and organizations

The main governmental bodies and organizations that enforce environmental legislation in Saudi Arabia are identified in the following Table.

Table ‎2.1 Main national governmental bodies and organizations

| Governmental Body / Organization | Main Functions |
| --- | --- |
| General Authority of Meteorology and Environmental Protection (GAMEP) | The GAMEP, formerly known as Presidency of Meteorology and Environment (PME), is the main institutional authority for the environmental affairs within the whole Kingdom, except for the industrial sites of Jubail, Yanbu, Jazan and Ras-AlKhair, where responsibility is delegated to the Royal Commission (RC). The GAMEP plays a prominent role in raising meteorological and environmental awareness among all members of Saudi society and reflecting the national perspective on dealing with the issues of the environment and meteorology. The GAMEP is responsible for preparing, issuing, and updating relevant environmental standards and for approving the environmental aspects of EIA studies. |
| Ministry of Energy, Industry and Mineral Resources | The Ministry of Energy, Industry and Mineral Resources, previously known as the Ministry of Petroleum and Mineral Resources, is primarily responsible for developing and implementing policies concerning oil, gas, and natural minerals. |
| Ministry of Environment, Water and Agriculture | The Ministry of Environment, Water and Agriculture (MEWA) is responsible for policies and regulations aimed at preserving the environment and natural resources, to achieve prosperity and sustainability of the environment, water, and agriculture. It is under MEWA’s responsibility to license the abstraction of groundwater and regulate the establishment of any wastewater treatment plant regarding public health and environmental aspects. The MEWA acts by directly engaging the private sector and the competent authorities. |
| Royal Commission (RC) for Jubail and Yanbu Environmental Protection and Control Department (EPCD) | The RC for Jubail and Yanbu is responsible for conducting pollution associated with the development and operation of industrial cities. The RC issued the Royal Commission Environmental Regulations (RCER) providing standards and guidelines to specifically control the following sections within the industrial cities: environmental regulatory system, penalties system, air environment, water environment, hazardous materials management, dredging, noise and reporting & record keeping. |

The Soil and Groundwater baseline will follow *The Environmental Protection Standards* promulgated by the Presidency for Meteorology and Environment [PME, 2002] (presently the GAMEP[[1]](#footnote-2)) and its predecessor, the Meteorology and Environmental Protection Administration [MEPA, 1982, 1988]. The objective of these requirements is to protect the ecological resources within the northern Arabian Gulf and the Saudi Red Sea from degradation attributable to exploration and development of petroleum resources.

## National Legislation and Regulations

The Soil and Groundwater surveys will be prepared in accordance with the national legislation and standard:

* Kingdom of Saudi Arabia - Presidency of Meteorology and Environment. General Environmental Regulations and Rules for Implementation. 28 Rajab 1422 H (15 October 2001).
* Kingdom of Saudi Arabia - Royal Commission for Jubail and Yanbu. Royal Commission Environmental Regulation 2015 - Volume I – II (and Appendix). Environmental Permit Program.

## Ratified Conventions

Saudi Arabia has ratified or is a signatory to several international agreements and conventions. Of possible relevance to the Soil quality and Groundwater conditions aspects is the following:

* the United Nations Convention on Desertification and the Montreal Protocol on the protection of ozone layers in the upper atmosphere.

## International standards and guidelines

The Soil quality and Groundwater conditions surveys will be prepared taking into account best practices, international standards, and guidelines, listed below:

*Soil sampling*

* NCSS (2012) Field Book for Describing and Sampling Soils National Soil Survey Center Natural Resources Conservation Service U.S. Department of Agriculture;
* ISO 22475-1:2006 (en) Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for execution;
* USEPA (2020) LSASDPROC-300-R4 – Soil Sampling Operating procedure. Region 4 U.S. EPA, Laboratory Service and Applied Science Division Athens, Georgia; and
* National Academies of Sciences, Engineering, and Medicine 2019. Manual on Subsurface Investigations. Washington, DC: The National Academies Press. https://doi.org/10.17226/25379.

*Groundwater sampling and testing*

* Environment Protection Authority State Government of Victoria (2000) GROUNDWATER SAMPLING GUIDELINES. ISBN 0 7306 7563 7;
* International Groundwater Resources Assessment Centre (IGRAC) (2008). IGRAC is an initiative of UNESCO and WMO. “Groundwater monitoring for general reference purposes”, International Working Group I – Utrecht, June 2006 Revised March 2008;
* ISO (2003) - Hydrometric determinations - Pumping tests for water wells - Considerations and guidelines for design, performance, and use. Int. standard, 14686, Geneva;
* Margane A. (2004) – Guideline for groundwater monitoring. BGR and ACSAD Technical Cooperation Project “Management, protection and sustainable use of groundwater and soil resources in the Arab Region”, 7, Damascus;
* National Water Quality Management Strategy (2000) Australian Guidelines for water quality monitoring and reporting. Conservation Council of Australia and New Zealand;
* USEPA (1991) - Handbook of suggested practices for the design and installation of ground-water monitoring wells. US-EPA, 160014-891034, Ed. by Aller L. T., Bennett W., Hackett G., Petty R. J., Lehr J. H., Sedoris H., Nielsen D.M. & Denne J. E. Las Vegas, Nevada;
* USEPA (1992) - RCRA Ground-Water Monitoring Draft Technical Guidance. U.S. EPA, Office of Solid Waste, Washington, D.C.; and
* UNESCO (1998) - Monitoring for Groundwater Management in (Semi-) Arid Regions. UNESCO, Studies and Reports in Hydrology, 57, Ed. by Henny Dr. Ir & van Lanen A. J., Paris.

*Environmental investigation*

* USEPA (1996) – Environmental Investigation Standard Operating Procedures and Quality Assurance Manual. U.S. Environmental Protection Agency Region 4 Georgia;
* ASTM E1903-97\_03-25-2010 1997. Standard Guide for Environmental Site Assessments: Phase II Environmental Site Assessment Process (Reapproved 2002);
* ASTM-E1903-11-Phase-II-ESA 2011. Standard Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process;
* ASTM E1527–05 - Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process;
* CCME (2016) Guidance Manual for Environmental site characterization in support of environmental and human health risk assessment – Volume 3 Suggested operating procedures. Canadian Council of Ministers of the Environment.

*Additional guidelines*

* IFC (International Finance Corporation of World Bank Group) General EHS Guidelines; and
* IFC EHS Guidelines for Petroleum Refining, Large Volume Petroleum-based Organic Chemicals Manufacturing and Petroleum-based Polymers Manufacturing.

# Monitoring Equipment

This Section provides a description of different methodologies potentially applicable for the field activities to be carried out as part of the herein described Soil quality and Groundwater conditions surveys.

Field activities will include:

* Site location and preparation;
* Soil sampling;
* Installation of monitoring wells;
* Groundwater Level Measurements and Hydrogeological Tests;
* Groundwater sampling; and
* Geophysical surveys (Electrical and Electromagnetic).

## Site Location and Preparation

Soil and groundwater investigation activities will be planned, staged, and conducted in accordance with the established purpose, scope of work and evolving geological - hydrogeological model.

Prior to the start of soil and groundwater survey, preparatory activities will be undertaken including:

* A desktop review of available literature, including maps, reports, etc;
* A preliminary site walk-over, to assess site and environmental constraints, traffic management requirements, underground / overhead services and other workplace health and safety issues, AND
* If needed, geophysical surveys (Ground Penetrating Radar – GPR or Cable Avoidance Tool - CAT) or trial pits to safely locate drilling points.

### Cable Avoidance Tool and Ground Penetrating Radar

To safely locate drilling points a geophysical survey may be carried out using:

* Cable Avoidance Tool (CAT). The CAT can be used to locate cables on groundwork, excavation, and construction sites so that they could be avoided. The CAT can detect the signals that radiate naturally from metallic services; it can work in combination with a Genny that utilises a unique signal that the CAT can detect.
* Ground-penetrating radar (GPR). GPR uses energy waves in the microwave band, ranging in frequency from 1 to 1000 MHz. The transmitter sends electromagnetic energy into the soil and other material. Ground Penetrating Radar works by emitting a pulse into the ground and recording the echoes that result from subsurface objects. The GPR sections will be developed according to an acquisition grid with a regular mesh of orthogonal lines. The survey area will be defined based on the characteristics of the site.

The definition of which type of survey is needed will be made during the preliminary site walk-over, based on the location of the investigation points and site characteristics.

Figure ‎3.1 Example of CAT (on the left) and GPR (on the right)

Graphical user interface

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### Trial Pits

If needed, trail pits down to approximately 1 meter below ground level will be excavated to verify the absence of buried structures / lines / utilities at the investigation points. Trial pits will be realized by hand-digging or with excavating equipment such as a backhoe.

Trial pits could also be used to collect soil samples for laboratory analysis.

The Occupational Safety and Health Administration (OSHA) prohibits personnel to enter into a trial pit extending more than 5 ft (1.5 m) below ground level or within any pit displaying evidence of instability, without proper sheeting and bracing.

Once verified the absence of structures / lines / utilities, the trial pit will be properly backfilled according to standard practices for compacted fill. This will prevent possible issues later with subsidence or settlement problems due to improperly placed fill materials.

## Soil Sampling

The sample location and numbers will be selected based on available satellite images and visual reconnaissance survey to cover all soil types and the existing physiographic features.

The sampling activities may include the collection of composite soil samples that are samples obtained by combining several subsamples from the same area to represent the average concentrations of the area and volume of material over which the combined discrete samples were taken.

Composite sampling should never be conducted where volatile or semi-volatile analyses are required, as the compositing process can result in losses of volatile constituents.

Simple manual exploratory probing and representative sampling techniques are used as preliminary or supplementary measures to determine basic ground characteristics, typically of near-surface soils. Hand probes are made to obtain reconnaissance information concerning the thickness and lateral extent of soft, compressible organic soils. Small-diameter, flush-coupled, steel rods are pushed into the ground by hand to refusal in the underlying inorganic soil.

There are also a variety of hand augers and digging tools available to collect representative samples of the near-surface soil conditions. Various sizes and styles of cutter heads are available, and extensions may be added for greater penetration depths. Small gasoline-engine-powered hand augers will increase the depth of penetration and decrease the difficulty of performing the work.

The next paragraphs describe two typologies of samplers that could be used as part of the Soil quality survey as well as the procedures that will be adopted for collecting samples.

### Samplers

Depending on the specific characteristics of the site, sampling will be performed using:

* Spoons; or
* Hand augers.

### Spoons

Stainless steel or non-metallic spoons may be used for surface soil sampling below ground surface where conditions are generally soft and non-indurated, and there is no problematic vegetative layer to penetrate. In case of using of stainless-steel spoons, consideration will be given to the procedure used to collect the volatile organic compound sample.

If the soil being sampled is cohesive and holds its in situ texture in the spoon, syringe used to collect the sub-sample should be plugged directly from the spoon. If, however, the soil is not cohesive and crumbles when removed from the ground surface for sampling, consideration should be given to plugging the sample directly from the ground surface at a depth appropriate for the investigation Data Quality Objectives.

Figure ‎3.2 Example of Stainless-steel spoons

### Hand Augers

Hand augers may be used to advance boreholes and collect soil samples in the surface and shallow subsurface intervals. The bucket will be advanced by simultaneously pushing and turning using an attached handle with extensions (if needed).

Hand augers are the most common equipment used to collect shallow subsurface soil samples. Auger holes are advanced one bucket at a time until the sample depth is achieved. When the sample depth is reached, the bucket used to advance the hole is removed and a clean bucket is attached. The clean auger bucket is then placed in the hole and filled with soil to make up the sample and removed.

The practical depth of investigation using a hand auger will depend upon the soil properties and depth of investigation. In sand, augering is usually easily performed, but the depth of collection is limited to the depth at which the sand begins to flow or collapse. Hand augers may also be of limited use in tight clays or cemented sands. In these soil types, the greater the depth attempted, the more difficult it is to recover a sample due to increased friction and torqueing of the hand auger extensions.

Because of the tendency for the auger bucket to scrape material from the sides of the auger hole while being extracted, the top several inches of soil in the auger bucket will be discarded prior to placing the bucket contents in the homogenization container for processing.

Figure ‎3.3 Examples of Hand Augers

### Soil Sampling Procedure

The below procedure will be implemented for the collection of soil samples.

* Sampling equipment will be located at an appropriate, accessible, and clean location;
* Plastic sheeting will be used to protect equipment from dirt or other contaminants;
* The cleanliness of sample sites will be considered to avoid any potential contamination;
* The field monitoring equipment will be checked;
* Decontamination materials and equipment will be prepared, as necessary;
* A reference book or sampling sheets will be prepared to document sample collection, observations and results of field screening;
* Where the soil sample is taken from an apparatus (for example, a shovel, a split spoon sampler, a bucket, etc.), the sample will be collected from an area which has not been in contact with the apparatus, to avoid potential cross-contamination;
* For each sampling point, the location (area, depth), the composition of the soil sample (soil type, colour, moisture, density, etc), and any unusual features (staining, odours, waste materials, construction debris or other non-native constituents) will be documented. Also, field notes (including the photographing of the sample and sample location) will be compiled; and
* At the end of each day, consistency between collected samples and samples logged on the Chain-of-Custody form(s) will be verified.

### Analytical Protocol

Samples for soil quality will be collected to characterize the physical properties and determine the contaminants of metals, nutrients, hydrocarbons, and pesticides in the soil. Samples will be collected at seventy monitoring wells distributed across the development sites.

The parameters of soil chemistry will be crustal and toxic trace metals, e.g., aluminum, arsenic, barium, cadmium, copper, iron, lead, manganese, mercury, nickel, zinc and organics, e.g., polycyclic aromatic hydrocarbons (PAH) and total organic carbons (TOC). The list of parameters and techniques with the reference methods are provided in the below.

Table ‎3.1 Parameters and analytical methods for soil characterization study

| **Parameters** | **Techniques** | **Reference Method** |
| --- | --- | --- |
| **Physical** | | |
| Nature of sediments and Particle size | Grain size analysis | Sieving and Pipette Analysis [2000] [[http://pubs.usgs.gov/of/2000/of00-](http://pubs.usgs.gov/of/2000/of00-)358/text/chapter1.htm] |
| **Chemical** | | |
| Polycyclic Aromatic  Hydrocarbon | GC Agilent 6890N, MS | EPA 3545 & 8270 |
| TOC | Combustion and NDIR  analysis | US EPA 9060 A |
| Aluminum | Digestion and Analysis | USEPA 3050 & 6010 |
| Arsenic | Digestion and Analysis | USEPA 3050 & 6010 |
| Boron | Digestion and Analysis | USEPA 3050 & 6010 |
| Cadmium | Digestion and Analysis | USEPA 3050 & 6010 |
| Copper | Digestion and Analysis | USEPA 3050 & 6010 |
| Chromium | Digestion and Analysis | USEPA 3050 & 6010 |
| Iron | Digestion and Analysis | USEPA 3050 & 6010 |
| Lead | Digestion and Analysis | USEPA 3050 & 6010 |
| Manganese | Digestion and Analysis | USEPA 3050 & 6010 |
| Mercury | Direct Combustion AAS  analysis | USEPA 7473 |
| Nickel | Digestion and Analysis | USEPA 3050 & 6010 |
| Vanadium | Digestion and Analysis | USEPA 3050 & 6010 |
| Zinc | Digestion and Analysis | USEPA 3050 & 6010 |
| Soil microbial biomass | Chloroform fumigation extraction (CFE) | Brookes et al. (1985) |
| Subterranean soil invertebrates | Microscopic identification by morphology and enumeration | Swift and Bignell (2001) |

Additional details regarding the analytical protocol and the standards for preparation and analytical methods, can be found in the document developed by Wood-KFUPM[[2]](#footnote-3).

## Installation of Monitoring Wells

Groundwater condition survey will be completed using monitoring wells (MWs) to be installed across the development areas for:

* Groundwater sampling for ex situ analysis;
* Monitoring and/or profiling in situ groundwater parameters;
* Monitoring of groundwater level fluctuations, and
* Aquifer testing.

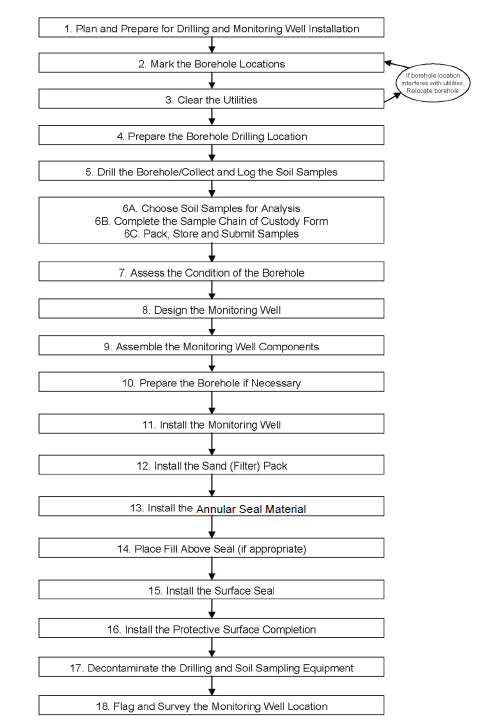
The location of the monitoring wells will be defined considering the following elements:

* The site shall be accessible for the rig and the support vehicles;
* The site should be clear of overhead electric cables, underground cables/ pipelines/ drainage lines, etc;
* The site shall be accessible for observers in all seasons and can be reasonably safeguarded against vandalism;
* Adequate space shall be available at the site for setting up drilling equipment;
* Installing the well does not cause damage to environmentally sensitive sites;
* Monitoring wells will be placed in locations where they are not likely to be disturbed by construction; and
* Locations of monitoring wells will be selected to complement the boreholes drilled during other NEOM surveys.

The number of monitoring wells to be installed at each of the survey areas will be defined based on recognized environmental characteristics and the type of development activities foreseen.

The Figure ‎3.4 below illustrates the defines the various steps necessary for the realization and installation of a monitoring well.

Figure ‎3.4 Groundwater monitoring wells installation steps[[3]](#footnote-4)



### Drilling

Drilling and installation of monitoring wells will follow (international) acknowledged practices. For the monitoring wells to be installed, the most suitable drilling method will be defined based on the rock types expected and the well functions required. Following are described the potential drilling techniques based on the type of material:

* Unconsolidated rocks: All Rotary drilling methods; cable-tool drilling; driven wells (rammed filters or direct-push wells); or
* Consolidated rocks: Direct-Rotary drilling; cable-tool drilling; down-the-hole hammering.

Figure ‎3.5 Rotary drilling techniques in comparison with other boreholes methods (Source Paul Mayne) and drilling rig and hallow stem

Diagram

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Certain drilling techniques can cause smearing (for example, rotary auger) or compaction (cable tool) of borehole walls and may also promote transport of geological formation materials and drilling fluids into different aquifer zones. In a worst-case scenario, this can result in almost complete blockage of the well screen resulting and in non-representative groundwater samples when the boreholes are monitored.

For this reason, the choice of the best drilling technique can be made according to the area of intervention and the specific site feature. In general, it is planned to carry out drilling activities by means of rotary drilling methods as they are very well suited for drilling such pilot holes and subsequent boring, due to the flexibility in drilling with different types and bit sizes.

All drilling and installation activities of the piezometers will be carried out by suitably trained technical personnel.

The drilling diameter will be defined according to the litho-stratigraphic characteristics for each well but will be suitable for the subsequent installation of the 100 mm / 50 mm well casing, as recommended by RC.

During the drilling activities lubricant use will be minimised and restricted to degradable or inert lubricants, such as vegetable oil or PTFE (Teflon) based, and in any case always agreed.

A borehole log will be completed to clearly identifying the subsurface geology encountered as the borehole is advanced. The log will identify the presence of potentially contaminated soils. The borehole log will identify the final borehole depth in meters, as well as the depth to groundwater when initially encountered.

### Groundwater Monitoring Well Installation

As indicated by the Royal Commission (*Royal Commission Environmental Regulation 2015 - Volume I – II (and Appendix)*. Environmental Permit Program), the groundwater monitoring wells will have a minimum internal diameter of 100 mm (4 inch) or 50 mm (2 inch) and consist of Schedule 40 PVC (polyvinyl chloride), flush joint threaded; be new and visually clean.

All PVC used will conform to ASTM F-480[[4]](#footnote-5). The use of solvents, glues or rubber sealants will be prohibited.

The groundwater monitoring well will consist of a casing (blind section), and well screens. The well screen will be installed at an elevation to straddle the water table (to allow for the rise and fall of the water table).

Once the PVC pipe including the screen and blank sections are installed, the silica sand filter is packed around the well screen to at least two (2) feet above the screen taking care that uniform packing is achieved. This acts as a sand filter to allow the ingress of groundwater into the monitoring well while restricting unwanted sediments etc. The silica sand (or similar material) will have a consistent grain size with a uniformity coefficient of less than 2.5 or less. The grain size shall be selected to filter out fines present in the geological formation and will typically be within 0.7mm – 1.25mm.

Centralizer may be used to keep (non-prepacked) screens in the centre of the borehole.

Bentonite chips follow, forming a clay (impervious) seal to prevent ingress of surface water which may contaminate the underlying ground water and monitoring samples.

The Bentonite chips will be untreated, pellet form, premium grade, sodium bentonite. The thickness of the bentonite seal will be no less than 600 mm. The remaining area around the blind PVC section (annular space) is packed with cement Bentonite grout annular seal.

To easily identify installed monitoring wells, a tag or plate will be attached to the housing with identification markings. The installation of crash barriers will be optional however is recommended in areas where there the potential for damage by vehicular movement etc.

The well casing and screen material should meet the following requirements:

* The materials will maintain their structural integrity and durability in the environment in which they are used over the entire operating life time;
* They will be resistant to chemical and microbiological corrosion and degradation in contaminated and uncontaminated groundwater;
* They will be able to withstand the physical forces acting upon them during and following their installation, and during their use;
* They will not chemically alter groundwater samples; and
* They will be easy to install during the construction and the material itself or its stability (tensile strength, compressive strength, and collapse strength) will not alter after installation.

Following Figure ‎3.6 illustrates the monitoring well characteristics.

Figure ‎3.6 Design Diagram of a Typical Groundwater Monitoring Well[[5]](#footnote-6)

Diagram

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### Development of Monitoring Wells

The aim of well development is to test the required functionality of the monitoring well. Well cleaning and development can be regarded as one of the most crucial elements of well installation, especially if rotary drilling has been applied.

All bores intended for monitoring water quality will be developed after drilling to remove fine sand, silt, clay and any drilling mud residues from around the well screen to ensure the hydraulic functioning of the well. Development should be carried out as soon as possible after drilling and installation, however, a minimum of 24 hours will be allowed for bentonite chips to fully hydrate and grout to cure (harden and set).

Development will continue until a defined endpoint has been reached, such as:

* chemical indicator stability - using field measuring techniques for pH, EC and dissolved oxygen, development is continued until these parameters stabilise in abstracted water; or
* reduced turbidity - development is continued until the abstracted water is reasonably clear and free of suspended solids.

The following methods may be used for well development:

* Mechanical surging;
* Air lift pumping;
* Pumping and backwashing,
* High-velocity hydraulic jetting, or
* High-velocity hydraulic jetting combined with simultaneous pumping.

## Groundwater Level Measurements and Hydrogeological Test

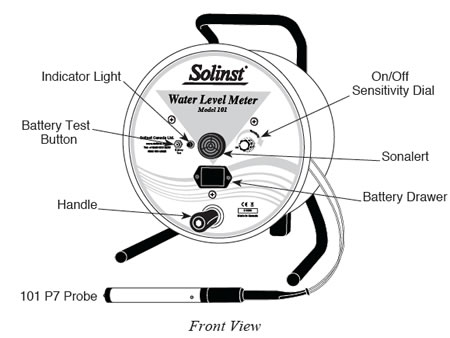
### Groundwater Level Measurements

Groundwater levels are measured and reported following well development and once the water level in the monitoring wells has stabilized. This typically occurs within one to several days after installation. In fine textured soils it may take groundwater levels several weeks or months to stabilize. In coarse textured materials, groundwater levels can stabilize within minutes.

Groundwater levels in monitoring wells will be measured using a water level sounder or interface probe. The measurements must always be made from a known fixed reference point, typically the top of the well casing. The sounding tape will be rinsed with distilled or demineralized water before and after each measurement.

Groundwater measurements in wells will be representative for the actual regional state of groundwater in the aquifer. Data collections will be organized on the basis of forms, graphs or other formats.

Figure ‎3.7 Example of water level sounder or interface probe



### Hydrogeological Test

Two parameters define the quantitative hydrogeological properties of an aquifer, namely permeability and storage:

* Permeability is concerned with the ability of an aquifer to permit groundwater flow under a hydraulic gradient; and
* Storage concerns the volume of water available within the aquifer and subsequently released when water levels are depressed around a discharging well.

Together these two parameters can be taken to control the response time for pumping effects in an aquifer. For this reason, where needed, in order to deepen the hydrogeological knowledge of the survey area, a series of hydrogeological tests will be carried out, which could include:

* Preliminary test to verify extractable rates and set the equipment/meters;
* Step Draw-Down test;
* Constant-rate test;
* Constant-discharge test; and
* Recovery test.

### Preliminary Test

The equipment preliminary test provides a check that the pumping equipment, discharge-measuring devices and water level measuring instruments are functioning satisfactorily, and that all the equipment is in a safe condition with all safety devices fully functional. It will also provide sufficient data for planning the tests, including data with which to determine appropriate values for valve settings for subsequent pumping tests.

### Step Draw-Down Test

The purpose of a step test is to establish short-term yield-drawdown relationships and thereby define those elements of head loss attributable to laminar flow (Darcian conditions) and other components of head loss such as those attributable to turbulent flow. The step test comprises pumping the well in a series of steps, each of which is at a different discharge rate. At least four steps are advisable, and the final discharge rate will approach the estimated maximum yield of the well. If the latter cannot be attained, then the maximum capacity of the pump will be substituted. Care will be taken to avoid excessive drawdown as this could result in the pump running dry and so being damaged.

The steps may be taken consecutively, the pumping rate being changed at the end of each step, or intermittently, pumping being stopped after each step to permit groundwater levels to recover before commencing the next step. In consecutive steps, the pumping rate will be either increased in equal increments from the first to the last step or decreased in equal decrements from the first to the last step.

The latter is less usual. In intermittent steps, the pumping rate will be changed at random, the resultant data being analysed as a series of discrete tests.

Normally, each of the steps should be of equal duration. It is rarely necessary for each step to last for more than 2 hours but it is often convenient, both operationally and for plotting graphs, etc., for each step to last at least 100 min.

Where observation wells are present, groundwater-level measurements will be taken in them in addition to the pumping well. Observation wells are not necessary in the analysis of well performance but some indication will be given of the range of groundwater-level fluctuation that will be produced in a test of longer duration.

### Constant-discharge Test

Constant-discharge tests are carried out by pumping at a constant rate for a period of time dictated by the discharge rate and the local hydrogeological conditions. The purpose of a constant-discharge test is to obtain data on the hydraulic characteristics of an aquifer and aquitard within the radius of influence of the pumped well.

Observation wells are necessary to determine fully the aquifer properties. Longer tests would be required for example to adequately assess the influence of boundaries. The effect of a recharge boundary is a deceleration in the rate of drawdown. Where the recharge source is a specific feature, such as a watercourse or a lake, the time that elapses before the onset of this deceleration will increase in proportion to the square of the distance between the pumping well and the recharge source. Eventually, drawdown will stabilize for the remainder of the test. If a delayed-yield effect occurs, the development of the time-drawdown relationship will be delayed.

It is not possible to estimate accurately in advance the length of this delay unless it has occurred in nearby wells previously tested in the same aquifer. If a delayed yield is expected, an extension of the duration of the test should be considered.

### Constant-drawdown Test

A constant-drawdown test will have the same purpose as a constant-discharge test. In theory, constant drawdown tests can be performed upon any aquifer, providing that a pump with a variable discharge rate can be controlled in such a manner as to keep the drawdown to a particular constant amount. If the groundwater rest level is not expected to vary during the test period, then the constant drawdown is at a constant level, otherwise it is essential that the levels in control observation wells be used to estimate the pumping level needed to maintain constant drawdown.

Constant-drawdown tests are used for tests with suction pumps, for the design of dewatering schemes, for overflowing wells, for tests in piezometers and for tests using over-capacity pumps.

In a well that is not overflowing, the test should be carried out in the same manner as a constant-discharge test, except that the discharge rate must be controlled so as to keep the drawdown constant. Particularly accurate measurement of the discharge rate is necessary.

In a well that is overflowing, no pumping is necessary. The procedure is to shut off the flow at the wellhead, and then to measure the head of water thus contained. The well is then uncapped as near instantaneously as possible, thus reducing the head to near wellhead level. The discharge rate is then measured at the frequency recommended for a constant discharge rate. The advantage of this type of test is that no pumping plant is required. Estimates for transmissivity, and crude estimates of the storage coefficient, can be made without use of observation wells but such estimates are no more valid than similar estimates made without observation wells during conventional pumping tests.

### Recovery test

The recovery test can be carried out upon any aquifer after a constant-discharge test or a variable-discharge test. The recovery test requires careful measurement of the duration and rate of pumped discharge prior to the discharge ceasing. The recovery test can form a useful check on values of transmissivity derived from a discharge test. The specific yield or storage coefficient may be determined less accurately by this means. In the case of an unconfined aquifer, this is largely due to the incomplete resaturation of the interstices within the unconfined aquifer dewatered during the test.

A recovery test dependent upon water levels measured in the test well may only be performed if a foot valve has been fitted to the rising main. This is because, in the absence of such a valve, there tends to be a rapid rise in water level as water surges in from the rising main and perhaps also from the weir tank if used. A recovery test may be performed using only water-level data obtained from observation wells if the rising main in the test well is not fitted with a foot valve. Observations should be made for a period at least as long as the pumping test itself.

## Groundwater Sampling

One groundwater sample will be collected from each of the monitoring wells and then subjected to the required chemical analysis.

The purpose of groundwater sampling is to retrieve a water sample that represents the characteristics of water below the ground surface. To obtain a true representative sample, it is necessary to remove the stagnant water from the groundwater well casing before a sample is taken; this is called purging.

Following are described the sampling methodology that can be used during the groundwater sampling.

### Sampling Methodology

The following procedure described by the RC (*Royal Commission Environmental Regulation 2015 - Volume I – II (and Appendix)*. Environmental Permit Program), will be applied during groundwater sampling:

* Lower the measuring device into the groundwater well until it hits the water and gives a beep;
* Measure the depth from tape to the top of the well casing;
* Subtract the height of the casing above the ground level from the measurement;
* Lower the tape to the bottom of the well to get depth of the water column. Use above measurements to get height of the water column in the well (used to calculate purging) with reference to top of casing;
* The probe will give a different signal if product on the water is detected determine thickness of the product using the probe and log the thickness found;
* Record the result as water level (in meters bgs) with the date of the measurement on the groundwater monitoring sampling record;
* Use a plastic ground sheet to keep equipment clear of contact with the ground. Place a meter and half square of heavy duty polyethylene on the ground where the sampling equipment is kept to prevent contact with the soil. Replace for every well; and
* Wash the measuring device thoroughly according to the decontamination procedure before using it again to prevent contamination.

Depending on the amount of water present in the monitoring well, the purging and sampling activities can be performed using:

* A Bailer: A groundwater well can be purged using a bailer, only when a reasonably small volume of water is to be removed, typically used when there is little or very slow recharge of the well during purging, or with a short water column in a two inch diameter well. A bailer is a simple mechanical device that can used to draw water from the groundwater well. It consists of some form of tubing with a one-way check valve at the bottom. When the bailer is lowered into the groundwater well casing below the water level, it fills with water. The check valve closes once the bailer containing the water sample is lifted to the surface. Bailers come in various types (polyethylene, Teflon, stainless steel, acrylic), lengths (from 30 cm to 180 cm), widths (19 mm to 90 mm) and with numerous features like weighted, unweighted, single check-valve, double check valve, controlled flow bottom, etc.; or
* Pump: The most efficient purging of the well prior to sampling is accomplished using a pump. Small electric pumps in plastic housings that operate from a 12-volt battery are the most convenient pumps to use for groundwater purging and sampling. There are several types of submersible, battery operated, pumps available, which have slightly different options such as variable flow rate and ability to pump to a certain depth. The overall length of the pump should be around 25cm to allow for ease of cleaning. The pump should be able to push out water from a depth of around 7.6 meters or more. If the well continually runs dry during purging, note the length of time needed to recharge. If more than two hours to recharge, see directions under Sampling.

Figure ‎3.8 Example of bailer and pump system

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### Analytical Protocol

Groundwater samples will be collected from each monitoring well and analyzed for ions, metals, microbial, nutrients, hydrocarbon suite and pesticide suite.

In situ parameters such as temperature, salinity, DO, pH, TDS, specific conductivity, and turbidity will be measured using standard methods and calibrated equipment.

For ex-situ parameter analysis, water samples will be collected from the monitoring wells and transferred to appropriate sampling bottles required for the estimation of nutrients (ammonia, nitrate, nitrite and phosphate), sulphide, cyanide and trace metals.

Some parameters, including sulphide and cyanide will be carried out on-site. Water samples for nutrients and remaining contaminants will be transported to Laboratory in frozen conditions for analyzes in the labs. The ground samples will be preserved as per the nature of the analytes to be measured in CEW-RI laboratories.

The list of parameters and techniques with the reference methods are provided in the below Table 4.

Table ‎3.2 Physical and chemical parameters to be measured for groundwater with details on the applied techniques and reference methods

|  |  |  |
| --- | --- | --- |
| **PARAMETERS** | **TECHNIQUES** | **METHOD** |
| **PHYSICAL** | | |
| Temperature | Digital Thermometer (YSI) | YSI EXO2 Multiparameter Sonde  (Xylem, USA) |
| pH | Potentiometer | YSI EXO2 Multiparameter Sonde  (Xylem, USA) |
| Turbidity | Nephelometry | YSI EXO2 Multiparameter Sonde  (Xylem, USA) |
| Total dissolved solids | Conductometric method | YSI EXO2 Multiparameter Sonde  (Xylem, USA) |
| Electrical conductivity | Conductometric method | YSI EXO2 Multiparameter Sonde  (Xylem, USA) |
| Dissolve Oxygen | Potentiometer | YSI EXO2 Multiparameter Sonde  (Xylem, USA) |
| Alkalinity | Potentiometric titration | APHA (1995) – 2320 B |
| **CHEMICAL** | | |
| Ammonia Free (as N) | Flow Injection Analysis (SYSTEA) | ISO 11732:1997 |
| Barium | ICP-MS | US EPA 200.8 |
| Cadmium | ICP-MS | US EPA 200.8 |
| Calcium | ICP-MS | US EPA 200.8 |
| Chloride | Ion chromatogram | US EPA 300.1 |
| Chromium | ICP-MS | US EPA 200.8 |
| Copper | ICP-MS | US EPA 200.8 |
| Cyanide | Ion Selective Electrode | APHA 4500-CN-F |
| Fluoride | Ion chromatogram | US EPA 300.1 |
| Iron | ICP-MS | US EPA 200.8 |
| Lead | ICP-MS | US EPA 200.8 |
| Magnesium | ICP-MS | US EPA 200.8 |
| Mercury | Direct Combustion AAS | US EPA 7473 |
| Nickel | ICP-MS | US EPA 200.8 |
| Nitrite-N | Segmented Flow Analysis (SKALAR) | APHA-4500-NO2-B |
| Nitrate-N | Segmented Flow Analysis (SKALAR) | APHA-4500-NO3-I |
| Phosphate - total | Segmented Flow Analysis (SKALAR) | APHA-4500-P |
| Potassium | ICP-MS | US EPA 200.8 |
| Sodium | ICP-MS | US EPA 200.8 |
| Strontium | ICP-MS | US EPA 200.8 |
| Sulphate | Ion chromatogram | US EPA 300.1 |
| Sulphide | Ion Selective Electrode | APHA 4500-S2--G |
| Zinc | ICP-MS | US EPA 200.8 |

Additional details regarding the analytical protocol and the standards for preparation and analytical methods, can be found in the document developed by Wood-KFUPM[[6]](#footnote-7).

## Geophysical Surveys

Geophysical investigations are used to estimate the physical properties of the subsurface by measuring, analyzing, and interpreting electrical, electromagnetic, and magnetic fields measured at the ground surface or within boreholes.

Compared to more traditional forms of subsurface exploration (i.e., borings and soundings), geophysical methods offer several advantages (Wightman et al. 2003, Anderson et al. 2008, AASHTO 2017):

* Because surface geophysical methods are non-invasive, they provide the ability to cover a large area in a time- and cost-effective manner to gain an understanding of the overall subsurface conditions. As noted above, this enables optimizing the locations of borings and soundings during subsequent phases of a subsurface exploration program or interpolating between existing borings and soundings.
* Geophysical methods are robust in the sense that they are based on fundamental physical principles with relatively little reliance on empiricism; and
* Surface geophysical methods are also useful for sites where borings and soundings are difficult or impractical, such as gravel deposits or contaminated soils. The equipment used for many geophysical tests is highly portable, which may allow testing at sites that are not easily accessible using conventional drilling equipment.

As part of the herein described activities, the following geophysical surveys will be performed:

* Electromagnetic survey; and
* Vertical Electrical Sounding (VES).

Aim of geophysical survey is to investigate in detail the quantitative and qualitative characteristics of the groundwater in the study area and finally to identify the components of an optimal management plan for the study of the groundwater.

### Electromagnetic Survey

Electromagnetic geophysical methods use the flow of electrical currents through the ground to evaluate subsurface characteristics. Electrical (or galvanic) methods commonly induce the currents via electrodes that are directly coupled to the ground and measure the resulting potential (i.e., voltage) difference via a separate pair of electrodes. But it is also possible to measure currents and potentials that occur naturally due to subsurface processes. Electromagnetic (or induction) methods use eddy currents that are induced in the ground by time-varying magnetic fields generated by an electrical current within coils that are not directly coupled to the ground.

From these measurements, the vertical and lateral distribution of electrical resistivity (or its inverse–conductivity) can be calculated. Because the resistivity of earth materials is affected by mineralogy, porosity, chemistry of the pore fluids, and degree of saturation, electrical resistivity surveys can be used to define subsurface layering, locate cavities, and delineate the groundwater table. For example, clays tend to have low resistivities because of the presence of exchangeable cations in the pore fluids, while sands containing fresh water have higher resistivities. The resistivity of an earth material usually decreases as the moisture content of the material increases.

Electromagnetic methods can be broadly divided into two groups: Frequency-domain electromagnetics (FDEM) methods and time-domain electromagnetic (TDEM) methods. In FDEM methods, a transmitter coil emits a sinusoidally varying current at a specific frequency. A receiver coil measures the secondary field generated by the induced eddy currents in the subsurface.

The most common type of FDEM method for engineering applications is the terrain conductivity method (McNeill 1990). Terrain conductivity electromagnetic systems are instruments that use two loops or coils as transmitter and receiver, respectively. For shallow profiling, the two coils are located a fixed distance apart in a boom that is carried by one person. For deeper profiling, two people are needed: one person generally carries the transmitter coil, while a second person carries the second coil that receives the primary and secondary fields. Terrain conductivity meters are operated in both the horizontal and vertical dipole modes.

These terms describe the orientation of the transmitter and receiver coils to each other and the ground, and each mode gives a significantly different response with depth. When used in the vertical dipole mode, the instruments are more sensitive to the presence of relatively conductive, steeply dipping structures; whereas in the horizontal dipole mode, the instruments are relatively insensitive to this type of structure and can give accurate measurement of ground conductivity near them.

Because terrain conductivity meters read directly in apparent conductivity and most surveys using the instrument are done in the profile mode, interpretation is usually qualitative and used to identify anomalies. Any anomalous areas are investigated further with other geophysical techniques or borings and soundings. Information about the variation of conductivity with depth can be obtained by measuring two or more coil orientations or intercoil separations, or both, and using commercially available software to perform an inversion of the measured data to obtain a 1D profile of conductivity at the sounding location.

A common TDEM resistivity sounding survey consists of a square transmitter coil laid on the ground and a receiver coil located in the center of the transmitter coil. The TDEM method measures the decaying secondary field induced in the subsurface by the current in the transmitter coil. By making measurement of the voltage out of the receiver coil at successively later times, measurement is made of the current flow and, thus, also of the electrical resistivity of the earth at successively greater depths. The measured apparent resistivity as a function of time can be interpreted using commercially available software to calculate a 1D profile of resistivity at the sounding location.

The choice of the type of survey and the definition of the acquisition geometry will be defined directly in the site, according with the geological and morphological asset.

Figure ‎3.9 Example of Electromagnetic equipment (left) and terrain conductivity results (right)

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### Vertical Electrical Sounding (VES)

Vertical electrical sounding (VES) is a geophysical method for investigation of a geological medium. The method is based on the estimation of the electrical conductivity or resistivity of the medium. The estimation is performed based on the measurement of voltage of electrical field induced by the distant grounded electrodes (current electrodes).

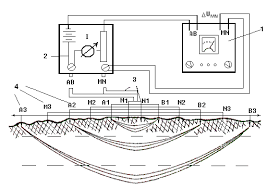
There are two types of resistivity surveying:

* Vertical Electrical Sounding (VES): Vertical electrical sounding or electrical drilling retains current and potential electrodes along a straight line at the same relative spacing around a fixed central point. It presumes that current penetrates continuously deeper with increasing separation of current electrodes. The electrical sounding infers variation of resistivity with depth from a given point on the ground for near-horizontal layers of formation below. The method is useful for determining loose horizontal overburden thickness over hard rocks in river valleys and groundwater projects; and
* Constant Separation Traversing: Constant separation traversing is obtained by progressively moving an electrode spread with fixed electrode separation along a traverse line, the electrodes’ configuration being aligned either in the direction of traverse (longitudinal) or at right angles to it (transverse).

In a vertical electrical sounding (VES), apparent [resistivity](https://www.sciencedirect.com/topics/physics-and-astronomy/electrical-resistivity) measurements are made at different [electrode](https://www.sciencedirect.com/topics/physics-and-astronomy/electrodes) spacings, centered about a common point. As the electrode array size increases, we ‘sound’ to greater depths, as shown in the earlier examples. The Schlumberger array is commonly used for VES, keeping the potential electrode dipole (M and N) fixed and moving the current electrode dipole (A and B). This is a popular choice because the fixed potential electrode dipole means that not only the measurements are relatively insensitive to lateral variation in resistivity but also, from a practical standpoint, surveys can be completed more efficiently as only one of the dipoles is moved for each measurement. The disadvantage is that for small MN spacings, the signals (potential differences) can be relatively weak and thus high-sensitivity instrumentation may be required. VES surveys require just four [electrodes](https://www.sciencedirect.com/topics/physics-and-astronomy/electrodes), each with a suitable cable to connect to the instrument.

The choice of the type of survey and the definition of the acquisition geometry will be defined directly in the site, according with the geological and morphological asset.

Figure ‎3.10 Example of VES equipment (right) and scheme of VES (left)

## QA/QC Protocol

The soil and groundwater sampling activities will be performed according to the standard Wood Quality Assurance / Quality Control (QA/QC) program to ensure that data collected as part of the herein described activities will be valid, adequately documented and sound with the project quality goals.

### Soil and Water Sample Handling Protocol

Attention to personnel, clothing and equipment hygiene when taking and handling soil and water samples will be given the highest priority during soil and groundwater investigation activities.

Cleanliness of the sample preparation areas will be guaranteed to avoid potential for cross-contamination.

Similar attention will be given to the appropriate provision of sample containers, washing and labelling, and preservatives they may contain. Cooler boxes and refrigerated containers will be thoroughly cleaned. Carriage of chemicals and preservatives will be accompanied by Safety Data Sheets. Use of formaldehyde for the preservation of biological tissue is not acceptable due to the risk to human health and safety; instead, a 70% ethanol mix will be used.

### Decontamination

A relevant aspect of the QA/QC protocol is the procedures for cleaning/decontamination. To reduce the potential for cross-contamination, the activities will be carried out according to the quality protocol described in the following paragraphs.

All equipment used for the drilling of monitoring wells and soil borings will be pressure decontaminated before each drilling / sampling.

Material and equipment used for soil sampling and, in case of use of a submersible pump, for each monitoring well the pump will be decontaminated as follows:

* Cleaning with phosphate free detergent; and
* Rinse with deionized water.

Field technicians conducting the sampling activities will use disposable latex gloves for soil, groundwater, and soil gas sampling.

### Sample Labelling

Samples will be collected in laboratory supplied jars, properly labeled prior to sample shipment to the laboratory. The following information will be recorded with a waterproof marker on each sample label:

* Sample ID;
* Sample date; and
* Sampler initials.

### Sample Conservation

Once labeled, all sample containers will be preserved on ice or in vehicle refrigerators (depending on the length of time to delivery) prior to shipment / delivery to the laboratory for the analytical determinations.

### Sample Transportation

A complete Chain-of-Custody (COC) record will accompany all samples. When transferring samples, the individuals relinquishing and receiving the samples will sign, date, and note the time. The original copy of the COC Record will accompany the samples to the laboratory. This record allows for the documentation of sample custody transfer from the sampler to the laboratory. The following procedures will be used for transfer and shipment of the samples:

* The samples will be properly packaged for shipment and dispatched to the analytical laboratory with a signed COC enclosed in each sample cooler. Coolers containing soil samples will be shipped to the laboratory utilizing an express commercial courier; and
* The original COC will accompany each sample shipment, and field personnel will retain a copy.

Each COC will include the following information:

* Sample type;
* Sample ID (location, sampling point);
* Date of collection;
* Required analyses;
* Sampler’s name;
* Sampler’s signature;
* Shipment date; and
* Signature of laboratory personnel receiving the container.

Signatures of all the people involved with management of the soil and groundwater samples will be reported on the COC record.

### QA/QC Samples/Checks

Duplicate samples are samples collected concurrently with a first sample representative of the same population and carried through all steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variance of the total method including sampling and analysis

For soils, a 10% of duplicate samples will be collected for analytical determinations.

For groundwater, at 10% of the selected sampling locations, triplicate samples will be collected for analytical determinations.

Duplicate hydrographic profiling (measurements of in situ parameters such as temperature, salinity, DO, pH, TDS, specific conductivity, and turbidity using YSI multiprobe Environmental monitoring system) will be carried out from 10% of selected sampling locations.

Laboratory reagent blanks (LRB) and laboratory calibration standards (LCS) will be run routinely. After every ten samples, the continuous calibration standard (CCS) will be used to check the calibration of the instrument. For every batch of 20 samples, two duplicate (DUP) samples, one Matrix Spike (MS) sample, and one Matrix Spike Duplicate (MSD) will also be run. The spiking of the samples will be in the range of 1-5 times the analyte concentration. The percentage recovery will be calculated based on spiking and the limit of recovery is set in the range of 70-130%, as per the USEPA recommendation, for the acceptance of the test results.

### Field Instrument Quality Control

All equipment that requires initial and ongoing calibration will be tested at the intervals recommended by the manufacturer or daily, whichever is the most frequent. A schedule of calibration for all such equipment will be prepared and provided in the Survey Standard.

Calibration activities will be reported monthly and calibration certificates for the used equipment will be available, if applicable.

### Data Validation

Field and analytical data will be verified for precision, accuracy, and representativeness on the basis of the control procedures described in the previous paragraphs. Data completeness and comparability will be checked through the control of:

* That the requested analyses will be completed/performed;
* The samples will be delivered to the analytical laboratory in proper/intact condition;
* The analyses will be conducted within the required analytical method holding times; and
* The analytical determinations will be performed with comparable and consistent methodology and method detection limits (MDL).

# Survey and Monitoring Methods

Equipment purchased for permanent deployment will be new and shall be shown fully functional prior to deployment. A field check shall also be conducted immediately after deployment.

The equipment will be maintained for the specified duration of deployment. Acquisition of data from fixed equipment will be reported monthly.

An indicative list of the instruments which may be used for the various activities is given below.

## Site Preparation and Geophysical Survey

For Site preparation and Geophysical survey activities the following equipment will be potentially used:

* Cable Avoidance Tool (CAT);
* Ground-penetrating radar (GPR);
* Spade (manual excavator);
* Mechanical excavator;
* Stakes and red ribbon;
* Electromagnetic survey tool; and
* Vertical Electrical Sounding (VES) tool.

## Soil Sampling

For Soil sampling the following equipment will be potentially used:

* Soil auger / Hand Shovel;
* Portable GPS;
* Decontamination supplies (for example, non-phosphate detergent, distilled/de-ionized water, isopropyl alcohol, etc.);
* Logbook(s);
* Cool box;
* Sample Bottles;
* Sample preservation supplies (as required by the analytical methods); and
* Sample tags or labels.

## Drilling, Water Level Measurements, Hydrogeological Test and Groundwater Sampling

The boreholes will be drilled by using a mobile truck-mounted drilling rig. Prior to mobilization, the rig will be properly inspected and tested to ensure compliance with safety and environmental standards.

A wide variety of conventional and modified drilling equipment is available - ranging from small, handheld portable drills and augers to large equipment for offshore use. The equipment must be capable of meeting the project requirements, have sufficient mobility, and be able to convert rapidly from one drilling technique to another. Consideration should be given to the nature of the formations to be penetrated (e.g., soft clay, dense sand, hard rock) and the type of sample that is required (e.g., bulk, disturbed, undisturbed). Hydraulic-feed machines are usually preferable because they can maintain a constant advance pressure through varying formations, which minimizes erosion and disturbance of the surrounding material.

The conventional rotary drill rig can make several types of borings (including augering and rotary drilling); installing casing; obtaining drive samples and hydraulic-push samples; coring rock, and direct-push placing various in situ tests. Rotary drill rigs are quite versatile and adaptable to a variety of different geologies. The typical applications of the most common variants of rotary drill rigs are summarized below.

Figure ‎4.1 Rotary drill rigs that could be used

Graphical user interface, text

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The following equipment will be potentially used for Groundwater activities:

* Submersible pump or bailer;
* Water level measuring device (interface probe o flow meter);
* Flowmeter;
* Diver water level data loggers;
* Indicator field parameter monitoring instruments - pH, dissolved oxygen (DO), turbidity, specific conductance, and temperature (multiparametric);
* Generator;
* Portable GPS;
* Decontamination supplies (for example, non-phosphate detergent, distilled/de-ionized water, isopropyl alcohol, etc.);
* Logbook(s), and other forms (for example, well purging forms);
* Cool box;
* Sample Bottles;
* Sample preservation supplies (as required by the analytical methods); and
* Sample tags or labels.

# Baseline reporting

Based on the results of the Soil quality and Groundwater conditions survey activities herein described the Baseline report will be prepared.

Next paragraphs provide main details of the report content.

## Data Presentation

Most raw data and processed output will be geographically explicit and will be presented in a form compatible with NEOM’s Geodatabase requirements - e.g., georeferenced database (dbf format).

All terrestrial and marine coordinates will be in WGS 84 and presented in degrees and decimal minutes. All vertical data will be in meters and use the mean sea level (Jeddah, 69) as datum.

Each data batch will be labelled with a prescript code to identify which masterplan area it belongs to.

All survey data will be provided in shapefile or dbf format (not Excel) with field headings, units, etc. following the geodatabase requirements, unless clearly incompatible (e.g., imagery) whereupon the appropriate format will be defined and used.

On completion of all surveys, a final version of all data tables will be presented to NEOM.

## Soil Quality Survey

The definition of soil quality aims to investigate in detail the quantitative and qualitative characteristics of the soil surface.

In the onshore and land sites, soil samples will be collected from the most representative stations and from different depths to detect the potential soil contamination.

The main purpose of collecting the soil samples is to establish the baseline conditions of the existing and planned construction sites as well as the variation in the physical landforms.

For chemical and physical parameters, data and graphical analyses will be carried out using SPSS, Excel 2016 (Microsoft), and ArcGIS (Version 10.2.2.3552, ESRI).

Statistical significance will be set at α = 0.05 for tests and regressions. Least squares linear regressions will be calculated to determine relationships between individual pairs of parameters. Equations, 99% prediction intervals, correlation coefficients, and p values will be determined for each relationship.

Levels of toxic metals will be compared against GAMEP and other international sediment quality guidelines.

## Groundwater Conditions Survey

The main objective of the groundwater condition study is to develop a hydrogeological conceptualization understanding of the NEOM area. It will cover the characterization of the aquifer, the geometrical (area covered and thickness) characteristics of the aquifer, the qualitative and partially the quantitative characteristics by applying different (geological, geophysical, geochemical, geostatistical) methods.

The groundwater activities results will be interpretated as follows:

**Hydrochemical Analysis and Risk assessment model of the groundwater**: Groundwater samples from the study area will be collected and the chemical analysis (pH, total hardness, alkalinity, conductivity, temperature, salinity, inorganic contents and metals) of the samples will be carried out by standard procedures. Each of the chemical parameters will be analyzed individually, by groups (principal components analysis or advanced techniques), and statistical analysis will be applied to produce reliable maps of the spatial distribution of the qualitative characteristics of the groundwater. Other available software will be used to map the spatial distribution of chemical parameters and charts produced (Piper, Durov, Stiff, Wilcox and Dispersion) of the main chemical parameters to determine how these parameters control the quality of the groundwater in the study area. Finally, a risk assessment model and a groundwater quality index (GQI) - based on principal components and the dominant ions - for the study aquifer using GIS will be calculated.

The Royal Commission for Jubail and Yanbu published upper limits for ambient water quality on most of the parameters that will be measured in the proposed study. The results will be compared with the GAMEP or RC standards for the ambient ground water quality and any exceedance of these critical values will be reported.

**Hydrogeophysical survey and determination of hydraulic parameters of the groundwater**: The geophysical methods (Electrical and Electromagnetic) will provide a detailed mapping and characterization (lithology, water level, water flow, water saturation, transmissivity, hydraulic conductivity, indirectly qualitative information, etc.) of the groundwater. It should be noted that the hydrogeophysical methods, in conjunction with existing hydro-geological information, could provide a complete model of the hydrogeological regime of the study area. A comprehensive analysis, based on the acquired and archived data, of both positive and negative impacts on groundwater conditions across the broader study area that are likely to result from the proposed project, will be provided.

**Geological, hydrogeological and tectonic study of the area under investigation**: The analysis will be performed using topographic maps, satellite images, and available literature. The groundwater level will be measured in all available and open wells. During the mapping, all possible point source contamination sites from the broader area will be traced (using mainly satellite images). All of the above will be imported to GIS and the correlation between the available data (water supply, water level, chemical analysis, hydrowell location, tectonic/geological structures) will be applied.

**Database (in GIS) to store and manage the available spatial information**: Information about the study area concerned, potential aquifer, available geological, hydrogeological, hydrometeorological and chemical data, possible groundwater contamination problems due to anthropogenic intervention either due to natural sources (e.g. presence of gypsum), will be reviewed and integrated into the final report. A database (in ArcGIS) will be developed to store and manage the available spatial information. The collected data will be imported to the GIS database, and several thematic maps will be generated. These maps will help to:

* Understand of the hydrogeological regime of the study area;
* Determine the spatial lack of information that needs to be obtained later;
* Identify geological/tectonic features whose presence may be ignored due to lack of available information; and
* Conduct a preliminary statistical resolution and completeness analysis.



1. General Authority of Meteorology and Environmental Protection [↑](#footnote-ref-2)
2. Development of Regional Baseline Standards and Conduction of Surveys for NEOM Environment (RFP – 100775) [↑](#footnote-ref-3)
3. resource: CCME (2016) Guidance Manual for Environmental site characterization in support of environmental and human health risk assessment – Volume 3 Suggested operating procedures. Canadian Council of Ministers of the Environment [↑](#footnote-ref-4)
4. Standard Specification for Thermoplastic Water Well Casing Pipe and Couplings. [↑](#footnote-ref-5)
5. EPA 1994 [↑](#footnote-ref-6)
6. Development of Regional Baseline Standards and Conduction of Surveys for NEOM Environment (RFP – 100775) [↑](#footnote-ref-7)