International Environmental Governance Capacity Building Cooperative Agreement

Improving Solid Waste Disposal in San Cristobal Municipality, Dominican Republic

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

CAFTA-DR Environmental Cooperation Program

BATTELLE

ERG

SCS ENGINEERS

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Executive Summary

At the request of the Ministry of Environment and Natural Resources (MARN) of the Dominican Republic, the United States Agency for International Development (US AID), and the United States Environmental Protection Agency (US EPA) are assisting the Municipality of San Cristobal with the management of municipal solid waste. US EPA established a project team that included US AID, MARN, Battelle Memorial Institute, Eastern Research Group, SCS Engineers, and Horizon Consultants to develop a plan to improve operations and environmental conditions at the current dumpsite, construct an engineered landfill, and move MSW disposed of at the existing dumpsite into a proposed engineered landfill.

This report and conceptual plan would provide San Cristobal with a roadmap for addressing these concerns through the transition from the existing dumpsite to an engineered landfill at the same location based on modern landfill design standards and best practices. Environmental concerns such as groundwater contamination, surface water contamination, and air emissions would be addressed by the construction of an engineered landfill. A properly designed and constructed landfill would prevent groundwater contamination through the use of lined disposal cells and a leachate management system that prevents contaminants from contacting soil and groundwater. Surface water would be managed to limit contact with the waste mass. Surface water channels would be diverted around the engineered landfill and stormwater that falls within the boundaries of the Site would be collected, controlled and treated on site as necessary. Air emissions would be reduced initially by extinguishing the fires on the Site. The control of landfill gas (LFG) produced during the decomposition of waste would be controlled through the use of daily and final cover materials. Eventually, the installation of a LFG collection and control system would also limit odors and the emissions of LFG, which contains methane (a greenhouse gas) and other organic compounds that contribute to local air pollution.

Safety would be improved by controlling public access to the Site. Although not part of this conceptual design, a customized landfill management plan would inform operators on how to properly manage the landfill to maximize its performance while ensuring the safety of workers and the public with approved access to the Site. The design and proper management of the Site would also make it compliant with current international standards for solid waste management and environmental impacts, providing a plan for the future, long-term operation of the Site, including potential resource recovery (e.g., LFG for beneficial use) and overall sustainability.

Immediate actions to improve existing dumpsite conditions and operations are detailed in Section 4 and include the following:

- Improving access roads and perimeter security.
- Establishing a proper working face and daily cover.
- Establish equipment operations and maintenance plan.
- Establishing recordkeeping procedures.
- Controlling surface water.
- Controlling open burning.
- Formalizing the informal sector.
- Forming a monitoring and maintenance program.

The proposed conversion and expansion plan to an engineered sanitary landfill is found in Section 5. The proposed plan includes provisions to build new engineered cells outside the existing dumpsite area along with construction sequencing that allows the Site to continue receiving new incoming waste while facilitating movement of existing waste into the new engineered cells. A sub-surface Site characterization was conducted involving the installation of 14 boreholes and seven piezometers to better define the existing geology and hydrogeology at the Site (Section 5.2). A current waste-in-place estimation was conducted based on field observations, past studies and evaluation of historical aerial photos.

In addition to conceptual design and construction plans (found in Appendix C), plans for the control of surface water run-on and run-off, LFG and leachate were considered and are presented in Sections 5 and 6. Plans for groundwater and LFG monitoring are included in Section 6.

Implementation of this plan will take considerable planning, coordination and funding. Section 7 includes an overview of the cost estimates associated with design, construction, operation, closure and post-closure monitoring of the engineered landfill. A summary of the costs is as follows:

Plan	Estimated Costs (USD)
Conversion/expansion plan	5,607,800
Closure	3,165,580
GCCS (per phase)	281,716
Post-closure (total over 30 years)	2,356,034

A detailed breakdown of the cost items is found in Appendix D.

Finally, Section 8 provides a brief introduction to the most common types of contracts and agreements for landfill development, construction and management that can be considered in implementing the project. A list of contracting resources and sample contracts is found in Appendix A, along with an initial list of potential financing partners that can provide the type(s) of financial support necessary for the development of the Site.

List of Acronyms

ASTM	American Society for Testing and Materials
BOO	build, own, and operate
BOOT	build, own, operate, and transfer
CCAC	Coalition for Clean Air and Climate
CDEEE	Corporacion Domincana de Empresas Electricas Estatales
cm	centimeter
CO_2	carbon dioxide
CH_4	methane
EIA	Environmental Impact Assessment
ERG	Eastern Research Group
g	gravity of Earth
GCCS	Gas Collection and Control System
GEF	Global Environmental Facility
GMI	Global Methane Initiative
ha	hectare
HCSA	Horizon Consultants
HDPE	high-density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance (model)
IDB	Inter-American Development Bank
IPCC	Intergovernmental Panel on Climate Change
km	kilometer
kN	kilonewton
kPa	kilopascal
LandGEM	Landfill Gas Emissions Model
LFG	landfill gas
LFGE	landfill gas energy

LLDPE	linear low-density polyethylene
m	meter
m^2	square meter
m^3/min	cubic meters per minute
m^3/hr	cubic meters per hour
m^3/sec	cubic meters per second
MARN	Ministry of Environment and Natural Resources (Dominican Republic)
MCF	methane correction factor
Mg	megagram or tonne
mil	thousandth of an inch
mm	millimeters
MSW	municipal solid waste
MW	megawatt
O&M	operation and maintenance
PCSTABL5M	computer program for the general solution of slope stability problems by two-dimensional limiting equilibrium methods
RFIQ	request for expression of interest and qualification
RFP	request for proposals
ROI	radius of influence
SCS	SCS Engineers
SPT	standard penetration test
UNEP	United Nations Environment Programme
US AID	United States Agency for International Development
US EPA	United States Environmental Protection Agency
US	United States
USCS	United Soil Classification System
USD	US Dollars
USTDA	United States Trade and Development Agency

1.0 Introduction

a. Project Overview

At the request of the Ministry of Environment and Natural Resources (MARN) of the Dominican Republic, the United States Agency for International Development (US AID) and the United States Environmental Protection Agency (US EPA) are assisting the Municipality of San Cristobal with the management of its current municipal solid waste (MSW) dumpsite.

US EPA established a project team—including US AID, MARN, Battelle Memorial Institute, Eastern Research Group (ERG), SCS Engineers, and Horizon Consultants (HCSA)—to conduct field work and develop a plan to improve environmental conditions, improve current dumpsite operations, construct an engineered landfill, and move MSW disposed at the existing dumpsite into an engineered landfill.

Over several months, the project team met with the Municipality, site operators and other stakeholders to gather information to complete this plan. In addition, the team conducted several field visits and a site assessment in 2017 and 2018.

b. Project Objectives

The team developed this plan by evaluating existing data and international best practices on landfill design, construction and operation. In addition, the plan includes considerations and recommendations for properly managing MSW disposal, landfill gas (LFG), leachate, surface water run-on and run-off, and closure and post-closure of the Site. Most importantly, it includes near-term recommendations to improve operations and environmental conditions at the existing dumpsite. It also includes a design concept for a proposed engineered landfill which could be constructed at the Site, and a closure/re-location plan for existing dumpsite areas. The design concept also includes estimated investment costs.

The conceptual plan and operational guidance were presented to key stakeholders in August 2018 to provide guidance on improving operations and management at the Site. The plan also serves as a preliminary guide for contracting and attracting investment to develop and construct an engineered landfill and close the existing dumpsite.

2.0 Site Background

The Municipality began using the Site in 2014. The Site currently receives truckloads of waste from San Cristobal (pop. 250,000), Cambita Garabitos (pop. 45,000) and Hatillo. MSW is collected by various private trucking companies that service residential and commercial areas. Estimates of waste received at the Site range from 210 to 270 Mg/day[1] (1 Mg = 1 tonne = 1 metric ton). The current active dumpsite covers about 6 hectares (ha) (60,000 m^2); the total property area of the Site is approximately 22 ha.

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[1] Caso de Aplicación de la Herramientas para el Cálculo de Emisiones de Contaminantes Climáticos de Vida Corta a Partir del Sector de Residuos Sólidos, Red Centroamericana de conocimiento e intercambio de experiencias para la gestión integral de residuos sólidos (Redgirs), 2016.

View of the Site facing east.

Currently, the Site is operated as a semi-controlled open dump. There is uncontrolled access, no liner system or groundwater monitoring or LFG controls, minimal compaction of the waste, and no soil cover applied to the waste. Portions are on fire. These conditions are producing significant challenges at the Site such as unsafe waste scavenging, uncontrolled fires, blowing litter, leachate run-off into an adjacent creek, and uncontrolled LFG emissions. These conditions have resulted in concerns and complaints from surrounding communities, which have been communicated to the Municipality via "Juntas Comunitarias."

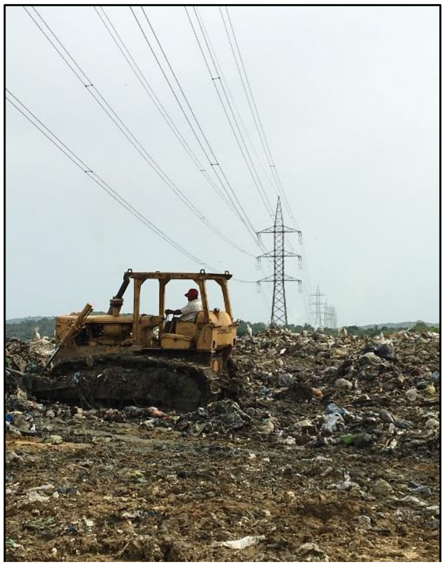
The Site hosts an active recycler population, estimated at approximately 115 people who originate from the Dominican Republic (30%) and from Haiti (70%). Of this population, approximately 75 people enter each day to pick, sort, package and sell recyclables such as plastics, cardboard, metals and glass. According the Municipality, the majority of the waste pickers are registered and have received basic vaccinations to better protect their health.

The Site is located on five parcels of land, totaling approximately 22 ha. An adjacent property near the current active dumpsite area contains a large quantity of mixed plastics, which historical aerial photos show have accumulated over the past several years. There does not appear to be any active sorting or packaging of recyclables for shipment and sale from this area.

Waste pickers sorting through waste in the active dumpsite area.

Private property containing a large quantity of plastics.

High-tension power lines cross over the Site, controlled by the Ministry of Energy and Mines and operated by the Corporacion Domincana de Empresas Electricas Estatales (CDEEE). The access road into the Site passes through residential areas, in some areas passing immediately adjacent to homes.



Power lines crossing active waste disposal area.

A natural run-off area runs through the Site, fed by a buried culvert and discharging on the southern edge of the waste disposal area. Drainage from the Site containing leachate runs south into a series of ponds, which continuously discharge leachate into the Arroyo Najayo.

Pond containing leachate at the southernmost edge of the property.

3.0 Design and Operational Objectives

There are five key objectives for the development, and ultimately execution, of this plan:

- Environmental protection
- Public and worker safety
- Compliance
- Performance
- Sustainability

According to the United Nations Environment Programme (UNEP), managing solid waste is one of the most daunting tasks for local governments worldwide. Open dumpsites pose threats to both human and environmental health, including both land and water resources. UNEP (2005) also states, "It is a matter of national policy that dumpsites be closed because of the adverse effects on society and the environment. It is incumbent upon both national and local authorities to adopt better and environmentally sound waste disposal methods by shifting from their current policy and practice of open dumping to controlled dumping and transition to sanitary landfilling."

This report and conceptual plan provide the Municipality with a roadmap for addressing these concerns through the transition from the existing dumpsite to an engineered landfill at the same location and based on modern landfill design standards and best practices. Environmental concerns such as groundwater contamination, surface water contamination and air emissions would be significantly minimized by the construction of an engineered landfill. A properly designed and constructed landfill would prevent groundwater contamination through the use of lined disposal cells and a leachate management system that prevents contaminants from contacting soil and groundwater. Surface water would be managed to limit contact with the waste mass (i.e., reduce leachate generation). Surface water channels would be installed around the engineered landfill, and stormwater that falls within the boundaries of the Site would be collected, controlled and treated onsite, as necessary. Air emissions would be reduced initially by extinguishing the current fires on the Site. The control of LFG produced during the decomposition of waste would be controlled through the use of daily and final cover materials. As an interim step, vents (chimineas) could be installed to allow LFG to escape from the Site to prevent migration of the gas into nearby structures. Eventually, the installation of an LFG collection and control system would also limit odors and LFG emissions which contains methane (a potent greenhouse gas) and other non-methane organic compounds that contribute to local air pollution.

Safety would be improved by controlling public access to the Site. Although not part of this conceptual design, a tailored landfill management plan would inform operators on how to properly manage the landfill to maximize its performance while ensuring the safety of workers and the public with approved access to the Site. The design and proper management of the Site would also make it compliant with current international standards for solid waste management and environmental impacts, providing a plan for the long-term operation of the Site, including potential resource recovery (e.g., LFG for beneficial use), and the overall sustainability of the Site and the surrounding community.

4.0 Best Practices Recommendations to Improve Site Operations

The following is a summary of immediate, low-cost, short-term recommendations and actions that would improve operating efficiency, working conditions, and environmental controls at the Site. These recommendations are based on industry best practices and supported by field observations, photos and specific examples from the Site. These actions would also reduce environmental impact to the surrounding property and communities, and could ultimately serve to maximize the Site's lifespan and optimize its sustainability. These improvements would also help the Site transition to an engineered landfill and establish best practices for its proper operation and maintenance (O&M).

4.1 Improving Access Roads and Perimeter Security

4.1.1 Current Practice: Access Roads

The current Site access road is poorly maintained, narrow and subject to wet weather, making it difficult to navigate for waste and recyclables collection vehicles.

Section of the current access road showing exposed waste and poor drainage.

4.1.2 Improved Practice: Properly Maintaining Access Roads

Plans for improving existing access roads, both permanent or temporary, should be prioritized due to the importance of vehicles having safe access to the disposal and recyclable staging area(s). Properly maintained roads also reduce damage to vehicles. The existing access road should be widened and graded periodically using the Site's tracked dozer. If locally available, a grader can also be used—possibly rented short-term—in combination with a dozer to more effectively maintain the roads, even if only used periodically. Generally, permanent roads have two lanes (each at least 4 meters wide) and are properly sloped to allow for drainage. Onsite soil and gravel are an inexpensive means to widen the road and fill in any surface depressions.

Best Practice: Properly maintained landfill access road.

Temporary roads are used to transport the wastes from the permanent road to the working face, since the location of the working face changes. Compaction of the soil with adequate slope for proper drainage is acceptable. The soil may be overlaid with any available tractive materials such as gravel.

Local climate conditions primarily direct maintenance frequency for the permanent and temporary roads: wet season requires more frequent repair; dry season usually requires less frequent repair.

4.1.3 Current Practice: Perimeter Security

There is a single fence along certain portions of the border of the Site. The fence is designed primarily to keep livestock from entering the Site while also capturing some blowing litter.

Current perimeter fencing along a section of the Site.

4.1.4 Improved Practice: Enhancing Perimeter Security

Perimeter fencing combined with berms or ditches should be used to define the boundaries of the Site, control access (e.g., unauthorized vehicles, pickers), and keep out animals. The current fencing should be extended and maintained around the current limits of waste placement at the Site. The current type of fencing is inexpensive to construct and maintain, assists with capture of blowing litter into the surrounding area, and reduces entry by livestock grazing nearby. If available, portable litter fences are a preferred method for controlling blowing waste over the Site's current fencing. It would also help prevent the waste footprint from extending beyond current limits into areas, especially where new, engineered cells may be constructed.

Best Practice: Portable litter fencing can be moved daily to the working face and positioned in the prevailing wind direction.

Waste pickers currently enter and leave from several locations around the perimeter of the Site. Additional fencing could direct the pickers to enter/exit from the front gate to help the landfill operator account for their location and how many pickers are inside the Site in an emergency (fire, landslide, severe storm).

Other forms of security include a lockable front gate to control unauthorized access to the Site. Signage is also an inexpensive means to inform the public that access to the Site is controlled, list the hours of operation, and are listed; and display any other notifications (no illegal dumping, no fires).

4.2 Establishing a Proper Working Face and Cover to Enhance Site Operations

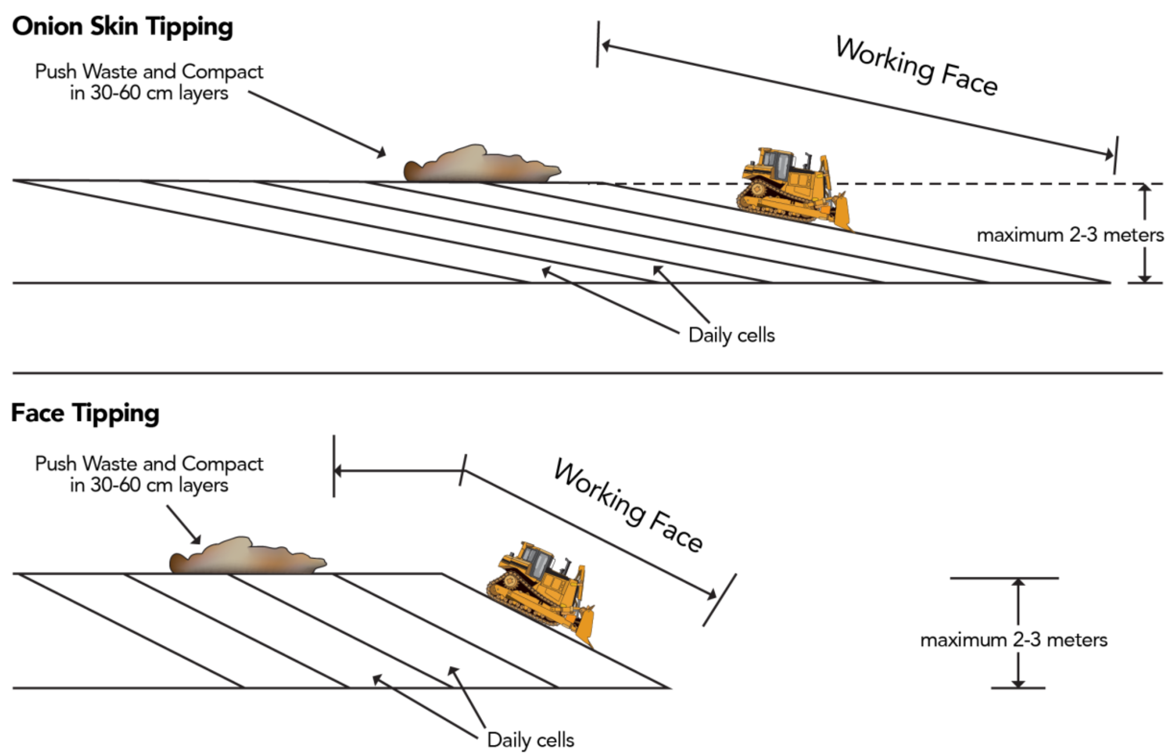
4.2.1 Current Practice: Working Face

There is currently no defined working face at the Site, where all incoming trucks carrying waste are directed to dump loads on any given day. This leads to inefficiency in using existing space, causes problems with surface water and leachate drainage, results in disorganization among pickers, and increases safety hazards (disorganized vehicle, personnel movements) within the Site.

Waste is randomly dumped throughout the Site.

4.2.2 Improved Practice: Establish a Working Face

Establishing a proper working face (or tipping area) in combination with a filling plan is fundamental to extending the operating life of a landfill. A defined working face as shown below confines the incoming waste that is placed (or tipped) to as small an area as possible. Waste movement usually is confined to spreading the waste on the working face with a compactor or tracked dozer after loads are deposited by trucks.



<u>Best Practice</u>: Proper working face and waste filling sequencing.

The working face usually represents one day's waste placement. At the end of each day, the working face should be covered by a layer of soil (a minimum of 0.15 m thick), and an adjacent working face is established the next day. Availability of locally sourced soil or other cover materials is crucial due to the large quantities needed in landfill operations. Applying soil to the working face daily or every couple of days reduces nuisances such as vectors that can carry disease (i.e., flies, mosquitos), animals such as birds and rodents, odors and fires, which are currently common at the Site.

A defined area should be established each day which is the working face, with a graded access road, sloped grade for drainage, and defined tipping and scavenging areas for the waste pickers (primarily to prevent injuries by equipment). Once the waste is deposited at the toe of the working face, a compactor or tracked dozer pushes the waste up the face to spread the waste into a thinner layer, usually less than 0.60 m deep. The working face should be compacted and seek to minimize the slope (~ 20–30%) which affects compaction of the waste. As the slope increases, vertical compaction pressure decreases; the lower the slope, the higher the compaction.

Wet weather problems are a serious concern at the Site, as the soils become muddy and slippery. Provisions should be made to continue operations in areas less susceptible to problems during bad weather. Diverting stormwater away from the working face and roadways would lessen the problem.

4.3 Enhancing Current Operations (Filling, Grading and Compaction)

4.3.1 Current Practice: Equipment

Good landfill operations depend on suitable and properly maintained equipment to:

- Spread waste after dumping
- Compact waste
- Spread and compact the daily or intermediate cover
- Move soils or other materials
- Construct and maintain roads

Single operating tracked dozer currently employed at the Site.

Currently, a single operational tracked dozer is the only available piece of landfill equipment, which severely reduces the efficiency of landfill operations. If the vehicle breaks down, there is no backup equipment to take its place. In addition, this equipment is not designed to excavate or haul/load cover soil.

4.3.2 Improved Practice: Establish Equipment Operations and Maintenance Plan

Best Practice: Front-end loader adds versatility to improve landfill operations.

Ideally, a second tracked dozer in combination with a wheeled loader should be considered. A wheeled loader can excavate, lift and carry material such as cover soil (load in a dump truck) that a tracked loader cannot perform. A second tracked loader would also allow for the current loader to be taken out of service for routine maintenance and allow more versatility in terms of maintaining the working face.

The most effective, versatile and expensive piece of equipment is the landfill compactor. Compactors are designed specifically to push, crush and compact waste (with high efficiency) in difficult landfill environments.

Compactors can achieve high compaction, which helps extend the operating life of the landfill (allowing additional waste placement without reducing disposal capacity).

Other pieces of equipment at the Site were observed to be inoperable and should be evaluated to determine if repairs can be cost-effectively made to restore their operation. Repairing equipment can be more economical than purchasing new equipment. The best way to avoid costly repairs is to develop and follow an equipment maintenance and service plan. At least one employee should be trained to routinely maintain the equipment following the manufacturer's service plan.

***Best Practice*: Landfill compactor designed to spread and compact waste.**

The purchase of a landfill compactor and wheeled loader should be evaluated. Operating a sanitary landfill with the currently used tracked dozer(s) is inefficient, increases the cost of landfill operations, and reduces the lifespan of the Site.

4.4 Establishing Recordkeeping Procedures

4.4.1 Current Practice: Recordkeeping Procedure

There is currently no defined area for registry, documentation or weighing of trucks bringing waste to the Site. Recording waste disposed of at the Site is fundamental to understanding how much waste is being accepted (daily, monthly, annually) and the impact on design capacity of the Site. The most accurate way to determine the lifetime capacity of the Site is from waste disposal records.

4.4.2 Improved Practice: Establish Recordkeeping Procedures

A mobile office trailer or control structure should be located at the entrance, positioned so that all incoming trucks must pass by it (i.e., scalehouse). Information should be collected from each incoming truck including the date, time, hauling company, waste origin, estimated weight and waste content (i.e., residential, commercial, industrial, agricultural, special). Paper receipts should be kept in a file that documents the incoming waste. Measures should be taken to ensure that only authorized haulers bring waste to the Site.

***Best Practice*: Scalehouse for weighing incoming and outgoing collection vehicles and maintaining records.**

***Best Practice*: Recording the weight of incoming collection vehicles. A computer allows for improved recordkeeping (data storage, analysis).**

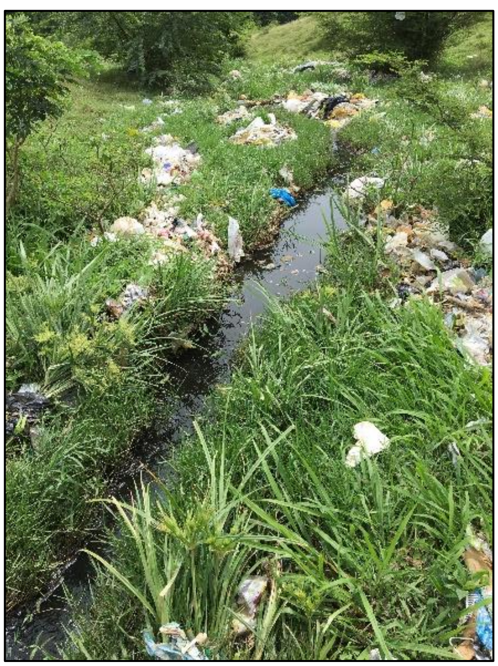
4.5 Surface Water Management

4.5.1 Current Practice: Surface Water Management

As the following images show, the Site is situated on an overall sloped area and is bisected by a natural run-off area carrying water through the waste. Waste and leachate enter this natural run-off area from the dumpsite. (Leachate usually contains dissolved or entrained environmentally harmful substances that may enter the environment—e.g., contaminating waterways.)

The Site is in a valley.

A natural run-off area runs through the Site.



The natural run-off area carries leachate offsite.

Leachate from the natural run-off area enters Arroyo Najayo.

4.5.2 Improved Practice: Controlling Surface Water

***Best Practice*: Proper stormwater controls minimize erosion.**

Run-on and run-off of surface waters can lead to erosion, water ponding (which can create mosquito breeding areas) and paths for leachate migration. To mitigate these effects, drainage control systems should be installed in and along the perimeter of the existing disposal area. These can be simple ditches designed to slope and divert surface waters away from the Site. The path of the drainage system should convey the surface waters at adequate velocities to prevent stagnation or deposition but not cause scouring.

Surface water should be directed to holding ponds that can contain the leachate. There are several holding ponds throughout the Site, including one at the far south end of the Site adjacent to Arroyo Najayo. The pond adjacent to the Arroyo Najayo should be excavated to increase its holding capacity. If possible, an aeration system should be installed in this pond to decrease the level of contamination in the leachate prior to discharge.

In the design of the proposed engineered landfill, the natural run-off area would be routed around the Site. However, the current stream should be widened, cleaned and armored to prevent erosion and reduce leachate run-off from the Site into Arroyo Najayo.

Existing leachate containment pond.

***Best Practice*: Recolección y aeración de los lixiviados.**

4.6 Controlling Fires

4.6.1 Current Practice: Open Burning and Subsurface Combustion

The open burning of waste and subsurface combustion is common at the Site. Waste pickers ignite the waste piles to burn off the materials to access the recyclables. Burning these materials is a public health concern for the pickers and surrounding community. Dizziness, asthma, coughing, skin diseases, arthritis, and urinary tract and kidney infections have been linked to the smoke from open burning. The fires also increase the risk of a much larger-scale fire, which could start when ashes/embers blow into adjacent waste piles.

Subsurface combustion is difficult to manage as fire within the waste mass ignites and continues to burn and migrate underground. There are several dangers from subsurface combustion, such as ground collapse (pickers or workers can fall through cavities and become injured or burned) and air pollution. Subsurface combustion also consumes the organic materials, which can contribute to reduced LFG generation (decomposed organics primarily contribute to LFG formation); if LFG wells or vents are present, they can melt and become inoperable.

Smoldering waste piles are common at the Site.

4.6.2 Improved Practice: Controlling Open Burning

Because burning has been practiced for a long time at the Site, it is essential to thoroughly extinguish any fires before applying any cover or capping. Where burning is relatively shallow, the waste in the affected area is spread out to allow for complete combustion, after which water may be applied. Sand or silty materials may also be applied instead of water. If burning is relatively deep, it may be necessary to isolate the burning area by excavating trenches around it. The waste is then spread or regularly agitated to allow for complete combustion. The ashes subsequently produced are then smothered with sand or soil. All waste pickers should be informed that burning of waste is not allowed, and that those who start fires will be prohibited from re-entering the Site.

Best Practice: Excavator used to remove burning waste combined with continual water application.

4.7 Informal Recycling Sector

4.7.1 Current Practice: Informal Waste Pickers

According to Site personnel, about 75 waste pickers are active on the Site on any given day. Waste pickers risk a number of public health problems such as disease and exposure to air pollution (from open burning of waste), injuries caused by working in waste without any protective equipment (sharp objects, needle sticks, falls), and being struck by vehicles. There are no sanitary facilities (toilets, showers, water for consumption). There is daily exposure to solar radiation, wind and high temperatures. Pickers often not only live off the waste but in the waste—dangerous living conditions, especially for children.

4.7.2 Improved Practice: Formalizing the Informal Sector

To improve landfill operations, working conditions and safety for the waste pickers, at a minimum the following best practices should be followed:

- All waste pickers should be registered to account for each person working on the Site.
- Entry and exit of all waste pickers should be controlled daily at a defined location, preferably the office trailer or control building.
- Basic safety and hygiene awareness training should be provided to all those entering the Site.

- Waste pickers should not be allowed in the active disposal area.
- Waste loads that are known to contain recyclables should be tipped at a designated area where waste pickers can sort through the waste to remove them.
- Children should not be allowed into the Site. All waste pickers should be informed that fires are not allowed on Site.
- A first aid kit and basic training on how to use it should be provided to all waste pickers and Site personnel.
- Waste pickers should consider forming a cooperative or organization to self-educate on hygiene, safety and waste sorting practices. There are many examples of waste pickers successfully formalizing to improve their livelihoods and improve landfill operations. For additional ideas for formalizing the informal sector, there are a number of resources available covering economical and easily maintainable programs that are improving lives and socioeconomic circumstances.
- See Appendix A for a list of additional waste picker resources.

Waste pickers sorting recyclables on the Site.

Best Practice: Waste pickers receiving health and safety training.

4.8 Monitoring and Maintenance

4.8.1 Current Practice: Blowing Litter

Evidence of blowing litter from the Site is common. This litter can enter neighbor properties or local waterways.

4.8.2 Improved Practice: Forming a Monitoring and Maintenance Program

A daily perimeter walk should be conducted to clear waste from fencing and in areas prone to frequently blowing litter. The perimeter walk should ensure the perimeter fence is intact, identify areas of blowing litter, and identify fires or release of leachate from the Site.

Waste blowing from the Site.

Waste should also be removed from the primary access road on a weekly basis. The waste could either be collected into a truck for transport to the active disposal area or bagged for transport to the active disposal area. See Section 6.7 for more details about monitoring.

In addition, the containment pond at the southernmost end of the Site should visited daily to ensure it is containing the contaminated leachate flowing off the active waste disposal area. Fires should be identified as quickly as possible and extinguished.

5.0 Conversion and Expansion Plan to Engineered Landfill

The conversion/expansion plan to convert the dumpsite into an engineered landfill has two main parts:

- Design and construction of engineered cells in 9.2 ha dedicated to MSW disposal.
- Re-location of waste placed in approximately 8.2 ha of the property.

To develop the conversion/expansion plan, it was first necessary to:

- Determine the required regulatory environmental permits and/or authorizations needed.
- Perform a site characterization.
- Develop a landfill conceptual design.
- Estimate the capital costs.

The following sections describe these components.

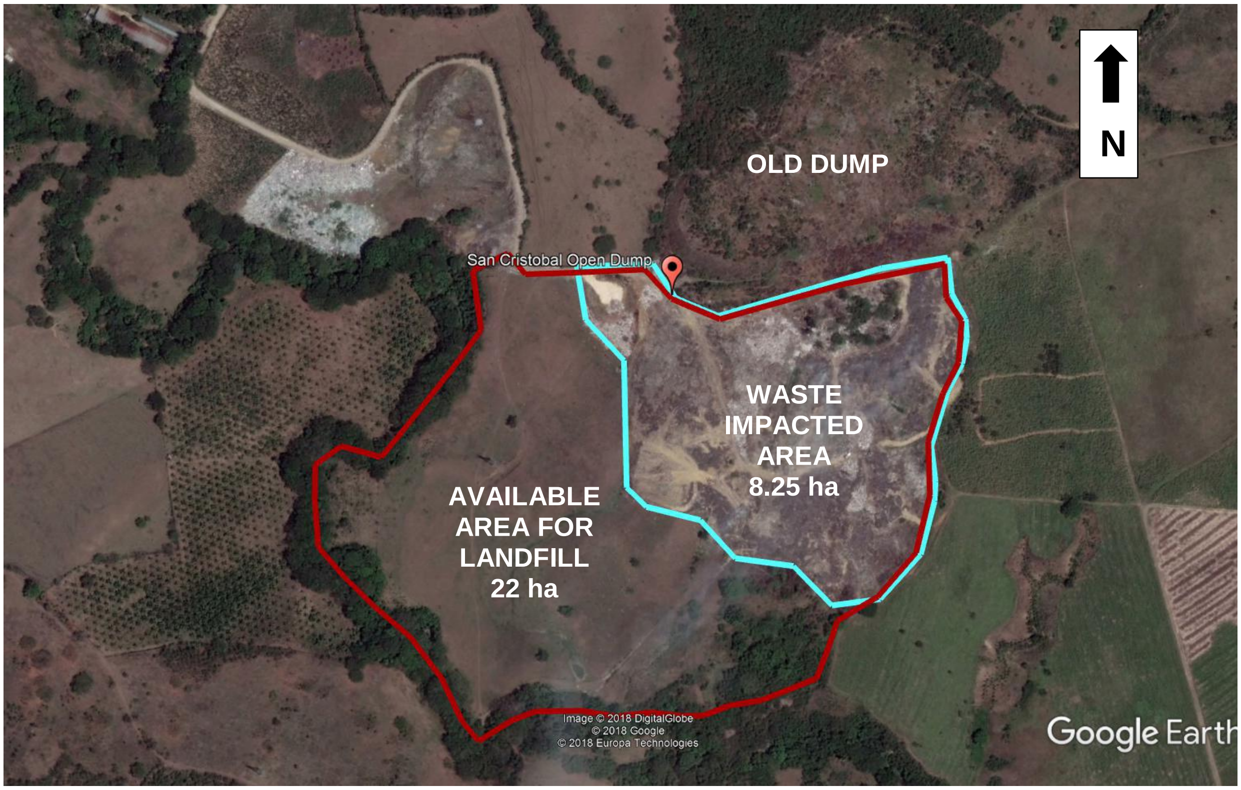


Figure 1. Site Plan Showing Waste-Impacted Area and Available Area for Proposed Engineered Landfill

Figure 1 shows the waste-impacted area and the total area available for the proposed engineered landfill. The total area for the proposed engineered landfill is composed parcels 478-A (14.1 ha) and 478-B, 478-C and 478-D (5.8 ha in total). The area is surrounded on the north by agricultural land and the existing dump area, on the west and south by Arroyo Najayo, and on the east by a natural run-off channel.

5.1 Applicable Regulations

The team researched and analyzed current environmental regulations.[2] It was determined that the applicable environmental regulations for permitting, siting, construction, operation, closure and post-closure care of a sanitary landfill are the following:

- ***Law 64-00, Article 38, 41, 15***. Law for sustainable conservation, protection, improvement, and restoration of the environment and natural resources.
- ***Environmental Assessment Regulation 09-2014.*** Regulation for the environmental authorizations process established by Law 64-00, to prevent, control and mitigate potential environmental and natural resources impact caused by construction, projects or activities.
- ***Non-Hazardous Waste Regulation 06-2003.*** Regulation for the protection of human health and life quantity of populations and to promote preservation and protection of the environment by establishing guidelines for municipal non-hazardous solid waste. This rule provides requirements for the storage, collection, transport and final disposal, as well as general requirements for reduction, reutilization and recycling.

[2] Input from MARN was requested and provided by Yvelisse Perez of the Solid Waste Department.

5.1.1 Permitting Process

MARN is the entity in charge of the environmental permitting process. According to Environmental Assessment Regulation 09-2014, this project would be considered a “Category A” project and requires an Environmental License.

The permitting process has the following steps:

1. The information required for initial submittal is available at the MARN website, “Environmental Authorizations” section (http://ambiente.gob.do/wp-content/uploads/2016/10/Formulario-%C3%BAnico-de-Registro-proyecto-obra-o-actividad-Res.-11-2016-1-1.docx; also see Attachment A). The questionnaire must be submitted in original and one copy on an 8 1/2 × 11 folder containing the required documentation. The submittal must be at the main MARN building, at the Environmental License Services Department.
2. MARN issues terms and specifications to prepare an Environmental Management and Adaptation Program and an Environmental Impact Assessment (EIA). The EIA must be performed by a consultant approved by MARN. (See http://ambiente.gob.do/wp-content/uploads/2017/04/ListadodeGestores.pdf for a list of MARN-approved consultants.)
3. Once the EIA is submitted and meets all the terms and specifications, MARN has up to 190 days to review and approve or deny the environmental license. Note that MARN determines the cost associated with the environmental license depending on the projected environmental impact.
4. The project also requires a bond for 10% of the total cost of the physical construction or investment needed to implement the environmental management and adaptation program.
5. The Environmental License need to be reviewed at five, seven and 15 years. After the 15^{th} year, review is required every 10 years, assuming all requirements are being met through the environmental compliance reports and technical inspections.

5.1.2 Other Relevant Environmental Requirements

Non-Hazardous Waste Regulation 06-2003 provides the following requirements for siting, designing, constructing and operating a sanitary landfill:

- 6.1.7: Conduct an Estudio de Evaluación Ambiental in accordance with Law 64-00 Article 38.
- 6.1.11: Minimum distances to airports or human settlements:
  - 3,000 m from an airport with motor turbine planes.
  - 1,500 m from an airport with motor piston planes.
  - 1,500 m from any human settlement or demonstrate that they would not be affected.
  - Distance from electrical towers, oil or water pipelines, highways, etc.
- 6.2.1: Landfills must not be located on 100 year return flood zones or demonstrate that would not affect flow in such area.
- 6.2.2: Must not be located in wetlands, swamps, creeks, rivers or anything similar.
- 6.2.3: 1,000 m from superficial waters with continuous flow; include a buffer zone to retain the maximum precipitation in the last 10 years.
- 6.3.1: 100 m from wells used for human consumption (domestic, industrial, irrigation or animal).
- 6.3.2: 60 m from a geological fault.
- 6.3.3: Away from any unstable slopes.
- 6.3.4: Away from areas with differential settlements.
- 6.4.1: Requires the following:

- Control and monitoring of stormwater run-off.
- Control and monitoring of superficial water or groundwater.
- Control and monitoring of leachate.
- Treatment of water or leachate meeting water discharge regulations.

- 6.4.2: Control of gas accumulation and emissions.
- 6.4.3: Control, treatment and use of gas to produce energy.
- 6.4.5: Reduce to the maximum any risk or nuisances such as:
  - Odors and dust.
  - Blowing litter.
  - Noise and traffic.
  - Birds, parasites and insects.
  - Formation of aerosols.
- 6.4.6: To prevent fire risks, cover waste daily.
- 6.4.7: Have an emergency prevention plan for fires.
- 6.4.8: Place waste to ensure stability.
- 6.4.9: Limit access to the Site.
- 6.4.13: Have a closure plan.

5.2 Site Characterization

The Site lies within the Municipality limits, approximately 8 km southeast of the Municipality center, in the Doña Ana sector. Currently, the area covered by waste is approximately 8.25 ha. The proposed engineered landfill would be located on 22 ha, currently owned or being acquired by the Municipality.

The area is near the coast of the Caribbean Sea, with a hilly topography as one proceeds inland into the central mountain range. The climate in San Cristobal is tropical, with a maximum average temperature of about 32.4 °C and a minimum average temperature of 19 °C. The annual rainfall is 1,600 millimeters (mm), with lower rainfall from November to April, and higher rainfall from May to October.

To design an engineered landfill, it is important to determine the amount of waste in place, the types of solid present in the subsurface, the phreatic level, and the groundwater flow direction. The subsections below describe these properties of the Site.

5.2.1 Waste-in-Place Estimation

Waste in place estimation was estimated based on three reports provided by the Municipality:

- During a visit in February 2018, the waste in-place was estimated at 1.2 million tonnes.
- A study performed by the Climate and Clean Air Coalition (CCAC) reports the amount of waste disposed of in 2016 based on a per capita generation rate of 1.10 kg/day and a population of almost 250,000 people. Based on this estimate, the average daily disposal rate is 210 Mg/day.
- A waste intake survey performed from March 5 to 18, 2018, estimated an average daily disposal rate of 200 Mg/day.

The third of these reports (estimating an average of 200 Mg/day) was considered to be the most reliable, and was used to estimate waste in place.

In addition, a review of historical aerial images (from Google) was performed for the Site. These images show that waste started to be placed in the area in approximately June 2014. Given that data and an average rate of 200 Mg/day, close to 403,000 Mg of waste in place was estimated. Table 1 presents the estimated waste disposal acceptance rates until 2019. Estimations assumed project implementation would occur in 2019, and disposal in the proposed engineered landfill would start in early 2020.

Table 1. Estimated Waste Disposal History

Year	Annual (Mg)	Accumulated Waste (Mg)	Comments
2014	36,500	36,500	Disposal started June 2014
2015	73,000	109,500	Assume disposal rate at 200 Mg/day
2016	73,000	182,500	Assume disposal rate at 200 Mg/day
2017	73,000	255,500	Assume disposal rate at 200 Mg/day
2018	73,000	328,500	Assume disposal rate at 200 Mg/day
2019	74,460	402,960	Assume 4% annual disposal increase

Note: This estimate is consistent with the daily waste disposal estimate reported in the CCAC report.

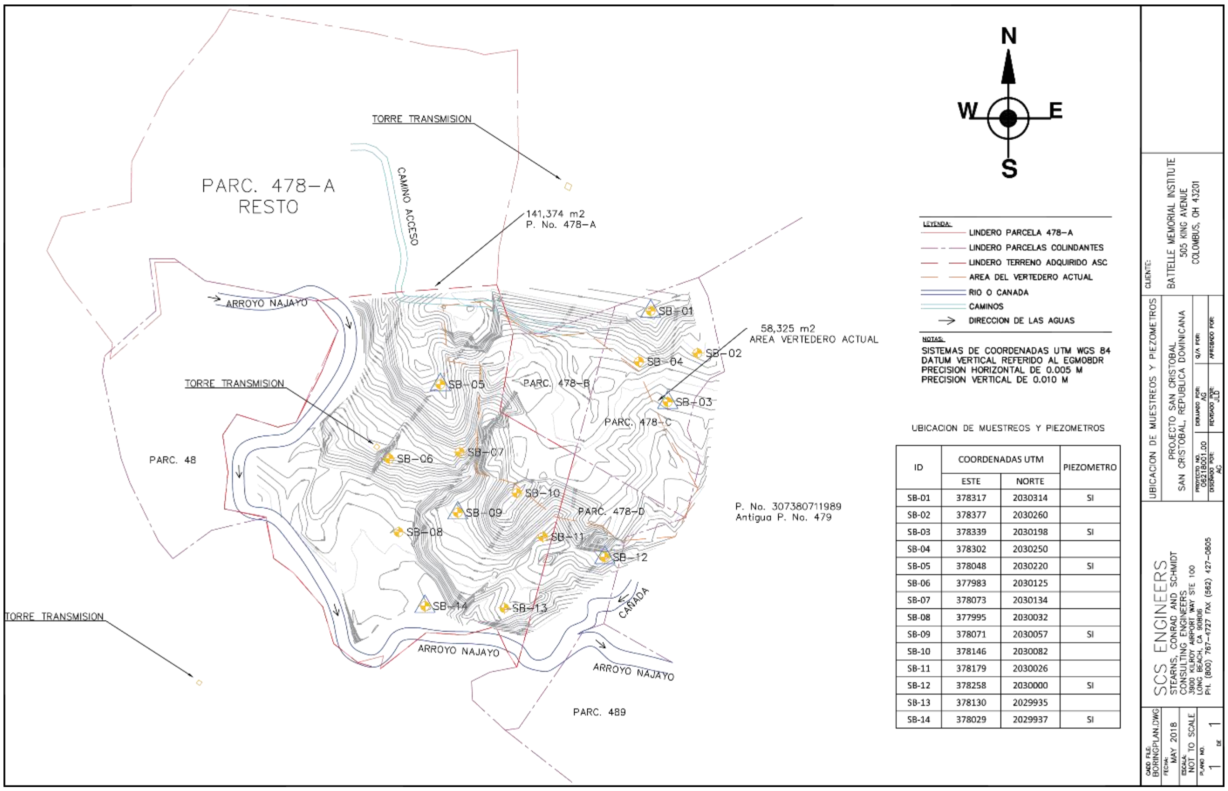
5.2.2 Subsurface Exploration

The Site's subsurface was investigated to establish the soil's physical and engineering properties and groundwater phreatic level. Battelle contracted drilling and geotechnical laboratory testing services to HCSA, which carried out drilling and field activities under the supervision of SCS Engineers between June 4 and 15, 2018. Field activities included:

- Drilling 14 hollow-stem auger borings (SB-01 through SB-14) to various depths while performing standard penetration tests (SPTs) at 1.5 m depth intervals; collecting undisturbed samples at various boring depths using a split spoon sampler for material visual classification and laboratory testing.
- Installing six standpipe piezometers for groundwater phreatic level measurements and slug tests.
- Excavating 14 test pits to 2.4–3.0 m below the ground surface to collect bulk samples for laboratory testing.
- Conducting laboratory testing on select boring and bulk samples to characterize the subsurface materials. Tests included:
    - Grain size with hydrometer (ASTM D 422 and D 1140).
    - United Soil Classification System (USCS) soil classification (ASTM D 6913).
    - Natural moisture (ASTM D 2216).
    - Standard proctor moisture density relationship (ASTM D 698).
    - Atterberg limits (ASTM D 4318).
    - Flexible wall hydraulic conductivity—remolded sample (ASTM D 5084).
    - Consolidated undrained triaxial (ASTM D4767).
- Installing piezometers for groundwater phreatic level measurements.

- Performing in situ slug tests (ASTM D 4044) for the six installed piezometers.

The locations of the 14 borings (SB-01 through SB-14) and six piezometers (SB-01, 03, 05, 09, 12 and 14) are presented in Figure 2 (see Table 1 in Appendix B for details on each boring and piezometer). These locations, along with the drilling and sampling and laboratory testing protocols, were established to be representative of the subsurface conditions. Documentation and results from HCSA's drilling, sampling and laboratory testing performed are included in the Geotechnical Factual Report (see Appendix B).



ID	COORDENADAS UTM		PIEZOMETRO
	ESTE	NORTE	
SB-01	378317	2030314	SI
SB-02	378377	2030260	
SB-03	378339	2030198	SI
SB-04	378302	2030250	
SB-05	378048	2030220	SI
SB-06	377983	2030125	
SB-07	378073	2030134	
SB-08	377995	2030032	
SB-09	378071	2030057	SI
SB-10	378146	2030082	
SB-11	378179	2030026	
SB-12	378258	2030000	SI
SB-13	378130	2029935	
SB-14	378029	2029937	SI

Figure 2. Boring Locations

From the soil borings and laboratory testing, the subsurface is composed of the following layers:

- Topsoil.
- Clay/sand.
- Shale ("pizarra").

Table 2 summarizes the average results for the laboratory tests on soil samples in the project area.

Table 2. Summary of Laboratory Tests

Material	USCS	Depth Min (m)	Depth Max (m)	Gravel (%)	Sand (%)	Fines (%)	PL (%)	LL (%)	PI (%)	Max Density (kg/m³)	Optimum Moisture (%)	Natural Moisture (%)
Fat clay—high plasticity	CH	1.5	12.2	1	7	92	27	57	31	1,832	14	21
Clay—low plasticity	CL	1.5	7.6	1	21	78	21	41	20	1,962	10	20
Clayey gravel	GC	1.5	7.6	48	26	27	27	22	45	2,056	10	15
Shale	CH	9.1	24.4	1	6	94	94	27	60	1,861	14	17
Silty sand	SM	1.5	7.6	0	67	33	33	23	29	-	-	-

Table 3 summarizes the modified proctor compaction tests on the clay and shale soils.

Table 3. Summary of Compaction Tests

Material	USCS	Boring No.	Depth (m)	Max Density (kg/m³)	Optimum Moisture (%)
Shale	CH	SB-10	12.2	1,861	14.1
Lean clay with sand	CL	SB-01	1.8	1,920	10.5
Fat clay	CH	SB-04	2.1	1,815	15.6
Fat clay	CH	SB-05	3.0	1,861	16.0
Fat clay	CH	SB-06	2.4	1,806	16.1
Lean clay with sand	CL	SB-08	1.5	1,989	10.2
Fat clay	CH	SB-09	2.4	1,845	9.9
Lean clay	CL	SB-12	2.4	1,977	8.8
Clayey gravel	GC	SB-14	1.5	2,056	10.0

Table 4 summarizes the hydraulic conductivity tests on the clay and shale soils.

Table 4. Summary of Hydraulic Conductivity

Material	USCS	Boring No.	Depth (m)	Max Density (kg/m^3)	Optimum Moisture (%)
Fat clay	CH	SB-03	6.1	$4.5x10^{-7}$	10
Shale	CH	SB-05	15.2	$7.8x10^{-8}$	5
Fat clay	CH	SB-07	6.1	$7.3x10^{-7}$	10
Fat clay	CH	SB-08	7.6	$6.7x10^{-8}$	10
Fat clay	CH	SB-12	7.6	$8.9x10^{-8}$	10

Table 5 summarizes the consolidated undrained triaxial tests on the clay and shale soils.

Table 5. Summary of Triaxial Testing

Material	USCS	Boring No.	Sample	c' (kg/m^2)	f' (deg)
Fat clay	CH	SB-03	SH-1	128.9	31.7
Shale	CH	SB-10	SH-1	512.7	34.8

Table 6 summarizes the slug tests on the piezometers.

Table 6. Summary of Slug Test

Piezometer ID	K (cm/sec)
SB-01	1.13×10^{-006}
SB-03	3.66×10^{-007}
SB-05	2.33×10^{-007}
SB-09	1.50×10^{-007}
SB-12	1.40×10^{-007}
SB-14	1.17×10^{-005}

Groundwater was monitored at the six piezometers. Table 7 summarizes the groundwater monitoring measurements.

Table 7. Summary of Groundwater Measurements

ID	Northing (m)	Easting (m)	Ground Elevation (m)	Piezometer Groundwater Measurements from Ground Surface[1]					
				Jun-8 (m)	Jun-15 (m)	Jun-29 (m)	Jul-11[2] (m)	Jul-27 (m)	Aug-10 (m)
SB-01	2,030,314	378,317	83.3	-	4.0	3.9	3.6	3.9	3.7
SB-03	2,030,199	378,348	74	-	2.6	2.04	2.10	2.1	2.9
SB-05	2,030,232	378,046	78	3.7	3.1	2.5	2.0	2.2	3.3
SB-09	2,030,047	378,077	67.8	-	18.6	7.4	7.4	7.4	7.6
SB-12	2,029,999	378,258	68.2	-	5.4	5.59	5.58	5.6	6.2
SB-14	2,029,947	378,018	59.5	3.2	3.2	3.1	3.1	2.8	2.8

(1) Piezometers installed June 8–15, 2018.

(2) Day after rain storm.

Figure 3 shows a potentiometric surface interpolated from the groundwater measurements. The general groundwater flow direction is from north to south, ranging in elevation from 83 m in the northeast corner of the property to 50 m in the southern part of the property.

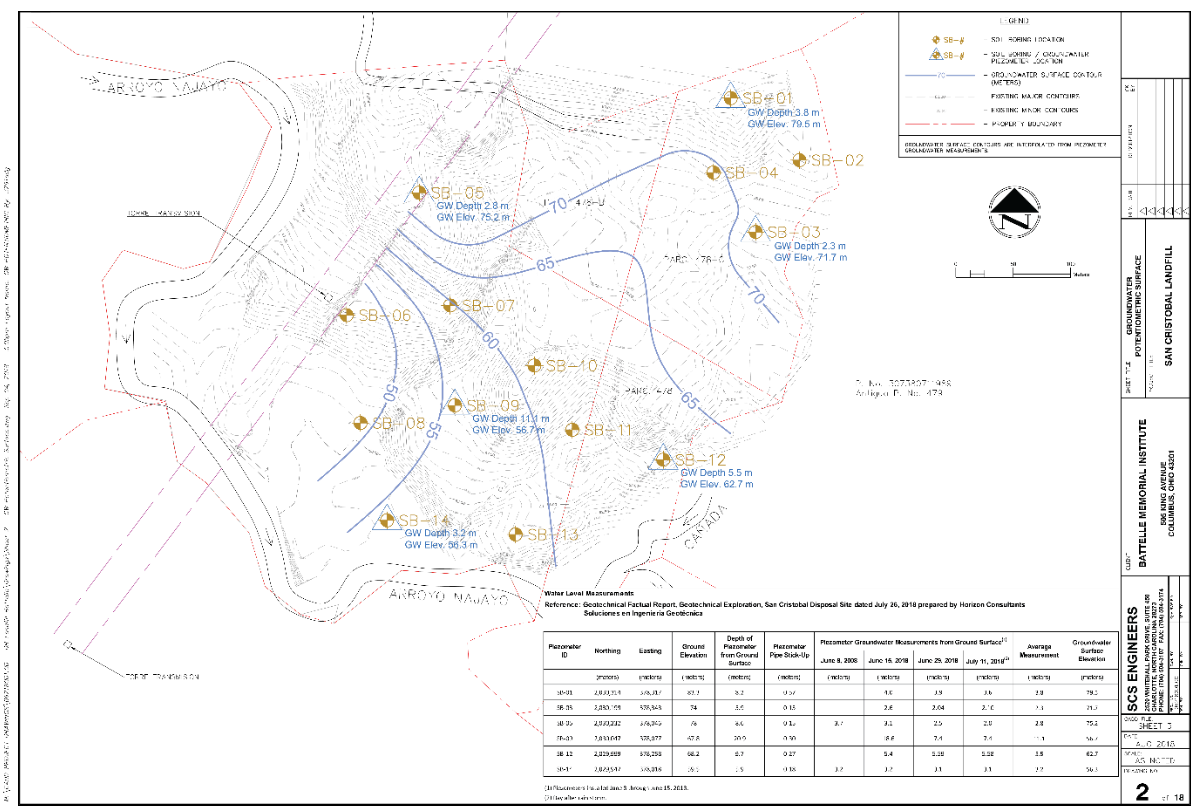


Figure 3. Groundwater Potentiometric Map

5.3 Expansion Options

The proposed engineered landfill waste limits were determined based on the following limiting factors:

- 15 m offset from the centerline of power lines.
- 20 m offset from Site property lines.
- 20 m offset from Arroyo Najayo.
- Away from the Arroyo Najayo flooding area.

After applying the limiting factors, the team determined that approximately 9.2 ha are available for the development of the proposed engineered landfill in five different cells.

In order to minimize cost on relocation of existing waste into the proposed engineered landfill, the first two cells would be located in areas with minimum or no impact of waste disposal. Areas of no or minimal waste impact are shown as Cells 1 and 2 in Figure 4. Cells 1 and 2 provide 2.53 ha for disposal of new incoming waste and relocation of existing waste.

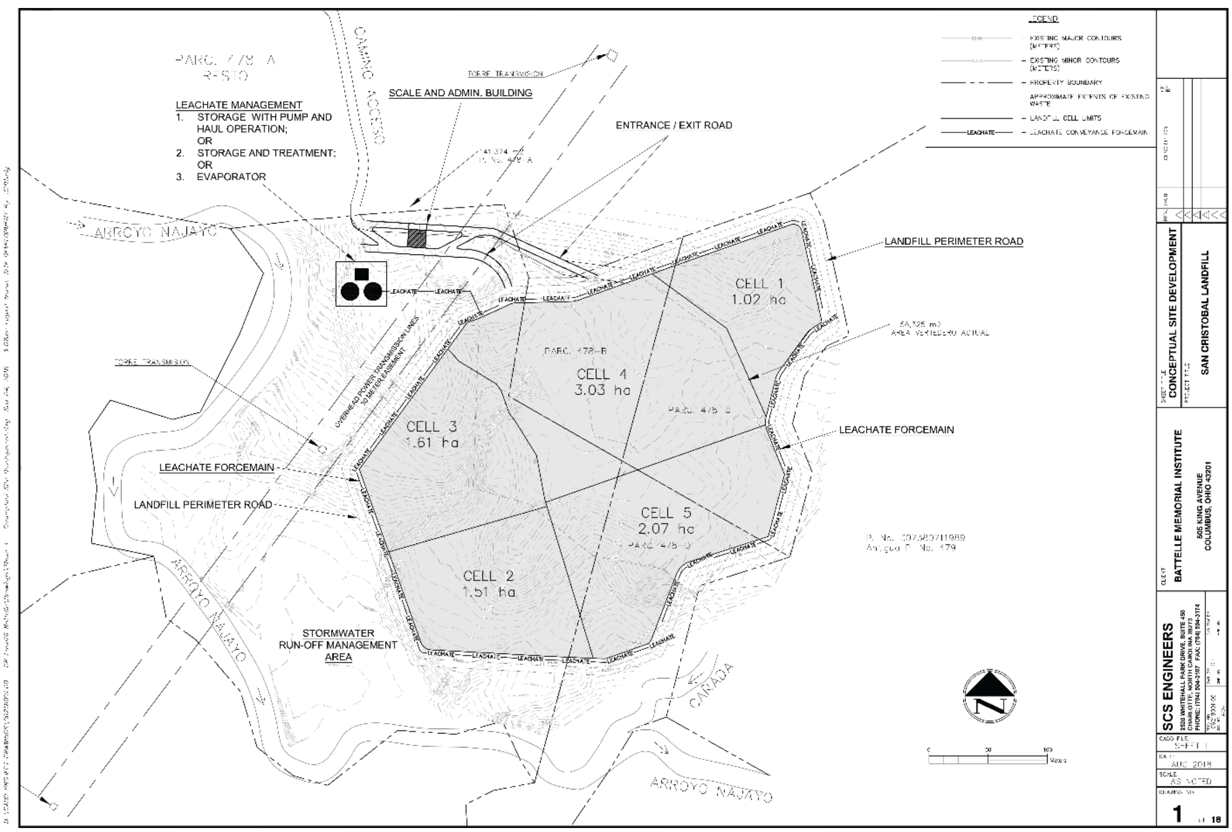


Figure 4. Conceptual Proposed Engineered Landfill Cell Layout

5.4 Conceptual Design

The conceptual design is to construct an engineered landfill that meets the current waste disposal needs, as well as relocation of existing waste from the existing dumpsite. To contain the waste, engineered systems are proposed for both the bottom liner system and a final cover system. Both are shown in Figures 5 and 6.

In addition, the proposed systems to support the proposed engineered landfill consist of a scale house, an administration building, an entrance checkpoint, perimeter roads, a stormwater storage pond, a leachate storage facility and a landfill management system.

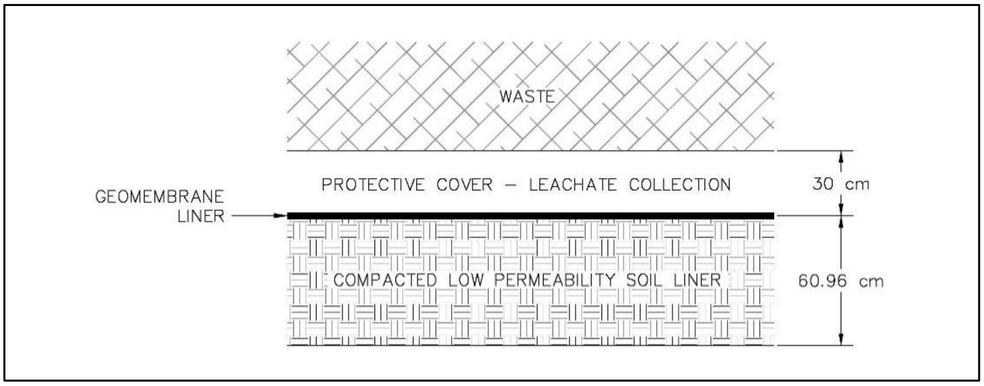


Figure 5. Bottom Liner System

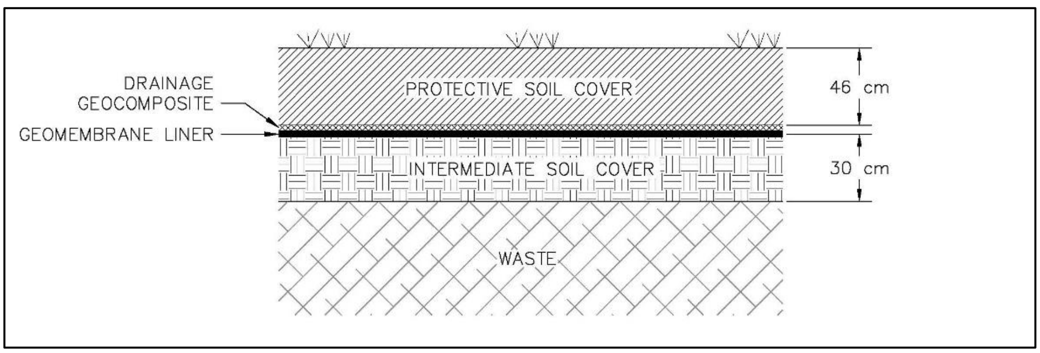


Figure 6. Landfill Final Cover System

5.5 Construction Sequencing

As the conceptual design drawings show (see Appendix C), the proposed engineered landfill is divided into five cells with a combined area of approximately 9.2 ha. To construct the proposed engineered landfill cells, existing waste would need to be moved in phases rather than all at once. The proposed engineered landfill construction and existing waste relocation sequence is as follows:

This sequence is dependent on the actual cell construction duration as well as the quantity and rate at which existing waste is moved to the constructed landfill cells.

As discussed in Section 5.2.1, the existing dumpsite's waste in place is estimated at 402,960 Mg. It is estimated that organic waste decay would reduce that amount by approximately 41% by July 2020, when waste transfer to the proposed engineered landfill begins. Continued decay of organic waste waiting to be excavated and transferred would reduce the total amount deposited into the proposed engineered landfill to 216,332 Mg (a 46% reduction of disposed waste) by 2023, when it is estimated that the transfer of all of the existing dumpsite waste would be completed. Table 8 presents the proposed engineered landfill development program.

Table 8. Proposed Engineered Landfill Development Summary

Cell ID	Area (ha)	Air Space (m^3)	Air Space(1) (Mg)	Estimated Existing Waste Relocation(1) (Mg)	New Waste Placement	
					Start	End
1	1.02	54,911	39,097		Jan-20	Jul-20
2	1.51	97,985	69,765	34,883	Aug-20	Dec-20
3	1.61	177,963	126,710	63,355	Jan-21	Oct-21
4	3.03	421,324	299,983	118,095	Nov-22	Jan-24
5	2.07	557,694	397,078	0	Feb-24	Sep-28
Total	9.24	1,309,877	932,633	216,332		

(1) It is estimated that half of the cells' capacity would be used to relocate existing waste, to provide room for new waste disposal.

5.6 Waste Transfer from Unlined Areas

The proposed engineered landfill Cell 1 would be used for disposal of new waste, while Cell 2 would be for relocation of existing waste for construction of Cell 3. Landfill Cells 3 and 4 would be for disposal of new incoming waste and for relocation of existing waste. It is estimated that existing waste transfer would end in 2023. Cell 5 would also be for disposal of new incoming waste only. It is estimated, based on the implementation year being 2019, that close to 216,332 Mg would need to be moved into the proposed engineered landfill over several years to permit receipt of new incoming waste.

5.7 Leachate Management

The following criteria provide the basis of the methodology and conceptual design for the leachate collection, storage and treatment for the proposed engineered landfill:

- LCS is adequately sized to maintain less than 30 cm of leachate depth on the landfill bottom system under normal operating conditions.
- New leachate storage tank(s) or ponds(s) can store the peak and average leachate volume generated from the proposed engineered landfill.
- To alleviate leachate production, the proposed engineered landfill is constructed in phases rather than all at one time. The landfill phases are separated by a temporary berm.
- Leachate is treated by evaporator equipment using heat generated from LFG combustion.

US EPA's Hydrologic Evaluation of Landfill Performance (HELP) model, version 3.07, was used in the evaluation of the proposed leachate collection and management system for the proposed engineered landfill. Components were evaluated using specific assumptions that represent a conservative approach using storm events and operating conditions that reflect both average and peak leachate generation.

5.8 Leachate Generation

The approach for estimating the average and peak leachate generation rates and corresponding maximum level of leachate buildup over the landfill bottom liner system uses the HELP model. The proposed landfill conceptual design was evaluated for four different possible landfill conditions to estimate leachate generation for average and peak flow conditions. The first, second and third conditions were simulations using 5 m, 15 m and 29 m of in-place waste. The fourth condition is a simulation using an in-place waste thickness of 29 m with a final cover system (cap). For the HELP model simulations, the average temperature and precipitation data similar to the Municipality along with estimated solar radiation and transpiration were used to model the climatic conditions for the Site.

Each of the conditions was simulated using the HELP model with the following landfill physical characteristics:

- 4.0% average bottom slope and a maximum drainage length of 45 m.
- Final cover surface slope of 25% and 38 m drainage length.
- Final top surface slope of 5% and 10 m drainage length.

The HELP model inputs for the landfill conditions evaluated are summarized in Tables 9 and 10.

In addition to estimating average and peak leachate generation rates using the HELP model, the team simulated a newly opened cell with no waste as a possible worst-case condition for the proposed landfill. This storm surge leachate flow generated from a newly opened cell with no waste was simulated using the rational formula *(Q = CIA)* and a rainfall intensity of 64 mm/hour for a 25-year, 60-minute duration storm event. The estimated volume of leachate produced from this rainfall intensity is based on a landfill cell area of 1 ha anticipated to be open for waste placement.

Table 9. HELP Model Inputs (During Operations)

Layer	Material	Layer Type	Thickness (cm)	Effective Saturated Hydraulic Conductivity (cm/sec)
1	Waste	Vertical percolation	500 1,500 2,900	1.0×10^{-3}
2	Bottom liner system protective cover/leachate collection	Lateral drainage	30	1.0×10^{-3}
3	Geomembrane liner	Flexible membrane liner	0.15	2.0×10^{-13}
4	Compacted low-permeability soil liner	Barrier	60.96	1.0×10^{-7}

Table 10. HELP Model Inputs (Closure)

Layer	Material	Layer Type	Thickness (cm)	Effective Saturated Hydraulic Conductivity (cm/sec)
1	Protective soil cover—soil with vegetation	Vertical percolation	15	4.2×10^{-5}
2	Protective soil cover—soil	Vertical percolation	31	4.2×10^{-5}
3	Drainage geocomposite	Lateral drainage	0.50	10
4	Geomembrane liner	Flexible membrane liner	0.10	4.0×10^{-13}
5	Intermediate soil cover	Vertical percolation	30	4.2×10^{-5}
6	Waste	Vertical percolation	2,900	1.0×10^{-3}
7	Bottom liner protective soil cover/leachate collection	Lateral drainage	30	1.0×10^{-3}
8	Geomembrane liner	Flexible membrane liner	0.15	2.0×10^{-13}
9	Compacted low-permeability soil liner	Barrier	30	1.0×10^{-7}

5.9 Leachate Generation Results

Tables 11, 12 and 13 summarize the results from the HELP model and storm surge simulations for the proposed engineered landfill.

Table 11. Summary of Leachate Generation Results for 1 ha Area

Landfill Operating Condition (Waste Depth)	Estimated Peak Daily Leachate Generation per Hectare (m^3/day)	Estimated Average Daily Leachate Generation per Hectare(1) (m^3/day)	Average Depth of Leachate on Landfill Bottom System (cm)
5 m	13	4	26.50
15 m	11	4	23.48
29 m	2	0.3	1.62
Closure	0	0	0

(1) HELP model annual average result divided by 365 days per year.

Table 12. Summary of Leachate Generation Results for Newly Open Cell (Storm Surge Condition)

Landfill Bottom Area *(A)*	Storm Intensity *(I)*	Run-Off Coefficient *(C)*	Storm Surge Flow ($Q = 0.278 \times C \times I \times A$)	Daily Storm Surge Volume
0.0304 km^2 (3.04 ha)	64 mm/hr	1.0	0.54 m^3/sec (540 liters/sec)	46,656 m^3 (15,347 m^3/ha)

5.10 Leachate Collection

The team estimated the hydraulic capacity of the leachate collection piping, as designed, for conveying the HELP-model-estimated peak daily leachate generation flow as shown in Table 11, as well as the calculated storm surge flow as shown in Table 12. The conceptual design for landfill leachate collection consists of 250 mm diameter perforated pipe surrounded by gravel placed in the longitudinal middle of each landfill cell, draining to a sump.

To calculate the hydraulic capacity for the proposed leachate collection pipe, the team used the Manning formula: $Q = (1.0/n) \times A \times R^{2/3} \times S^{1/2}$, where n is the coefficient of roughness (0.015), A is the cross-sectional area of the pipe, R is the hydraulic radius, and S is the slope of the hydraulic gradient (0.04 m/m). The pipe hydraulic capacity results are provided in Table 13.

Table 13. Leachate Collection Pipe Hydraulic Capacity

Pipe Diameter	Pipe Area *(A)*	Roughness Coefficient *(n)*	Hydraulic Radius[(1)] *(R)*	Pipe Slope *(S)*	Pipe Hydraulic Capacity
250	0.049 m^2	0.015	0.0625	0.04 m/m	0.11 m^3/sec

(1) Based on a full pipe.

The calculated leachate flow for the largest landfill bottom drainage area of 3.04 ha (30,400 m^2) and the maximum HELP model peak daily leachate generation of 13 m^3/day/ha is 0.00046 m^3/sec. The 250 mm diameter pipe is adequate to convey the anticipated peak daily leachate generation flow. However, it does not have the hydraulic capacity to convey the entire leachate flow generated during a storm surge from the largest newly open cell, meaning leachate would back up into the landfill bottom liner system. The leachate backup would drain over an estimated 3.9 days.

5.11 Leachate Pumping

The conceptual design for the proposed engineered landfill includes submersible electric pumps installed in each leachate collection sump, five in total, to remove leachate from the landfill bottom to an onsite leachate storage facility via a forcemain. Examples of submersible electric pumping systems specifically used for landfill applications are included in Appendix E.

The leachate pumps should be sized based on the greatest HELP model simulation peak daily leachate generation flow from Table 11, 13 m^3/day/ha, and the largest landfill cell bottom drainage area of 3.04 ha. Leachate production from the cell that is newly opened with none or minimal waste is when leachate production caused by precipitation is expected to be the highest. The volume of leachate generated from a newly open cell could reach 46,656 m^3/day or 0.54 m^3/sec (see Table 12).

A summary of the pumping evaluation results is included in Table 14. It is recommended that each sump contain a single electric pump capable of pumping at least 0.84 m^3/min. When a cell is newly opened for waste disposal and the possibility for leachate production caused by precipitation is evident, a larger temporary pump may be required to evacuate the leachate from the cell in a timely manner. For each installed submersible electric leachate pump, a replacement pump should be kept on site in case of pump failure or maintenance downtime.

Table 14. Leachate Pump Evaluation

Pumping Rate (One Pump) (m^3/sec)	Estimated Peak Daily Leachate Generation (m^3/sec) / Leachate Flow Daily Volume (m^3)	Leachate Collection Sump (Sump Volume = 50 m^3)		Pump Run-Time per 24 Hours (hrs)
		Sump Fill Time (min)	Sump Draw-Down Time (min)	
0.002	0.00046 39.74	30	417	7.0
0.004	0.00046 39.74	30	208	3.5
0.006	0.00046 39.74	30	139	2.3
0.008	0.00046 39.74	30	104	1.7
0.010	0.00046 39.74	30	83	1.4
0.012	0.00046 39.74	30	69	1.2
0.014	0.00046 39.74	30	59	1.0

5.12 Leachate Storage

The estimated peak daily leachate flow from the proposed engineered landfill is 31,847 m^3/day. The estimated average daily leachate flow is 37 m^3/day. These peak and average flows are based on waste filling scenarios expected to produce the maximum leachate production as shown in Tables 15 and 16.

The recommended leachate storage capacity for the proposed engineered landfill is 45 days for the estimated average daily leachate generation or 1,665 m^3. In the event of a peak daily leachate generation, additional resources would be required to transport and treat the additional leachate produced from the landfill.

Table 15. Leachate Storage Evaluation (Peak Daily)

Landfill Filling Scenario	Landfill Bottom Drainage Area (ha)	Estimated Peak Daily Leachate Generation per Hectare(1) (m^3/day)	Peak Leachate Volumes (m^3/day)
Cells 1, 2, 3 and 4 @ 15 m of waste	7.17	11	78.87
Cell 5 open cell	2.07	15,347	31,768
Total	9.24		31,847

(1) Based on HELP model and storm surge simulations.

Table 16. Leachate Storage Evaluation (Average Daily)

Landfill Filling Scenario	Landfill Bottom Drainage Area (ha)	Estimated Average Daily Leachate Generation per Hectare(1) (m^3/day)	Average Leachate Volumes (m^3/day)
Cells 1, 2, 3 and 4 @ 15 m of waste	7.17	4	28.68
Cell 5 @ 5 m of waste	2.07	4	8.28
Total	9.24		37

(1) Based on HELP model simulation results.

5.13 Landfill Gas Management

LFG is a natural byproduct of the decomposition of organic material in anaerobic (without oxygen) conditions. LFG contains roughly 50–55% methane and 45–50% carbon dioxide (CO_2), with less than 1% non-methane organic compounds and trace amounts of inorganic compounds.

When MSW is first deposited in a landfill, it typically undergoes an aerobic (with oxygen) decomposition stage during which little methane is generated. Then over time, anaerobic conditions are established and methane-producing bacteria begin to decompose the waste and generate methane. LFG emissions can produce environmental and safety issues if not managed properly. Methane is a greenhouse gas (23 times more potent than CO_2) that contributes to climate change and produces safety hazards, as it can ignite or even explode in certain conditions. LFG also causes odor problems in the surrounding areas.

Best management practices can be applied to successfully control LFG emissions and mitigate safety issues and its impact to the surrounding areas.

6.0 Proposed Engineered Landfill Improvement Plan

6.1 Estimated Proposed Engineered Landfill Life Expectancy

The proposed engineered landfill is expected to operate at an average waste disposal rate of 200–250 Mg/day. Operating 365 days/year, the annual disposal rate is estimated to be 73,000 Mg with a 2% annual growth rate. To calculate the estimated life of the proposed landfill airspace, an in-place density of 1,200 lb/yd^3 or 0.712 Mg/m^3 was used. The life expectancy would increase or decrease dependent on several factors, including waste characteristics, compaction of waste achieved during placement, and rate of waste decomposition.

The proposed engineered landfill has an estimated total available waste disposal airspace volume of 1,309,877 m^3. This was calculated using AutoCAD Civil 3D digital terrain models generated from the proposed landfill bottom and top of waste grades.

With an estimated landfill airspace volume of 1,309,877 m^3, a conservative disposal rate of 73,000 tonnes per year and an average in-place waste density of 0.712 Mg/m^3, it is estimated that the disposal capacity for the landfill would be reached in approximately 8.75 years. The capacity and life expectancy for the proposed landfill is summarized in Table 17.

Table 17. Proposed Engineered Landfill Capacity and Life Expectancy

Cell ID	Area (ha)	Air Space (m^3)	Air Space(1) (Mg)	Estimated Existing Waste(3) (Mg)	Start(2)	End(2)
1	1.02	54,911	39,097		Jan-20	Jul-20
2	1.51	97,985	69,765	34,883	Aug-20	Dec-20
3	1.61	177,963	126,710	63,355	Jan-21	Oct-21
4	3.03	421,324	299,983	118,095	Nov-21	Jan-24
5	2.07	557,694	397,078	0	Feb-24	Sep-28
Total	9.24	1,309,877	932,633	216,332		

(1) Airspace in Mg based on 0.712 Mg/m^3 in-place waste density. Airspace numbers are rounded to whole numbers.
(2) Assuming implementation of project during 2019 and disposal into landfill starts January 2020.
(3) Considers 46% waste reduction of after total decay of food waste.

Note that the life of the proposed engineered landfill could be extended by increasing the in-place waste density during waste compaction; a density of 0.8 Mg/m^3 can be provide a life of approximately 9.8 years and a waste in place density of 1.0 Mg/m^3 can provide a life to 12.25 years, almost three additional years of landfill life.

6.2 Conceptual Design

The area of the proposed engineered landfill is 9.24 ha, with a final waste grade at elevation 98 m. The proposed engineered landfill was divided into five phases with varied areas and intermediate waste grades dependent on the phased construction and operations approach.

Drawings showing the conceptual design for the proposed engineered landfill (see Appendix C) are listed as follows. The drawings show a reasonable depiction of Phase 1–5 construction, at final grade, and at intermediate waste fill grades. In general, the drawings include plans and details for:

- Permanent and temporary access roads.
- Perimeter and interior interim berms.
- Landfill bottom containment system.
- Leachate collection and management.
- General stormwater management.
- LFG collection and control system (GCCS).

Table 18 presents a list of the conceptual design drawings (see Appendix C).

Table 18. Proposed Engineered Landfill Conceptual Design Drawings

Drawing	Description
0	Cover sheet
1	Conceptual site development

Table 18. Proposed Engineered Landfill Conceptual Design Drawings

Drawing	Description
2	Groundwater potentiometric surface
3	Conceptual landfill development
4	Conceptual landfill closure plan
5	Landfill profiles
6	Leachate management
7	Cell 1 subgrade plan
8	Cell 1 top of waste and cell 2 subgrade plan
9	Cell 1 and 2 top of waste and cell 3 subgrade plan
10	Cell 1, 2 and 3 top of waste and cell 4 subgrade plan
11	Cell 1, 2, 3 and 4 top of waste and cell 5 subgrade plan
12	Cell 1–5 top of waste
13	Stormwater management details
14	Landfill details
15	Landfill details
16	Landfill details
17	Landfill details

6.3 Capping

Once the proposed engineered landfill has reached final waste grades, an engineered final cover system will be installed. Its main purpose is to prevent the infiltration of precipitation into the waste mass, minimizing leachate production. It also provides a barrier between the waste and the public and environment and increases LFG collection efficiency. The proposed system's layers, from top to bottom, are:

- 46 cm of geosynthetics protective cover soil, with the top 15 cm capable of supporting native plant growth.
- Geosynthetics consisting of a drainage geocomposite having a minimum hydraulic conductivity of 10 cm/sec and a 1 millimeter (mm) linear low-density polyethylene (LLDPE) liner.
- 30 cm of intermediate soil cover placed over the in-place waste before placement of the geosynthetics. The intermediate soil cover should consist of low-permeability soils placed to protect the integrity of the geosynthetics from the underlying waste.

See Figure 7 below for an illustration.

The final cover system should be placed on a slope of no less than 5% to promote positive stormwater drainage. The maximum slope is 33% (the conceptual design has a maximum slope of 25%), to promote both static and seismic stability of the landfill final cover system and waste mass. Details for the final cover system are provided in Drawing 1 of the conceptual design drawings (see Appendix C).

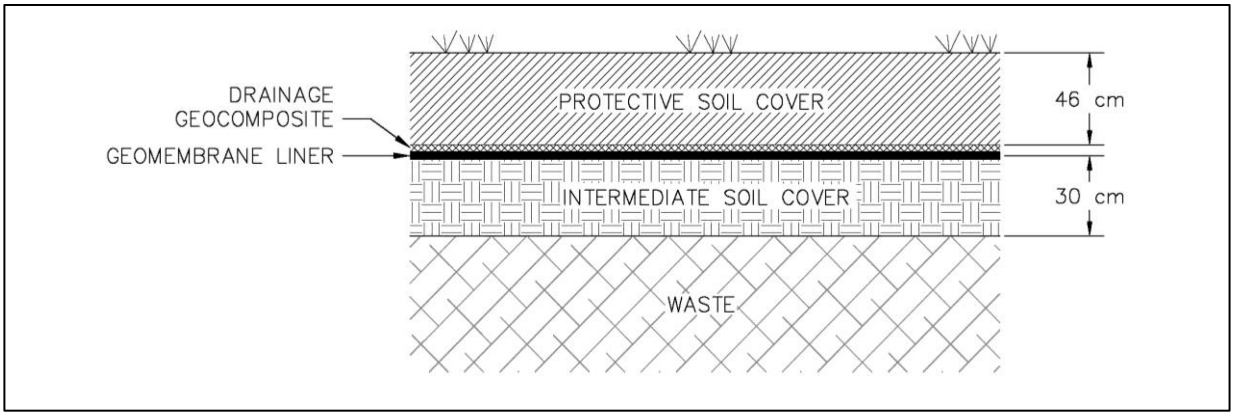


Figure 7. Landfill Final Cover System (Cap)

6.4 Slope Stability Evaluation

As shown in Drawing 5 (see Appendix C), slope stability was modeled for two cross-sections using PCSTABL5M: the west–east (W–E) section and the south–north (S–N) section. The cross-sections are aligned perpendicular to the proposed final grading slopes.

Shear strength properties of the sanitary waste were based on practical experience and on review of published literature on solid waste properties and values applied in similar municipal solid waste materials. Shear strength of the soil materials and geosynthetic materials proposed for the Site are based on the soil classification and standard proctor test results, as well as the team's familiarity and experience with similar soil/geosynthetic materials used in the past. Table 19 presents the assumed values for each of the parameters and material types used in the slope stability analysis.

Table 19. Assumed Geotechnical Properties

Material Type	Description	Total Weight (kN/m^3)	Saturated Weight (kN/m^3)	Cohesion/ Adhesion (kPa)	Friction Angle (Degrees)	Comments
1	Foundation soil	18.6	22.4	25.0	35.0	Estimate only
2	Structural fill	17.7	21.7	0.0	32.0	Estimate only
3	Final cover	17.0	17.0	0.0	28.0	Assume one layer
4	MSW	7.0	7.0	12.0	30.0	Average values based on SCS experience
5	Bottom liner system interface	17.0	17.0	0.0	21.0	Assume values of interface shear strength between textured geomembrane and clayey soil

The recommended minimum safety factors for the conditions analyzed were taken from US EPA's *Technical Guidance Manual for Design of Solid Waste Disposal Facilities*. The minimum factor for static loading conditions is 1.5 and the minimum factor for the seismic or pseudo-static loading conditions (such as during an earthquake event) is greater than or equal to 1.0.

The proposed final slope along the W–E section is at 1(V):4(H), or 25% slope. The maximum waste height is about 30 m and the perimeter berm height from the sump is 5 m. Based on published seismic hazard map for the Santo Domingo area, the peak ground acceleration at 2% of exceedance in 50 years is 0.40g.

For the W–E section, the static safety factor was calculated to be 2.87 and the seismic safety factor was calculated to be 1.01 under circular failure mode. The calculated factors are greater than the minimum requirement recommended by US EPA, indicating that the slope evaluated is stable under the conditions used in the analysis. For the block-type failure surface along the interface of the bottom liner system, the static factor was calculated to be 2.37 and the seismic factor was calculated to be 0.79. This static factor is greater than US EPA's minimum recommended requirement, indicating that the slope evaluated is stable; however, since the seismic factor is less than 1.0, a permanent displacement evaluation was performed using Newmark's Permanent Displacement Chart.

Assuming an earthquake with a magnitude of 8.25 and using a yield acceleration of 0.28g when the safety factor is equal to 1.0, it was found that the permanent displacement calculated using Newmark's chart ranges from 4 to 13 cm, with an average of 7 cm. This is less than 30 cm, in accordance with industry standards.

For the S–N section, the static safety factor was calculated to be 2.97 and the seismic safety factor was calculated to be 1.01 under circular failure mode. These calculated factors are greater than the minimum requirement recommended by US EPA, which indicates that the slope evaluated is stable. For the block-type failure surface along the interfaces of the bottom liner system, the static factor was calculated to be 2.32 and the seismic factor was calculated to be 0.74. This static factor is greater than US EPA's minimum recommended requirement, which indicates that the slope evaluated is stable; however, since seismic factor is less than 1.0, a permanent displacement evaluation was performed using Newmark's chart.

Assuming an earthquake with a magnitude of 8.25, and using a yield acceleration of 0.26g when the safety factor is equal to 1.0, it was found that the permanent displacement calculated using Newmark's chart ranges from 7 to 23 cm, with an average of 12 cm. This permanent displacement is less than 30 cm in accordance with industry standards.

Although the static safety factor calculated is above the recommended value of 1.50, and assuming that the leachate collection system is in-place, constant removal of leachate head to maintain less than 0.3 m head above the liner during landfill operation is recommended.

The results of the global slope stability analysis indicate that the proposed final waste fill slopes are stable under the conditions analyzed. It should be noted that in most landfill cell construction in the US, it is preferable to use a textured high-density polyethylene (HDPE) liner on the cell floor because of easier installation, less welding, and enhanced quality control/quality assurance during construction.

6.5 Surface Water Management and Erosion Control

Stormwater collection and management is important during landfill construction and operations to minimize soil erosion and to minimize the generation of leachate created by stormwater infiltration through the landfill final and intermediate soil cover. It is important that the landfill have adequate slopes and precipitation run-off collection and management features (ditches, benches, pipes, storage basins, etc.) to avoid ponding of water and excessive soil erosion.

The conceptual design drawings (see Appendix C) include a general layout and details for stormwater conveyance and management features recommended to be incorporated into construction and operation. Further stormwater run-off and conveyance analysis is recommended prior to construction and landfill operations to refine the quantity, layout, geometry and sizes for the stormwater conveyance and management features. Recommended stormwater conveyance and management features include:

- Temporary and permanent ditches (channels) and pipes to convey stormwater run-off from the landfill with a longitudinal slope between 3% and 6% and sideslopes no greater than 25% to lessen the possibility of channel erosion. In addition, to assist in alleviating channel erosion, temporary matting along with grass seeding is recommended to be incorporated in ditch (channel) construction as well as riprap being placed in high flow or velocity areas.

- Landfill sideslope benches to collect and convey stormwater run-off from the landfill, approximately 5 m wide and placed along the landfill slope every 12 m in elevation. It is recommended that the benches have a longitudinal slope between 3% and 6%. These benches can be constructed in the waste with soil cover or constructed of compacted soil placed on the landfill sideslope, also known as tack-on berms.
- Placement of downslope drain pipes at low points along sideslope benches and at locations along the bench as needed to promote conveyance of stormwater from the landfill. These pipes should be secured to the landfill at sufficient intervals with a soil mass or with other methods.
- Storage basins to accumulate stormwater conveyed from the landfill and release it over time, and to assist in the removal of sediment and other contaminants from stormwater run-off. The basin should have enough volume to store the stormwater volume generated from the estimated peak run-off from landfill. Its flow length should be at least twice its width to promote settlement of sediment and contaminants from the collected stormwater run-off. Discharge from a basin is through a principal spillway which can either be a riser pipe or concrete structure with orifice(s) surrounded by gravel and connected to an outlet solid pipe or through a weir constructed of riprap and gravel. The recommended minimum pond storage is 252 m^3/ha draining to the pond and a detention time of 24–48 hours. See Figure 8 for a schematic of a typical stormwater storage basin.

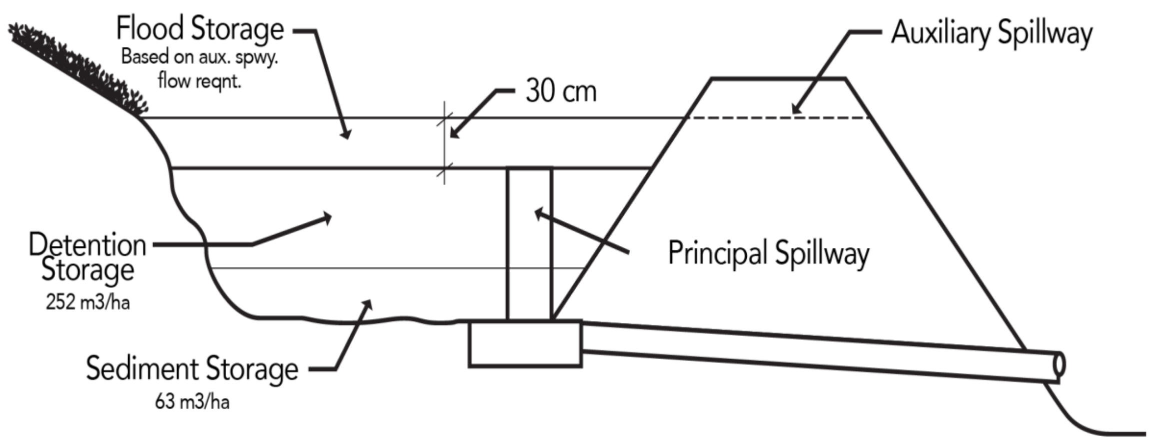


Figure 8. Schematic of Typical Stormwater Storage Basin

6.6 LFG Management

6.6.1 LFG Generation and Recovery Projections

A LFG generation and recovery projections analysis was performed for the proposed engineered landfill. The analysis provides estimates of LFG generation from the existing dumpsite and LFG generation and recovery potential from the proposed engineered landfill. The report assumes that the implementation of the project would occur in 2019.

Background on the SCS International Model

SCS developed a proprietary international LFG model that employs a first-order decay equation for estimating LFG generation based on annual waste disposal rates, the amount of methane that 1 tonne of waste produces (L_0 value), and the rate at which waste decays and produces LFG (k value). The model k and L_0 variables were developed based on waste composition data and climate information. Data used for developing model input parameters are discussed below.

The model uses the same input variables and is similar to the US EPA's Landfill Gas Emissions Model (LandGEM). The most significant difference between the models is the assignment of multiple k and L_0 values in the model. While the simple (single k and L_0) first order decay equation used in LandGEM is appropriate for modeling US landfills, this approach does not adequately model LFG generation at landfill sites in developing countries—mainly due to their very different waste composition and site conditions, which create different patterns of waste decay and LFG generation over time. Such models have the inherent assumption that average waste decay rates do not vary over time. This assumption creates significant error when modeling landfills with a high percentage of food waste because LFG productivity declines over time as food waste is consumed and only slowly decaying materials remain.

The SCS model employs separate modules with different k and L_0 values that separately calculate LFG generation from the different waste components. This "multi-phased" first-order decay model approach recognizes that the significant differences in the types of waste disposed of in developing countries require changes to the model structure as well as to the values of the input variables. A similar approach has been adopted by the Intergovernmental Panel on Climate Change (IPCC), which published a landfill methane generation model in 2006 that applies separate modules for four different waste categories.

6.6.1.1 LFG Recovery Scenarios

Three LFG recovery scenarios were developed that reflect different levels of effort and amounts of resources available to install and operate an effective GCCS. The three scenarios all assume the following:

- The proposed engineered landfill would receive all wastes delivered to the Site starting in January 2020.
- Wastes from the existing dumpsite would be excavated and moved to the proposed engineered landfill between July 2020 and early 2023, according to the schedule shown in Table 1.
- A GCCS would be installed at the proposed engineered landfill and begin operating in 2022. The LFG collection system would be installed initially in Cells 1, 2 and 3, and be expanded annually while the proposed engineered landfill continues to receive waste.
- The proposed engineered landfill would be designed to limit leachate accumulation in the waste mass, and ongoing efforts would be undertaken to manage leachate accumulation in the extraction wells, including installing and operating de-watering pumps in the wells.
- The proposed engineered landfill would close in 2028, and a final cover would be installed and completed by 2030.

The three scenarios are defined as follows.

- The **"mid-range" recovery scenario** assumes the following:
  - A moderate level of skill and effort is employed in the implementation of the new GCCS, ongoing improvements to the collection system, and its O&M (e.g., including wellfield monitoring and adjustment at least twice per month).
  - A moderate degree of success is achieved in managing leachate accumulation.
- A **"high" recovery scenario** assumes the following:
  - A high level of skill and effort is employed in the implementation of the new GCCS, ongoing improvements to the collection system, and its O&M (e.g., including wellfield monitoring and adjustment at least once per week).
  - A high degree of success is achieved in managing leachate accumulation.
- A **"low" recovery scenario** assumes the following:
  - A relatively low level of skill and effort is employed in the implementation of the new GCCS, ongoing improvements to the collection system, and its O&M (e.g., including wellfield monitoring and adjustment at least once per month).
  - Efforts to manage leachate accumulation would achieve mixed results, and elevated liquid levels in extraction wells would limit their effectiveness.

6.6.1.2 LFG Model Input Assumptions

Waste Disposal Rates

The existing Site began operations in June 2014. Disposal rates have averaged approximately 200 Mg/day for an estimated annual rate of 73,000 Mg/year through 2018. A total of about 300,000 Mg of waste has been disposed of, as of August 2018. After 2018, waste disposal is projected to increase by 2% per year, based on the projected annual population growth rate. Waste disposal in the Site is projected to amount to 74,460 Mg in 2019. Under the proposed engineered landfill construction project, the existing dumpsite would close at the end of 2019.

All delivered wastes starting in January 2020 would be disposed of in the proposed engineered landfill. Waste disposal would continue at the Site from 2020 until the estimated Site capacity of 932,630 Mg is reached. Wastes would be excavated from the existing dumpsite starting in July 2020 and transferred to the proposed engineered landfill. It is assumed that the waste transfer from the existing dumpsite and deposition in the proposed engineered landfill would occur at the same annual rate as waste disposal, until all of the waste in the existing dumpsite has been removed. Based on the historical and projected waste disposal rates from 2014 to 2019, a total of 402,960 Mg would have been placed in the existing dumpsite at closure. Of this disposed amount, it is estimated that organic waste decay would reduce the amount of waste remaining in the existing dumpsite by approximately 41% by July 2020, when waste transfer to the proposed engineered landfill begins. Continued decay of organic waste remaining in the existing dumpsite waiting to be excavated and transferred would reduce the total amount deposited into the proposed engineered landfill to 216,332 Mg (a 46% reduction of disposed waste) by 2023, when it is estimated that the transfer of all of the existing dumpsite waste would be completed.

Table 20 shows the historical and projected future waste disposal rates for the existing dumpsite and proposed engineered landfill. Specifically, it lists:

- Cumulative amounts of waste disposed in the existing dumpsite at the end of each year (also listed in Table 1).

- Annual amounts of waste to be transferred from the existing dumpsite to the proposed engineered landfill.
- Amount of waste remaining in the existing dumpsite after accounting for organic waste decay and transfer to the proposed engineered landfill.
- Cumulative amounts of waste disposed of in the proposed engineered landfill and transferred from the existing dumpsite to the proposed engineered landfill at the end of each year.

Based on the estimated capacity of the proposed engineered landfill, the projected waste disposal rates, and the estimated amounts of waste transferred from the existing dumpsite to the proposed engineered landfill from 2020 to 2023, it is estimated that the proposed engineered landfill capacity of 932,630 Mg would be reached in mid-2028.

Table 20. Historic and Projected Future Waste Disposal Rates

Year	Existing Dumpsite				Proposed Engineered Landfill	
	Disposal Rate (Mg/yr)	Cumulative Total Waste Disposed (Mg)	Amount of Waste Transferred from Dump (Mg)	Total Waste Remaining After Decay and Transfer to Landfill (Mg)	Disposal Rate (Mg/yr)	Cumulative Total Waste Disposed Of and Transferred (Mg)
2014	36,500	36,500	0	35,566	0	0
2015	73,000	109,500	0	100,577	0	0
2016	73,000	182,500	0	155,412	0	0
2017	73,000	255,500	0	203,458	0	0
2018	73,000	328,500	0	246,892	0	0
2019	74,460	402,960	0	288,544	0	0
2020	0	402,960	36,758	218,526	75,950	112,528
2021	0	402,960	77,470	118,239	77,470	267,468
2022	0	402,960	79,020	23,265	79,020	425,508
2023	0	402,960	23,265	0	80,600	529,372
2024	0	402,960	0	0	82,210	611,582
2025	0	402,960	0	0	83,850	695,432
2026	0	402,960	0	0	85,530	780,962
2027	0	402,960	0	0	87,240	868,202
2028	0	402,960	0	0	64,430	932,632

Waste Composition

The rate and volume of LFG produced in a disposal site depends on the characteristics of the waste (moisture content, composition, and age) and a number of environmental factors, including the presence of oxygen in the waste mass, waste moisture, pH and temperature. The more organic waste present in a landfill, the more LFG is produced by methane-generating bacteria during decomposition. Rates of waste decay and LFG generation vary significantly with waste age and organic waste types, so that recently buried waste containing a high percentage of food waste would be much more productive than older waste with only slowly decaying materials remaining after the food waste has been consumed. The estimated composition of wastes disposed at the Site, based on available data (primarily from Santo Domingo), is shown in Table 21.

Table 21. Estimated Waste Composition

Waste Type	Percentage (%)
Food waste	36.3
Green waste	18.8
Paper	11.8
Textiles	1.3
Rubber/leather	1.0
Toilet paper	1.0
Plastics	17.8
Glass, ceramics, and debris	9.3
Metals	2.6
Other inorganic waste	0.1
Total	100

Based on the available waste composition data, the estimated organic content of disposed wastes is approximately 70%. For LFG modeling purposes, the organic waste is divided into three categories based on the estimated rate of waste decay and LFG generation:

- Fast-decay organic waste, including food waste, a portion of the vegetative waste, and toilet paper.
- Medium-decay organic waste, including paper and textiles.
- Slow-decay organic waste, including a portion of the vegetative waste, rubber, and leather.

Model k Values

Based on the precipitation rate and estimated waste moisture conditions at the proposed engineered landfill, model k values of 0.45, 0.073 and 0.038 per year were assigned for the fast, medium and slowly decaying organic waste fractions, respectively.

Methane Correction Factor

The IPCC recommends accounting for aerobic conditions in landfills by applying a “methane correction factor” (MCF) that varies from 0.4 (60% reduction in LFG generation for very shallow dumpsites) to 1.0 (no reduction for managed landfills). A MCF of 0.8 is recommended for unmanaged sites over 5 m deep.

The existing dumpsite would be assigned a MCF of 0.8 based on the IPCC classification system. However, the excavation of waste from the existing dumpsite and placement in the proposed engineered landfill would cause a large increase in aerobic waste decay during the period the waste is exposed to the air, until it is buried in the proposed engineered landfill. Due to this increase in aerobic decay, a MCF of 0.5 was applied to waste disposed of in the existing dumpsite from 2014 to 2019, which is equivalent to a 50% reduction in the L_0 values assigned based on waste composition (listed below).

For wastes disposed of in the proposed engineered landfill starting in July 2020 (excluding wastes moved from the existing dumpsite), a MCF of 1.0 was applied (no deduction for aerobic decay).

Model L_0 Values

Waste composition data were used to estimate L_0 values for the three waste categories listed above, based on the fraction of degradable organic carbon for each waste type. Separate L_0 values were calculated for the different waste categories. The L_0 values are as follows:

- Fast-decay waste: 74 m^3/Mg.
- Medium-decay waste: 179 m^3/Mg.
- Slow-decay waste: 185 m^3/Mg.

As noted above, an MCF of 0.5 was applied to waste disposed of before July 2020 in the existing dumpsite (and transferred to the proposed engineered landfill) to account for aerobic decay, which has the effect of reducing the L_0 values for the organic portion of this waste by 50%. The fraction of waste consisting of inert materials (e.g., construction and demolition waste, metals, plastics, glass and ceramics) was assigned an L_0 value of 0 as it is not expected to contribute to LFG generation. The relatively low L_0 value for fast-decay waste is largely due to the higher moisture content in food wastes (water being inert).

Collection System Efficiency

Three LFG recovery projections were developed to reflect a range of achievable collection efficiencies that vary depending on the level of effort and amount of resources available to operate the GCCS. Collection efficiency assumptions under the following 3 recovery projections:

1. The mid-range projection assumes that collection efficiency would be 40% in 2022, 50% in 2023, and 55% from 2024 until after the proposed engineered landfill closes. Collection efficiency is assumed to increase to 58% in 2032, and reach a maximum of 60% in 2033 after a final cover is installed. The mid-range recovery scenario is considered to be the best estimate of likely recovery and is recommended for use in an economic evaluation.

2. The low recovery projection assumes that collection efficiency would be 25% in 2022, 35% in 2023, and 40% from 2024 until after the proposed engineered landfill closes. Collection efficiency is assumed to increase to 43% in 2032, and reach a maximum of 45% in 2033 after a final cover is installed. The low recovery estimates is considered to be conservative and should be employed only if a large margin of safety is needed.

3. The high recovery projection assumes that collection efficiency would be 50% in 2022, 60% in 2023, and 65% from 2024 until after the proposed engineered landfill closes. Collection efficiency is assumed to increase to 68% in 2032, and reach a maximum of 70% in 2033 after a final cover is installed. The high recovery estimates are considered to be ambitious and attainable only if the maintenance of an optimal GCCS is considered to be a top priority.

In addition to the potential variability in collection efficiency and the level of O&M, mathematical modeling of LFG is inherently uncertain. The project team considered and tried to account for this modeling uncertainty in selecting the values for the high and low recovery scenarios when projecting LFG recovery rates. These low and high recovery projections should not be considered as minimum and maximum values, but as a likely range assuming the installation of a relatively comprehensive GCCS and other assumptions listed above.

6.6.1.3 LFG Model Results

LFG generation and recovery projections are presented in greater detail in Appendix D. Tables A-1 and A-2 in Appendix D provide the LFG model results, including:

- Annual disposal estimates and “waste-in-place” values.

- Projected LFG generation rates through 2040 (in m^3/hour and ft^3/minute).
- The k values used for the fast, medium and slowly decaying waste organic fractions.
- The L_0 values calculated for the fast, medium and slowly decaying organic waste fractions (not including the 50% reduction applied to waste disposed prior to July 2020).
- Projected collection efficiency (in %) and LFG recovery rates (in m^3/hour and ft^3/minute) under the low, mid-range and high recovery scenarios.

Table 22 below presents projected LFG recovery in 2022–2040 under mid-range, low and high recovery scenarios. LFG generation and recovery is projected to continue declining after 2040.

Table 22. Projected LFG Recovery Rates

Year	Mid-Range Recovery (m^3/hr)	High Recovery (m^3/hr)	Low Recovery (m^3/hr)
2022	196	245	123
2023	289	347	202
2024	356	421	259
2025	389	459	283
2026	417	493	303
2027	442	523	322
2028	466	551	339
2029	426	503	310
2030	332	392	241
2031	264	312	192
2032	230	270	171
2033	203	237	152
2034	178	207	133
2035	159	185	119
2036	144	168	108
2037	132	154	99
2038	123	143	92
2039	114	133	86
2040	107	125	80

Note: Projected LFG recovery rates are in m^3/hr, adjusted to 50% methane.

6.6.1.4 Model Limitations and Disclaimer

This report was prepared in accordance with the care and skill generally exercised by LFG professionals, under similar circumstances, in this or similar localities. No warranty, expressed or implied, is made as to the professional opinions presented herein. Changes in the landfill property use and conditions (for example, variations in rainfall, water levels, landfill operations, final cover systems, or other factors) may affect future gas recovery at the proposed engineered landfill. The quantity or quality of available LFG is not guaranteed.

6.6.2 Well Field Design and Layout

The initial step in performing a GCCS design is to lay out the location of the extraction wells. The wells should be placed at a sufficient density throughout the proposed engineered landfill to efficiently collect LFG. The spacing (or horizontal distance) between the wells is determined by the "radius of influence" (ROI). The ROI defines an area from which gas can be extracted without introducing excessive air into the waste mass. Detailed drawings showing the layout of the GCCS are found in Appendix C.

6.6.2.1 Well Vacuum

The amount of vacuum applied to each well directly affects the ROI. The pipe sizes set in the next section provide for at least 250 mm of water column vacuum to be available at each well.

6.6.2.2 Well Drilling Depth and Diameter

Limits on the drilling equipment available make it necessary to evaluate how deep and how wide the boreholes can be made. Typically, in Latin America, a well of 20 m depth and 60 cm diameter is technically and economically feasible.

Gas wells are generally designed to have a minimum of 6 m of solid pipe from the landfill surface down. After this, the rest of pipe length is perforated to allow the gas to flow into the pipe for collection. If the perforated sections are placed at depths shallower than 6 m from the landfill surface, the induced vacuum on the well can draw excessive amounts of air (specifically oxygen) into the refuse and potentially cause a condition of subsurface oxidation or landfill fire.

The base of gas wells must maintain a minimum distance of 3 m off the top to the bottom liner system in order to avoid penetration during well drilling/installation. Prior to construction, the actual landfill base grades should be carefully checked against the well schedule to make sure that the elevations shown in the schedule are accurate. If the base grade elevation is not known with much certainty, the 3 m buffer between the liner system and bottom of the well should be increased by the engineer as appropriate.

6.6.2.3 Radius of Influence

The factors that influence a well's ROI include the depth of the well, the length of slotted pipe provided for gas collection, and the amount of vacuum applied to the well. The movement of LFG through refuse is essentially the movement of a fluid through a porous medium.

The intersection of the ROIs of two adjacent wells is called the overlap. The degree to which the ROIs of the entire wellfield intersect is called the overlap factor. A target overlap range of 15–20% typically provides a reasonable coverage of the landfill area requiring control without over-stressing the landfill by installing too many wells. Since the system at this landfill may be used for power generation, the maximum allowable ROI was set at 40 m (2.85 times the length of the perforated pipe) to ensure conservative well coverage.

Once the GCCS reaches its final phase, the wellfield will consist of 67 vertical extraction wells. Wells would be installed and extended in three different phases.

6.6.3 Extraction Well Design

6.6.3.1 Well Construction

After the design depth is reached, the borehole would be backfilled with 30 cm of gravel. The slotted or perforated sections of pipe can then be lowered into the hole. When the slotted or perforated pipe length has been reached, solid sections are added until the pipe is raised above the ground surface.

The pipe would then be centered in the borehole, and gravel added around the outside until it has reached the depth shown on the plans. Soil backfill and a bentonite plug are then added, as shown on the plans, until the fill extends to the landfill surface. The borehole should be slightly overfilled and compacted to help minimize settlement of the well area which could result in collecting water around the well.

Lastly, the well is temporarily capped off until the header line is installed. This prevents emissions of raw LFG to the atmosphere. After the header line has been brought to the well, the wellhead assembly is installed. A drawing showing typical GCCS well construction is found in Appendix C.

6.6.3.2 Well Casing

The well pipe would be constructed of 150 mm diameter SDR-11 HDPE pipe. This material has proven to exhibit excellent compatibility with landfill materials so that it would resist corrosion and good chemical resistance. It provides enough flexibility that the well would have less of a chance of being broken during landfill settlement. HDPE also performs adequately under the temperatures generated within landfills. The gravel or crushed rock layer would consist of non-calcareous material (calcareous rocks can partially dissolve when exposed to leachate or landfill moisture).

6.6.3.3 Wellhead

The wellhead design must allow for system monitoring and control. Sampling ports must allow for the measurement of differential pressure for the calculation of gas flow values from each individual well. The wellhead must contain a valve which allows variable rates of vacuum to be applied to the system. Sampling ports must be strategically located so that LFG quality from the well can be measured. A permanent temperature probe must be placed on the well to measure LFG temperatures. A flexible hose connects the well to the header in order to allow differential settlement between the well and header. A pre-fabricated wellhead is shown on the conceptual plans. Field fabricated wellheads could be an option as long as they provide adequate means for measuring all parameters stated before. In addition, during the final design, the wellhead size should be examined to determine if a larger wellhead (up to 76 mm as opposed to 50 mm) should be selected to allow for larger gas flows. Figure 9 shows a typical LFG wellhead.

Figure 9. LFG Wellhead

6.6.4 Header And Lateral Pipe Design

The next step in designing a gas collection system is to lay out a route for the header line and laterals to connect each of the gas wells into the system, and convey the collected gas to a central location for destruction. After the design engineer has routed the most efficient header system for collecting gas from the extraction wells, the header pipe must be sized appropriately to convey the maximum expected gas flow. Typical design criteria, the typical method for sizing the header pipe, and typical header construction are discussed in this section.

6.6.4.1 Header Slope

All proposed header pipes outside the waste limits were designed to have a slope of not less than 0.5% in natural ground toward each condensate sump. Since the headers would be above ground in most parts of the Site, any settlements or low spots should be much easier to spot and correct.

6.6.4.2 Header Pipe Sizing

The velocity of the gas should be approximately 12.0 m/sec when gas flow is concurrent with condensate flow. If gas flow is countercurrent to condensate flow, the velocity should be approximately 6.0 m/sec. Flow conditions within any segment of header line should not consistently exceed the velocity limitations. Undersizing of the header pipe can cause excessive pressure losses throughout the system, which reduces gas collection efficiency. In some cases, pipe would be oversized to provide alternate gas pathways; in these cases the velocities may be even less than the guideline previously mentioned. A header pipe of 305 mm of diameter will be sufficient to carry out the maximum LFG flow.

6.6.5 Header Construction

The header pipe proposed for installation is HDPE pipe. HDPE pipe is ideal due to its compatibility with LFG and waste, its flexibility (if settlement occurs), its long-term stability, and its excellent chemical resistance. The pipe would be fusion-welded and placed above ground (except at condensate sumps, traps and road crossings). Steel rebar or some other method should be used to keep the pipe from “snaking” due to expansion and contraction associated with temperature changes. All pipes should be pressure-tested and any leaks repaired before the pipe is put into service. At all road crossings, the pipe would be protected by a section of corrugated metal pipe or other suitable material. Typically the protective casing is two pipe sizes larger than the gas line.

Control valves are located throughout the collection header network. The valves can manually shut off the applied vacuum to a particular section of header pipe. This allows portions of the well field to be isolated for monitoring and maintenance purposes.

6.6.6 Condensate Management

Once the GCCS wells and header line have been designed, the next step in the design process is to locate the condensate management/storage structures. Gas condensate is produced during the collection and transportation of LFG. The condensate must be removed at engineered low points in the extraction system header piping, or it would eventually fill up the header lines and impede gas flow. The header collection system alignment is designed to use the vertical relief provided by the landfill contours for gravity flow of condensate. Conceptual-level condensate management techniques are provided in the following subsections. It should be noted that, as a conceptual-level design, any final system must fully designed prior to construction to ensure efficient condensate management and collection.

To simplify condensate management at the proposed engineered landfill, the conceptual design includes nine condensate sumps at strategic points in the header pipe. An additional sump (for a total of ten) is included at what would be the low point in the entire system, off the landfill and at blower/flare station. This sump will collect the final condensate before the gas enters the condensate knockout and blower/flare system. It can also be used to collect drainage from the control device and knockout. The pump in this sump may be pneumatic or electrical. The conceptual plans (see Appendix C) show the discharge line from this pump as being installed in the header trench until it is 30 m past a high point in the header, at which point it discharges into the header line and flows to a condensate trap. This discharge line should be double-contained.

An option to explore would be to discharge condensate from the sumps into the leachate main, which would transport leachate to the leachate storage tanks prior to treatment. This could be less expensive than using a dedicated condensate pipe.

6.6.7 Control Equipment

6.6.7.1 Blower Equipment

The GCCS must be designed to handle the maximum expected gas flow rate from the entire area of the proposed engineered landfill that warrants control, over the intended use period of the GCCS equipment. Since the blower equipment is responsible for providing the vacuum that actually extracts the gas from the wellfield and moves it through the system, the sizing of the blower is crucial. Typically, equipment with two or more redundant blowers is required. For the final design, the appropriate size and number of blowers for the final system configuration will need to be determined. Figure 10 shows a typical LFG skid showing a knockout and blower.

Figure 10. Typical LFG Skid

The blower equipment must provide a uniform vacuum over a wide range of flow rates, since gas flow volumes would vary over the life of the GCCS. In the final design, it must be configured to accommodate the maximum and minimum flows that the blowers would need to handle.

In addition to being able to move the flow of LFG collected by the system, the blower must be capable of supplying sufficient negative pressure to overcome pressure drops and resistance through piping and equipment at the maximum gas flow rate, as well as supplying sufficient positive pressure for delivery of the collected gas to the control device for combustion.

Based on the low recovery scenario projections, the blower equipment would be required to handle the maximum expected gas flow rate of 1,500 m^3/hr upon construction of the final phase of the overall system. The number, configuration and types of blowers would be determined during the actual construction design, as they would need to be compatible with the control device requirements.

6.6.7.2 Control Device

The last consideration in designing a gas collection system is to size and select a control device for LFG. The control device can be an open or enclosed flare, a power generating facility that combusts the LFG to generate electricity, or a combination of these options. It is anticipated that an electricity generation project is implemented. Therefore, Table 23 provides the requirements for control devices, blower/flare equipment, and the recommended energy plant that should be considered at the conceptual level.

Table 23. Proposed Energy Plant Size and Major Control Equipment

Year of Operation	Low Recovery Scenario		Medium Recovery Scenario		High Recovery Scenario	
	Recom. Plant Size (MW)	Blower/ Flaring Needs (m^3/hr)	Recom. Plant Size (MW)	Blower/ Flaring Needs (m^3/hr)	Recom. Plant Size (MW)	Blower/ Flaring Needs (m^3/hr)
2023	0.5	350	0.6	500	0.8	550
2024	0.5	350	0.6	500	0.8	550
2026	0.5	350	0.6	500	0.8	550

Any enclosed combustion device (enclosed flare or power generating engines) should be selected to reduce volatile organic compounds by at least 98 weight-percent or reduce the outlet concentration of those compounds to less than 20 parts per million by volume, dry basis, as hexane at 3% oxygen. This reduction efficiency should be established by an initial performance test not less than 180 days after initial startup. It is critical that the control device configuration be able to meet all requirements at the GCCS's maximum anticipated flow rate of 1,500 m^3/hr. Since the proposed engineered landfill's collection and control system is constructed in phases, the control device must be carefully considered at all times so that it can adequately combust the maximum or minimum flows that it might receive. Figure 11 shows a typical LFG enclosed flare.

Figure 11. LFG Enclosed Flare

Lastly, the control device must be equipped to adequately address all desired testing, monitoring, reporting and recordkeeping needs. These needs typically include flow and temperature monitoring for all enclosed combustion devices, an auto-dialer when the system goes down, and LFG quality monitoring equipment for energy generation. Again, this aspect of the system should be carefully designed and specified during final design prior to construction.

Table 24 provides a list and quantities for major material and equipment project items. These items were estimated based on the low LFG recovery scenario and a proposed schedule for the installation/expansion of the GCCS. Conceptual design drawings for the GCCS are provided in Appendix C.

Table 24. List of GCCS Major Design Elements

GCCS ELEMENT	Phase I 2023	Phase II 2024	Phase III 2026
Vertical extraction well	32	20	15
Header piping (m)	800	380	365
Lateral piping (m)	1000	430	550
Condensate sump	3	1	0
Isolation valve	5	2	0
Blind flange	2	2	0
Road crossing	2	1	0

6.6.8 Landfill Gas to Energy Project

Based on the LFG generation and recovery projections, a landfill gas to energy (LFGE) project of 0.6 MW is sustainable under the mid-range scenario from 2024 thru 2030. The mid-range scenario is a conservative scenario that can be achieved with good operation and proper maintenance of the GCCS.

The investment cost for an LFGE project is about USD 2.5 million/MSW, plus a further cost depending on the interconnection point. At 0.6 MW, this project will thus cost about USD 1.5 million plus the cost of interconnection to the grid. This study did not investigate the latter; further study will be needed to estimate that cost.

Figure 12 illustrates the collection and processing of LFG and shows potential end uses of LFG including industrial/institutional uses, arts and crafts, pipeline gas, and vehicle fuel.

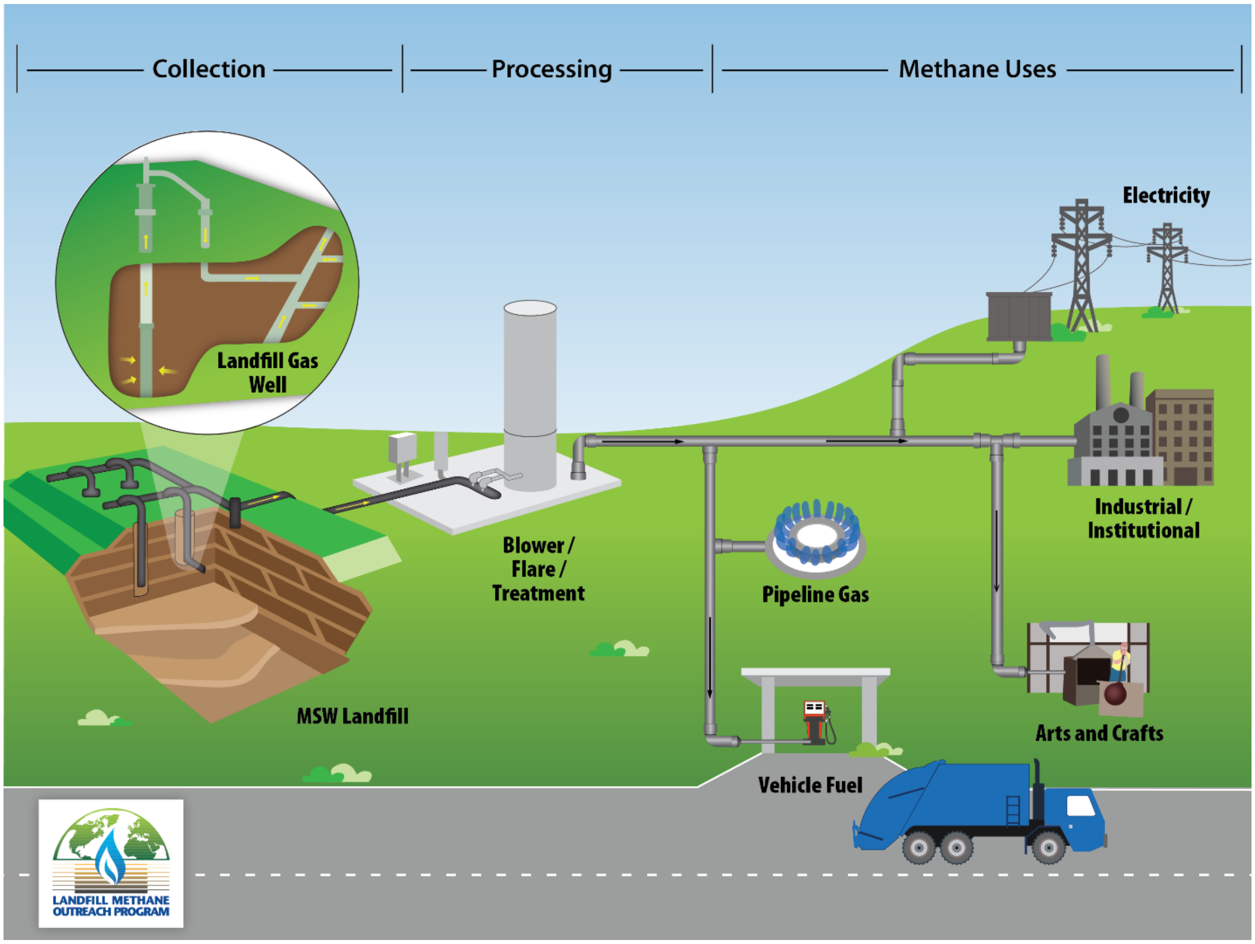


Figure 12. LFG Collection, Processing and Energy End Uses

Source: US EPA Landfill Methane Outreach Program.

6.7 Monitoring

To preserve the integrity of the proposed engineered landfill and environment, monitoring is recommended during operations and after the closure, consisting of:

- Groundwater and LFG monitoring.
- Landfill post-closure final cover inspections and maintenance

A site-specific groundwater and LFG monitoring program should be implemented and maintained for the proposed engineered landfill throughout landfill operations and the post-closure care period, typically 30 years. The program will monitor the groundwater and surface water at the Site on a semi-annual basis and verify that the landfill is functioning as intended, as well as provide an early warning system in the unlikely event of a release. If contamination is found in the groundwater or surface water, the action required would be determined at that time, based on the extent and concentration of the release. Copies of all required monitoring tests and reports will be provided to the Site operating record.

Groundwater monitoring parameters, sampling frequencies and reporting requirements will need to be developed, listed in the Site's groundwater monitoring plan, and followed by technicians conducting the monitoring. The groundwater monitoring wells identified therein would require sampling during landfill operations and during the post-closure care period.

Each time water levels are measured or a groundwater sample is collected, the integrity of the monitoring well will be inspected. A record of each inspection will be made and kept within the Site operating record. The following would be recorded during each inspection:

- Check well identification and make sure it is clearly marked.
- Check the protective casing for damage or corrosion.
- Check the concrete surface seals for cracks.
- Check the casing lock.
- View the well casing and check for damage.

If any damage is detected, the well will be repaired; if repair is not possible, it will be replaced before the next scheduled sample event.

Inspection of the final cover system will take place quarterly. It will consist of a field survey of the entire final cover system. Items of concern to be noted by the inspector include, but are not limited to, settlement, subsidence and signs of erosion. Following each inspection, a summary report of the condition of the final cover and the items requiring repair or maintenance will be recorded on an inspection form and filed in the post-closure log book for the Site. Areas that require further attention should be photographed and delineated on a map of the facility and attached to the inspection report. Since post-closure inspection personnel would most likely change during the post-closure period, the post-closure log book should be kept in a standardized format as part of the operating record of the facility so that new inspection personnel can easily review the results of past post-closure inspections of the Site.

Action should be taken immediately to address any items of concern identified during the inspection. Obvious repair items should be performed under the supervision of the post-closure maintenance manager.

Maintenance required for the final cover is anticipated to be minimal. The vegetative cover would be maintained as required.

6.7.1 Groundwater Monitoring

The monitoring program should monitor the groundwater by the collection of samples from the installed wells and laboratory testing for constituents listed in Table 25.

Table 25. Groundwater Monitoring Detection Constituents

Common Name	CAS RN
Antimony	(Total)
Arsenic	(Total)
Barium	(Total)
Beryllium	(Total)

Table 25. Groundwater Monitoring Detection Constituents

Common Name	CAS RN
Cadmium	(Total)
Chromium	(Total)
Cobalt	(Total)
Copper	(Total)
Lead	(Total)
Nickel	(Total)
Selenium	(Total)
Silver	(Total)
Thallium	(Total)
Vanadium	(Total)
Zinc	(Total)
Acetone	67-64-1
Acrylonitrile	107-13-1
Benzene	71-43-2
Bromochloromethane	74-97-5
Bromodichloromethane	75-27-4
Bromoform; tribromomethane	75-25-2
Carbon disulfide	75-15-0
Carbon tetrachloride	56-23-5
Chlorobenzene	108-90-7
Chloroethane; ethyl chloride	75-00-3
Chloroform; trichloromethane	67-66-3
Dibromochloromethane; chlorodibromomethane	124-48-1
1,2-dibromo-3-chlorpropane; DBCP	96-12-8
1,2-dibromoethane; ethylene dibromide; EDB	106-93-4
o-dichlorobenzene; 1,2-dichlorobenzene	95-50-1
p-dichlorobenzene; 1,4-Dichlorobenzene	106-46-7
trans-1,4-Dichloro-2-butene	110-57-6
1,1-dichloroethane; ethylidene chloride	75-34-3
1,2-dichloroethane; ethlyene dichloride	107-06-2
1,1-dichloroethylene; 1-1-dichloroethene; vinylidene chloride	75-35-4
cis-1,2-dichloroethylene; cis-1,2-dichloroethene	156-59-2
trans-1,2-dichloroethylene; trans-1,2-Dichloroethene	156-60-5
1,2-dichlorpropane; propylene dichloride	78-87-5
cis-1,3-dichlorpropene	10061-01-5
trans-1,3-dichlorpropene	10061-02-6
Ethylbenzene	100-41-4
2-hexanone; methyl butyl ketone	591-78-6
Methyl bromide; bromomethane	74-83-9
Methyl chloride; chloromethane	74-87-3
Methylene bromide; dibromomethane	74-95-3
Methylene chloride; dichloromethane	75-09-2

Table 25. Groundwater Monitoring Detection Constituents

Common Name	CAS RN
Methyl ethyl ketone MEK; 2-Butanone	78-93-3
Methyl iodide; Iodomethane	74-88-4
4-Methyl-2-pentanone; methyl isobutyl isobutyl ketone	108-10-1
Styrene	100-42-5
1,1,1,2-tetrachloroethane	630-20-6
1,1,2,2-tetrachloroethane	79-34-5
Tetrachloroethylene; tetracholorethene; perchloroethylene	127-18-4
Toluene	108-88-3
1,1,1-trochlorethane; methylchloroform	71-55-6
1,1,2-trichloroethane	79-00-5
Trichloroethylene; trichlorethene	79-01-6
Trichlorofluoromethane; CFC-11	75-69-4
1,2,3-trichloropropane	96-18-4
Vinyl acetate	108-05-4
Vinyl chloride	75-01-4
Xylenes	1330

Groundwater monitoring must be performed periodically and all records must be kept.

6.7.2 LFG Monitoring

The monitoring program should include periodic monitoring of LFG within the proposed engineered landfill property. The monitoring must be designed to identify possible migration of LFG outside the proposed engineered landfill property or if there are concentrations exceeding the lower explosive limit within the property.

Quarterly measurements must be performed in all enclosed structures and around the proposed engineered landfill by monitoring gas quality in the installed LFG probes. Figure 13 shows a technician using a portable analyzer attached to the wellhead to sample LFG. The detection level for methane gas migration at the property boundary is 15% by volume and 5% by volume within any structures.

If methane exceedances are detected in the structures and/or within property limits, corrective actions must be taken to protect human health and safety. Records of these monitoring events must be kept, in addition to all corrective actions taken to mitigate the issue.

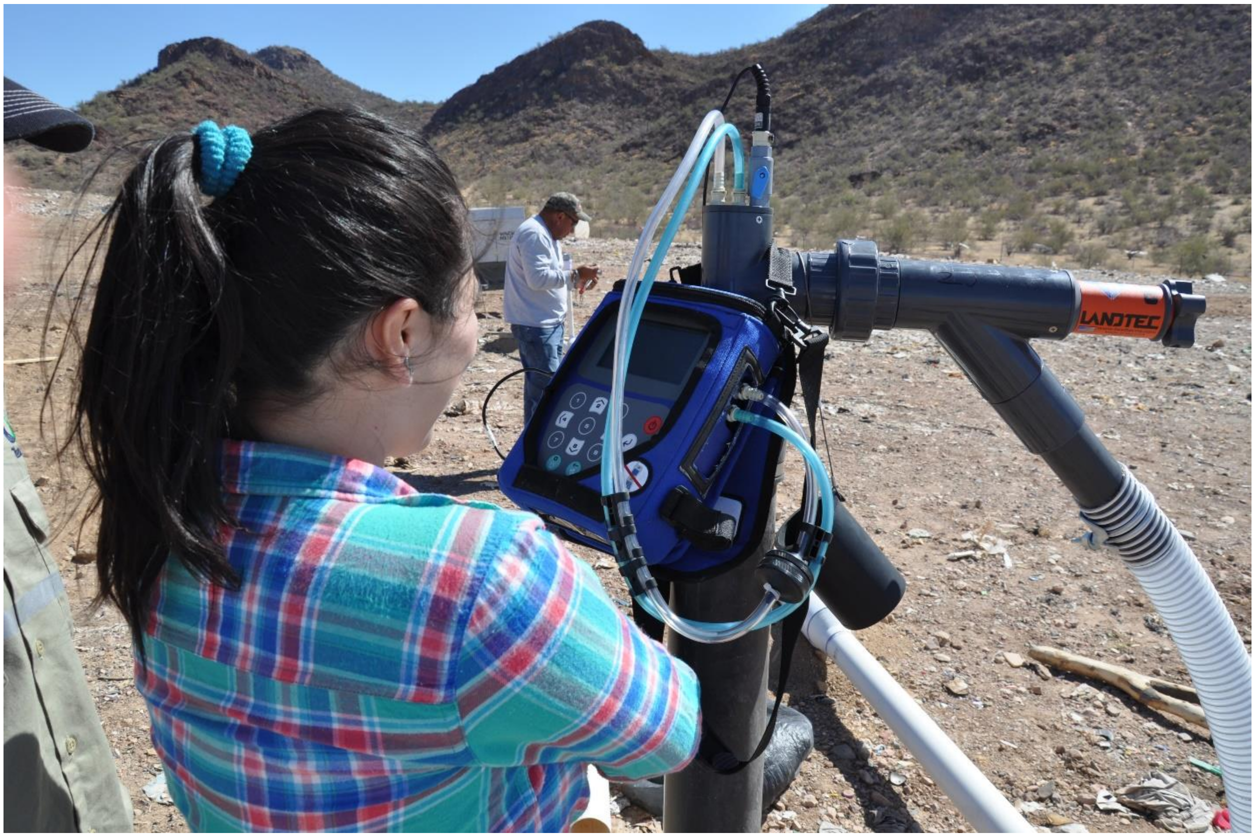


Figure 13. LFG monitoring

7.0 Cost Estimates

Project cost was estimated using costs for similar projects developed by SCS in the US and abroad. Typical costs published by US EPA and the Global Methane Initiative (GMI) were also used. The sources used were as follows:

- LFG Collection System Price Calculator (developed and maintained by SCS) using cost from construction projects.
- *Economic Impact Analysis for the Proposed New Subpart to the New Source Performance Standards,* Table 2-4, "Typical Cost Per Acre for Components of Landfill Construction," June 2014.
- *LFG Energy Project Development Handbook,* Section 4, Project Economics and Financing Section, Table 4-3, "LFG Electricity Project Technologies."

7.1 Conversion/Expansion Plan to Engineered Landfill

Estimated costs to construct the different phases of the proposed engineered landfill are summarized in Table 26 and provided in detail in Appendix D.

Table 26. Summary of Costs for Conversion/Expansion Plan

Item	Capital Cost Total (USD)	Phase I Cell 1-2 (USD)	Phase II Cell 3 (USD)	Phase III Cell 4 (USD)	Phase IV Cell 5 (USD)
Earthwork	$ 3,390,566	$ 944,948	$ 667,045	$ 1,234,140	$ 544,434
Geosynthetics	$ 435,040	$ 120,380	$ 76,060	$ 141,380	$ 97,220
Stormwater management	$ 53,420	$ 40,350	—	$ 12,500	$ 570
Leachate management	$ 1,364,600	$ 1,151,480	$ 67,875	$ 17,510	$ 127,735
Miscellaneous	$ 1,695,126	$ 1,118,695	$ 181,479	$ 194,166	$ 200,786
Subtotal	$ 6,938,752	$ 3,375,853	$ 992,459	$ 1,599,696	$ 970,744
5% contingency	$ 346,938	$ 168,793	$ 49,623	$ 79,985	$ 48,537
Total construction cost	$ 7,285,689	$ 3,544,646	$ 1,042,082	$ 1,679,680	$ 1,019,282
Cost per ha	$ 788,495				

Costs are in USD and based on average costs in the southeastern US.

7.2 Closure

Estimated costs to construct a final cover system on the proposed engineered landfill are summarized in Table 27 and provided in detail in Appendix D.

Table 27. Summary of Estimated Closure Cost

Item	Estimated Cost (USD)
Earthwork	$ 884,088
Geosynthetics	$ 1,282,989
Stormwater management	$ 454,229
Miscellaneous	$ 392,491
Construction cost subtotal	$ 3,014,838
5% contingency	$ 150,742
Total construction cost	$ 3,165,580
Cost per ha	$ 342,595

Costs are in USD and based on average costs in the southeastern US.

7.3 GCCS

Estimated costs to construct the GCCS on the proposed conceptual design are provided in USD and were developed based on average costs of similar projects in the US. Table 28 summarizes the estimated cost per project phase.

Table 28. Summary of GCCS Estimated Cost per Phase

Item	Phase I 2023	Phase II 2024	Phase III 2026
Engineering	$ 35,000	$ 35,000	$ 35,000
Mobilization	$ 6,500	$ 6,500	$ 6,500
Vertical extraction well	$ 340,480	$ 212,800	$ 159,600
Header piping (m) 300mm Ø	$ 96,432	$ 45,805	$ 43,997
Lateral piping (m) 12mm Ø	$ 42,189	$ 18,141	$ 23,204
Condensate sump	$ 61,425	$ 20,475	—
Isolation valve	$ 19,688	$ 7,875	—
Blind flange	$ 1,000	$ 1,000	—
Road crossing	$ 1,800	$ 900	—
Blower/flare station (550 m^3/hr)	$ 356,000	-	—
Subtotal	$ 960,514	$ 348,496	$ 268,301
Contingency 5%	$ 48,026	$ 17,425	$ 13,415
Total	$ 1,008,539	$ 365,921	$ 281,716

Costs are in USD and based on average costs in the southeastern US.

7.4 Post-Closure

The team estimated costs to provide post-closure care to the final cover system, gas and leachate management, environmental monitoring, and general care of the existing facilities on the proposed engineered landfill. The estimated post-closure care costs for a 30-year period are summarized in Table 29 and provided in greater detail in Appendix D.

Table 29. Summary of Estimated Post-Closure Cost

Item	Annual Cost (USD)	30-Year Cost (USD)
Administration and recordkeeping	$ 5,000	$ 150,000
Groundwater monitoring	$ 14,400	$ 432,000
Methane gas monitoring	$ 840	$ 25,200
Mowing vegetation	$ 428	$ 12,825
Final cover (cap) maintenance	$ 523	$ 15,675
Stormwater management	$ 300	$ 9,000
Leachate management	$ 8,378	$ 251,334
LFG management	$ 38,667	$ 1,160,000
Landfill inspections	$ 10,000	$ 300,000
Annual cost	$ 78,536	
30-year post-closure care cost		$ 2,356,034

Costs are in USD and based on average costs in the southeastern US.

8.0 Contracting and Investment Guidance

8.1 Contracting with the Private Sector

Public authorities around the world have developed different contracting models for the development, construction and operation of sanitary landfills. Based on the specific local economic conditions, the technical capacity of the local authority, and overall plans and goals for MSW, the Municipality would have to make the final decision on the type of contract(s) used for these purposes. This section briefly introduces the most common types of contracts and agreements for landfill development, construction and management. See Appendix A for a list of contracting resources.

8.1.1 Concession

Concessions are a type of contract in which a private company or consortium is selected through a competitive process to provide services for a fee. The private company would finance the development of the landfill and retains ownership for the length of the contract; the Municipality would be responsible for paying a previously negotiated tipping (gate) fee for every ton of waste disposed of at the landfill. This fee is typically set to be sufficient for the company to recoup depreciation on their investment, generate sufficient return on investment, and cover O&M costs.

Many types of concession agreements could meet the Municipality's goals. Two primary types are:

- **Build, own, operate, and transfer (BOOT).** After the concession term ends, the private entity would be required to transfer site ownership to the Municipality.
- **Build, own, operate (BOO).** Similar to BOOT, but ownership would not be transferred at the end of the concession term; the private entity would remain the owner of the Site.

8.1.2 Design and Construction Agreement

Rather than making a concession agreement for both development and operation services, the Municipality could contract for the development and management of the proposed engineered landfill under separate contracts with different private entities:

- An engineering and construction company (or consortium) would be contracted to design and construct the landfill. They would excavate the trash from the existing dumpsite, and design and implement a closure and remediation plan for the existing dumpsite.
- At the end of the contract, the Municipality would have an operating engineered landfill constructed to international standards, and a rehabilitated site where open dumping practices previously occurred. It could then either operate the landfill or enter into a separate service contract with a company to operate and manage the landfill.

8.1.3 Service Contracts/Agreements for Landfill Management

Several types of service contracts cover landfill management and assign this responsibility to a private entity. The type of contract or agreement depends on the level of financial, operational and technical risk the Municipality is willing to take, and the level of responsibility it would transfer to the contractor. The most common types of landfill management service contracts are:

- **O&M contract.** The private entity would provide all labor, supervision, equipment, materials, supplies and other items needed for O&M of the landfill. Day-to-day O&M would be the contractor's responsibility, and could also include closure of the landfill cells no longer in use. For the duration of the contract, the Municipality would pay a tipping fee per ton of MSW disposed of based on a negotiated rate.

- **Lease and operations agreement.** The private company would lease the landfill from the Municipality, paying a monthly leasing fee. The Municipality would retain the right to dispose of solid waste at the landfill; the contractor would not be allowed to accept waste for disposal from other sources without permission from the Municipality. The private entity could also assume the responsibility for the construction of the landfill, followed by day-to-day O&M and finally landfill closure.
- **Host agreement.** The private company would responsible for the design, construction and O&M of the landfill. Conditions of the agreement could allow the company to accept waste for disposal from sources other than the Municipality, with reimbursement in the form of a host community fee based on the amount of waste disposed of. The Municipality would have priority in using space in the landfill for disposal and retain the right to dispose of all types of allowed waste. It would be responsible for paying a tipping (gate) fee to the private contractor for the MSW disposed of.

These example types of contracts can be tailored to meet the needs and goals of the Municipality. They can also include provisions for the contractor to provide waste collection service, street sweeping services or any other solid-waste-management-related services. During the development of the contract, it is important to properly define the term and length of the contract. Lower costs can be achieved with contract terms long enough to allow the private contractor to recoup depreciation of capital expenses for certain equipment and facilities. Contracts typically have a duration of 20–30 years, with options for extension.

8.2 Bidding Procedures

To identify a private contractor, the Municipality should conduct an analysis of the strengths and weaknesses of contracting a private company for landfill development and O&M. The general steps of this process are listed in Figure 14 and explained in further detail below.

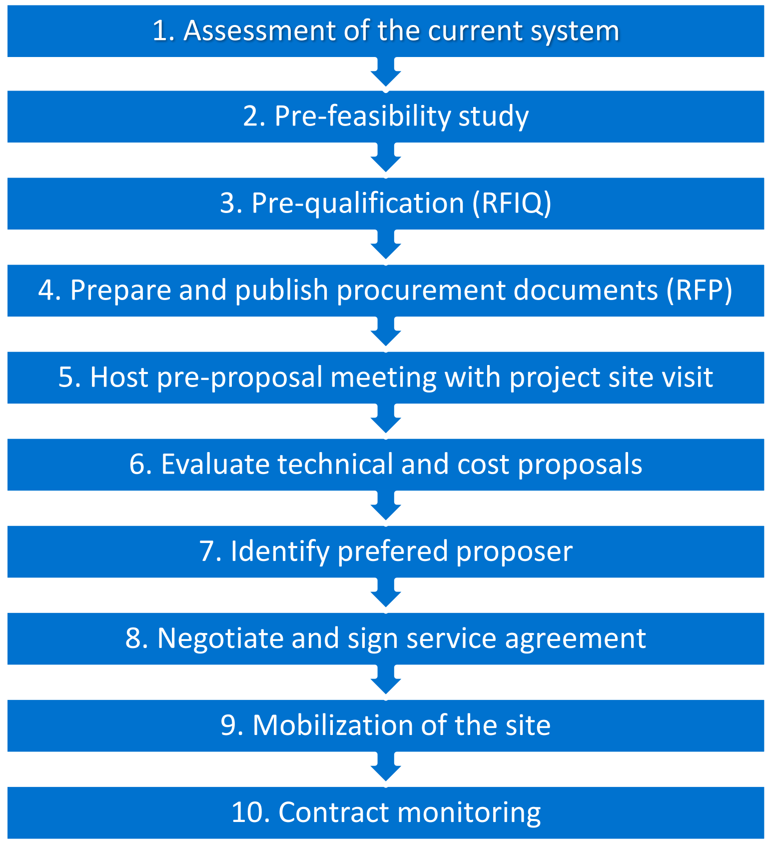


Figure 14. Process for Landfill Privatization

1. The first step of this process is to develop a complete assessment of the current solid waste management system including the available disposal options. This assessment should include an understanding of the individual parts of the system (e.g., waste collection, recycling, disposal) and the costs associated with each of them. This would allow the Municipality to understand the scope of services needed from the private contractor, identify the level of risk and responsibility the Municipality is ready to take, and decide which responsibilities can be transferred to the private contractor.

2. After the initial assessment of the current system is complete, a pre-feasibility study examining the impacts of landfill privatization should be conducted. This feasibility study would yield an analysis of the level of effort required by the Municipality and the economic impact these changes would have on the population that would have to pay for the improved system. Ultimately, the pre-feasibility study would help the Municipality define the scope of work required from the private contractor and the associated costs.

3. Once the Municipality decides to proceed with procuring services for landfill management, and based on the scope of services to be assigned to the contractor, qualification criteria need to be developed to identify qualified private companies capable of providing the requested services. To do this, the Municipality should publish a request for expression of interest and Qualification (RFIQ) to inform interested private companies about its needs and inviting them to submit their qualifications.

4. When qualified companies are identified, they would be invited to submit technical and cost proposals through a formal Request For Proposals (RFP). In addition to the scope of services, RFP documentation should include performance requirements, evaluation criteria and a scoring system. It should contain as much information as possible about the Site, the amount of waste that needs to be handled, the current status of the system, and the improvements needed for the potential proposers to

develop accurate proposals. During the RFP process, it is crucial to allow enough time for interested companies to develop quality proposals.

5. The Municipality should host a pre-proposal meeting for the qualified companies, offer a site visit and make available any relevant materials such as site plans and drawings.

6. Proposals received from the pre-qualified companies should be reviewed and scored against the evaluation criteria as published in the RFP for both the technical approaches and the proposed costs. The uniform scoring criteria should provide easy identification of the top proposals.

7. Ideally, at least three proposals should be identified as finalists, and contract negotiations can begin. Other mechanisms such as single-award are also possible.

8. Once the contract conditions are negotiated and agreed upon by both sides, the contract is signed.

9. The contractor proceeds with Site mobilization (e.g., construction and operation).

10. During the contract term, it is critical for the Municipality to have mechanisms in place for continuous monitoring and enforcement of the contract and the performance of the contractor to make sure the conditions and services agreed upon are honored. The Municipality can also hire a third-party engineering consultant or identify people within the existing staff to perform this type of monitoring and evaluation.

8.2 Project Investment Opportunities

This section provides an initial list of potential financing partners that can provide financial support for the development of the Site. The opportunities include grants for procurements, technical assistance and services to loans, loan guarantees, etc.

1. **CAF Development Bank of Latin America** is focused only on Latin America and provides financial services for sustainable development and regional integration projects. Environment and climate change is one of its areas of interest; it supports transformation projects toward low-carbon economies. It provides types of support including funding, technical assistance, capacity building and structuring projects. CAF has signed an accreditation agreement with the Green Climate Fund that allows Latin American countries easier access to GSF funds. (https://www.caf.com/en/topics/e/environment-and-climate-change/climate-change/?parent=33004)

2. **CCAC.** The Municipality has already worked with CCAC, and there may be opportunities to explore conducting an engineered landfill project assessment. Examples of the types of support CCAC provides can be found at http://www.waste.ccacoalition.org/.

3. **Global Environmental Facility (GEF).** GEF funds are available to developing countries and countries with economies in transition to meet the objectives of the international environmental conventions and agreements. GEF support is provided to government agencies, civil society organizations, private sector companies, and research institutions—among the broad diversity of potential partners—to implement projects and programs in recipient countries (https://www.thegef.org/). Climate change is one of GEF's focus topics; GEF provides support for the shift to a low-carbon economy (https://www.thegef.org/topics/climate-change).

4. **Inter-American Development Bank (IDB).** The IDB vision is a region with clean cities, capable of providing integrated services for solid waste management to the entire population, tailored to local realities, sustainable from the environmental and economic point of view, and socially inclusive. Toward this goal, the Water and Sanitation Initiative has created a specialized group for solid waste management and has established a long-term program to support IDB activities in the sector

(https://www.iadb.org/en/residussolides). IDB provides different types of financing mechanisms; more information can be found at https://www.iadb.org/en/about-us/overview.

5. **United States Trade and Development Agency (USTDA)**. USTDA awards grant funds to overseas project sponsors for a variety of activities, including technical assistance, training programs and early investment analysis/feasibility studies. USTDA responds to priorities that overseas project sponsors establish for themselves. If necessary, USTDA can help project sponsors define their priorities.
   a. The Global Procurement Initiative. Understanding Best Value is dedicated to helping public officials in emerging economies better understand the total cost of ownership of goods and services for infrastructure projects (https://www.ustda.gov/program/global-procurement-initiative-0). This program can be helpful during the development of the procurement approach and making decisions on the type of contracting that will be the most beneficial for the Site.
   b. The Dominican Republic has partnered with USTDA to promote the Global Procurement Initiative approach; as part of the program, 80 government officials attended a training and can provide assistance to local municipalities (https://www.ustda.gov/news/press-releases/2018/ustda-partners-government-dominican-republic-promote-value-based).

6. **World Bank Group.** The World Bank finances and advises on solid waste management projects using a diverse suite of products and services, including traditional loans, results-based financing, development policy financing, and technical advisory. World Bank–financed waste management projects address the entire lifecycle of waste—from generation to collection and transportation, and finally treatment and disposal.
   a. The Climate Finance Program provides financing for transitioning to a low-carbon, climate-resilient global economy. Funds are available for infrastructure development in developing and middle-income countries. (http://www.worldbank.org/en/topic/climatefinance#1)
   b. The International Finance Corporation provides financing opportunities for the private sector and can be used by the potential contractor to finance the engineered landfill and LFG system. (https://www.ifc.org/wps/wcm/connect/CORP_EXT_Content/IFC_External_Corporate_Site/Solutions/)
   c. The Global Partnership on Output-Based Aid provides innovative financing solutions to provide access to basic services such as water, sanitation, energy and health education for underserved communities. (http://www.gpoba.org/)

Appendix A: List of Technical and Contractual Resources

1. **Manual de Protocolo de Construccion Nuevos Rellenos Sanitarios con Revestimientos Compuestos.** Agencia de los Estados Unidos para el Desarrollo Internacional (USAID), Sistema de Integracion Centroamericana (SICA), and Comisión Centroamericana de Ambiente y Desarrollo (CCAD), 2010.
2. **Manual de Protocolo de Operacion Nuevos Rellenos Sanitarios para Desechos Solidos.** USAID, SICA, CCAD, 2010.
3. **Guía de Referencia de Sistemas de Tratamiento de Aguas Residuales Utilizados en Centro América.** B. Henry, S. Oakley, L. Salguero, P. Saravia, J. M. Vásquez; USAID, Agencia de los Estados Unidos para la Protección Ambiental (US EPA), SICA, CCAD, Tratado de Libre Comercio Centroamérica República Dominicana–Estados Unidos (CAFTA-DR).
4. **Diseño, Construcción, Operación y Cierre de Rellenos Sanitarios Municipales.** Eva Röben DED/Ilustre Municipalidad de Loja, Loja, Ecuador, 2002.
5. **Manejo Responsable de los Tubos Fluorescentes.** USAID, SICA, and CCAD, 2010.
6. **Manejo Responsable de los Residuos Electrónicos.** USAID, SICA, and CCAD, 2010.
7. **Manejo Responsable de las Pilas Secas.** USAID, SICA, and CCAD, 2010.
8. **Guía de Cierre Técnico, Monitoreo y Seguimiento de un Sitio de Disposición Final, Dirigida a las Autoridades Ambientales y Municipales,** Carlos Eduardo Meléndez Avalos, CCAD, 2008.
9. The **International Solid Waste Association (ISWA) and Solid Waste Institute for Sustainability** created the ISWA Winter School for participants to study the particular challenges of solid waste management in developing economies. The Winter School takes place at an engineered landfill (City of Denton, Texas) and mixes classroom instruction with hands-on field learning. Scholarships are available for qualified candidates.
10. The **Global Methane Initiative (GMI)** is an international public-private partnership including the Dominican Republic that advances cost-effective, near-term methane abatement and recovery and use of methane as a clean energy source in biogas (including agriculture, municipal solid waste, and wastewater), coal mines, and oil and gas systems. GMI features many helpful waste resources, tools and materials. https://globalmethane.org/sectors/technicalgroup.aspx?s=msw
11. **CCAC Municipal Solid Waste Initiative (CCAC MSWI)** is an international initiative that encourages actions by national, state, and local governments to avoid and reduce methane emissions by diverting organic waste from landfills, which includes preventing and reducing food waste and partnerships with the private sector. CCAC features many helpful waste resources, tools and materials. http://www.waste.ccacoalition.org/tool
12. **International Best Practices Guide for Landfill Gas Energy Projects.** US EPA, 2012. This guide provides an overview of landfill gas energy project development including technological, economic and political considerations that can affect project success. https://globalmethane.org/sectors/technicalgroup.aspx?s=msw
13. **Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean.** Conestoga-Rovers and Associates, 2004. This handbook was developed for the World Bank to facilitate the development of LFG management and landfill gas to energy projects in Latin America and the Caribbean. http://documents.worldbank.org/curated/en/954761468011430611/Handbook-for-the-preparation-of-landfill-gas-to-energy-projects-in-Latin-America-and-the-Caribbean
14. The **Landfill Gas Project Screening Tool** assesses the feasibility of an international landfill gas energy project at a particular landfill. http://www.waste.ccacoalition.org/document/landfill-gas-project-screening-tool-version-2.

Informal Sector Resources

1. **Women in Informal Employment: Globalizing and Organizing (WIEGO)** is a global network focused on securing livelihoods for the working poor, especially women, in the informal economy. WIEGO provides resources and publications including videos and case studies from around the world. http://www.wiego.org/
2. **Sonia Dias on the Informal Economy of Waste Pickers.** https://wastewise.be/2016/05/sonia-dias-on-the-informal-economy-of-waste-pickers/#.W4_9G-hKjcs
3. **Three Ways Waste Pickers Can Be Included in the New Circular Economy.** Sonia Dias, 2018. https://www.equaltimes.org/three-ways-waste-pickers-can-be?lang=en#.W4_-hOhKjcs

Investment and Contractual Resources

1. International Environmental Finance Tools. US EPA, 2011.
2. **Best Management Practices for Increasing Private Participation in Municipal Solid Waste Services.** CCAC, 2015. http://www.waste.ccacoalition.org/document/best-management-practices-increasing-private-participation-municipal-solid-waste-services.
3. **Primer for Cities for Accessing Financing for Municipal Solid Waste Projects.** Jeremy Gorelick (ISWA). 2017. http://www.waste.ccacoalition.org/document/primer-cities-accessing-financing-municipal-solid-waste-projects.

Appendix B: HCSA Geotechnical Factual Report Summary

BATTELLE

GEOTECHNICAL FACTUAL REPORT

GEOTECHNICAL EXPLORATION
SAN CRISTOBAL DISPOSAL SITE

Doña Ana, San Cristóbal, Republica Dominicana

AUGUST 13, 2018

Horizon Consultants
Soluciones en Ingeniería Geotécnica

BATTELLE

GEOTECHNICAL EXPLORATION
SAN CRISTOBAL DISPOSAL SITE

Doña Ana, San Cristóbal, Republica Dominicana

CONTENTS

Horizon Consultants
Soluciones en Ingeniería Geotécnica

GEOTECHNICAL EXPLORATION
SAN CRISTOBAL DISPOSAL SITE

Doña Ana, San Cristóbal, Republica Dominicana

1. Introduction

This report has been prepared at the request of Battelle and forms part of the studies for an environmental assessment. It presents the results of a geotechnical investigation carried out within an area identified for the development of the disposal site in San Cristobal, Dominican Republic.

The purpose of this exploration was to investigate the subsurface soil and ground water conditions at selected locations within the site for the evaluation of the physical/engineering properties. This report presents the factual information of the work performed in the field and laboratory test results.

The scope of our geotechnical services consisted of the following:

- Perform drilling and sampling of (14) hollow-stem auger soil borings and installation of six (6) standpipe piezometers.
- Conduct laboratory testing of selected samples to characterize the subsurface materials.
- Preparation of geotechnical field report presenting test location map and boring/piezometer logs.

The following section summarizes the activities that were undertaken well as the results of the field exploration.

2. Field Work

The field exploration program included 14 soil borings at the project site to evaluate subsurface conditions and was carried out between 4 to 15 June 2018. In total 6 standpipe piezometers were installed to measure the level of ground water table. 14 trial pits were excavated using CAT backhoe, advanced to depths of 8 – 10 ft. Coordinates were obtained using a handheld Garmin62S GPS and elevations where obtained by the provided topographic plan.

All works were conducted in accordance and supervision of the consulting engineer. Soil borings were drilled at the positions denoted on the appended boring location plan in **Appendix A**, which presents soil profiles, boring and trial pit logs. The boring information is presented on **Table 1.** A photographic sequence of the field activities is shown in **Appendix D**.

Drilling was carried out utilizing a trailer mounted drill rig (CME-55), and 8-inch diameter hollow-stem augers were used to advance the boreholes. Samples were obtained using a 140-pound hammer with a 30-inch free fall. Our CME-55 drill rigs use an automatic hammer release mechanism with efficiency (E_m) of 0.85 (85%). The standard penetration test (SPT) was performed at nominal 5 feet intervals. Soil samples were collected by split spoon and thin-walled tube (Shelby). Undisturbed samples were collected as appropriate and the information is summarized on **Table 2**.

Blow counts were recorded for every 6 inches, for a total penetration of 24 inches into the ground, following the procedures of ASTM D1586. No corrections have been applied for effects of automatic hammer drive energy, drill rod lengths, or sampler diameter. These borings were logged by a Horizon Consultants geotechnical engineer at the time of the drilling. Recovered samples descriptions are based on visual field and laboratory observations using classification methods of ASTM D2488.

When laboratory data are available, classifications are in accordance with ASTM D2487. The undisturbed sample tubes were sealed with paraffin wax to prevent the loss of moisture, while the disturbed samples were transported to the laboratory using sealed and moisture proof containers ASTM D4220.

Table 1. Exploratory borings

Boring/ Test Pit	Exploration Depth (feet)	Ground Elevation (m)	Ground Water Table El. (feet)	Easting (m)	Northing (m)	Installed Piezometer (Y/N)
SB-01	80	83.3	12.3	378317	2030314	Y
SB-02	42	77.5	NM	378374	2030267	N
SB-03	82	74	8.6	378348	2030199	Y
SB-04	42	76.5	9.5	378289	2030244	N
SB-05	81.32	78	12	378046	2030232	Y
SB-06	42	67.5	26	377991	2030132	N
SB-07	42	70.5	NM	378076	2030138	N
SB-08	41.4	61.1	NM	378000	2030054	N
SB-09	81.4	67.8	61	378077	2030047	Y
SB-10	42	74.5	13.5	378149	2030073	N
SB-11	42	66.5	NE	378172	2030022	N
SB-12	41.4	68.2	17.7	378258	2029999	Y
SB-13	42	64	NE	378137	2029931	N
SB-14	40.9	59.5	10.5	378018	2029947	Y
TP-01	10	83.3	-	378322	2030310	-
TP-04	8	76.5	-	378287	2030252	-
TP-05	10	78	-	378046	2030240	-
TP-06	8	67.5	-	377998	2030132	-
TP-08	8	61.1	-	377989	2030054	-
TP-09	8	67.8	-	378107	2030039	-
TP-12	8	68.2	-	378232	2029992	-
TP-14	8	59.5	-	378016	2029961	-

NE – not encountered NM – not measured

Table 2. Undisturbed samples collected

Boring No.	Depth (ft)	Shelby Sample No.	Recovery (in)	Soil Description
SB-03	32	1	16	Fat clay [CH]. Hard
SB-07	20	1	16	Fat clay [CH]. Hard
SB-09	67	1	6	Shale
SB-10	27	1	10	Shale
SB-11	22	1	20	Fat clay [CH]. Hard

3. Summarized Subsoils

The subsoils encountered within the boreholes are summarized on **Table 3** and includes the following:

- Topsoil – covers the site to an average depth of 1.3 ft and comprises a dark brown, very stiff, organic, clayey, containing roots.
- Clay – underlies the topsoil with an average thickness of 28 ft and consists of high – medium plasticity, light brown, hard.
- Shale – underlies the clay with an average thickness of 19 ft and where encountered is predominantly a completely weathered, extremely weak rock, fine grained, dark green color.
- Alluvium – occurs in some boreholes and underlies the clay with average thickness of 5 ft. It is medium to dense density, clayey sand or gravel.

Table 3. Summary of soil thickness

Soil Type	**Soil Thickness** (ft)		
	Min	Max	Average
Topsoil	0.0	3.0	1.3
Clay	0.0	38.7	27.9
Shale	0.0	50.3	18.7
Alluvium	0.0	18.0	5.1

4. Laboratory Tests

Laboratory testing was performed on representative samples collected during the field explorations to evaluate the geotechnical engineering properties of the subsurface materials. Tests included natural moisture content (ASTM D2216), particle-size sieve and hydrometer analysis (ASTM D422), Atterberg Limits (ASTM D4318), modified/standard proctor (ASTM D1557/698), triaxial CU (ASTM D4767), hydraulic conductivity (ASTM D5084), and slug test (ASTM D4044). Testing was completed in accordance with applicable ASTM standards.

Table 4 presents a summary of the average results laboratory tests performed to the soil samples obtained at the project area. The detailed laboratory test report is presented in **Appendix B.**

Table 4. Summary of laboratory tests

MATERIAL	USCS	Depth Min (ft)	Depth Max (ft)	Gravel (%)	Sand (%)	Fines (%)	PL (%)	LL (%)	PI (%)	Max Density (kg/m3)	Optimum Moisture (%)	Natural Moisture (%)
Fat Clay - High Plasticity	CH	5	40	1	7	92	27	57	31	1832	14	21
Clay - Low Plasticity	CL	5	25	1	21	78	21	41	20	1962	10	20
Clayey Gravel	GC	5	25	48	26	27	22	45	22	2056	10	15
Shale	CH	30	80	1	6	94	27	60	33	1861	14	17
Silty Sand	SM	5	25	0	67	33	23	29	6	-	-	24

4.1 Compaction Tests

Modified Proctor compaction tests were carried out on the clay and shale materials, the results are summarized in **Table 5** below.

Table 5. Summary of compaction tests

Material	USCS	Boring No.	Depth (ft)	Max Density (kg/m3)	Optimum Moisture (%)
Shale	CH	SB10	40	1861	14.1
Lean clay with sand	CL	SB01	6	1920	10.5
Fat clay	CH	SB04	7	1815	15.6
fat clay	CH	SB05	10	1861	16.0
Fat clay	CH	SB06	8	1806	16.1
Lean clay with sand	CL	SB08	5	1989	10.2
Fat clay	CH	SB09	8	1845	9.9
Lean clay	CL	SB12	8	1977	8.8
Clayey gravel	GC	SB14	5	2056	10.0

4.2 Hydraulic Conductivity

Soil samples were submitted for hydraulic conductivity analysis ASTM D5084. **Table 6** below summarizes the results. Please refer to **Appendix B** for detailed lab test results.

Table 6. Summary of hydraulic conductivity

Material	**USCS**	**Boring No.**	**Depth** (ft)	**Permeability** (cm/sec)	**Injection Pressure** (PSI)
Shale	CH	SB01	60	4.20E-07	10
Fat Clay	CH	SB02	20	1.80E-06	10
Fat Clay	CH	SB03	20	4.50E-07	10
Shale	CH	SB05	50	7.80E-08	5
Fat Clay	CH	SB06	35	6.50E-07	10
Fat Clay	CH	SB07	40	1.70E-07	10
Fat Clay	CH	SB07	20	7.30E-07	10
Fat Clay	CH	SB08	25	6.70E-08	10
Shale	CH	SB10	50	2.00E-07	10
Fat Clay	CH	SB11	15	9.50E-07	10
Fat Clay	CH	SB12	25	8.90E-08	10
Fat Clay	CH	SB13	30	5.30E-07	5
Shale	CH	SB14	35	2.70E-07	10

4.3 Consolidated Undrained Triaxial

Soil samples were submitted for consolidated undrained triaxial ASTM D4767. **Table 7** below summarizes the results.

Table 7. Summary of CU Triaxial

Material	**USCS**	**Boring No.**	**Sample**	c' (psf)	φ' (deg)
Fat Clay	CH	SB03	SH-1	26.4	31.7
Shale	CH	SB10	SH-1	105	34.8

5. In Situ Slug Tests

Instantaneous change in head (Slug) tests ASTM D4044 were conducted on all monitoring wells. On this test the slug is withdrawn from the well causing an instantaneous change of the water level in the monitoring well. While the water level recovers it is measured with the indicator instrument until the recovery of the water level is reached. Results of the slug tests are presented on **Appendix C**.

6. Groundwater

Monitoring wells were installed in six (6) borings for the purpose of taking ground water level measurements. Ground water level measurements began on June 15 2018, and are summarized on **Table 7**. All measurements are referred from ground level.

Table 7. Summary of water level measurements

Monitoring Location	Depth Well (ft)	Stickup PVC (ft)	08-Jun-18	15-Jun-18	29-Jun-18	* 11-Jul-18	27-Jul-18	10-Aug-18
SB01	26.9	1.87	-	13.2	12.8	11.8	12.9	12.2
SB03	19.5	0.42	-	8.6	6.70	6.88	6.8	9.4
SB05	28.1	0.49	12.0	10.1	8.3	6.7	7.2	10.7
SB09	68.7	1.00	-	61.0	24.4	24.3	24.3	25.0
SB12	31.7	0.89	-	17.8	18.34	18.31	18.3	20.2
SB14	19.2	0.59	10.5	10.5	10.3	10.1	10.4	9.3

* Day after rainstorm

Sincerely,

By **Horizon Consultants, S.A.**

Tirso A. Álvarez Fermín, Ph.D., P.E.
Geotechnical Consultant

Appendix C: Conceptual Design Drawings

CONCEPTUAL DESIGN

San Cristobal Landfill

PREPARED BY:

SCS ENGINEERS
3900 KILROY AIRPORT WAY
SUITE 100
LONG BEACH, CA 90806
+1 562-426-954

SCS JOB NO. 06218001.00
AUGUST 2018

REFERENCE MAP
NO SCALE

INDEX OF DRAWINGS

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: COVER SHEET

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

PROJ. NO. 06218001.00
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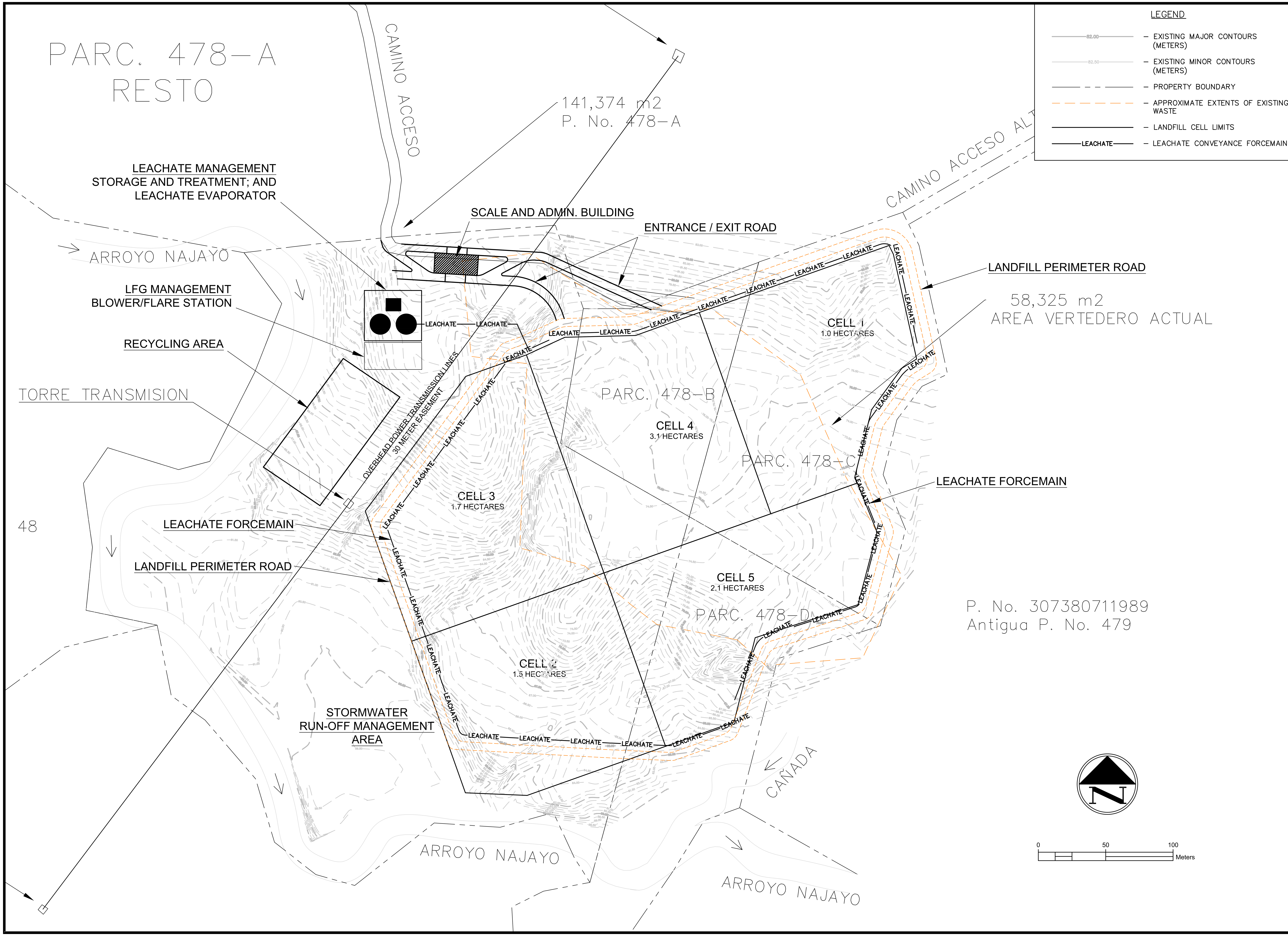

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PROJECT TITLE
SAN CRISTOBAL LANDFILL

CLIENT
BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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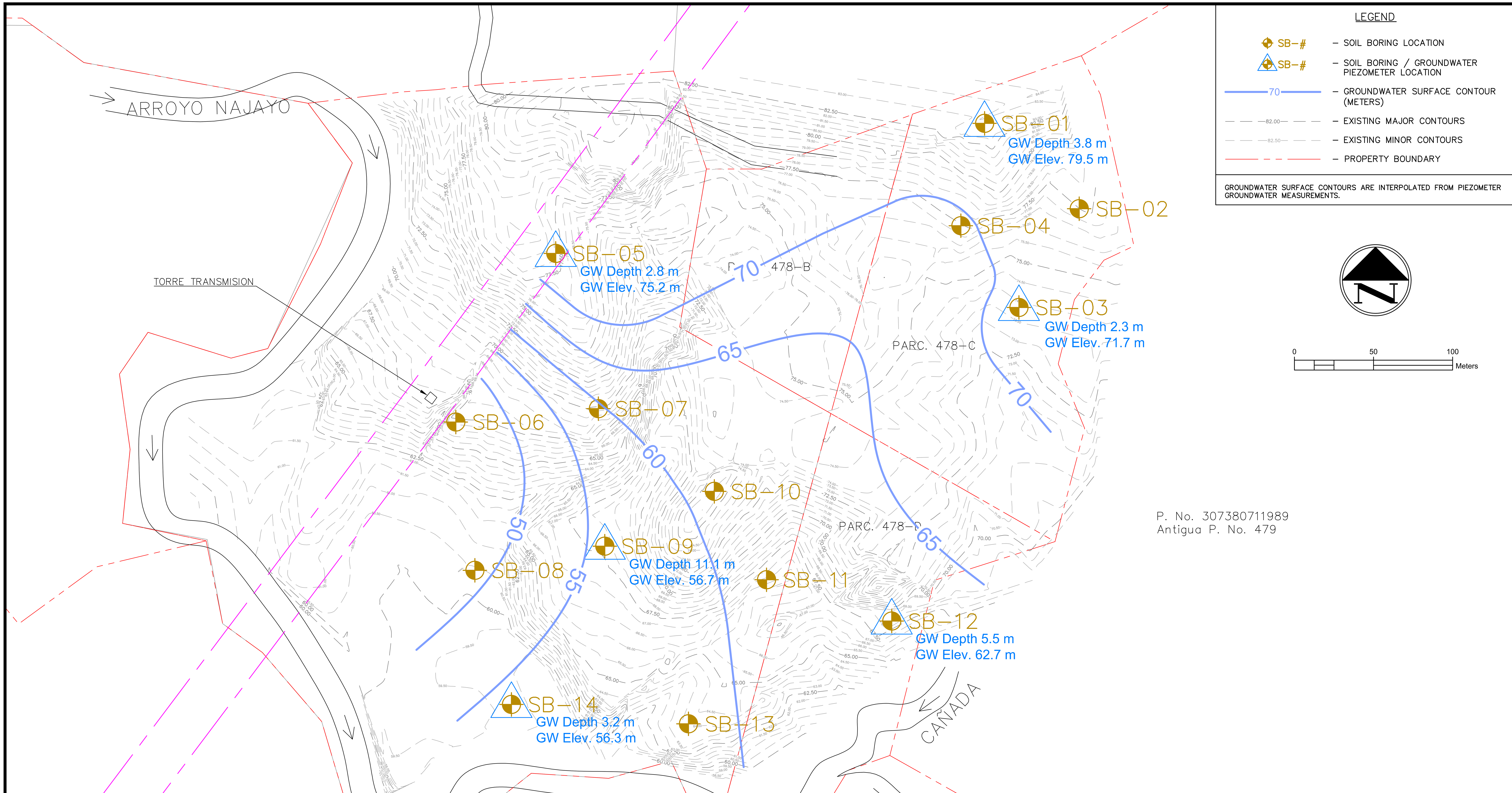


Water Level Measurements

Reference: Geotechnical Factual Report, Geotechnical Exploration, San Cristobal Disposal Site dated July 26, 2018 prepared by Horizon Consultants Soluciones en Ingenieria Geotécnica

Piezometer ID	Northing	Easting	Ground Elevation	Depth of Piezometer from Ground Surface	Piezometer Pipe Stick-Up	Piezometer Groundwater Measurements from Ground Surface(1) June 8, 2008	June 15, 2018	June 29, 2018	July 11, 2018(2)	Average Measurement	Groundwater Surface Elevation
	(meters)	(meters)	(meters)	(meters)	(meters)	(meters)	(meters)	(meters)	(meters)	(meters)	(meters)
SB-01	2,030,314	378,317	83.3	8.2	0.57		4.0	3.9	3.6	3.8	79.5
SB-03	2,030,199	378,348	74	5.9	0.13		2.6	2.04	2.10	2.3	71.7
SB-05	2,030,232	378,046	78	8.6	0.15	3.7	3.1	2.5	2.0	2.8	75.2
SB-09	2,030,047	378,077	67.8	20.9	0.30		18.6	7.4	7.4	11.1	56.7
SB-12	2,029,999	378,258	68.2	9.7	0.27		5.4	5.59	5.58	5.5	62.7
SB-14	2,029,947	378,018	59.5	5.9	0.18	3.2	3.2	3.1	3.1	3.2	56.3

(1) Piezometers installed June 8 through June 15, 2018.

(2) Day after rain storm.

REV. DATE DESCRIPTION CK. BY

SHEET TITLE
GROUNDWATER POTENTIOMETRIC SURFACE

PROJECT TITLE
SAN CRISTOBAL LANDFILL

CLIENT
BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

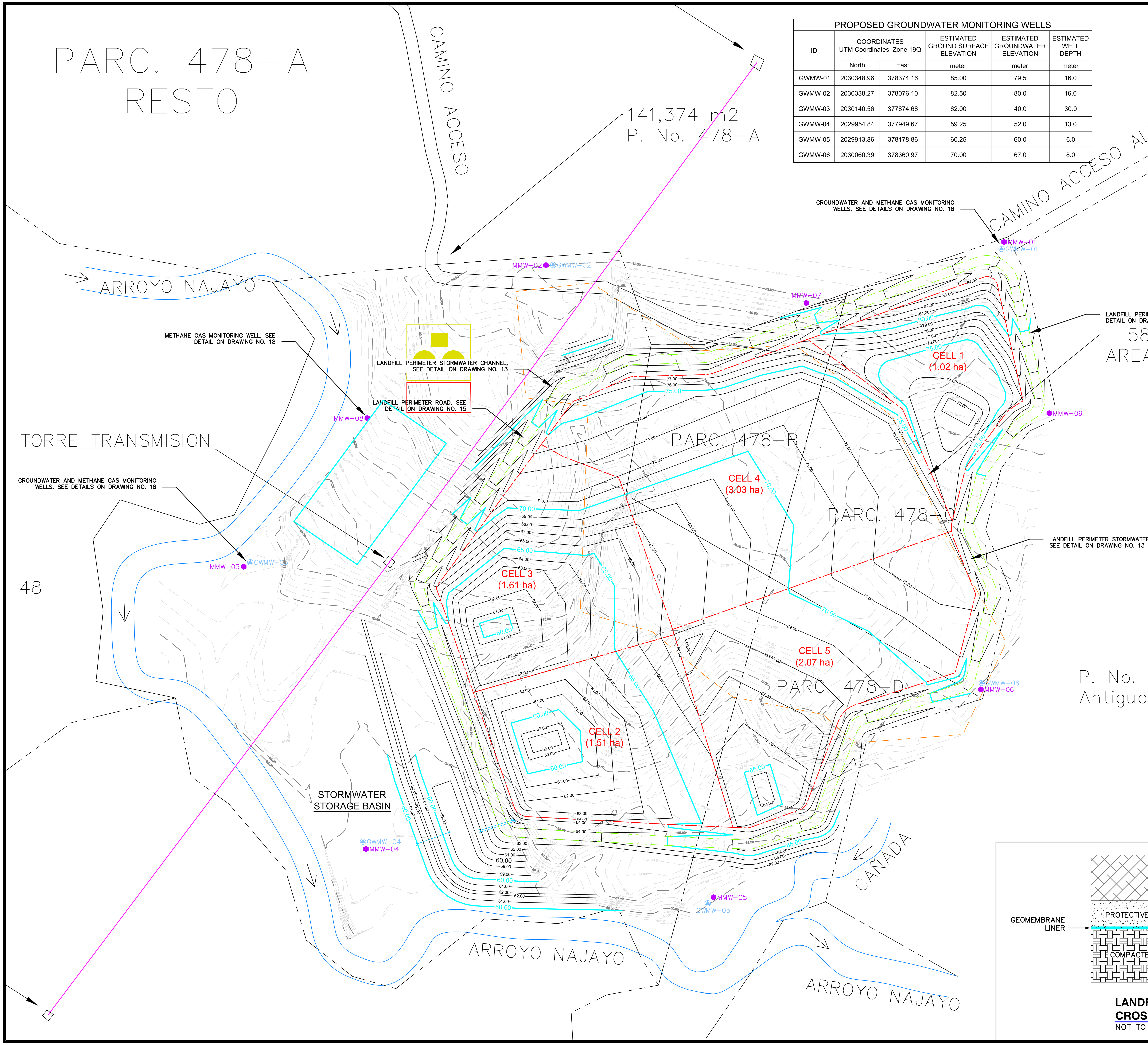
PROJ. NO. 06218001.00 DSN. BY: DWN. BY: CHK. BY: Q/A RVW BY: APP. BY:

CADD FILE: SHEET 3

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO.

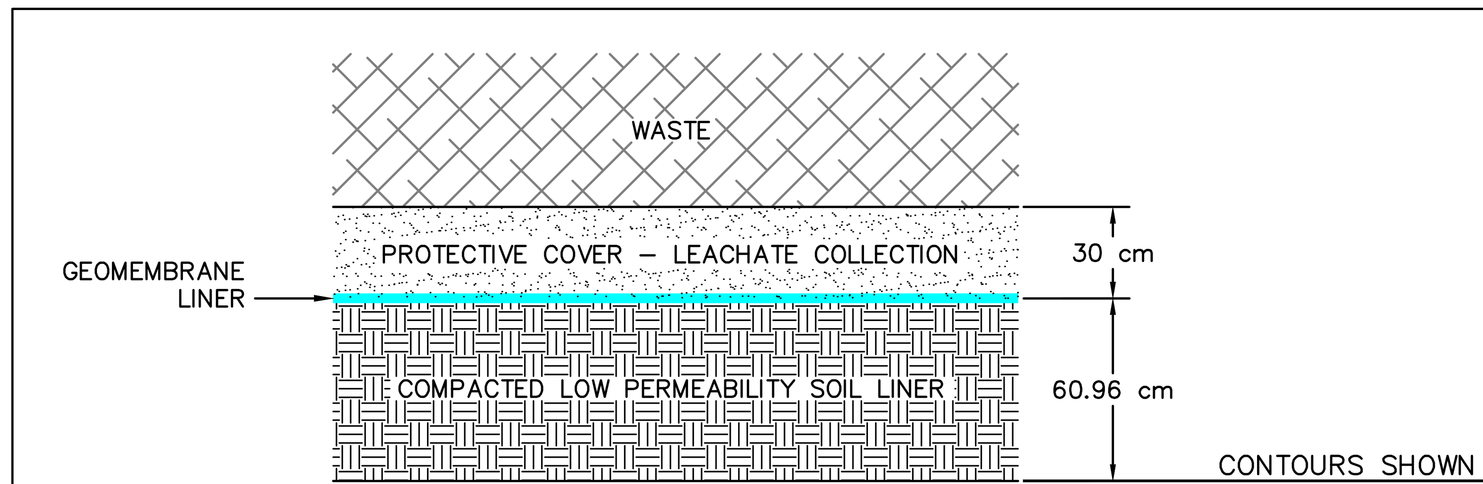


PROPOSED GROUNDWATER MONITORING WELLS					
ID	COORDINATES UTM Coordinates; Zone 19Q		ESTIMATED GROUND SURFACE ELEVATION	ESTIMATED GROUNDWATER ELEVATION	ESTIMATED WELL DEPTH
	North	East	meter	meter	meter
GWMW-01	2030348.96	378374.16	85.00	79.5	16.0
GWMW-02	2030338.27	378076.10	82.50	80.0	16.0
GWMW-03	2030140.56	377874.68	62.00	40.0	30.0
GWMW-04	2029954.84	377949.67	59.25	52.0	13.0
GWMW-05	2029913.86	378178.86	60.25	60.0	6.0
GWMW-06	2030060.39	378360.97	70.00	67.0	8.0

LEGEND

- 85.00 — PROPOSED MAJOR CONTOURS (METERS)
- 82.50 — PROPOSED MINOR CONTOURS (METERS)
- 82.00 — EXISTING MAJOR CONTOURS (METERS)
- EXISTING MINOR CONTOURS (METERS)
- LANDFILL CELL LIMIT
- PROPERTY BOUNDARY
- APPROXIMATE EXTENTS OF EXISTING WASTE
- GWMW-__ — PROPOSED GROUNDWATER MONITORING WELL
- MMW-__ — PROPOSED METHANE GAS MONITORING WELL

PROPOSED METHANE GAS MONITORING WELLS		
ID	COORDINATES UTM Coordinates; Zone 19Q	
	North	East
MMW-01	2030353.57	378375.86
MMW-02	2030338.11	378071.29
MMW-03	2030137.77	377870.42
MMW-04	2029949.93	377951.60
MMW-05	2029917.72	378182.76
MMW-06	2030056.02	378360.45
MMW-07	2030313.07	378244.42
MMW-08	2030227.96	377959.48
MMW-09	2030239.69	378405.95



LANDFILL BOTTOM SYSTEM CROSS-SECTION
NOT TO SCALE

REV. | DATE | DESCRIPTION | CK. BY

SHEET TITLE: CONCEPTUAL LANDFILL DEVELOPMENT

PROJECT TITLE: SAN CRISTOBAL LANDFILL

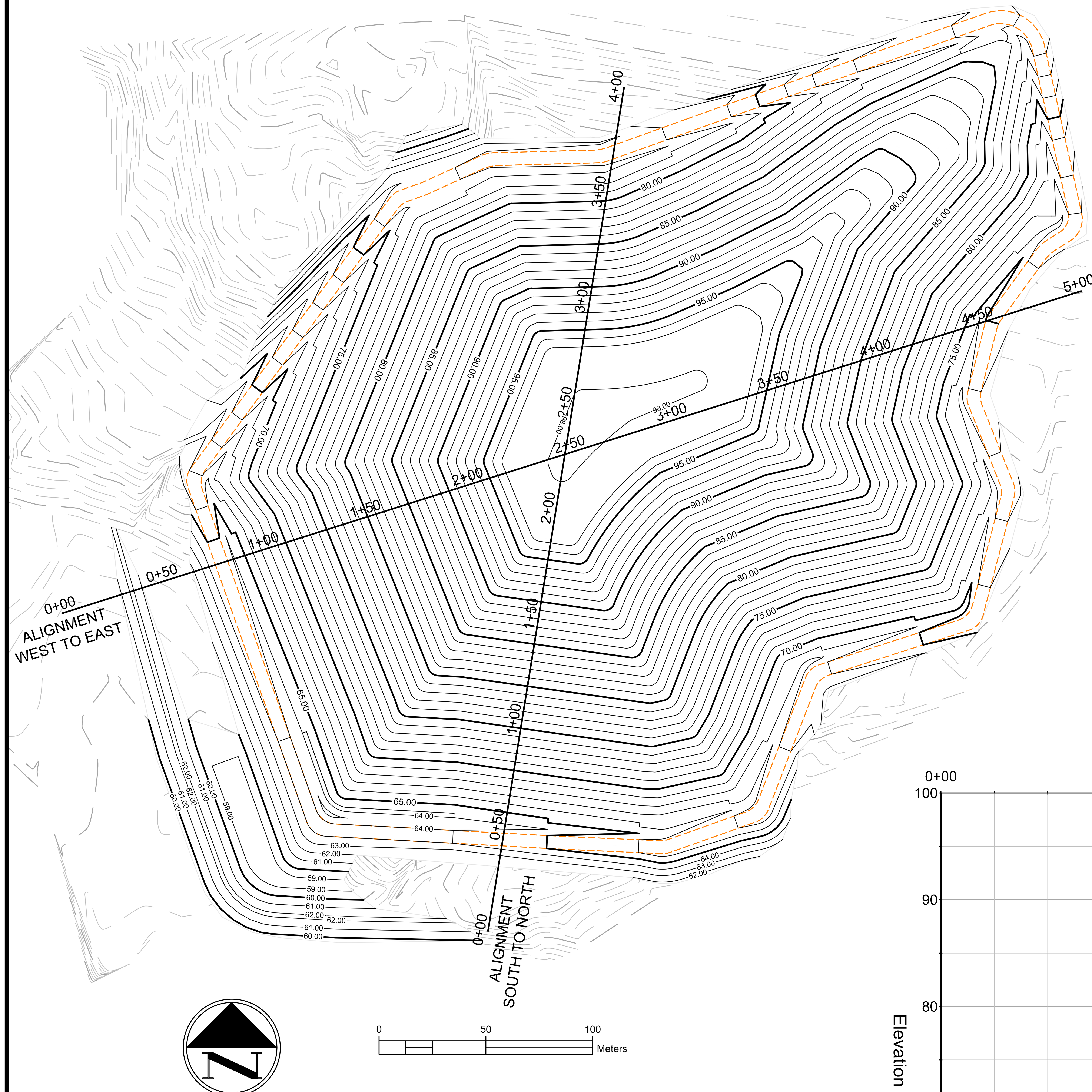
CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

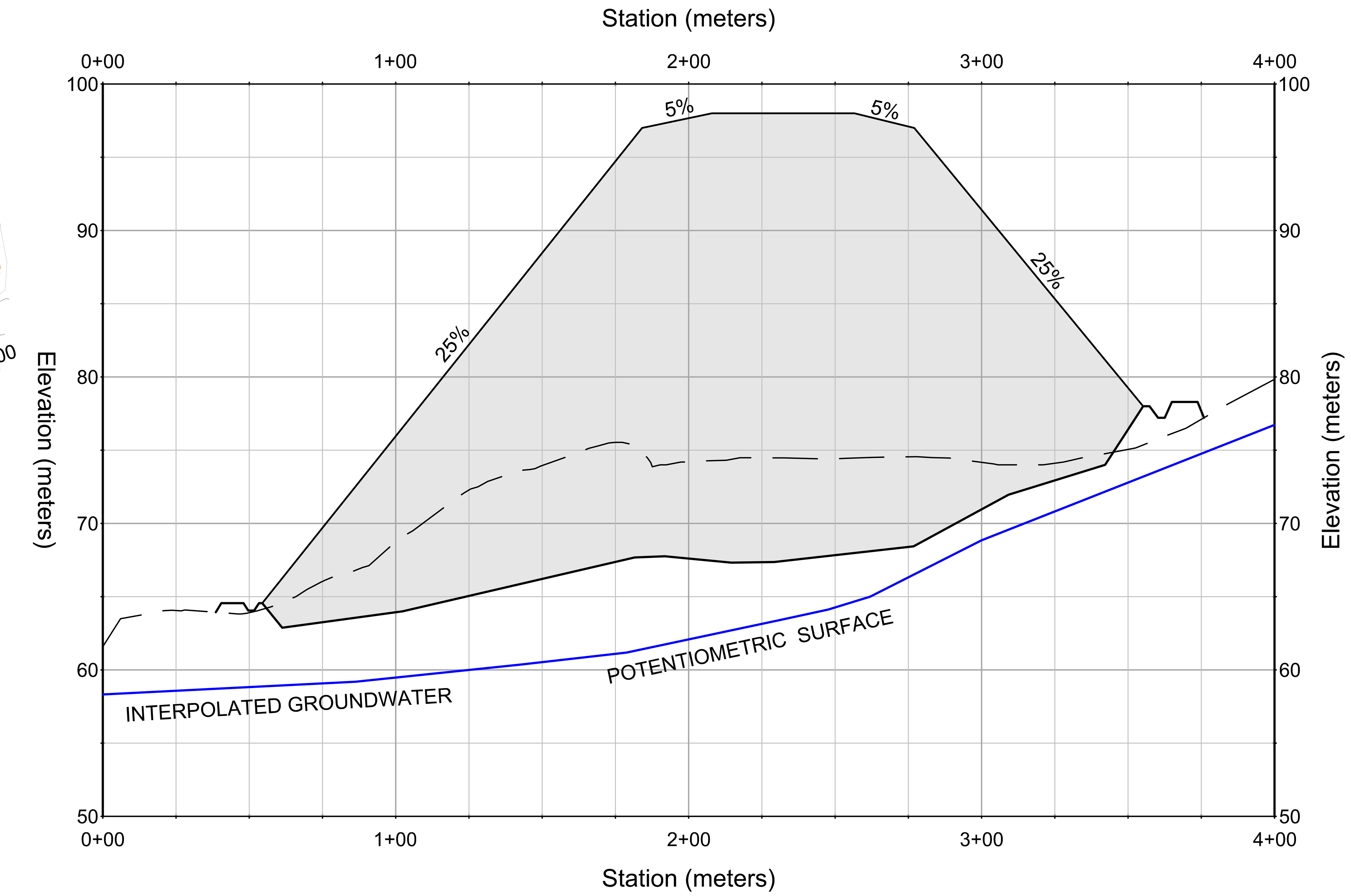
PROJ. NO. 06218001.00 | DSN. BY: ADG | DWN. BY: OH | CHK. BY: | Q/A RVW BY: | APP. BY:

CADD FILE: SHEET 3-CON...
DATE: AUG 2018
SCALE: AS NOTED
DRAWING NO. 3 of 18

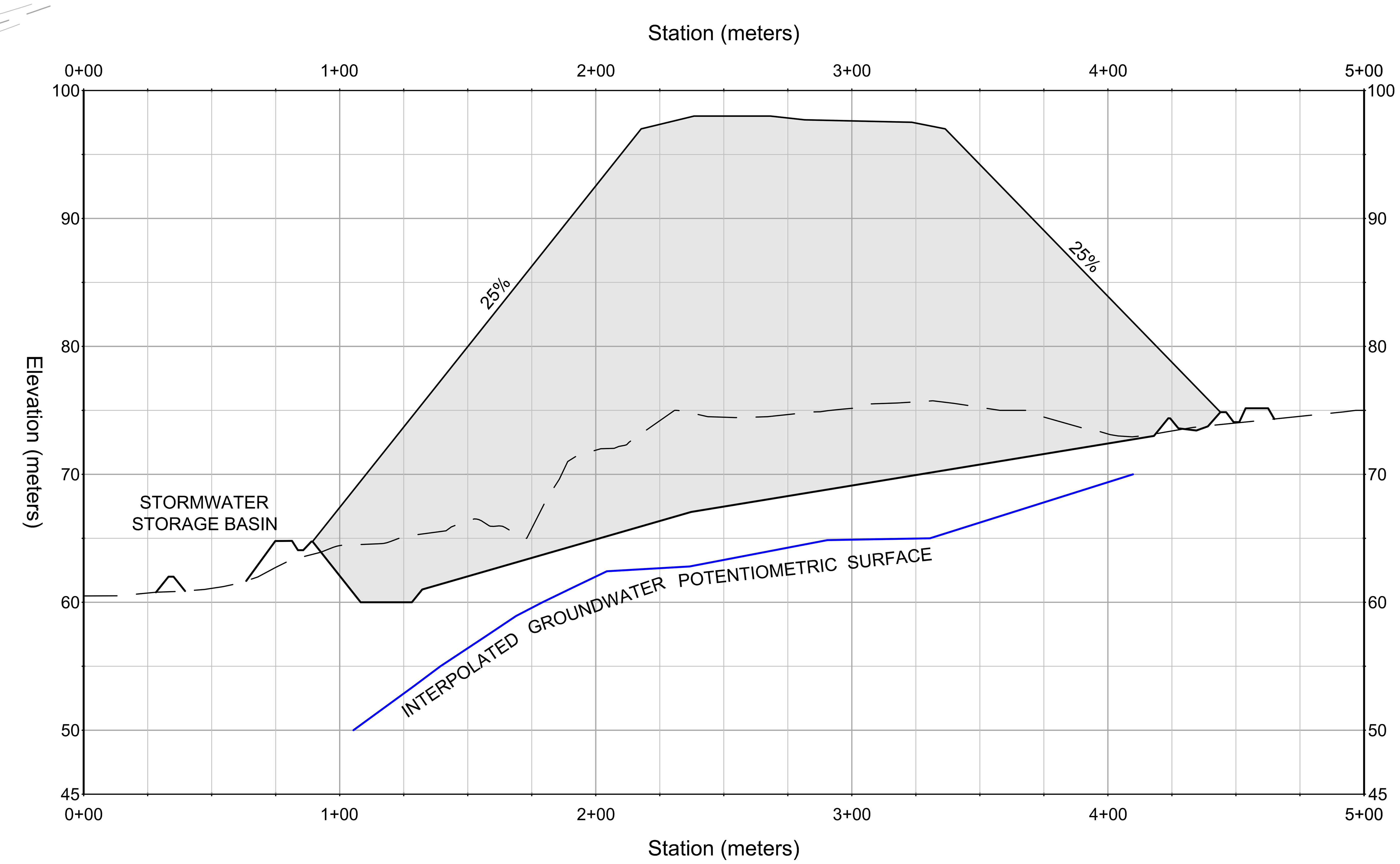
C:\Users\1903jld\Desktop\Work at Home\06218001.00 - DR Landfill Battelle\CADD\Drawings\Sheet 4 - Conceptual Closure Plan - 25%.dwg Sep 10, 2018 - 3:50pm Layout Name: LANDFILL CLOSURE PLAN By: 1903jld



Profile View - South to North



Profile View - West to East



REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: **LANDFILL PROFILES**

PROJECT TITLE: **SAN CRISTOBAL LANDFILL**

CLIENT: **BATTELLE MEMORIAL INSTITUTE**

505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

PROJ. NO. 06218001.00 | DSN. BY: ADG | DWN. BY: OH | CHK. BY: | Q/A RVW BY: | APP. BY:

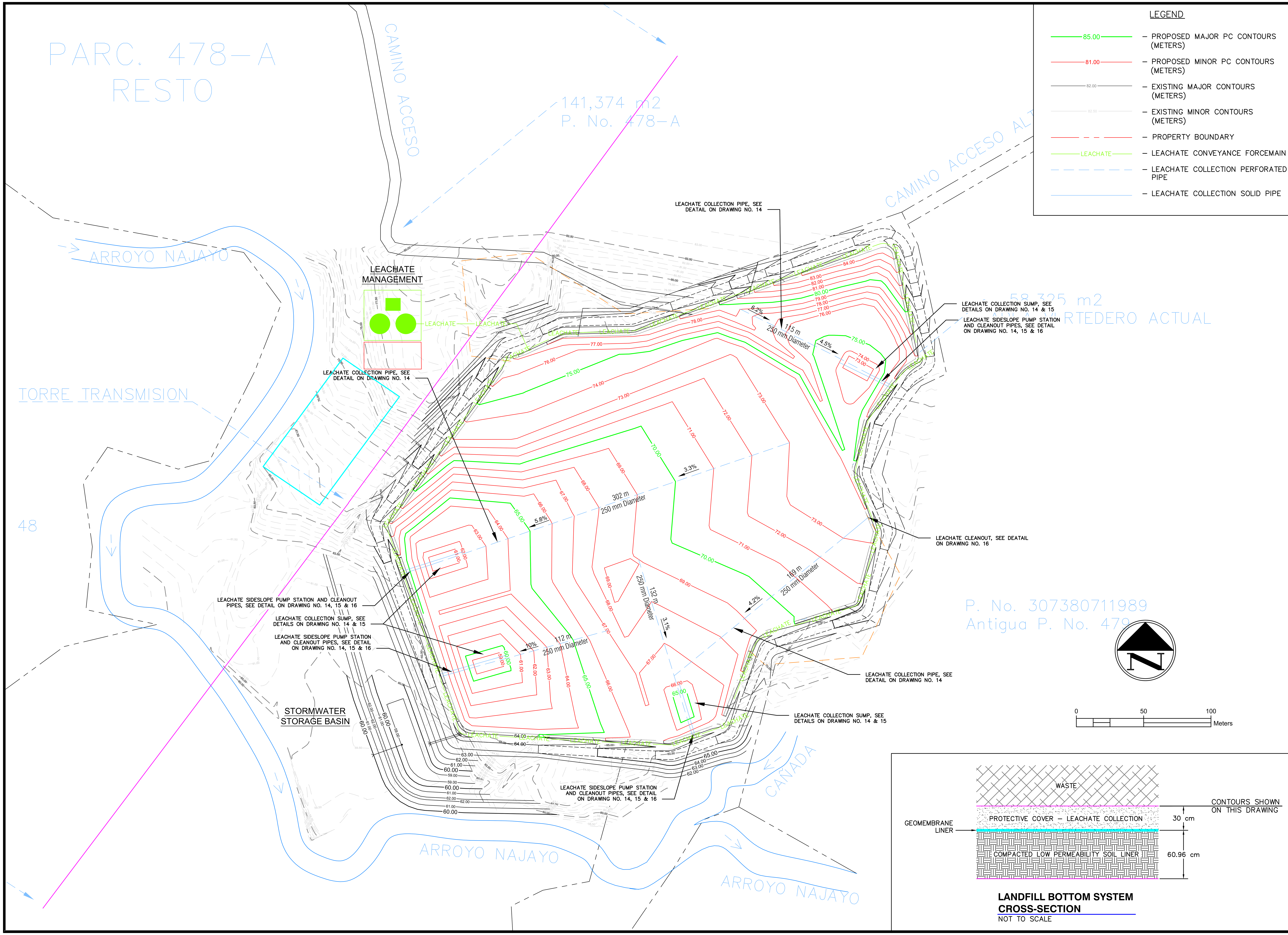
CADD FILE: SHEET 5

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. **5** of **18**

C:\Users\1903jld\Desktop\Work at Home\06218001.00 - DR Landfill Battelle\CADD\Drawings\Sheet 6 - Leachate Management.dwg Sep 10, 2018 - 3:54pm Layout Name: LANDFILL DEVELOPMENT By: 1903jld



REV. | DATE | DESCRIPTION | CK. BY

SHEET TITLE: CONCEPTUAL LEACHATE MANAGEMENT

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

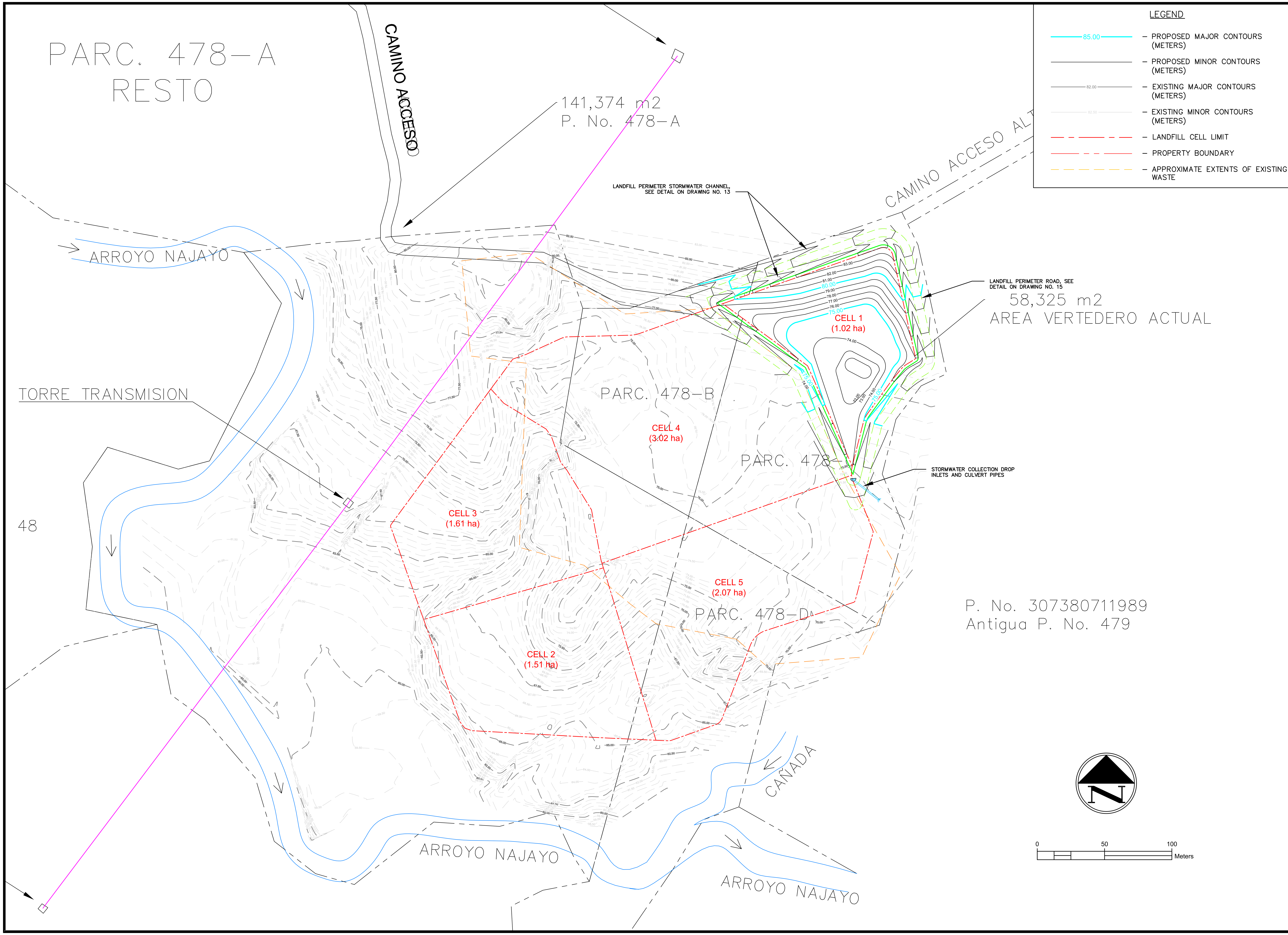
PROJ. NO. 06218001.00 | DSN. BY: ADG | DWN. BY: OH | CHK. BY: | Q/A RVW BY: | APP. BY:

CADD FILE: SHEET 6

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. 6 of 18



C:\Users\1903jld\Desktop\Work at Home\06218001.00 – DR Landfill Battelle\CADD\Drawings\Sheet 7 – Cell 1 Subgrade.dwg Sep 10, 2018 – 4:02pm Layout Name: LANDFILL DEVELOPMENT By: 1903jld

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE

CELL 1 SUBGRADE PLAN

PROJECT TITLE

SAN CRISTOBAL LANDFILL

CLIENT

BATTELLE MEMORIAL INSTITUTE

505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS

2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

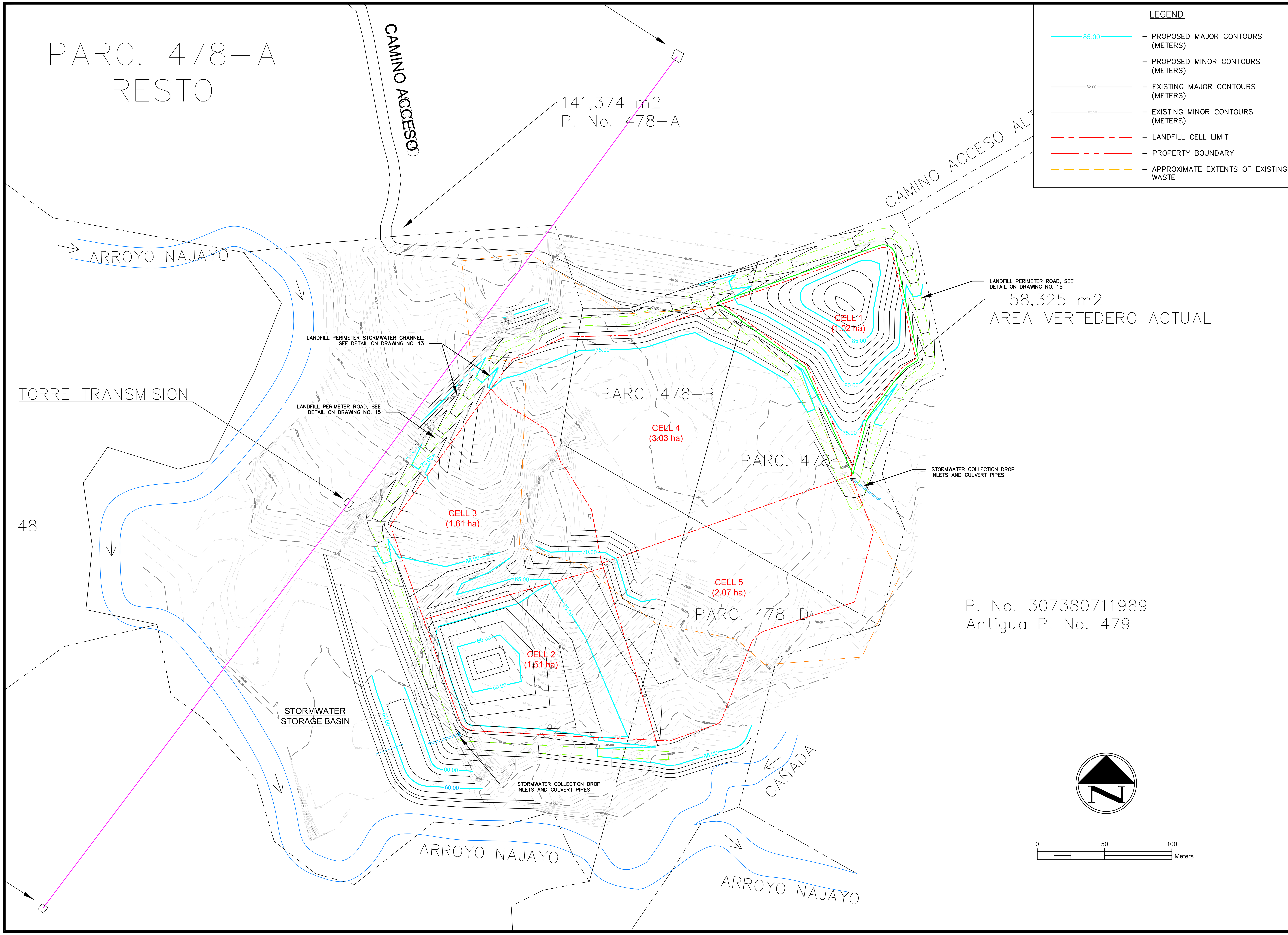
PROJ. NO. 06218001.00 | DWN. BY: OH | Q/A RVW BY:
DSN. BY: ADG | CHK. BY: | APP. BY:

CADD FILE: SHEET 7

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. 7 of 18



C:\Users\1903jld\Desktop\Work at Home\06218001.00 – DR Landfill Battelle\CADD\Drawings\Sheet 8 – Cell 1 Closure – Cell 2 Subgrades.dwg Sep 10, 2018 – 4:02pm Layout Name: LANDFILL DEVELOPMENT By: 1903jld

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: CELL 1 TOP OF WASTE AND CELL 2 SUBGRADE PLAN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

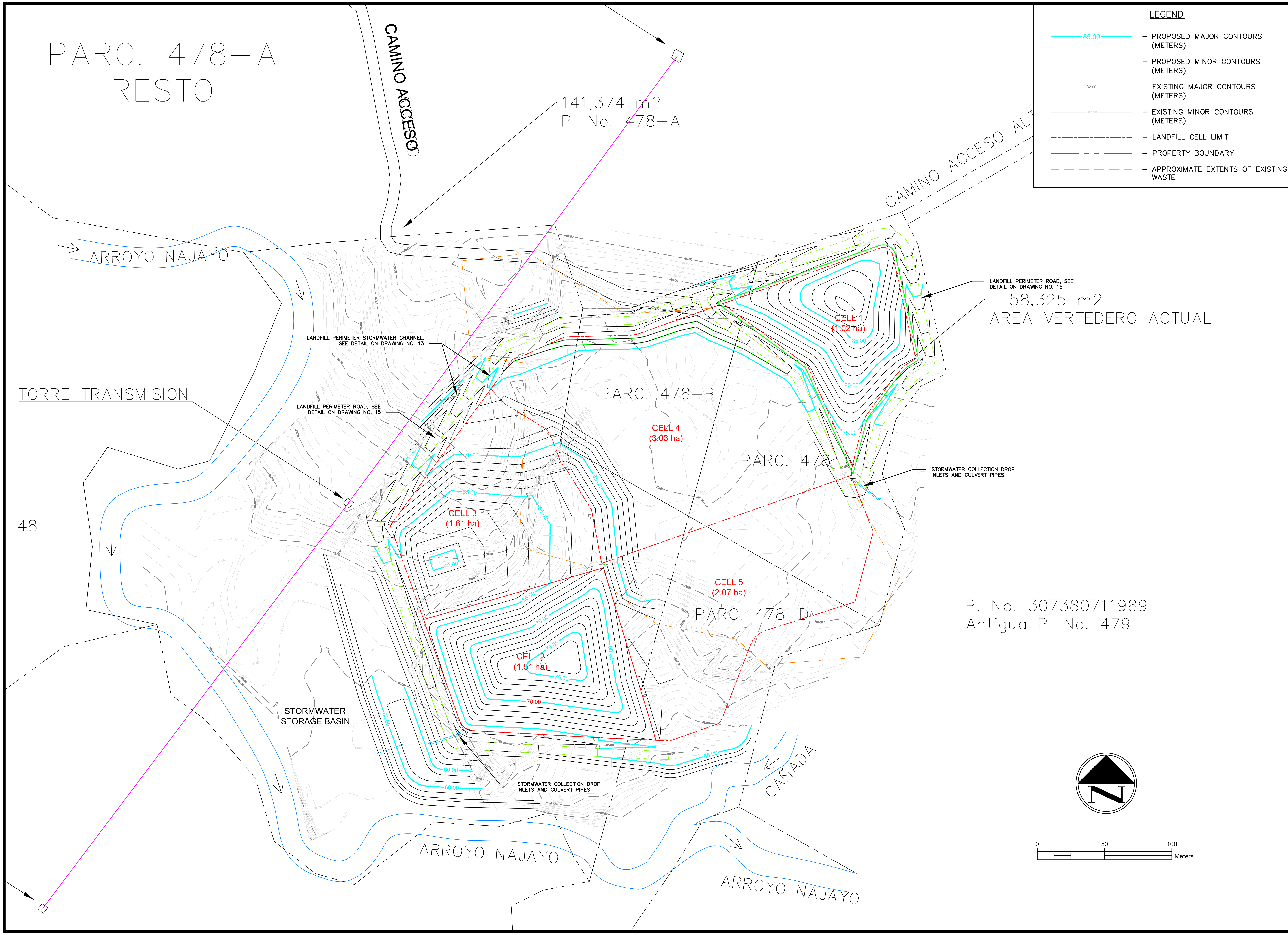
PROJ. NO. 06218001.00 | DSN. BY: ADG | DWN. BY: OH | CHK. BY: | Q/A RVW BY: | APP. BY:

CADD FILE: SHEET 8

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. 8 of 18



REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: CELL 1 & 2 TOP OF WASTE AND CELL 3 SUBGRADE PLAN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

PROJ. NO. 06218001.00 | DWN. BY: OH | DSN. BY: ADG | CHK. BY: | Q/A RVW BY: | APP. BY:

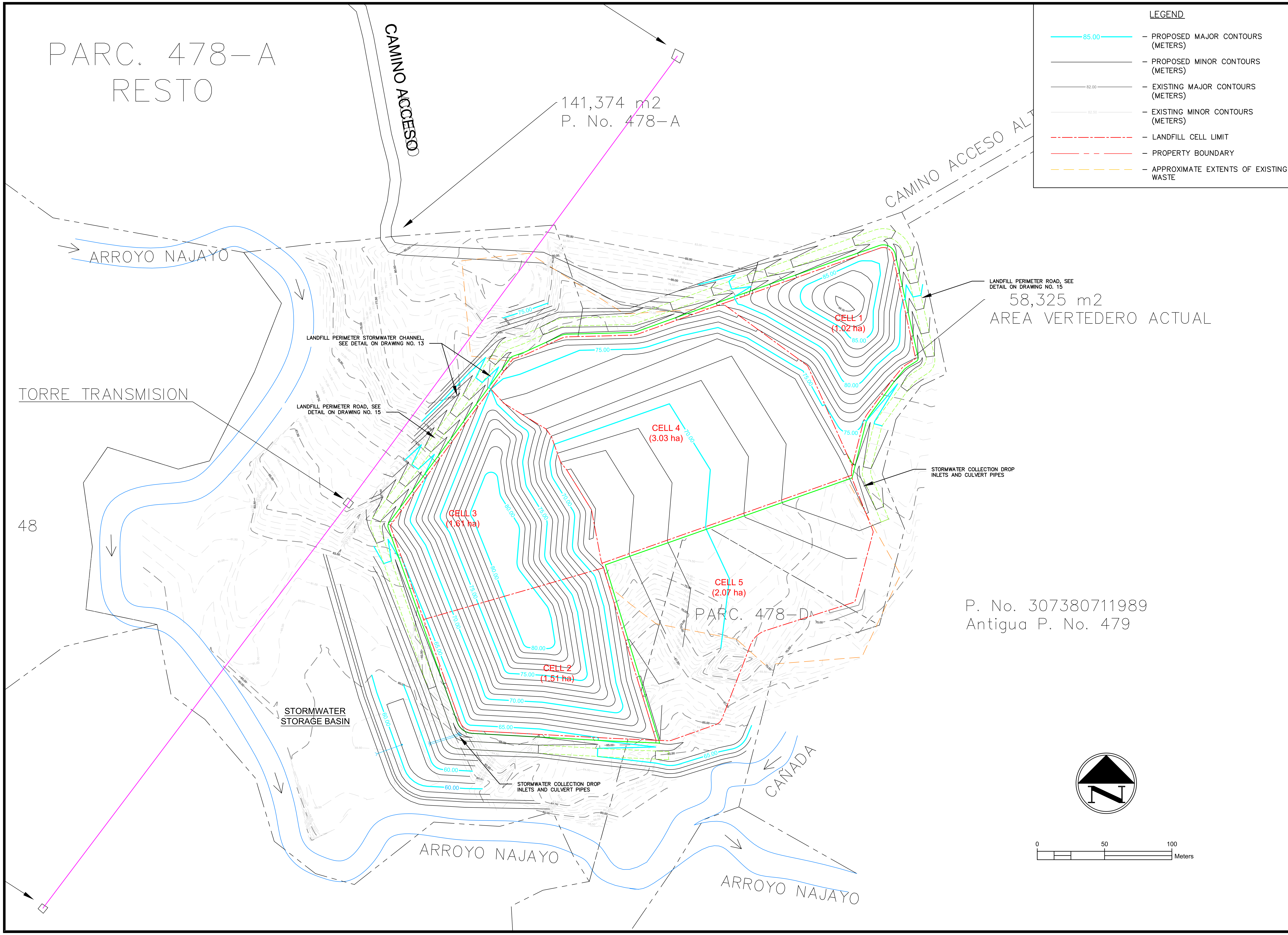
CADD FILE: SHEET 9–CEL...

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. 9 of 18

C:\Users\1903jd\Desktop\Work at Home\06218001.00 – DR Landfill Battelle\CADD\Drawings\Sheet 9 – Cell 2 Closure – Cell 3 Subgrades.dwg Sep 10, 2018 – 4:03pm Layout Name: LANDFILL DEVELOPMENT By: 1903jd



LEGEND

- PROPOSED MAJOR CONTOURS (METERS)
- PROPOSED MINOR CONTOURS (METERS)
- EXISTING MAJOR CONTOURS (METERS)
- EXISTING MINOR CONTOURS (METERS)
- LANDFILL CELL LIMIT
- PROPERTY BOUNDARY
- APPROXIMATE EXTENTS OF EXISTING WASTE

REV. | DATE | DESCRIPTION | CK. BY

SHEET TITLE: CELL 1 - 3 TOP OF WASTE AND CELL 4 SUBGRADE PLAN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

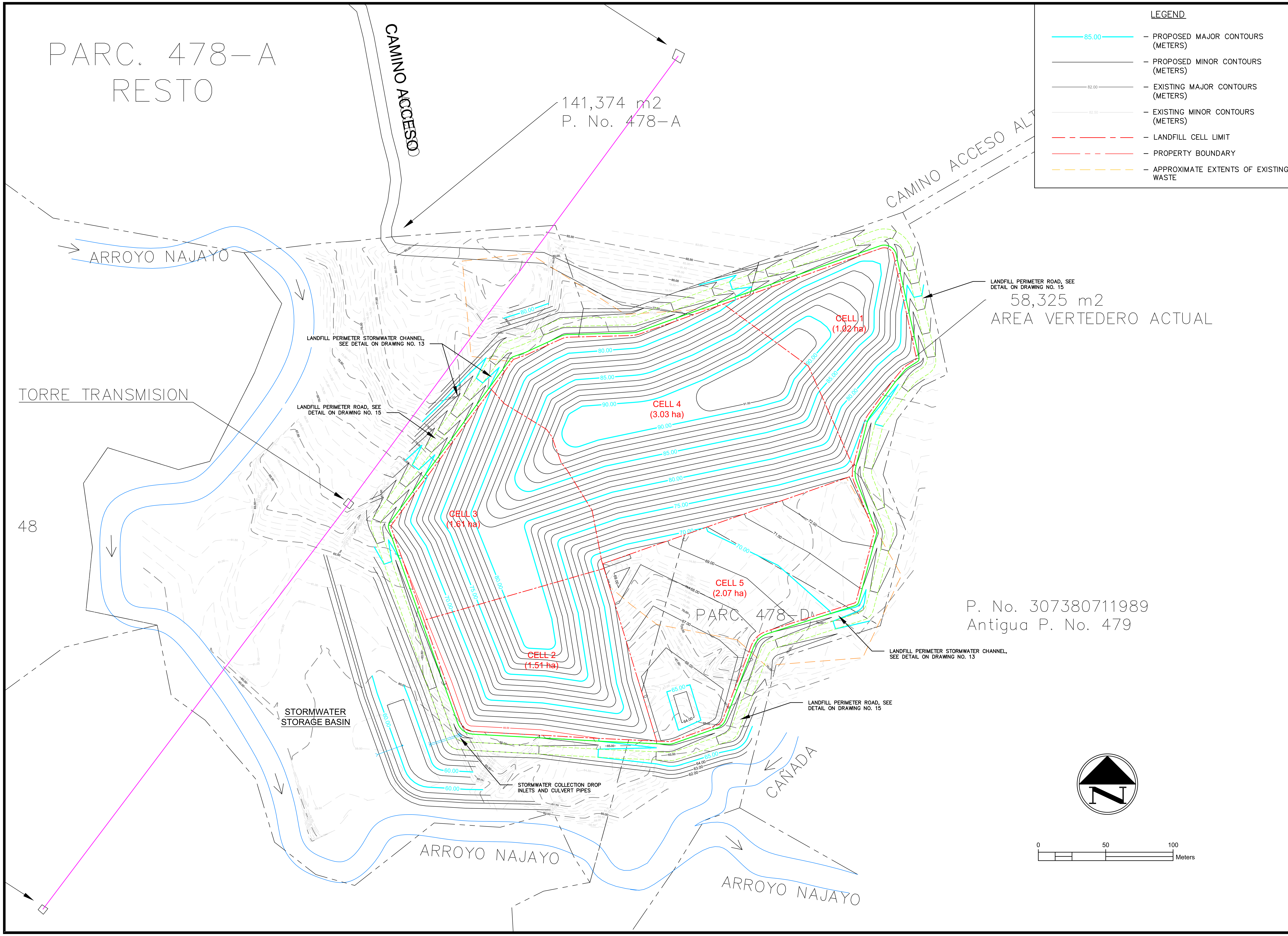
PROJ. NO. 06218001.00 | DSN. BY: ADG | DWN. BY: OH | CHK. BY: | Q/A RVW BY: | APP. BY:

CADD FILE: SHEET 10

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. 10 of 18



REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: CELL 1 - 4 TOP OF WASTE AND CELL 5 SUBGRADE PLAN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

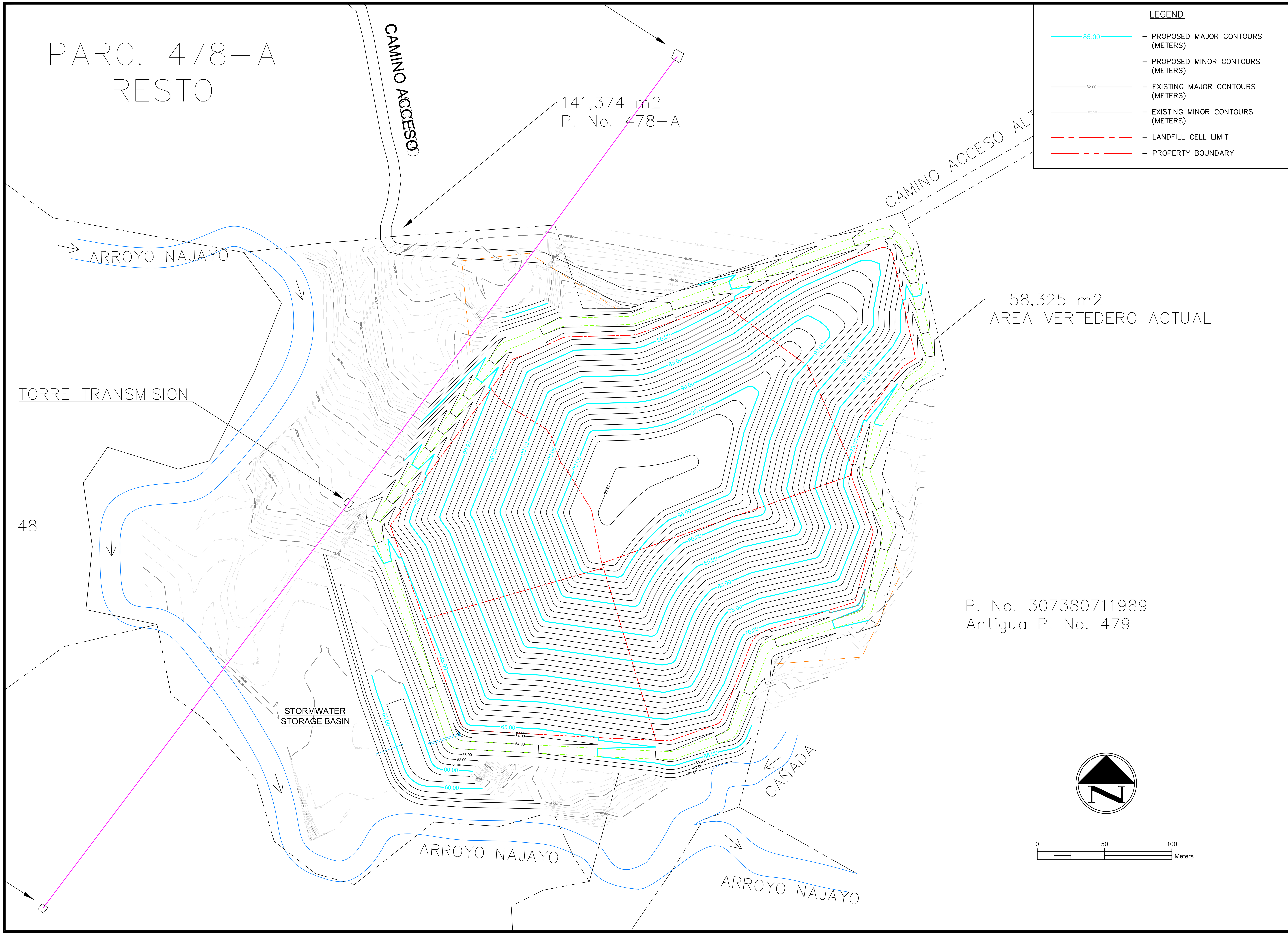
PROJ. NO. 06218001.00 | DWN. BY: OH | Q/A RVW BY: | DSN. BY: ADG | CHK. BY: | APP. BY:

CADD FILE: SHEET 11-CEL...

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. 11 of 18



REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE
CELL 1 - 5
TOP OF WASTE

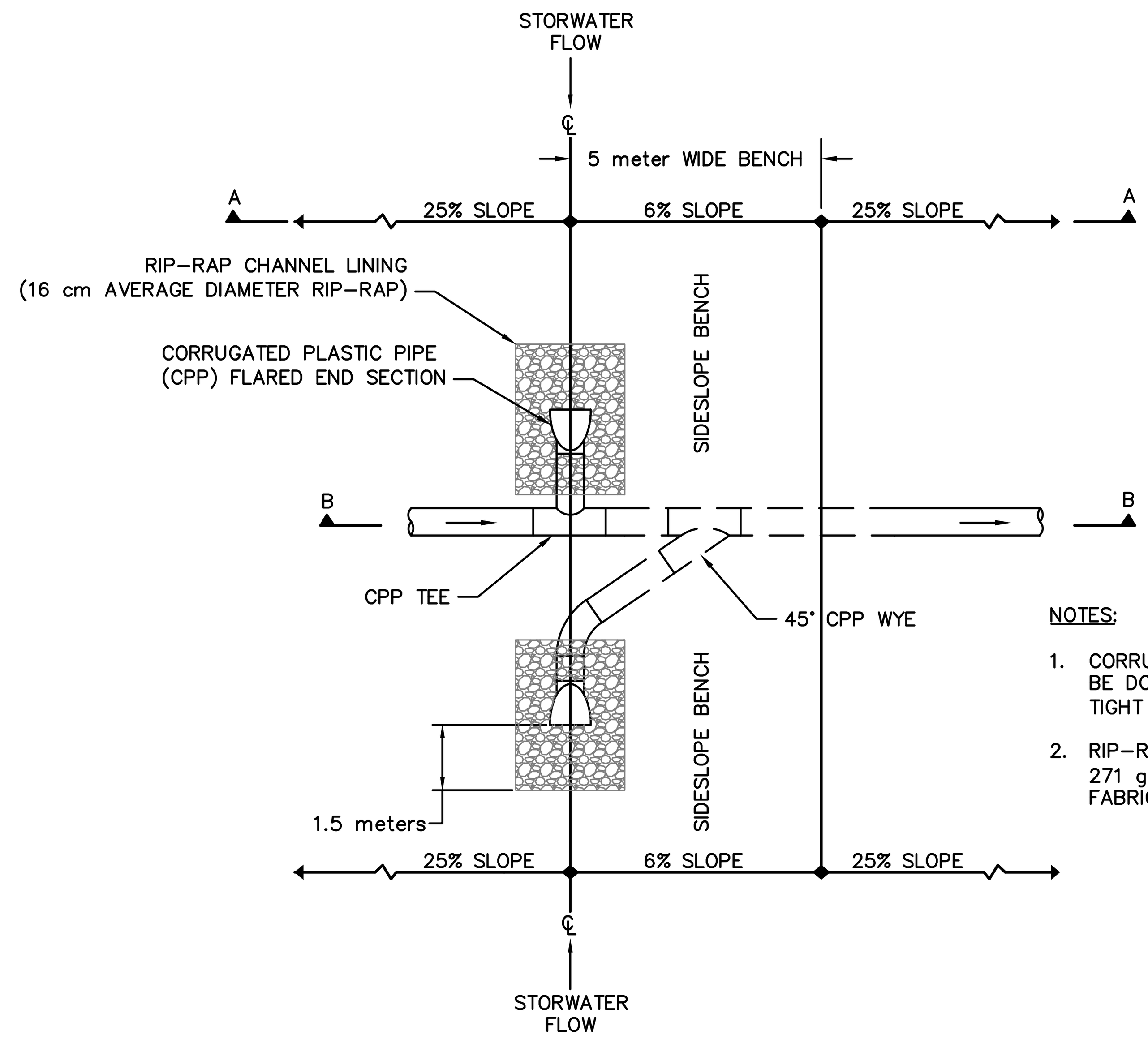
PROJECT TITLE
SAN CRISTOBAL LANDFILL

CLIENT
BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

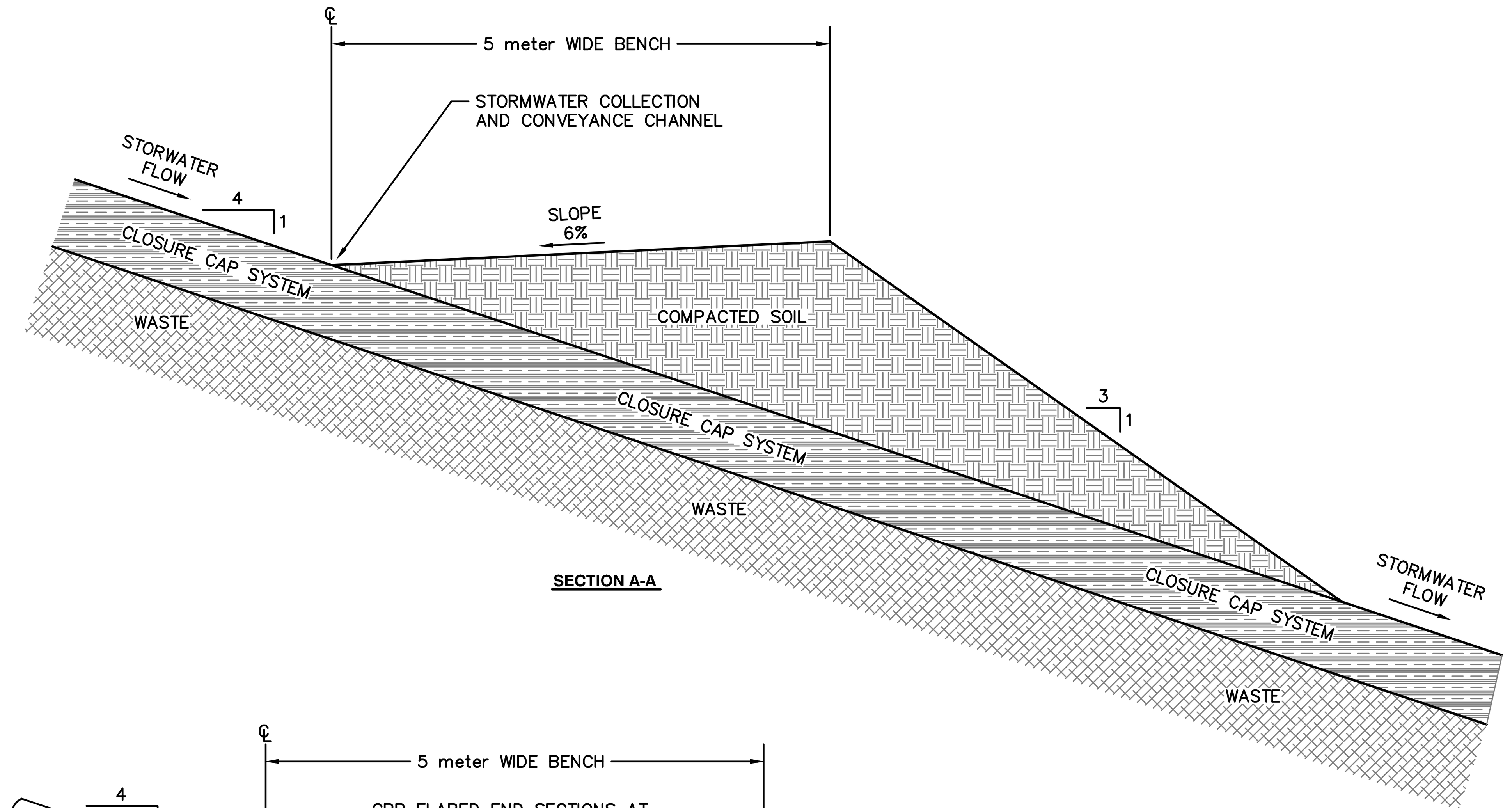
PROJ. NO. 02218001.00
DSN. BY: ADG
DWN. BY: OH
CHK. BY:
Q/A RVW BY:
APP. BY:

CADD FILE: SHEET 12
DATE: AUG 2018
SCALE: AS NOTED
DRAWING NO.
12 of **18**

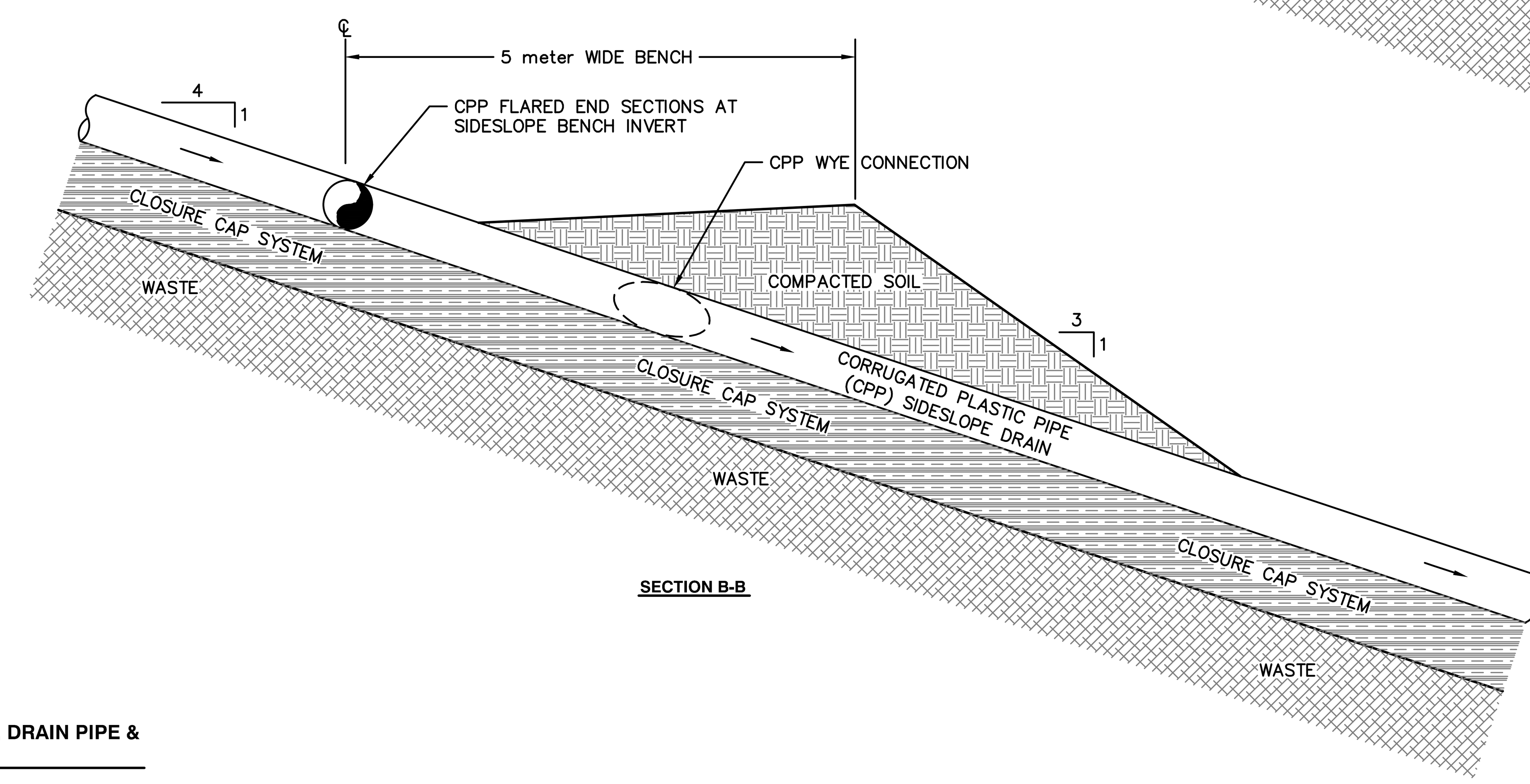


NOTES:

1. CORRUGATED PLASTIC PIPE (CPP) SHALL BE DOUBLE WALL SMOOTH CORE SOIL TIGHT (ST) PIPE.
2. RIP-RAP SHALL BE 46 cm THICK, WITH 271 g/m² NON-WOVEN GEOTEXTILE FABRIC UNDERLAYMENT.

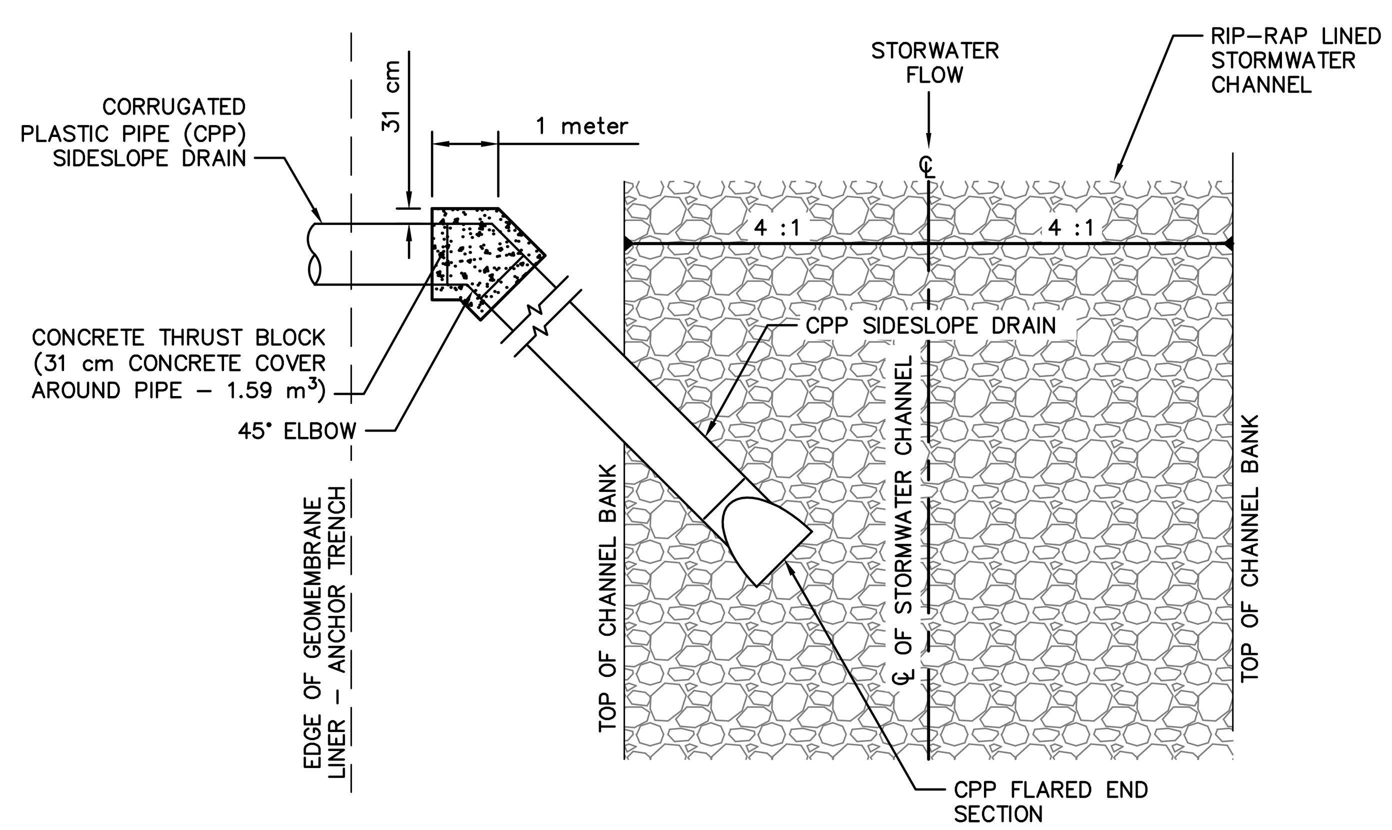


SECTION A-A



SECTION B-B

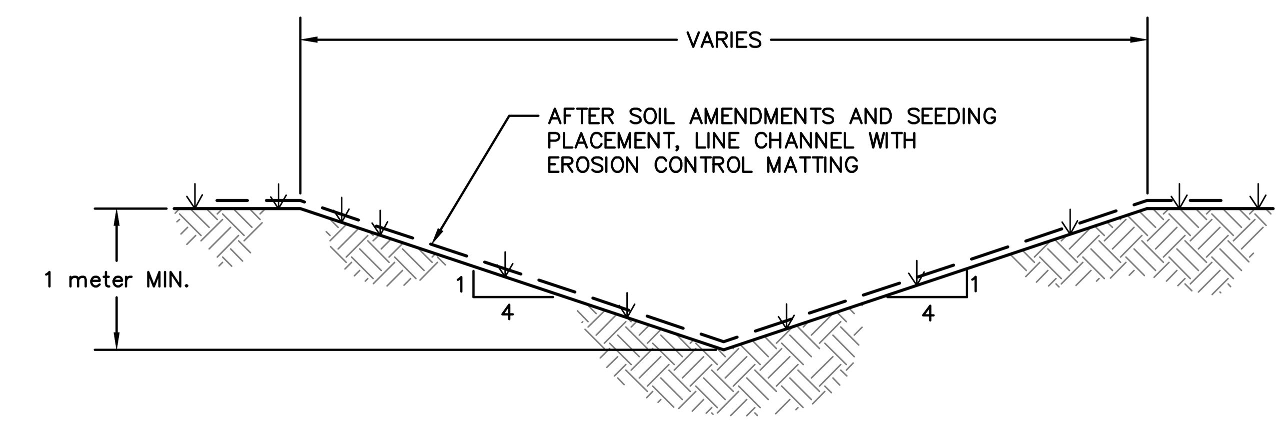
SIDESLOPE BENCH, DRAIN PIPE & PIPE INLET DETAIL
NOT TO SCALE



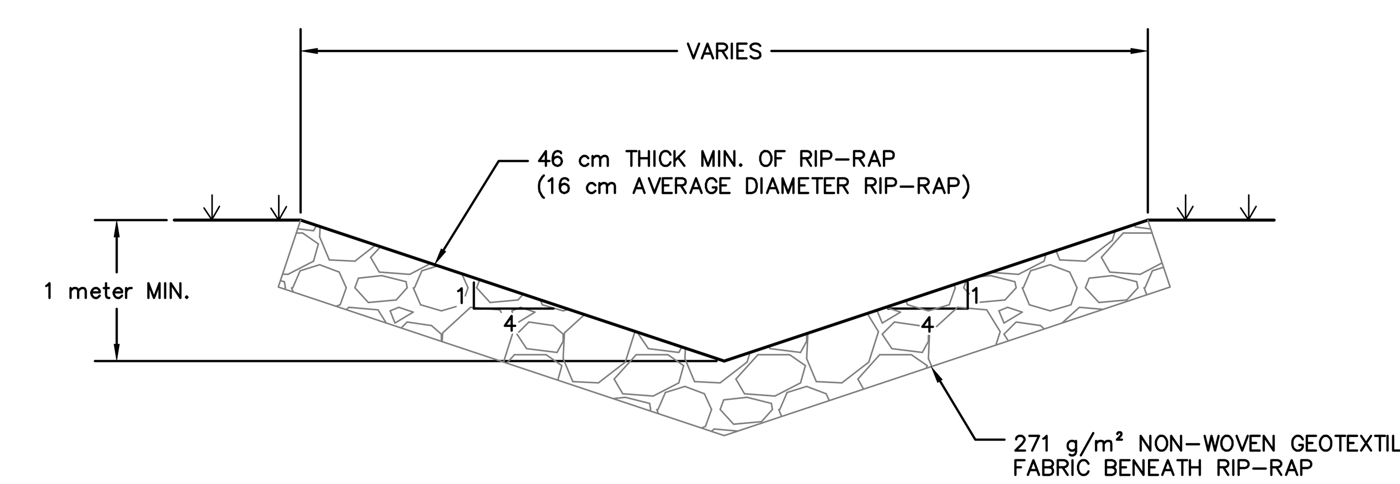
NOTE

1. CORRUGATED PLASTIC PIPE (CPP) SHALL BE DOUBLE WALL SMOOTH CORE SOIL TIGHT (ST) PIPE.

SIDESLOPE DRAIN PIPE OUTLET DETAIL
NOT TO SCALE



GRASS LINED CHANNEL



RIP-RAP LINED CHANNEL

STORMWATER CHANNEL DETAIL
NOT TO SCALE

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: **STORMWATER MANAGEMENT DETAILS**

PROJECT TITLE: **SAN CRISTOBAL LANDFILL**

CLIENT: **BATTELLE MEMORIAL INSTITUTE**
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

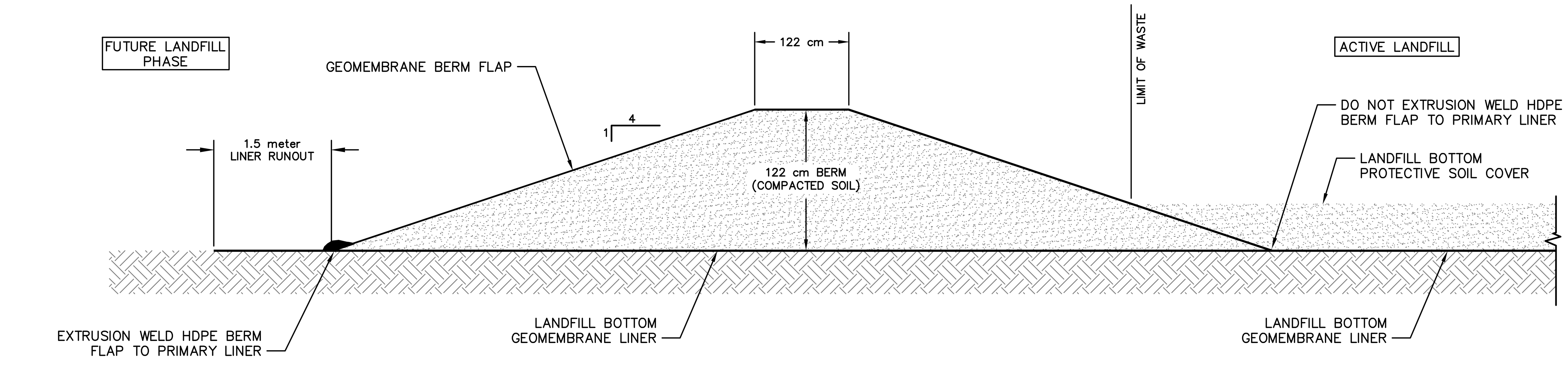
PROJ. NO. 06218001.00 | DWN. BY: OJH | CHK. BY: | Q/A RVW BY: | APP. BY: | DSN. BY: ADG

CADD FILE: DETAILS

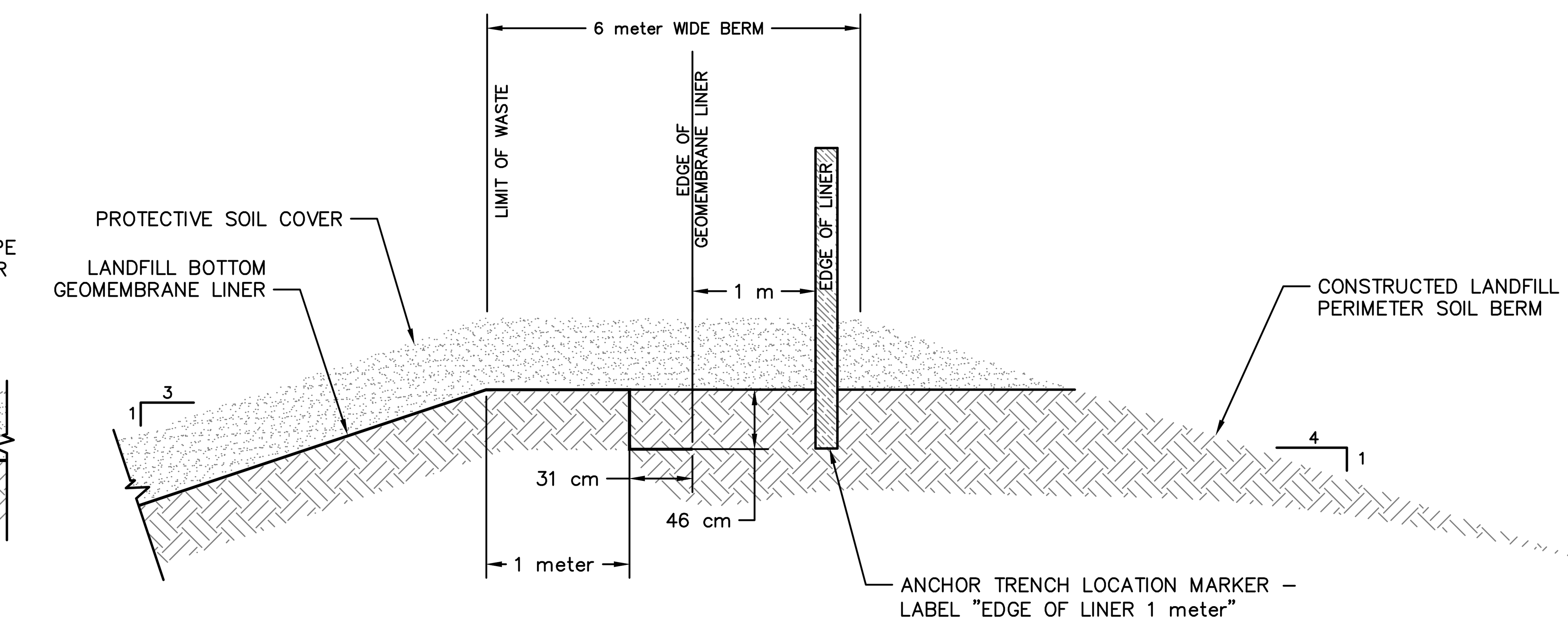
DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. **13** of **18**

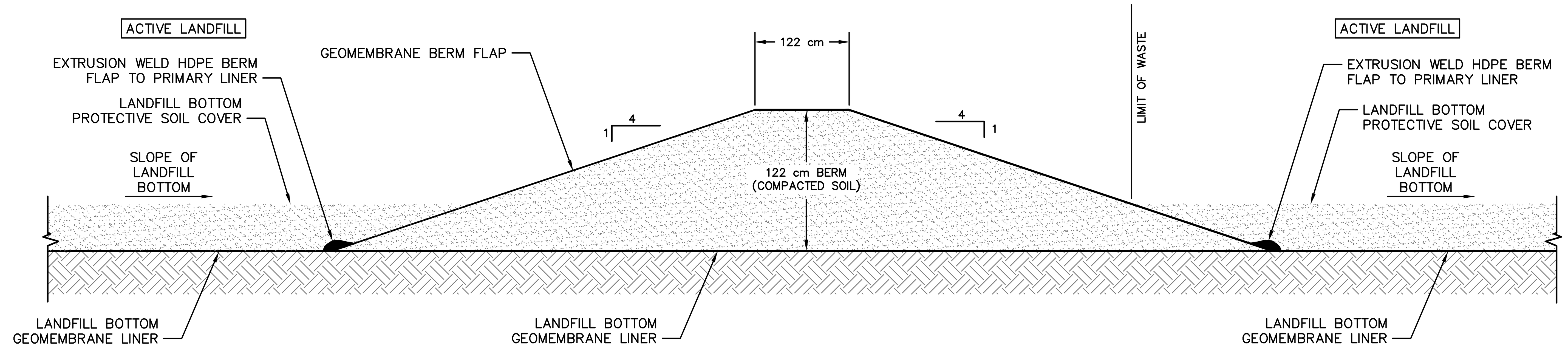


SOUTH SIDE OF LANDFILL PHASES I - II

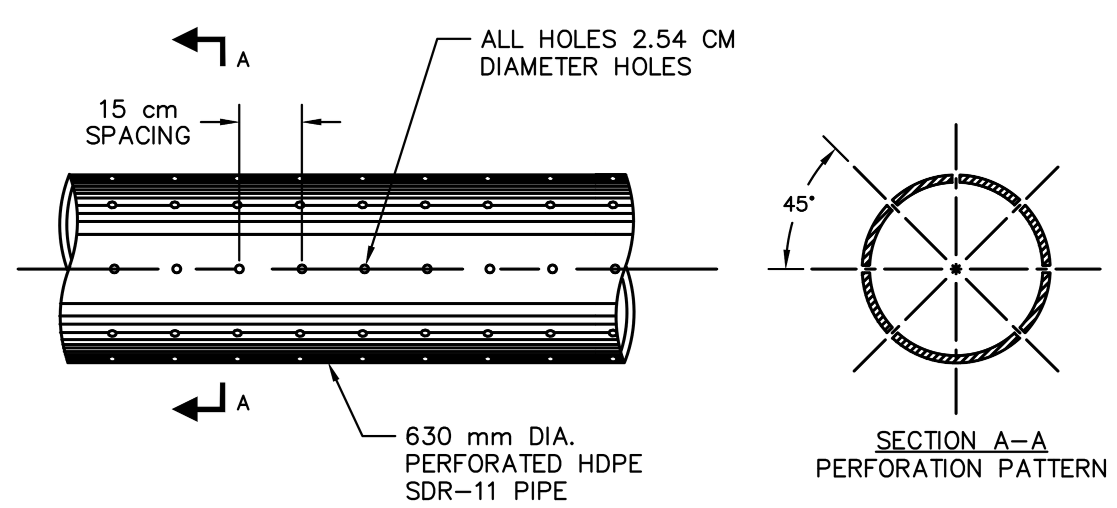


LANDFILL BOTTOM GEOMEMBRANE LINER ANCHOR TRENCH DETAIL

NOT TO SCALE

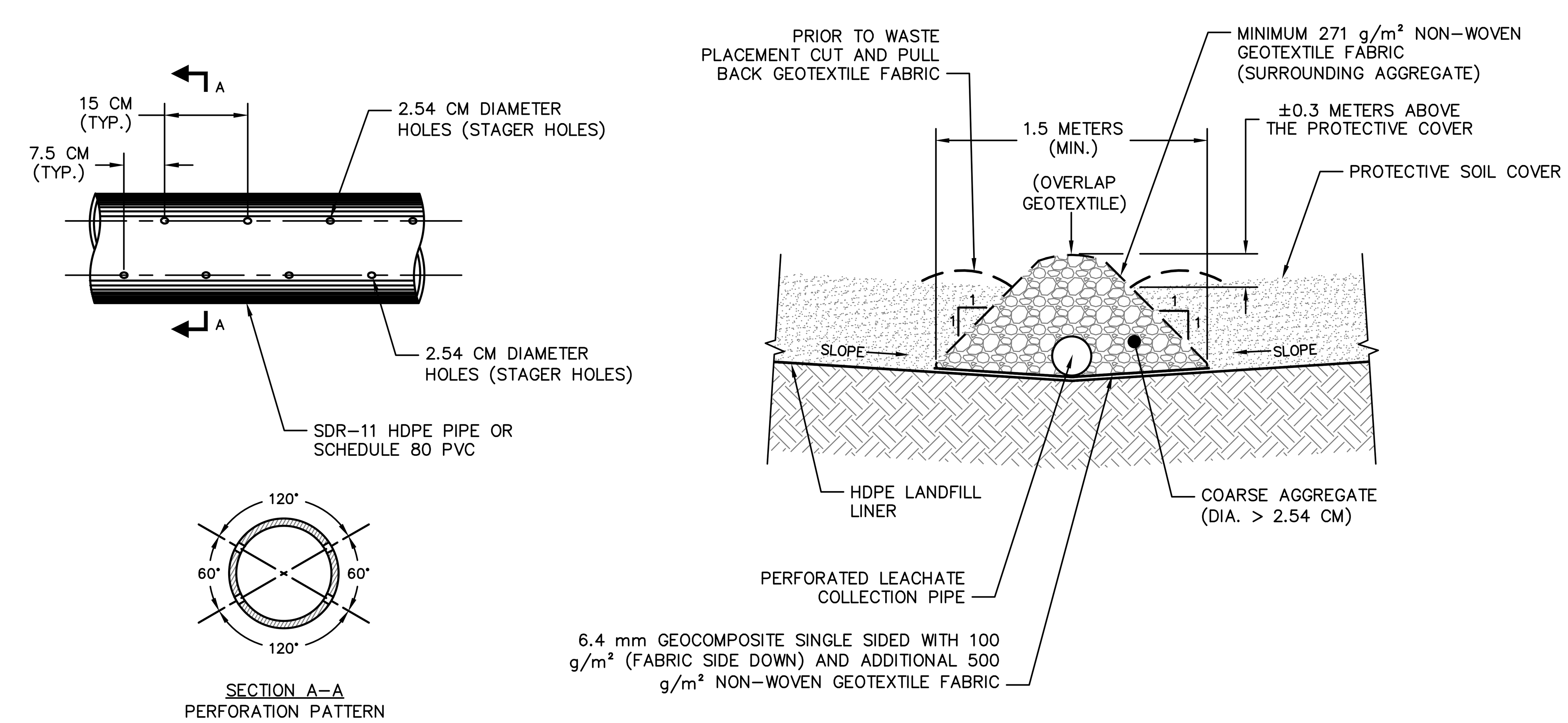


INTERNAL TO LANDFILL PHASE



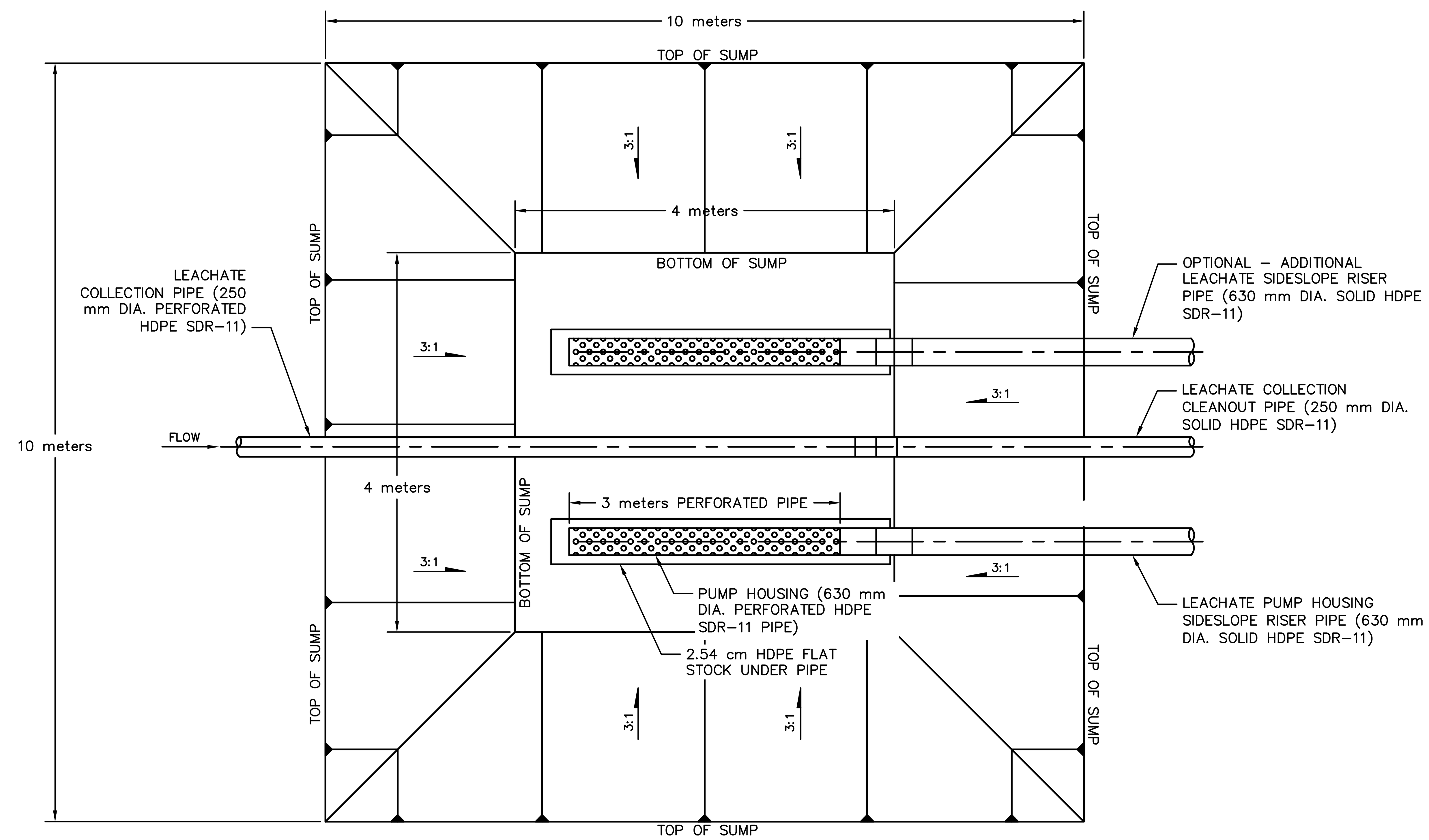
LEACHATE COLLECTION SUMP PUMP HOUSING PIPE DETAIL

NOT TO SCALE



LANDFILL BOTTOM LEACHATE COLLECTION PIPE DETAIL

NOT TO SCALE



LANDFILL BOTTOM LEACHATE COLLECTION SUMP DETAIL

NOT TO SCALE

REV.	DATE	DESCRIPTION	CK. BY
1			
2			
3			
4			
5			

SHEET TITLE: **LANDFILL DETAILS**

PROJECT TITLE: **SAN CRISTOBAL LANDFILL**

CLIENT: **BATTELLE MEMORIAL INSTITUTE**
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

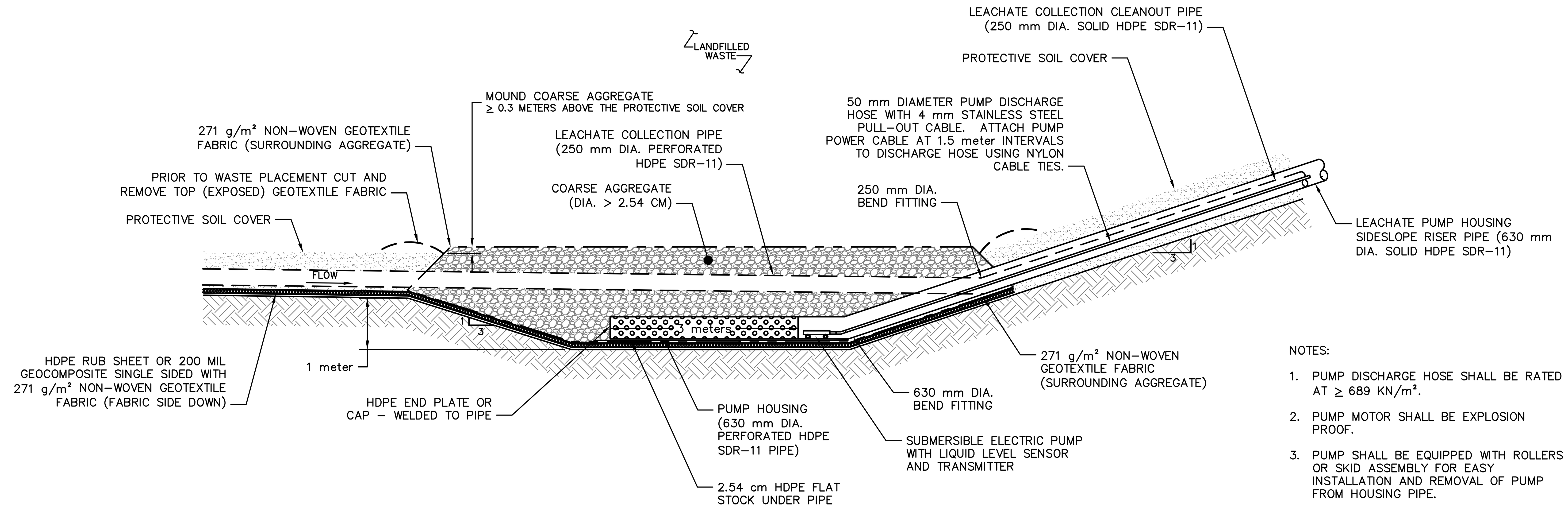
PROJ. NO. 06218001.00 | DSN. BY: ADG | DWN. BY: OJH | CHK. BY: | Q/A RVW BY: | APP. BY:

CADD FILE: DETAILS

DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. **14** of **18**

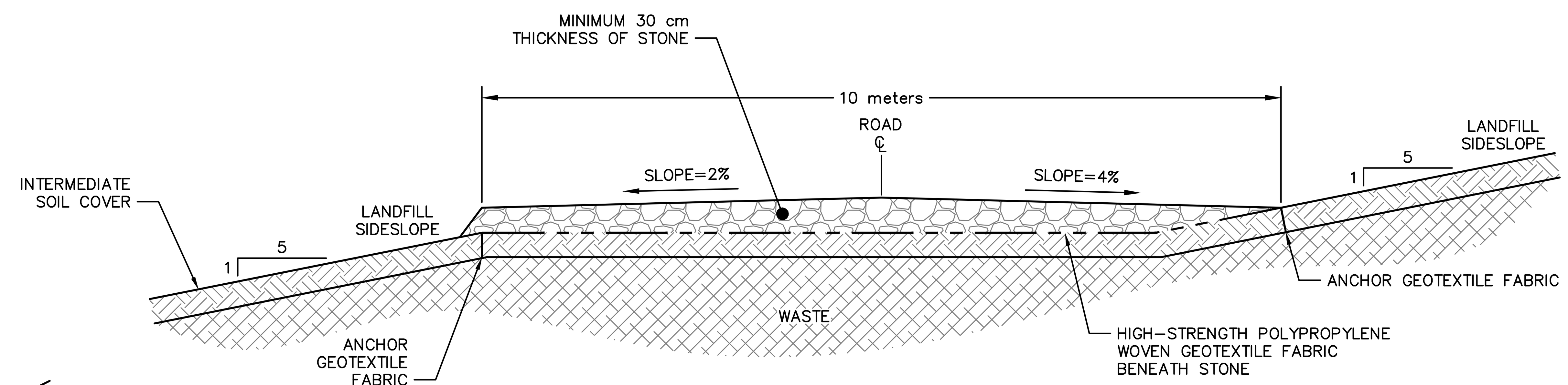


NOTES:

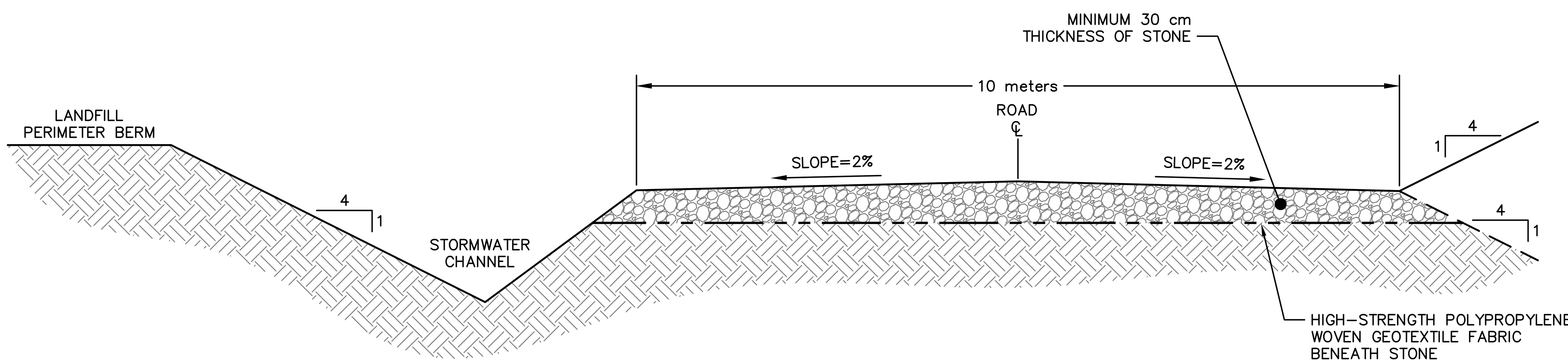
1. PUMP DISCHARGE HOSE SHALL BE RATED AT ≥ 689 KN/m².
2. PUMP MOTOR SHALL BE EXPLOSION PROOF.
3. PUMP SHALL BE EQUIPPED WITH ROLLERS OR SKID ASSEMBLY FOR EASY INSTALLATION AND REMOVAL OF PUMP FROM HOUSING PIPE.

LANDFILL BOTTOM LEACHATE COLLECTION SUMP AND RISER PROFILE

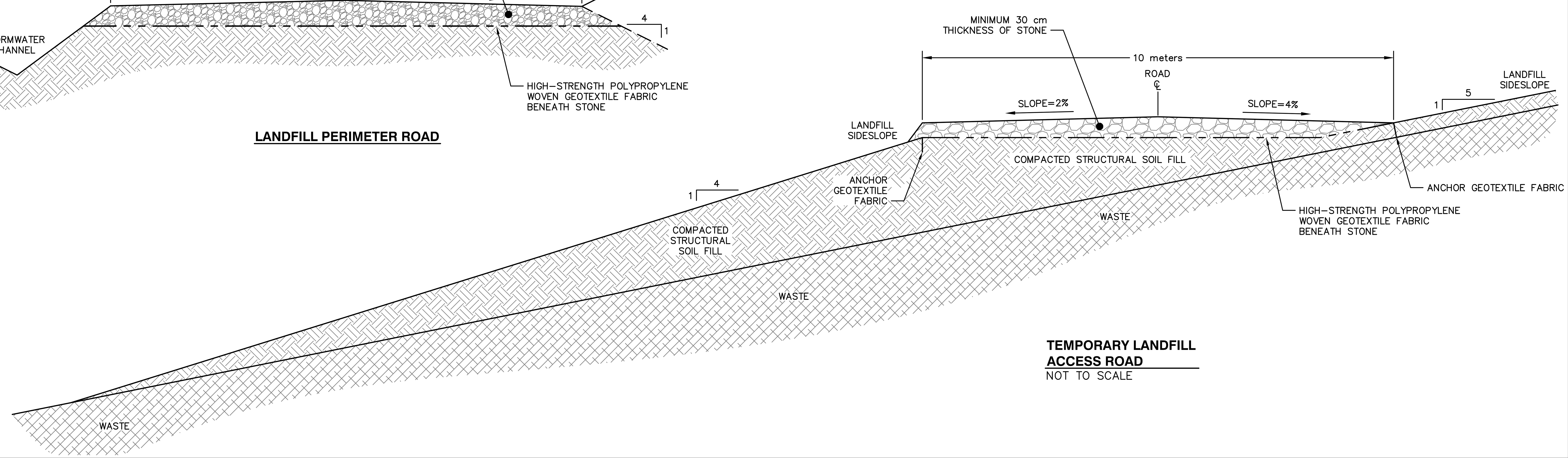
NOT TO SCALE



LANDFILL ACCESS ROAD



LANDFILL PERIMETER ROAD



TEMPORARY LANDFILL ACCESS ROAD

NOT TO SCALE

REV.	DATE	DESCRIPTION	CK. BY
△			
△			
△			
△			
△			
△			

SHEET TITLE: **LANDFILL DETAILS**

PROJECT TITLE: **SAN CRISTOBAL LANDFILL**

CLIENT: **BATTELLE MEMORIAL INSTITUTE**
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

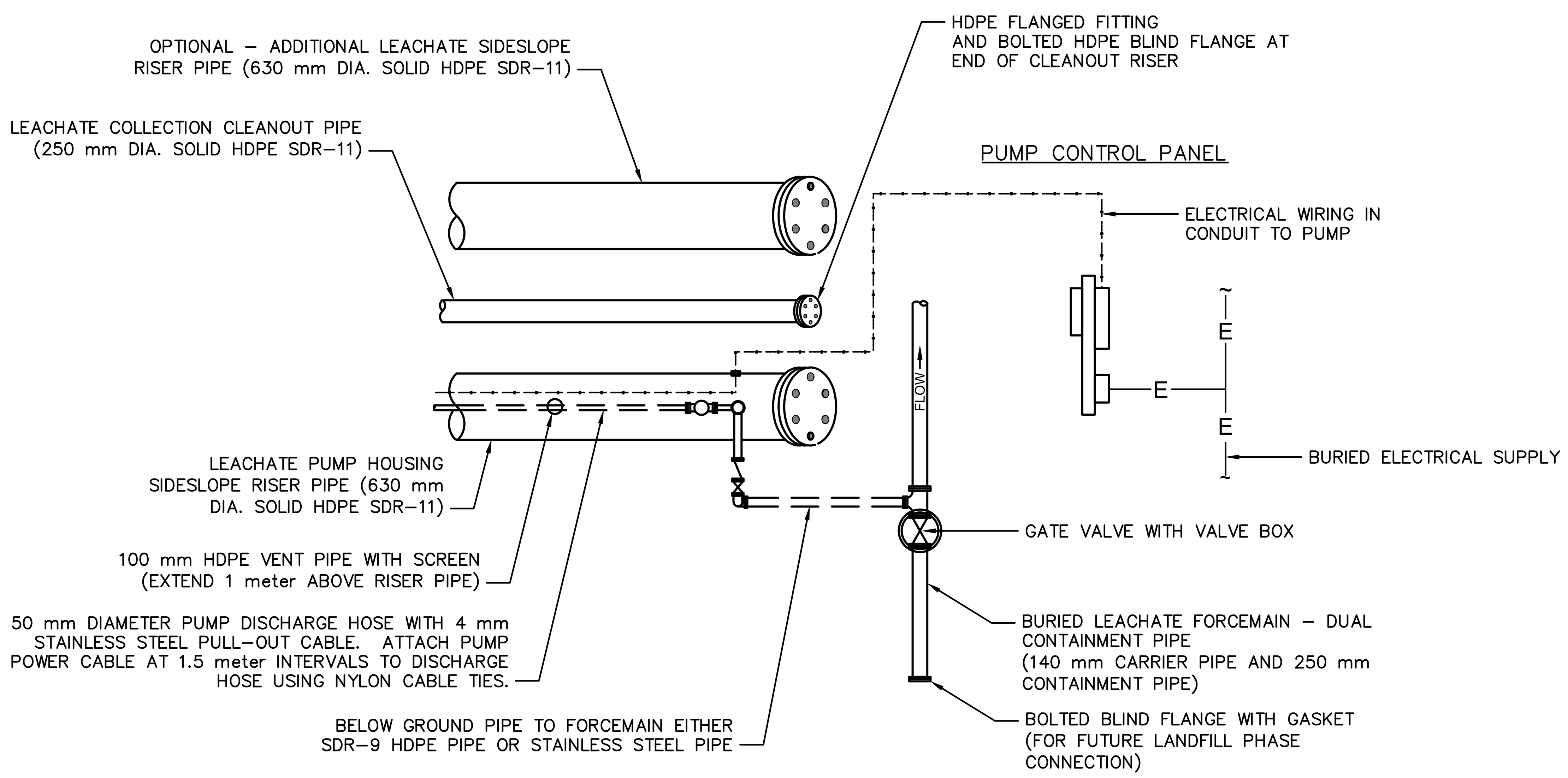
PROJ. NO. 06218001.00 | DSN. BY: ADG | DWN. BY: OJH | CHK. BY: | Q/A RVW BY: | APP. BY:

CADD FILE: DETAILS

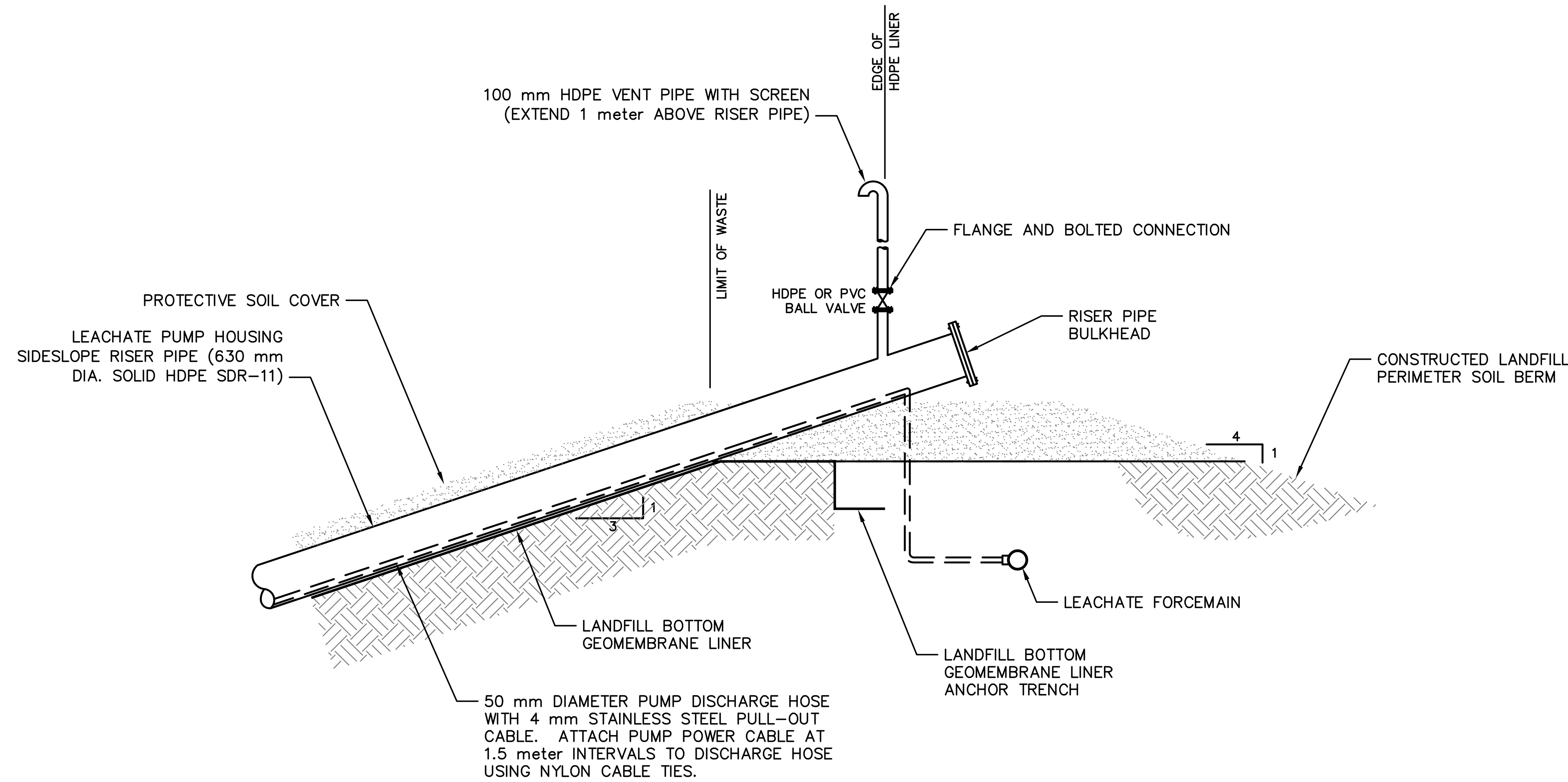
DATE: AUG 2018

SCALE: AS NOTED

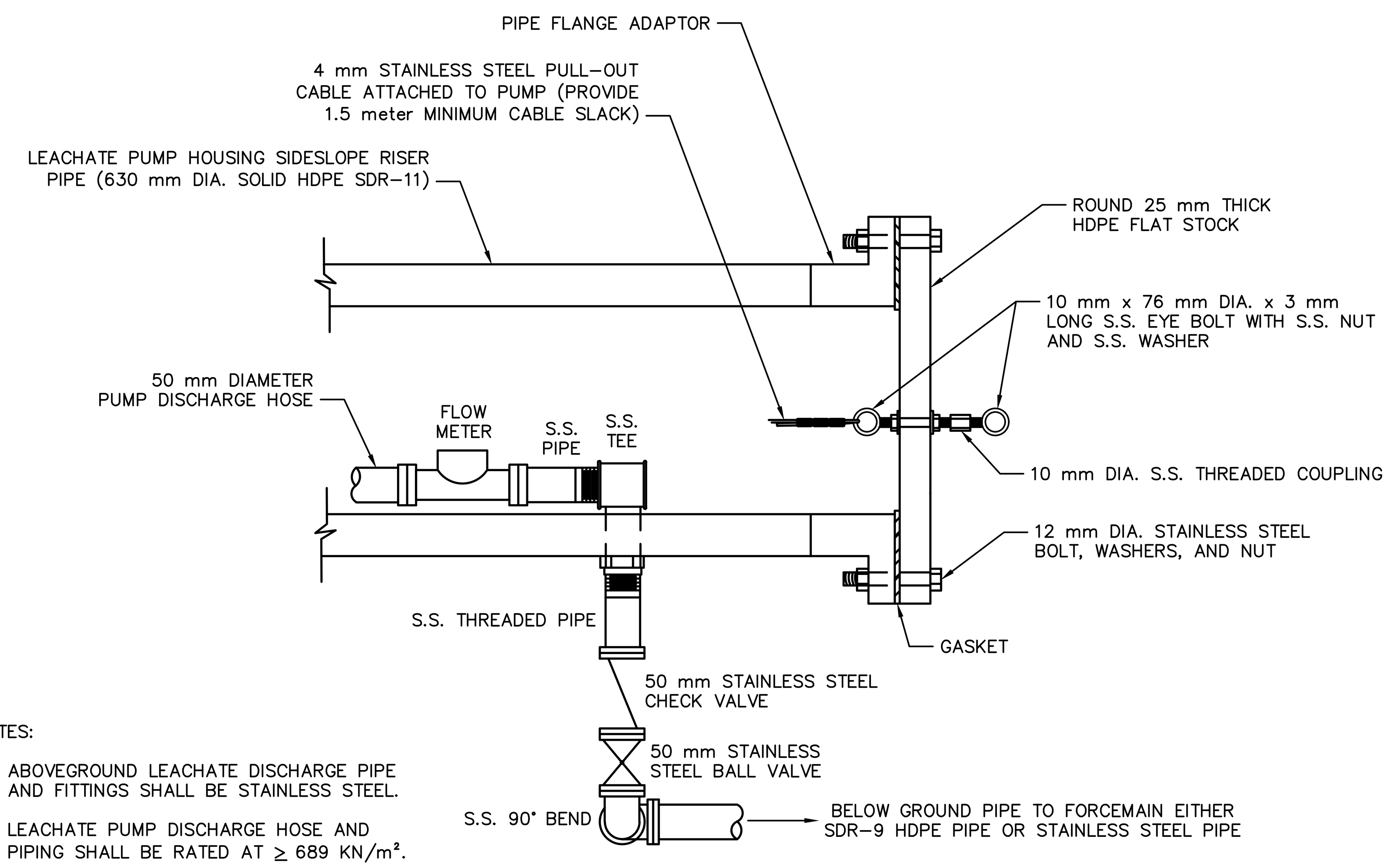
DRAWING NO. **15** of **18**



LEACHATE RISER DETAIL
NOT TO SCALE



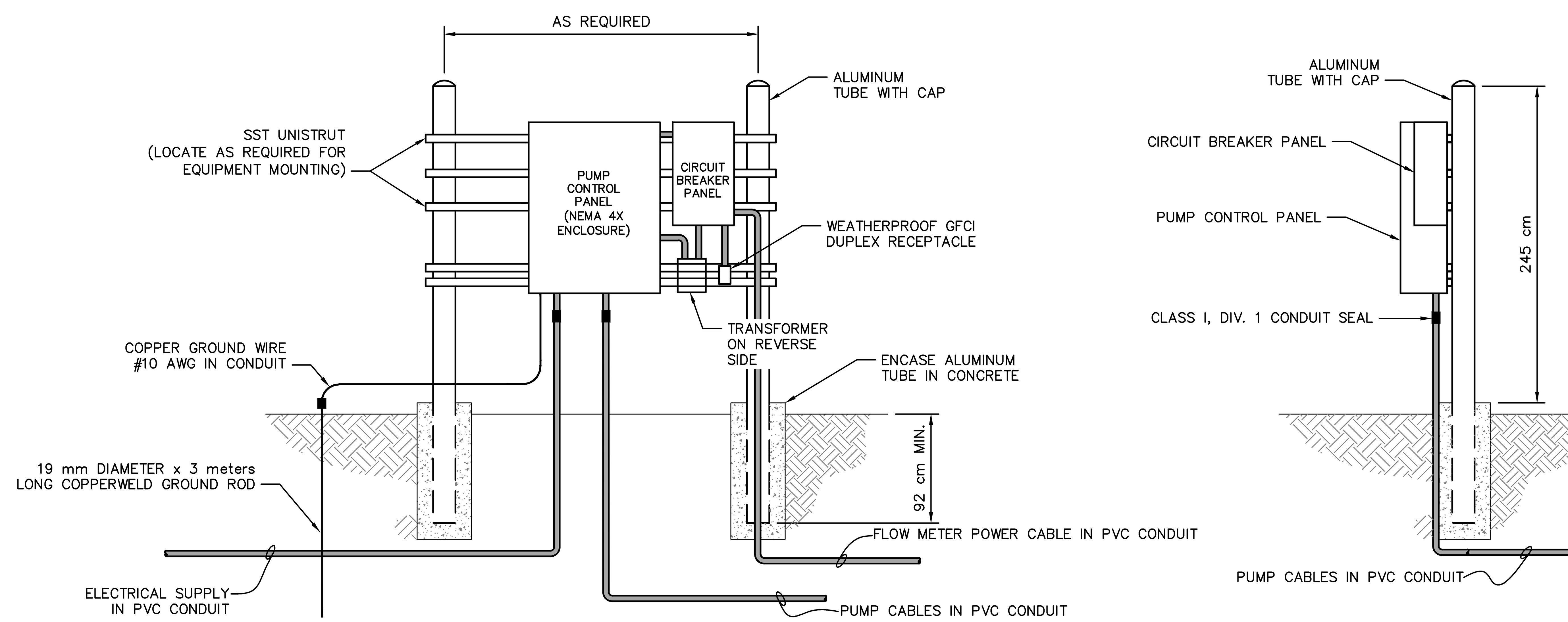
LEACHATE COLLECTION SIDESLOPE RISER PIPE PROFILE



NOTES:

1. ABOVEGROUND LEACHATE DISCHARGE PIPE AND FITTINGS SHALL BE STAINLESS STEEL.
2. LEACHATE PUMP DISCHARGE HOSE AND PIPING SHALL BE RATED AT ≥ 689 KN/m².
3. ALL EXPOSED LEACHATE DISCHARGE PIPING SHALL BE WRAPPED IN INSULATION.
4. FLOW METER AND AIR RELEASE VALVE CAN BE LOCATED OUTSIDE OF SIDESLOPE RISER PIPE.

RISER PIPE BULKHEAD AND FITTINGS
NOT TO SCALE



LEACHATE PUMP CONTROL PANEL DETAIL
NOT TO SCALE

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: **LANDFILL DETAILS**

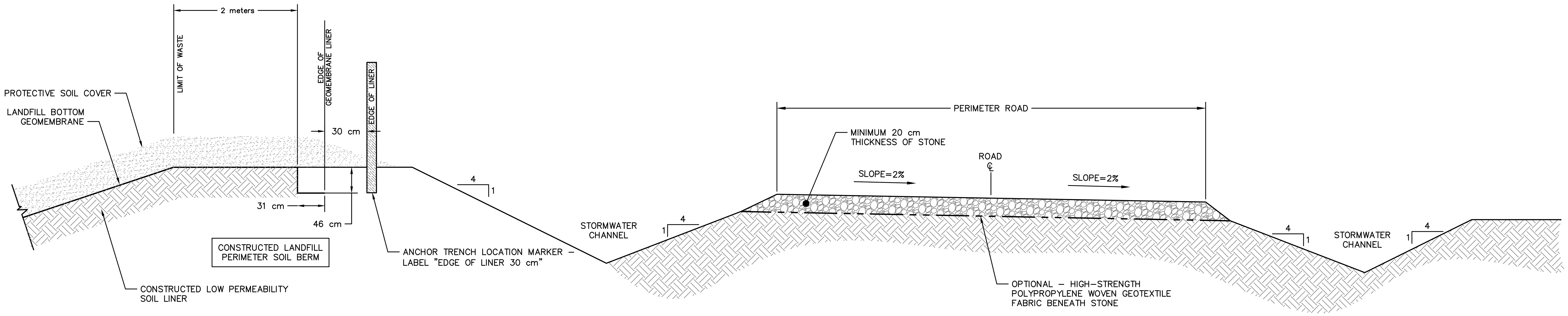
PROJECT TITLE: **SAN CRISTOBAL LANDFILL**

CLIENT: **BATTELLE MEMORIAL INSTITUTE**
505 KING AVENUE
COLUMBUS, OHIO 43201

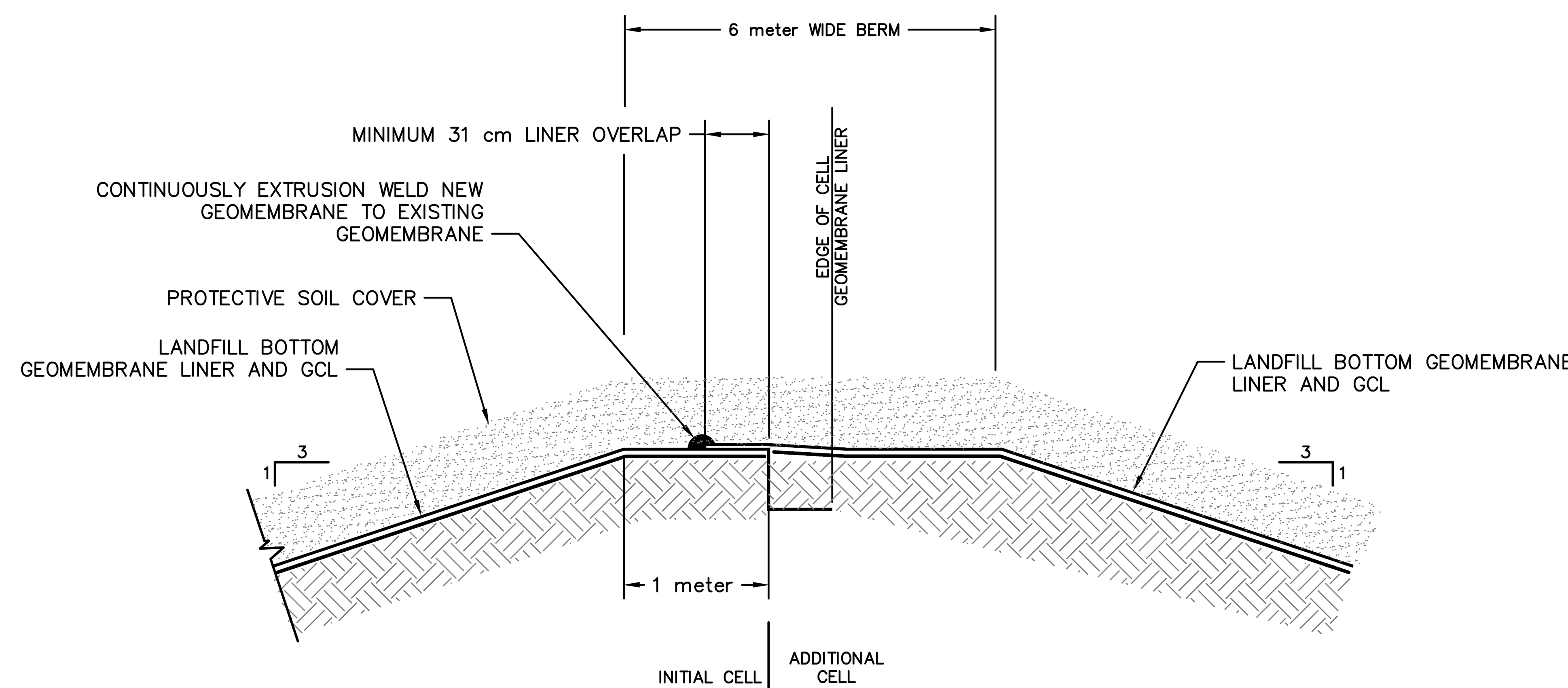
SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

PROJ. NO. 06218001.00 | DWN. BY: OJH | Q/A RVW BY: | DSN. BY: ADG | CHK. BY: | APP. BY:

CADD FILE: DETAILS
DATE: AUG 2018
SCALE: AS NOTED
DRAWING NO. **16** of **18**



LANDFILL BOTTOM GEOMEMBRANE LINER
ANCHOR TRENCH DETAIL
NOT TO SCALE



LANDFILL BOTTOM GEOMEMBRANE
LINER TIE-IN DETAIL
NOT TO SCALE

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: **LANDFILL DETAILS**
PROJECT TITLE: **SAN CRISTOBAL LANDFILL**
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2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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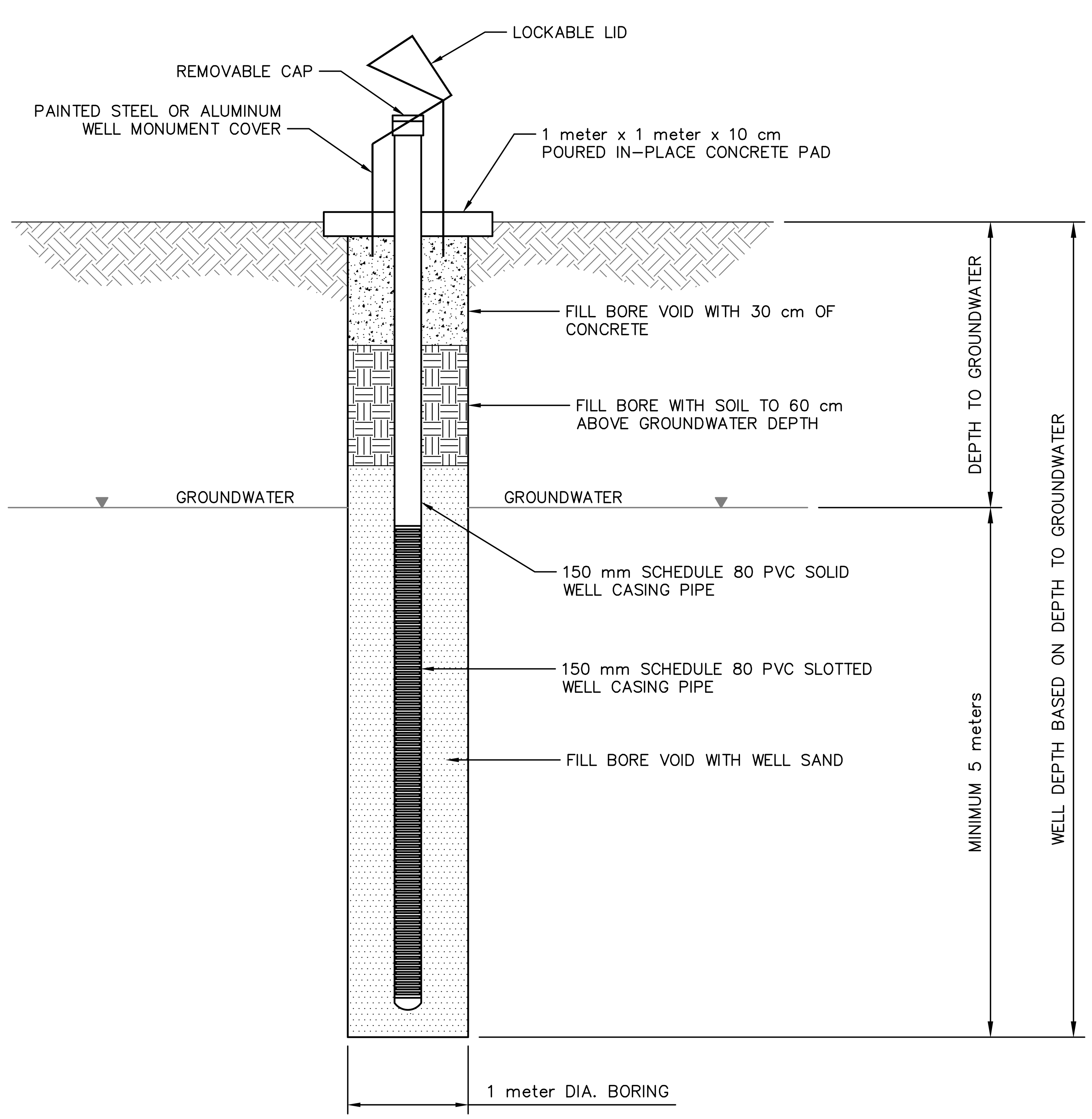
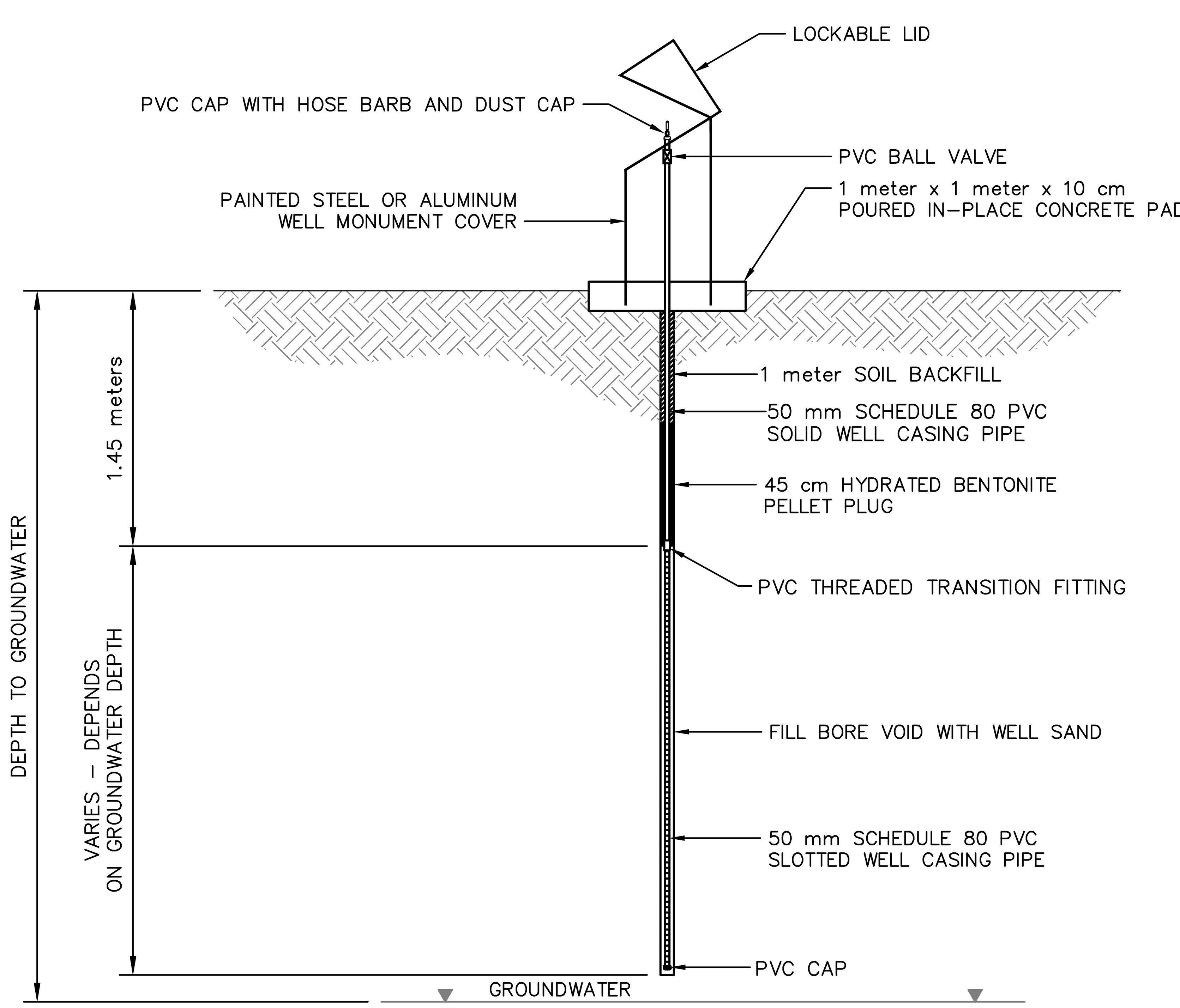
WELL SAND PACK SPECIFICATIONS

Screen Opening (in)	Sand Pack Mesh Name	1% Passing Size (d-1) (in)	10% Passing Size (d-10) (in)	30% Passing Size (d-30) (in)	Derived 60% Passing Size (d-60) (in)	Range for Uniformity Coefficient
0.005-0.006	100	.0035 - .0047	.0055 - .0067	.0067 - .0083	.0085 - .0134	1.3 - 2.0
0.010"	20-40	.0098 - .0138	.0157 - .0197	.0197 - .0236	.020 - .0315	1.1 - 1.6



TYPICAL GROUNDWATER MONITORING WELL DETAIL

NOT TO SCALE



TYPICAL METHANE GAS MONITORING WELL DETAIL

NOT TO SCALE

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: GROUNDWATER AND METHANE GAS MONITORING WELL DETAILS

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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DATE: AUG 2018

SCALE: AS NOTED

DRAWING NO. 18 of 18

GCCS CONCEPTUAL DESIGN

San Cristobal Landfill

PREPARED BY:

SCS ENGINEERS
3900 KILROY AIRPORT WAY
SUITE 100
LONG BEACH, CA 90806
+1 562-426-954

SCS JOB NO. 06218001.00
AUGUST 2018

REFERENCE MAP
NO SCALE

INDEX OF DRAWINGS

REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE: COVER SHEET
PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
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COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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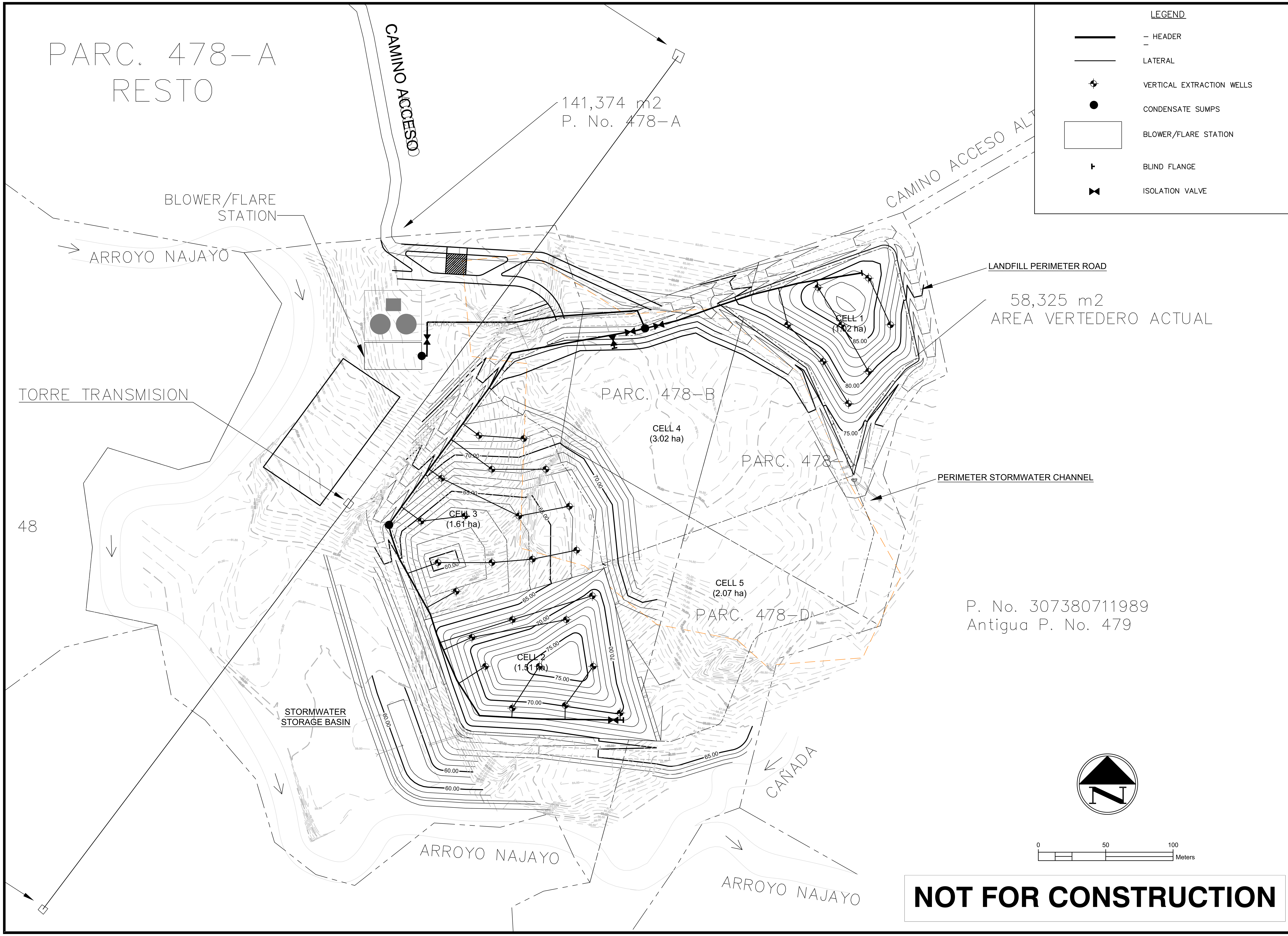
DATE: AUG 2018
SCALE: AS NOTED
DRAWING NO. 0 of 6

C:\Users\1903jd\Desktop\Work at Home\06218001.00 - DR Landfill Battelle\CADD\Drawings\Cover Sheet GCCS.dwg Aug 22, 2018 - 11:44am Layout Name: COVER SHEET By: 1903jd



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REV.	DATE	DESCRIPTION	CK. BY

SHEET TITLE
PHASE I
GCCS CONCEPTUAL DESIGN

PROJECT TITLE
SAN CRISTOBAL LANDFILL

CLIENT
BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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APP. BY:

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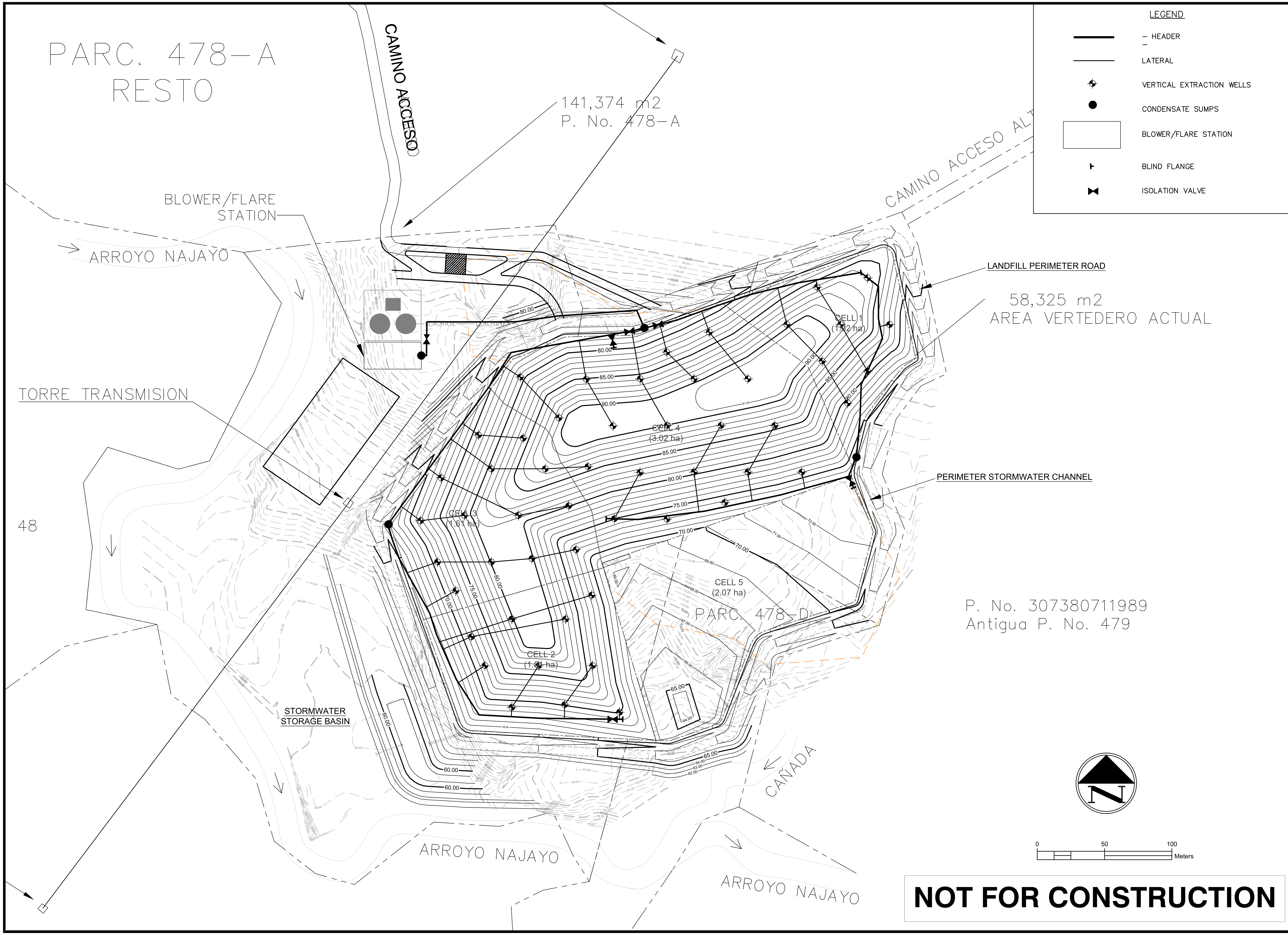

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SHEET TITLE: PHASE II GCCS CONCEPTUAL DESIGN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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DATE: AUG 2018

SCALE: AS NOTED

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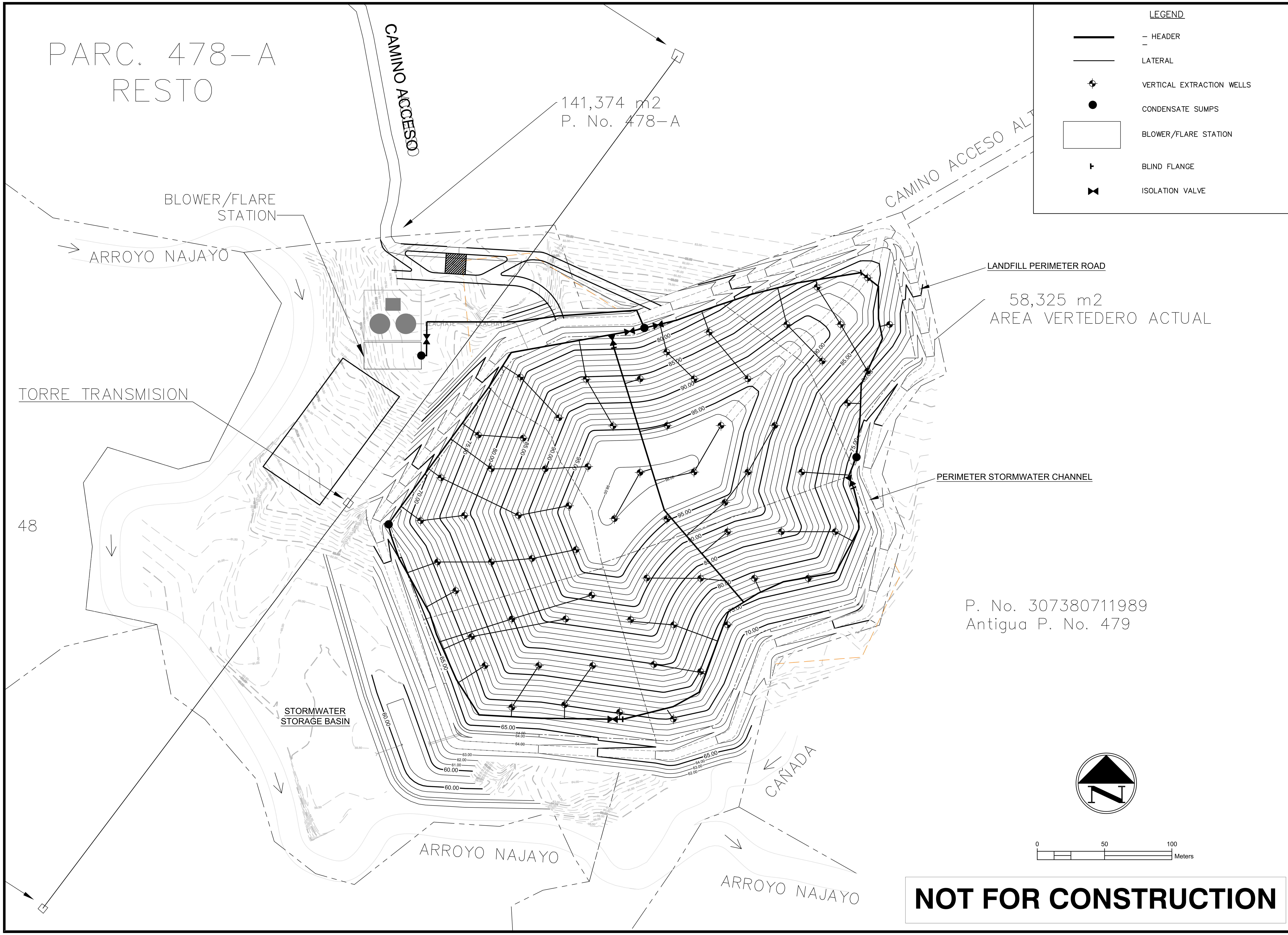

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SHEET TITLE: PHASE III GCCS CONCEPTUAL DESIGN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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CADD FILE: SHEET 3 GCCS

DATE: AUG 2018

SCALE: AS NOTED

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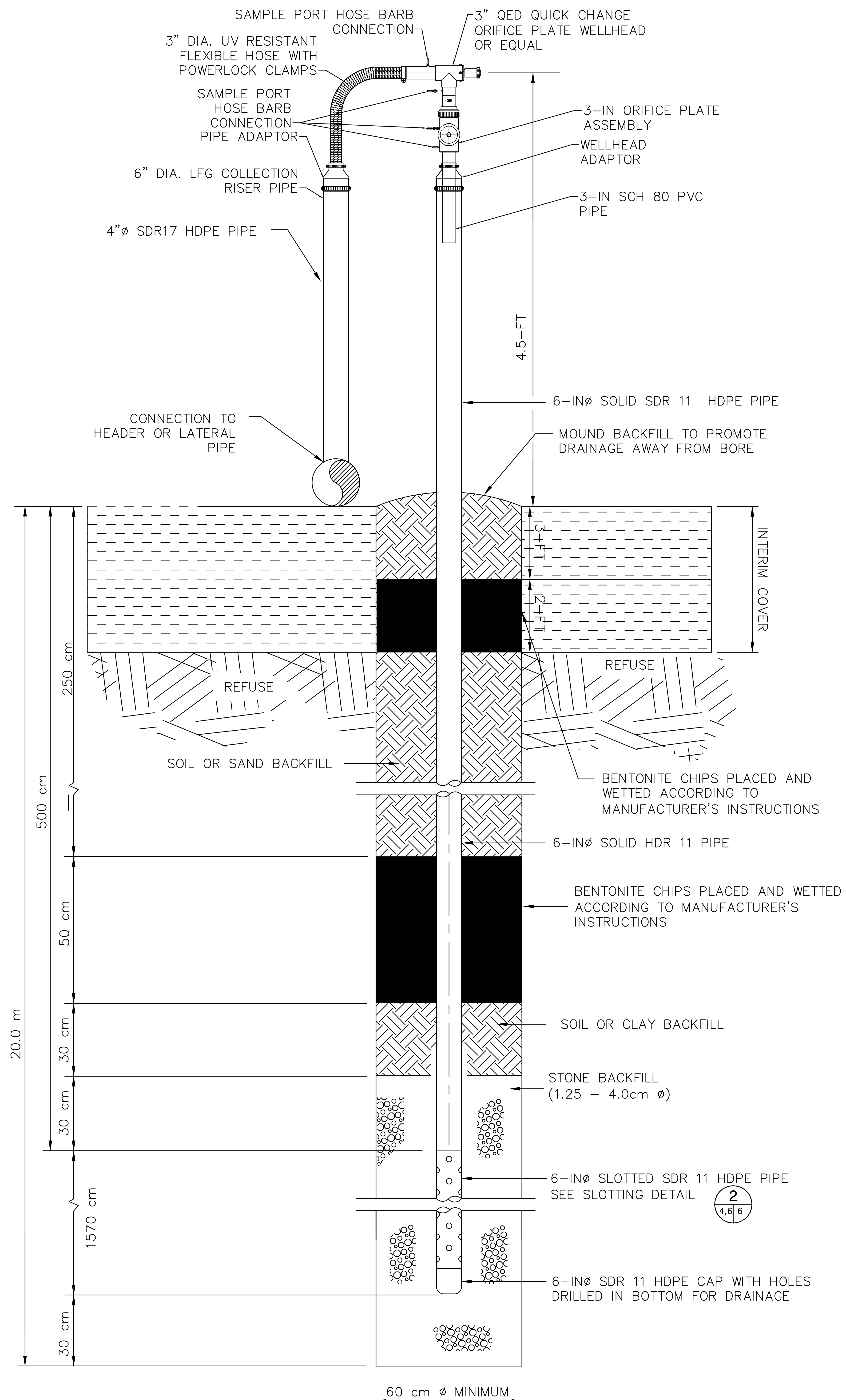
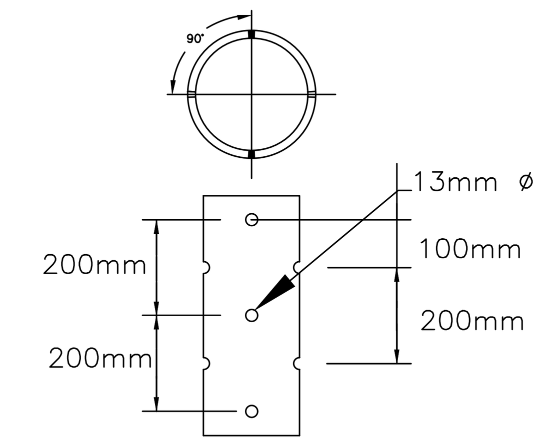
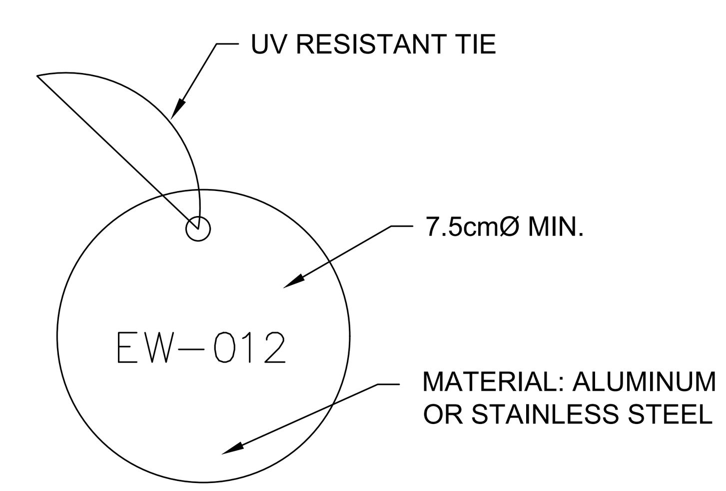


EXTRACTION WELL DETAIL 1 (5 | 6)
NO SCALE



NOTE: STAGGER PERFORATIONS BY 45° FOR ADJACENT ROWS

PERFORATED PIPE DETAIL 2 (6 | 6)
NOT TO SCALE



EMBOSS LETTERS ACCORDINGLY:
EW-012 = LFG WELL

IDENTIFICATION TAG DETAIL 3 (6 | 6)
NOT TO SCALE

GENERAL EXTRACTION WELL NOTES:

1. CONTRACTOR SHALL USE LANDTEC ACCUFLO ASSEMBLY MANUFACTURED BY LANDTEC, COMMERCE, CALIFORNIA, USA 800-821-0496 OR EQUIVALENT.
2. 6"ø X 2"ø FERNCO REDUCER FITTING SHALL BE PART NO. 1056-62 BY FERNCO (WWW.FERNCO.COM (810) 653-9626). CONTRACTOR SHALL PROVIDE RELATED STAINLESS STEEL CLAMPS.
3. USE MOLDED TEE AND REDUCER FOR CONNECTION TO 6"ø AND SMALLER HEADER OR LATERAL USE 4"ø BRANCH SADDLE CONNECTION FOR 8"ø AND LARGER HEADER CONNECTION.
4. DURING CONSTRUCTION, CONTRACTOR SHALL TEMPORARILY CAP THE RISER PIPE OF VERTICAL EXTRACTION WELL TO PREVENT DIRECT VENTING OF LFG THROUGH RISER PIPE. TEMPORARY CAP SHALL BE REMOVED DURING INSTALLATION OF WELLHEADS.
5. FLEXIBLE PVC PIPE SHALL BE MANUFACTURED BY KANAFLEX CORPORATION (310-637-1616) SERIES 101-PS AND FASTENERS SHALL BE KANAFLEX SERIES 101-PS POWER LOCK CLAMPS.
6. CONTRACTOR SHALL SUPPLY OWNER WITH ONE SPARE WELLHEAD ASSEMBLY AND 25 FEET (8M) OF SPARE 2-INCH DIAMETER FLEXIBLE PVC PIPE.
7. "BENTONITE CHIPS" REFER TO A WELL SEAL COMPRISED OF HYDRATED SODIUM BENTONITE PELLETS OR CHIPS. BENTONITE MATERIAL SHALL CONSIST OF CLAY GREATER THAN 85% SODIUM MONTMORILLONITE WITHOUT ADDITIVES.
8. THE CONFIGURATION SHOWN DEPICTS THE CONNECTION TO THE HEADER WHEN THE HEADER PIPE IS IN VICINITY OF THE WELL (I.E. LESS THAN 2M). FOR A CONNECTION TO THE HEADER GREATER THAN 2M, MAKE UP THE DISTANCE TO THE HEADER PIPING USING A 4" DIAMETER HDPE PIPE LAID ABOVE GRADE.

EXTRACTION WELL SCHEDULE NOTES:

1. WELL DEPTHS ARE TO BE 20 METERS IN MOST CASES. WELL DEPTHS ON LOWER ELEVATIONS MUST BE ADJUSTED ONLY BY ENGINEER BASED ON ACTUAL GRADES ENCOUNTERED. CONTRACTOR SHALL VERIFY SURVEY LOCATION AND EXISTING GROUND ELEVATION PRIOR TO DRILLING. CONTRACTOR SHALL IMMEDIATELY NOTIFY OWNER AND ENGINEER IF ELEVATIONS DIFFER FROM THOSE INDICATED PRIOR TO DRILLING.

2. THE CONTRACTOR MUST PROVIDE THE ENGINEER WITH THE ACTUAL EXISTING GROUND ELEVATIONS (BASED ON SURVEY DATA) PRIOR TO BEGINNING DRILLING.

3. CONTRACTOR MUST USE DRY DRILLING EQUIPMENT. WET ROTARY DRILLING EQUIPMENT MAY NOT BE USED.

5. WELLS ARE TO BE DRILLED TO DEPTH AND DIAMETER SHOWN ON PLANS. BORING DEPTHS SHOWN ARE ESTIMATED AND MAY BE ADJUSTED IN FIELD ONLY BY ENGINEER. UNDER NO CIRCUMSTANCES ARE DRILLING DEPTHS FROM WELL SCHEDULE TO BE EXCEEDED UNLESS APPROVED BY ENGINEER.

6. IF WATER IS ENCOUNTERED IN A BORING THE FOLLOWING PROCEDURES SHOULD BE FOLLOWED:
   A. CONTRACTOR MAY BE DIRECTED TO DRILL BEYOND POINT AT WHICH WATER WAS ENCOUNTERED. IF WET CONDITIONS REMAINS, BORING MAY BE TERMINATED AND LENGTH OF SLOTTED PIPE ADJUSTED BY ENGINEER.
   B. IF WATER IS ENCOUNTERED AT SHALLOW DEPTH, ENGINEER MAY DECREASE WELL DEPTH AND LENGTH OF SLOTTED PIPE OR RELOCATE WELL.

7. WHEN BORING IS ABANDONED AS DIRECTED BY ENGINEER, CONTRACTOR SHALL BACKFILL BOREHOLE WITH CUTTINGS REMOVED DURING DRILLING. IF CUTTINGS ARE NOT SUITABLE AS BACKFILL, CONTRACTOR SHALL USE SOIL BACKFILL MATERIAL. A 2-FOOT (600mm) THICK BENTONITE PLUG WILL BE PLACED IN BOREHOLE WITH DEPTH IS 4 FEET (1200mm) BELOW EXISTING GRADE. REMAINING 2-FEET (600mm) OF BOREHOLE SHALL BE FILLED WITH SOIL MATERIAL AND COMPACTED TO MATCH EXISTING GRADE.

NOT FOR CONSTRUCTION

REV.	DATE	DESCRIPTION	CK. BY
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SHEET TITLE: DETAILS GCCS CONCEPTUAL DESIGN
PROJECT TITLE: SAN CRISTOBAL LANDFILL
CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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DATE: AUG 2018
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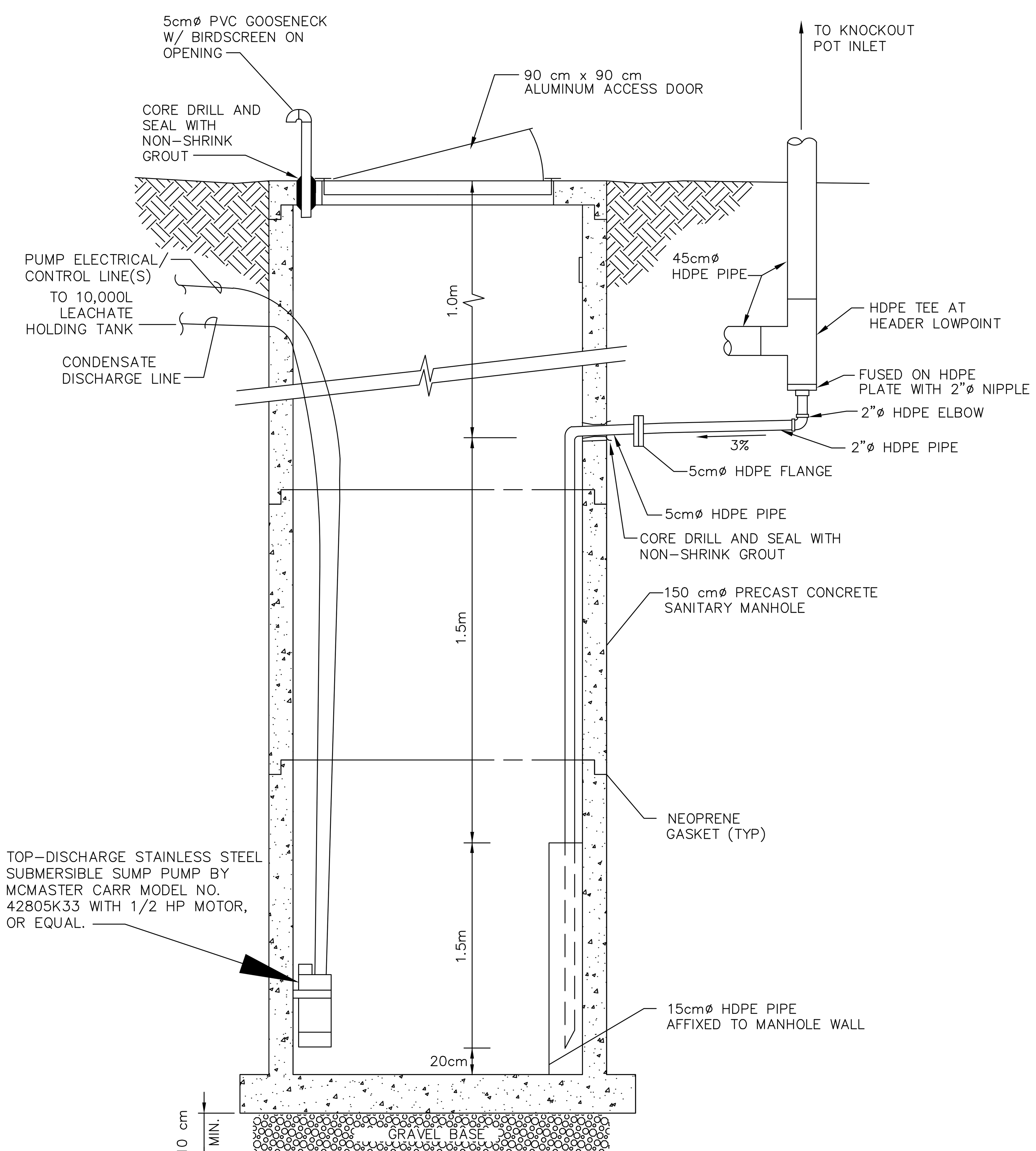
DRAWING NO. 4 of 6



NOTES:
1. IN LIEU OF INSTALLING SUBMERSIBLE PUMP, A STANDPIPE MAY BE INSTALLED SO THAT MANHOLE CAN BE SERVICED BY A VACUUM TRUCK.

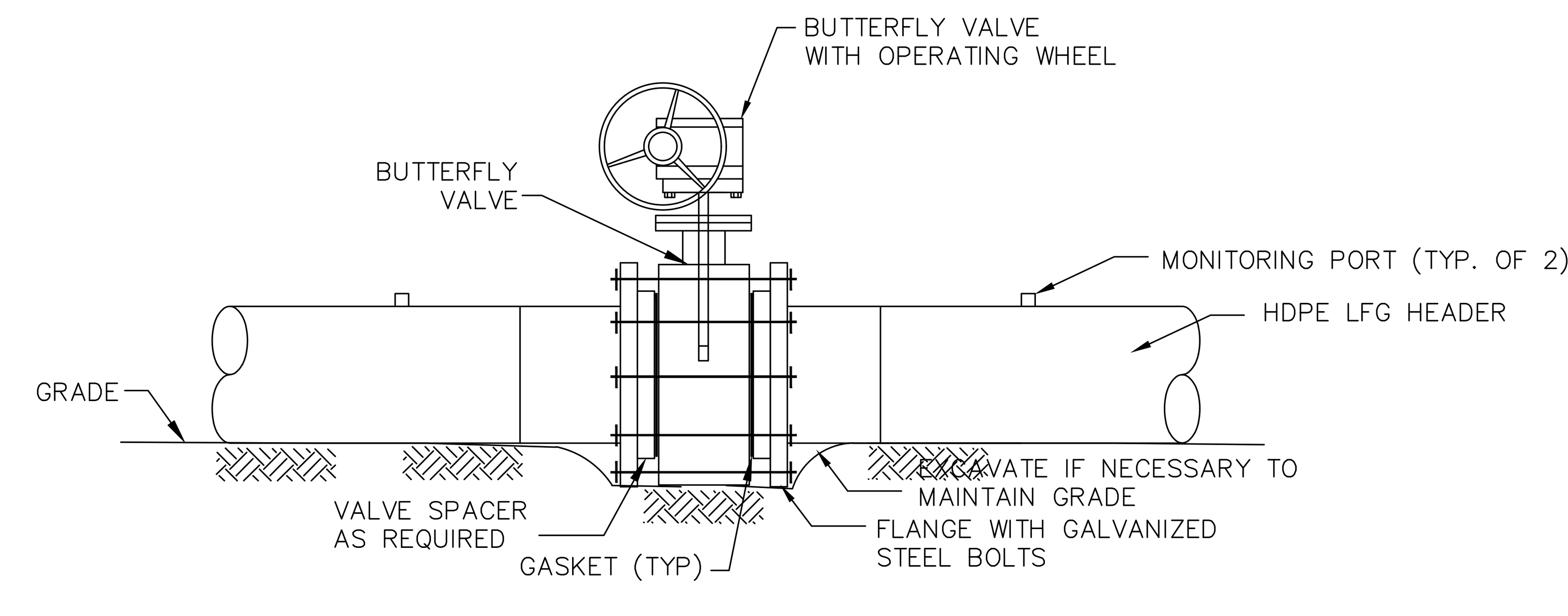
2. PAINT EXTERIOR AND INTERIOR SURFACES OF MANHOLE WITH A WATER PROOF COATING.

3. CONTRACTOR TO FIELD-VERIFY HEADER DEPTH AT LOW POINT PRIOR TO ODERING SUMP. SUMP INLET AND OVERALL DEPTH COULD VARY DEPENDING ON ACTUAL HEADER DEPTH.

4L LFG PIPING SHOWN ROTATED FOR CLARITY. SEE SITE PLAN FOR ORIENTATION.

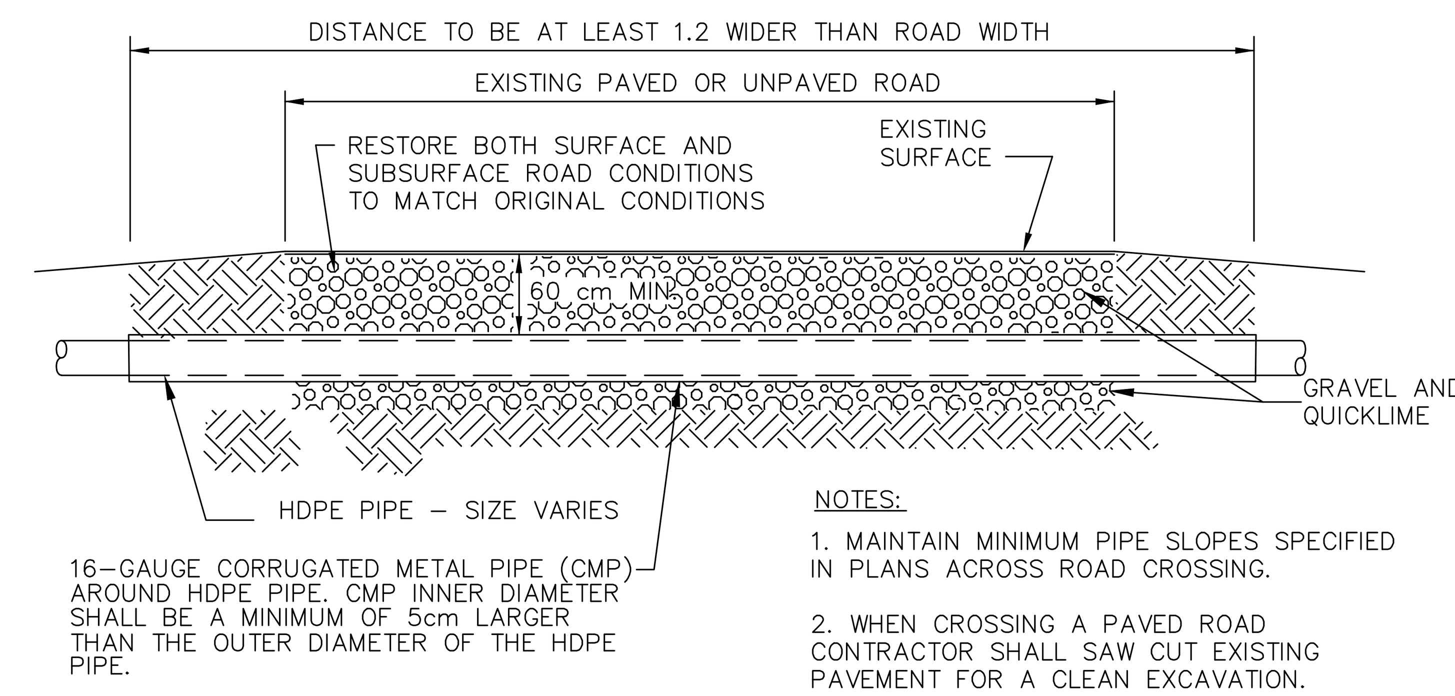
5. SUMP PUMP TO BE INSTALLED PER MANUFACTURER'S RECOMMENDATIONS. PUMP LEVEL TO BE SET SO THAT LIQUID LEVEL IN SUMP SHALL, AT A MINIMUM, NO EXCEED THE TOP OF THE OVERFLOW.

CONDENSATE SUMP 1 (3/7)
N.T.S.



ISOLATION VALVE NOTES:
1. ISOLATION VAVLES SHALL BE BUTTERFLY BUBBLE TIGHT, WAFER DESIGN, WITH A PVC BODY, NITRILE SEAT AND COMPATIBLE WITH FLAT FACE FLANGE.
2. PVC FLANGE GASKETS SHALL BE FULL-FACE NEOPRENE.
3. WRAP AND TAPE VALVE, FLANGE AND BOLTS IN POLYETHYLENE SHEETING PRIOR TO BACKFILLING.
4. PROVIDE 15cmø SDR17 PVC PIPE CASING AROUND SAMPLE PIPE FOR PROTECTION.
5. MONITORING PORTS AT BUTTERFLY VALVES SHALL BE QUICK CONNECTS RYAN HERCO PART NO. 0812-002. FOR INFORMATION, CONTACT RYAN HERCO AT (800)-848-1141.

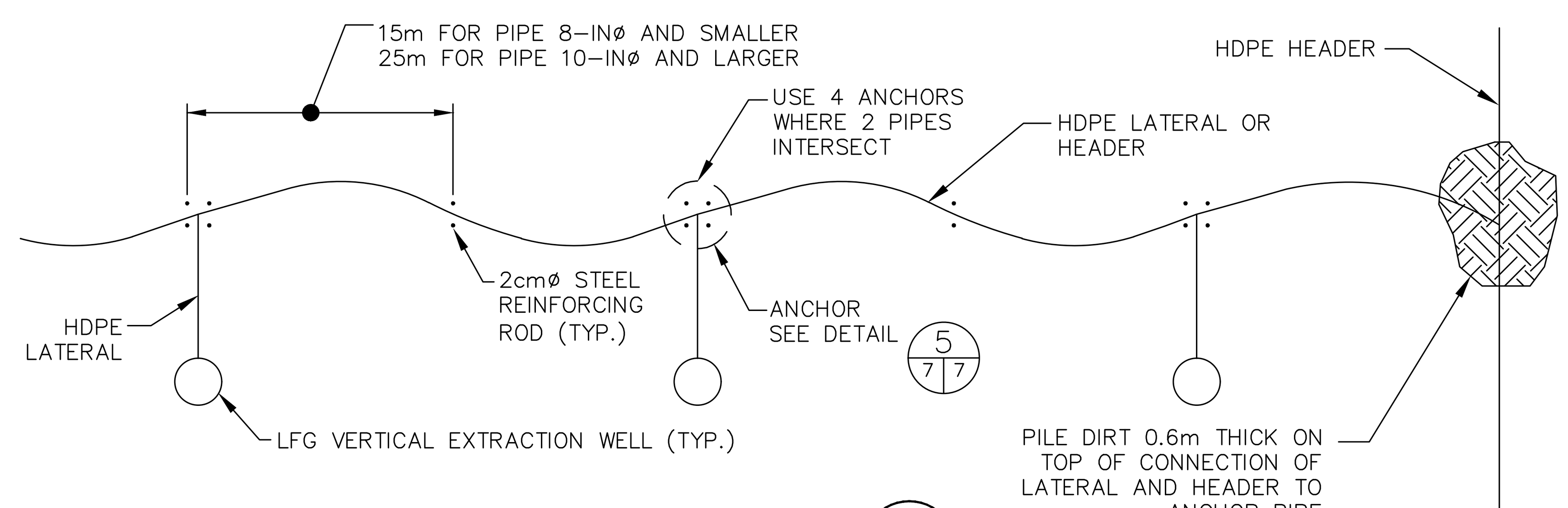
ISOLATION VALVE DETAIL 2 (3/7)
NO SCALE



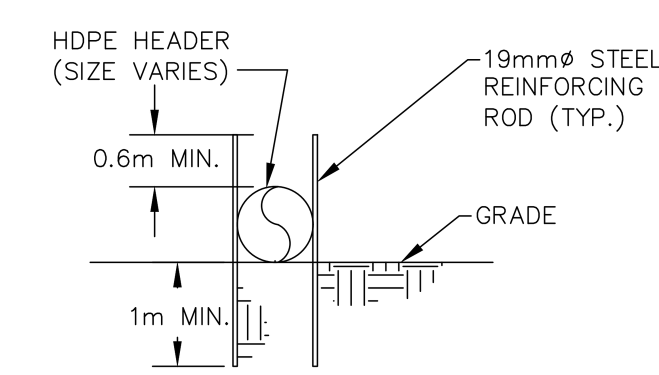
NOTES:
1. MAINTAIN MINIMUM PIPE SLOPES SPECIFIED IN PLANS ACROSS ROAD CROSSING.

2. WHEN CROSSING A PAVED ROAD CONTRACTOR SHALL SAW CUT EXISTING PAVEMENT FOR A CLEAN EXCAVATION.

ROAD CROSSING DETAIL 3 (3/7)
N.T.S.



ABOVE GROUND PIPE ANCHORING 4 (3/7)



ANCHOR DETAIL 5 (7/7)
NO SCALE

NOT FOR CONSTRUCTION

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SHEET TITLE: DETAILS GCCS CONCEPTUAL DESIGN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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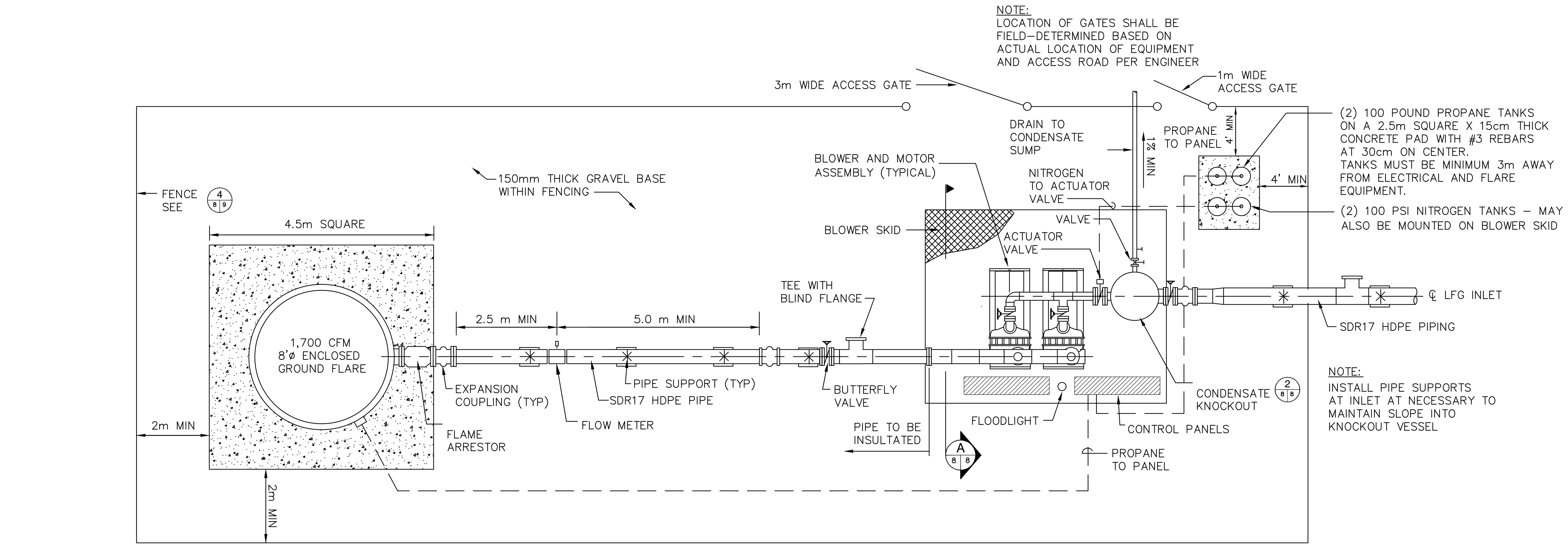


BLOWER/FLARE STATION LAYOUT (1 / 3 8)
NOT TO SCALE

GENERAL NOTES:

1. BLOWER/FLARE PLAN IS SHOWN FOR INFORMATION PURPOSES ONLY. IT IS A SCHEMATIC LAYOUT. ACTUAL CONFIGURATION OF 1,700 SCFM FLARE AND BLOWER SKID SHALL PROVIDED BY FLARE AND BLOWER MANUFACTURERS.

2. CONTRACTOR SHALL INSTALL PIPE SUPPORTS AS AT A MINIMUM OF 8-FOOT INTERVALS FOR STRAIGHT PIPE SECTIONS AND AS NEEDED TO ADEQUATELY SUPPORT PIPING, VALVES, FITTINGS, ETC. SEE DETAIL.

3. CONTRACTOR SHALL INSTALL PIPE EXPANSION JOINTS AS SHOWN AND AS NECESSARY TO ALLOW FOR THERMAL EXPANSION OF PIPING AND MECHANICAL EQUIPMENT OPERATION.

4. DRAINS FOR EACH BLOWER AND AND THE FLAME ARRESTER SHALL BE FITTED WITH SCH80 PVC SHUTOFF VALVES. THESE DRAINS SHALL BE MANUALLY DRAINED DURING SYSTEM OPERATION AS NECESSARY.

5. PROPANE TANKS SHALL BE MINIMUM OF 3m FROM FLARE AND ELECTRICAL EQUIPMENT.

6. 150mm GRAVEL BASE SHALL EXTEND APPROXIMATELY 1m BEYOND LIMITS OF FENCE. GRAVEL SHALL BE BETWEEN 1.25 cmø AND 3.75 cmø DIAMETER.

7. CONRACTOR SHALL PROVIDE A STANDARD OUTDOOR FLOODLIGHT WITH THE CONTROL PANEL AND SKID PACKAGE.

8. BLOWERS SHALL BE MOUNTED ONTO SKID WITH NEOPRENE PADS.

9. BLOWERS AND ASSOCIATED EQUIPMENT SHALL BE SUPPLIED AS A COMPLETE SKID PACKAGE, UNLESS OTHERWISE APPROVED BY ENGINEER.

10. THE CONTRACTOR SHALL INSTALL ALL CONDUITS AND CONDUCTORS NECESSARY FOR THE BLOWER MOTORS AND CONTROLS.

11. WHERE INDICATED, PIPING SHALL BE INSULTAED WITH 37.5 mm THICK ALUMINUM-CLAD INSULTAION.

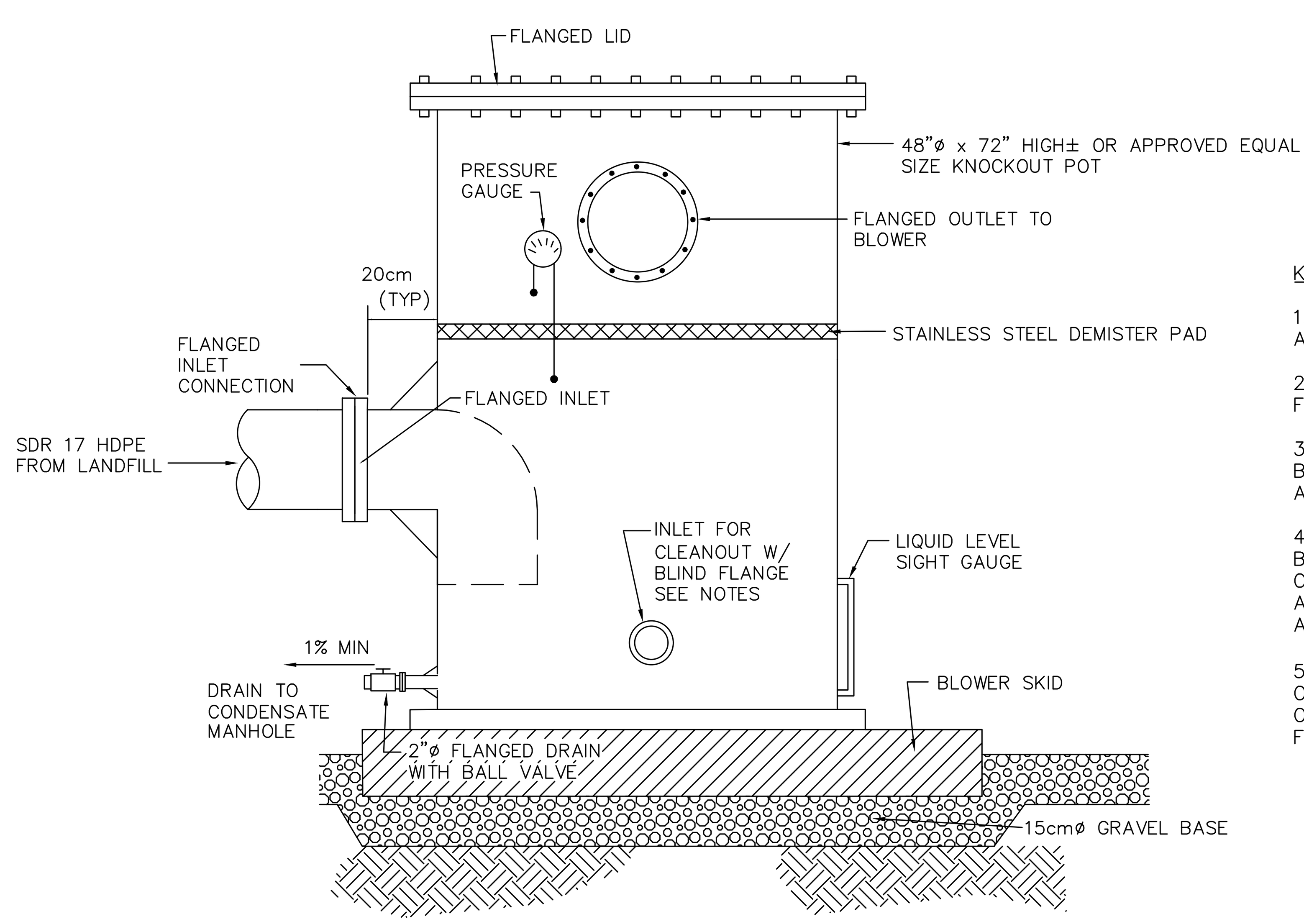
12. THE LANDFILL OWNER SHALL BE RESPONSIBLE FOR PROVIDING ELECTRICAL SERVICE FOR THE FLARE STATION TO WITHIN APPROXIMATELY 10m OF THE FENCELINE.

13. ALL BIOGAS PIPING SHALL BE HDPE UNLESS OTHERWISE SPECIFIED AND AS APPROVED BY ENGINEER.

14. ORIENTATION OF 4"ø CLEANOUT AT BOTTOM OF CONDENSATE KNOCKOUT SHALL BE SUITABLY ORIENTED TO ALLOW ACCESS.

15. CONDENSATE KNOCKOUT SHALL BE SECURED TO BLOWER SKID EITHER BY BOLTING DOWN OR AS APPROVED BY ENGINEER.

16. CONDENSATE KNOCKOUT SHALL BE FABRICATED TO WITHSTAND A MINIMUM OF 100 INCHES W.C. VACUUM.



CONDENSATE KNOCKOUT DETAIL (2 / 8 8)
NO SCALE

KNOCKOUT POT NOTES:

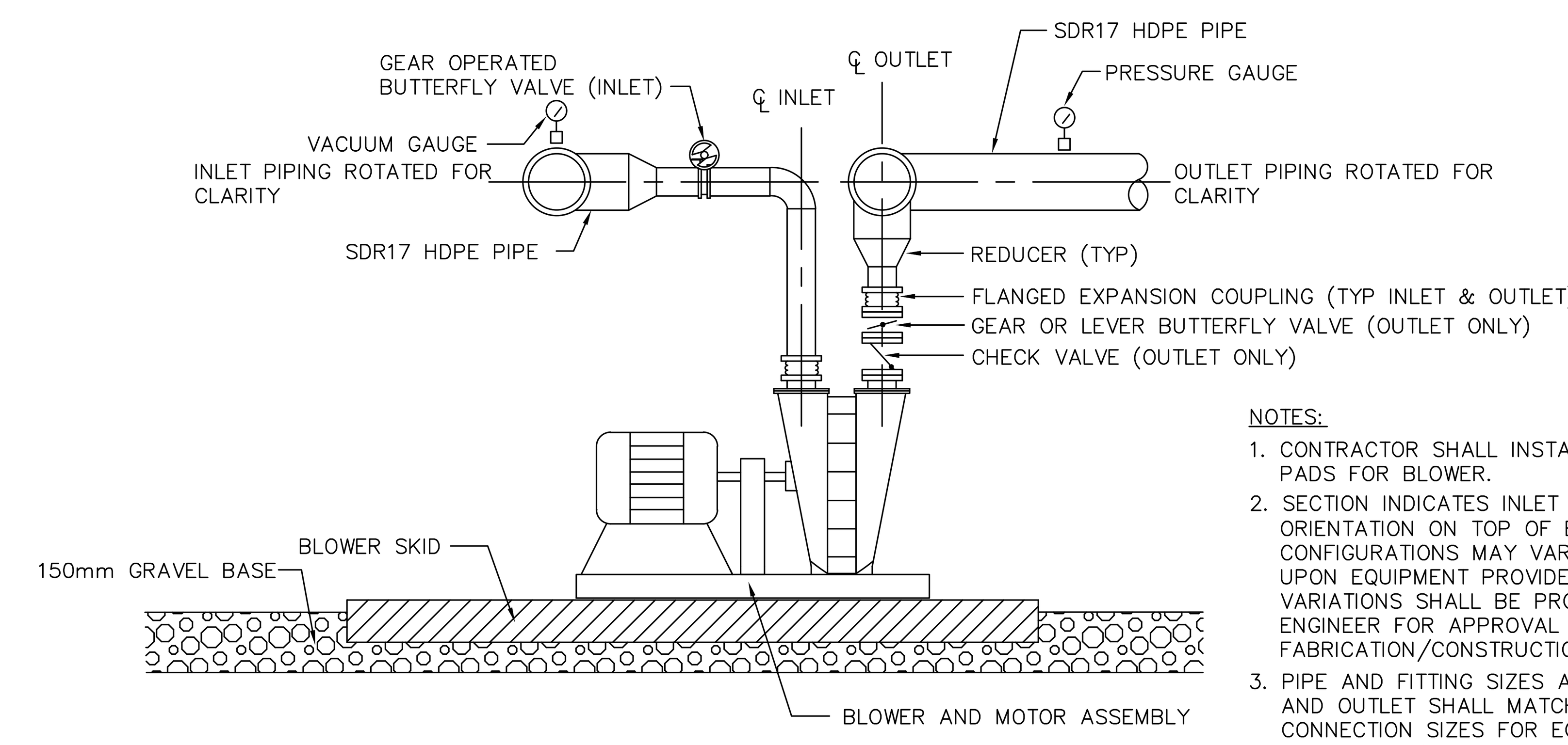
1. K.O. POT TO BE FABRICATED TO WITHSTAND A MINIMUM OF 100 IN.-W.C. VACUUM..

2. KNOCKOUT SHALL BE LEAK-TESTED BY FABRICATOR PRIOR TO SHIPPING.

3. K.O. POT TO BE SECURED TO SKID EITHER BY BOLTING DOWN, OR OTHER METHOD APPROVED BY ENGINEER.

4. KNOCKOUT POT CONSTRUCTION MAY EITHER BE HDPE OR STEEL, AND SHALL INCLUDE CORROSION PROTECTIVE COATING ON INTERIOR AND EXTERIOR RUST-PROOFING, AS APPROPRIATE.

5. ORIENTATION OF 4"ø CLEANOUT SHALL BE OPPOSITE SIDE OF KNOCKOUT VESSEL FROM OUTLET TO BLOWERS TO PERMIT EASY ACCESS FOR CLEANOUT.



NOTES:
1. CONTRACTOR SHALL INSTALL NEOPRENE PADS FOR BLOWER.
2. SECTION INDICATES INLET AND OUTLET ORIENTATION ON TOP OF BLOWER. ACTUAL CONFIGURATIONS MAY VARY DEPENDING UPON EQUIPMENT PROVIDED. ANY VARIATIONS SHALL BE PROVIDED TO ENGINEER FOR APPROVAL PRIOR TO FABRICATION/CONSTRUCTION.
3. PIPE AND FITTING SIZES AT BLOWER INLET AND OUTLET SHALL MATCH BLOWER CONNECTION SIZES FOR EQUIPMENT PROVIDED. CONTRACTOR SHALL INSTALL HDPE REDUCERS AS NECESSARY TO MATCH TO INLET AND OUTLET PIPING.

TYPICAL BLOWER SECTION (A / 8 8)
NO SCALE

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SHEET TITLE: BLOWER FLARE STATION GCCS CONCEPTUAL DESIGN

PROJECT TITLE: SAN CRISTOBAL LANDFILL

CLIENT: BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OHIO 43201

SCS ENGINEERS
2520 WHITEHALL PARK DRIVE, SUITE 450
CHARLOTTE, NORTH CAROLINA 28273
PHONE: (704) 504-3107 FAX: (704) 504-3174

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DATE: AUG 2018
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Appendix D: LFG Model Results

TABLE A-1
PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY UNDER MID-RANGE SCENARIO
SAN CRISTOBAL LANDFILL, DOMINICAN REPUBLIC

Year	Disposal Rate (Mg/yr)	Refuse In-Place (Mg)	LFG Generation			MID-RANGE RECOVERY SCENARIO				
						System Efficiency	Predicted LFG Recovery			Power Plant Capacity*
			(m3/hr)	(cfm)	(mmBtu/hr)	(%)	(m3/hr)	(cfm)	(mmBtu/hr)	(MW)
2020	75,950	**112,528**	0	0	0.0	0%	0	0	0.0	0.0
2021	77,470	**267,468**	248	146	4.4	0%	0	0	0.0	0.0
2022	79,020	**425,508**	496	292	8.9	40%	198	117	3.5	0.3
2023	80,600	**529,373**	678	399	12.1	50%	339	200	6.1	0.6
2024	82,210	611,583	743	437	13.3	55%	409	241	7.3	0.7
2025	83,850	695,433	764	449	13.6	55%	420	247	7.5	0.7
2026	85,530	780,963	791	465	14.1	55%	435	256	7.8	0.7
2027	87,240	868,203	822	484	14.7	55%	452	266	8.1	0.7
2028	64,430	932,633	855	503	15.3	55%	470	277	8.4	0.8
2029	0	932,633	826	486	14.8	58%	479	282	8.6	0.8
2030	0	932,633	640	377	11.4	60%	384	226	6.9	0.6
2031	0	932,633	504	297	9.0	60%	302	178	5.4	0.5
2032	0	932,633	412	242	7.4	60%	247	145	4.4	0.4
2033	0	932,633	348	205	6.2	60%	209	123	3.7	0.3
2034	0	932,633	302	178	5.4	60%	181	107	3.2	0.3
2035	0	932,633	268	158	4.8	60%	161	95	2.9	0.3
2036	0	932,633	243	143	4.3	60%	146	86	2.6	0.2
2037	0	932,633	222	131	4.0	60%	133	78	2.4	0.2
2038	0	932,633	205	121	3.7	60%	123	72	2.2	0.2
2039	0	932,633	191	112	3.4	60%	114	67	2.0	0.2
2040	0	932,633	178	105	3.2	60%	107	63	1.9	0.2

MODEL INPUT PARAMETERS:

Assumed Methane Content of LFG:	50%		
	Category 1	Category 2	Category 3
Decay Rate Constant (k):	0.450	0.073	0.038
CH4 Recovery Pot. (Lo) (ft3/ton):	2,385	5,723	5,935
Metric Equivalent Lo (m3/Mg):	74	179	185

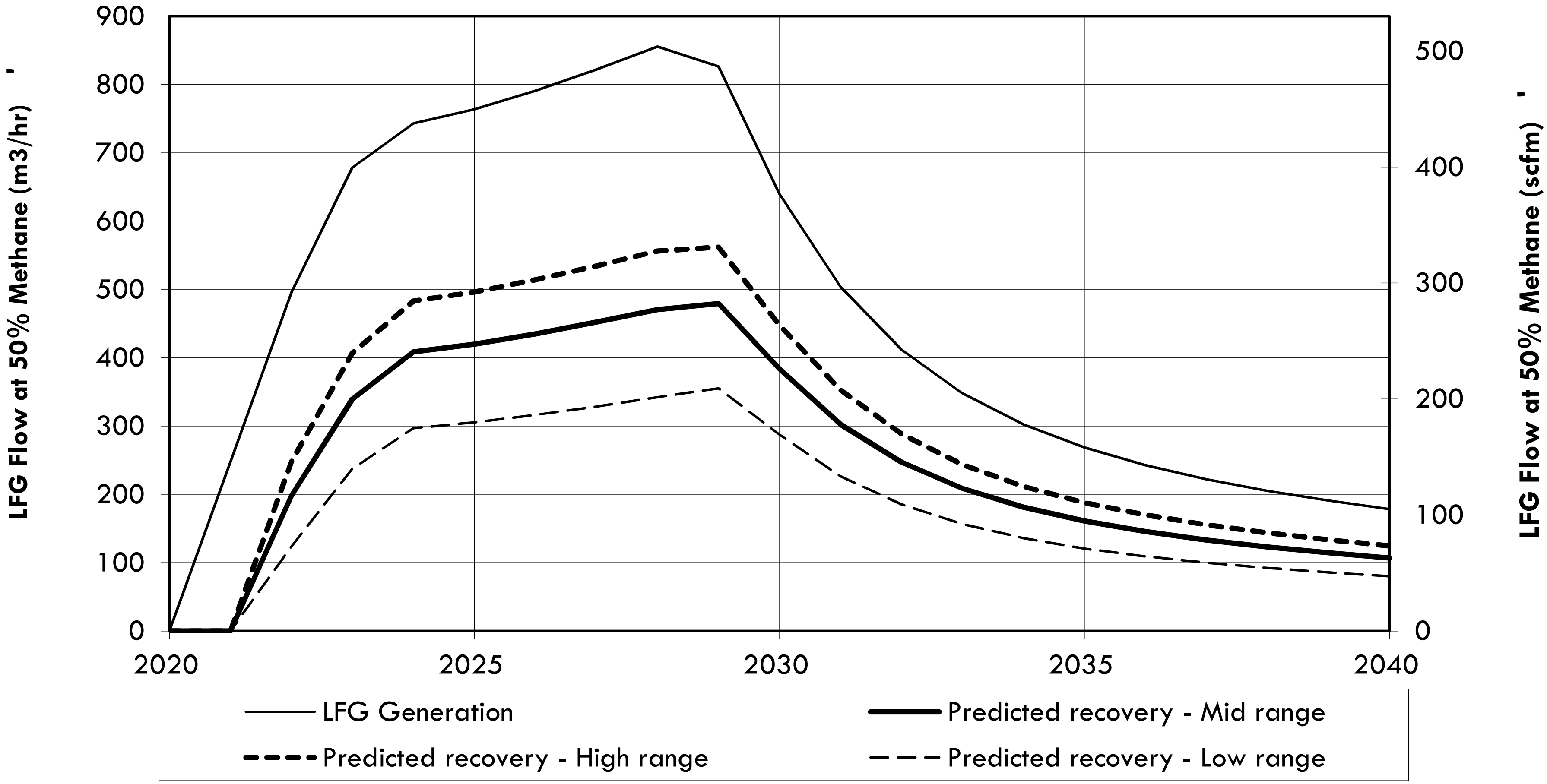
NOTES:
* Maximum power plant capacity assumes a gross heat rate of 10,800 Btus per kW-hr (hhv).

TABLE A-2
PROJECTION OF LANDFILL GAS RECOVERY UNDER HIGH AND LOW RECOVERY SCENARIOS
SAN CRISTOBAL LANDFILL, DOMINICAN REPUBLIC

Year	HIGH RECOVERY SCENARIO					LOW RECOVERY SCENARIO				
	System Efficiency (%)	Predicted LFG Recovery (m3/hr)	Predicted LFG Recovery (cfm)	Predicted LFG Recovery (mmBtu/hr)	Power Plant Capacity* (MW)	System Efficiency (%)	Predicted LFG Recovery (m3/hr)	Predicted LFG Recovery (cfm)	Predicted LFG Recovery (mmBtu/hr)	Power Plant Capacity* (MW)
2020	0%	0	0	0.0	0.0	0%	0	0	0.0	0.0
2021	0%	0	0	0.0	0.0	0%	0	0	0.0	0.0
2022	50%	248	146	4.4	0.4	25%	124	73	2.2	0.2
2023	60%	407	240	7.3	0.7	35%	237	140	4.2	0.4
2024	65%	483	284	8.6	0.8	40%	297	175	5.3	0.5
2025	65%	496	292	8.9	0.8	40%	305	180	5.5	0.5
2026	65%	514	303	9.2	0.9	40%	316	186	5.7	0.5
2027	65%	534	314	9.5	0.9	40%	329	193	5.9	0.5
2028	65%	556	327	9.9	0.9	40%	342	201	6.1	0.6
2029	68%	562	331	10.0	0.9	43%	355	209	6.3	0.6
2030	70%	448	264	8.0	0.7	45%	288	169	5.1	0.5
2031	70%	353	208	6.3	0.6	45%	227	133	4.1	0.4
2032	70%	288	170	5.2	0.5	45%	185	109	3.3	0.3
2033	70%	243	143	4.4	0.4	45%	157	92	2.8	0.3
2034	70%	212	124	3.8	0.3	45%	136	80	2.4	0.2
2035	70%	188	111	3.4	0.3	45%	121	71	2.2	0.2
2036	70%	170	100	3.0	0.3	45%	109	64	2.0	0.2
2037	70%	155	91	2.8	0.3	45%	100	59	1.8	0.2
2038	70%	144	85	2.6	0.2	45%	92	54	1.6	0.2
2039	70%	134	79	2.4	0.2	45%	86	51	1.5	0.1
2040	70%	125	73	2.2	0.2	45%	80	47	1.4	0.1

NOTES:
* Maximum power plant capacity assumes a gross heat rate of 10,800 Btus per kW-hr (hhv).

Figure A-1. LFG Generation and Recovery Projections
San Cristobal Landfill, Domincan Republic



8/14/2018

Appendix E: Estimated Costs to Construct the Proposed Engineered Landfill

Construction Cost Estimate
Phase I
Landfill Cells 1 and 2
San Cristobal Landfill

Landfill Area (square meters) = 25,300 **2.53 hectares**

	AREA OF WORK	TYPE	UNIT	CONSTRUCTION ESTIMATE These costs are in U.S. dollars, based on average costs in the southeastern U.S.		
				ESTIMATED QUANTITY	ESTIMATED PRICE PER UNIT ($)	EXTENDED COST($)
EARTHWORK						
1	Mobilization/Demobilization	GC Mobilization (5%)	LS	1	$ 92,634.85	$ 92,635
2	Subgrade	Waste Relocation	m^3	48,993	$ 5.25	$ 257,213
3	Subgrade	Excavation of Soils and Stockpiling On-Site	m^3	50,680	$ 5.25	$ 266,070
4	Subgrade	Rough and Finish Grading	hectare	2.53	$ 5,000.00	$ 12,650
5	Subgrade	Construct Perimeter Soil Berms, Channel, and Access Road	m^3	26,000	$ 2.60	$ 67,600
6	Liner System	60.96-cm Compacted Low Permeability Soil Liner (using on-site excavated soils - Permeability ≤ 1.0 x 10^{-7} cm/sec)	m^3	15,423	$ 4.15	$ 64,005
7	Liner System	Geosynthetics Anchor Trench Material and Installation	meter	547	$ 36.00	$ 19,692
8	Liner System	Furnish Protective Soil Cover from Off-Site Source (Permeability ≥ 1.0 x 10^{-3} cm/sec)	m^3	7,590	$ 18.50	$ 140,415
9	Liner System	30-cm Protective Soil Cover Installation	m^3	7,590	$ 3.25	$ 24,668
GEOSYNTHETICS						
10	Mobilization/Demobilization	Installer Mobilization and Demobilization	EA	2	$ 2,000.00	$ 4,000
11	Geomembrane	Supply and Install 60-mil HDPE Textured Liner	m^2	25,300	$ 4.60	$ 116,380
STORMWATER MANAGEMENT						
12	Stormwater Control	Drop Inlets and Culvert Pipes	LS	1	$ 12,500.00	$ 12,500
13	Stormwater Control	Seeding	hectare	3.0	$ 950.00	$ 2,850
14	E&S Control	Stormwater Storage Basin	EA	1	$ 25,000.00	$ 25,000
LEACHATE MANAGEMENT						
15	Leachate Collection	250 mm HDPE Perforated and Solid Pipe and Fittings includes Stone and Geotextile Fabric	meter	269	$ 170.00	$ 45,730
16	Leachate Collection	630 mm HDPE Leachate Sideslope Riser Perforated and Solid Pipe and Fittings	meter	110	$ 225.00	$ 24,750
17	Leachate Collection	Leachate Pump and Controls	EA	2	$ 30,000.00	$ 60,000
18	Leachate Collection	140 mm HDPE Leachate Forcemain (Dual Containment Pipe)	meter	1,100	$ 110.00	$ 121,000
19	Leachate Storage	Aboveground Storage Tanks with Secondary Containment (1,893 m^3 Total Capacity)	EA	1	$ 500,000.00	$ 500,000
20	Leachate Treatment	Leachate Evaporator	EA	1	$ 400,000.00	$ 400,000
MISCELLANEOUS						
21	General Condition	Bonds and Insurance (3%)	EA	1	$ 77,820.96	$ 77,821
22	Engineering and Bidding	Engineering and Bidding	EA	2	$ 40,000.00	$ 80,000
23	Construction Quality Assurance	Construction Quality Assurance	EA	2	$ 100,000.00	$ 200,000
24	Surveying	Construction and CQA Surveying	LS	2	$ 12,000.00	$ 24,000
25	Electrical	Electrical Service for Leachate Pumps and Controls	EA	2	$ 5,000.00	$ 10,000
26	One Scale and 230 m^2 Administration Buil	One Scale and 230 m^2 Administration Building	LS	1	$ 648,700.00	$ 648,700
27	Gravel Covered Perimeter Road	Gravel Covered Perimeter Road including Woven Geotextile Fabric Underlayment	m^2	6,234	$ 12.54	$ 78,174
					SUBTOTAL	**$3,375,853**
					5% CONTINGENCY	**$168,793**
					TOTAL CONSTRUCTION COST	**$3,544,646**

Construction Cost Estimate
Phase II
Landfill Cell 3
San Cristobal Landfill

Landfill Area (square meters) = **16,100** **1.61** **hectares**

	AREA OF WORK	TYPE	UNIT	CONSTRUCTION ESTIMATE These costs are in U.S. dollars, based on average costs in the southeastern U.S.		
				ESTIMATED QUANTITY	ESTIMATED PRICE PER UNIT ($)	EXTENDED COST($)
EARTHWORK						
1	Mobilization/Demobilization	GC Mobilization (5%)	LS	1	$ 38,856.17	$ 38,856
2	Subgrade	Waste Relocation	m^3	88,982	$ 5.25	$ 467,156
3	Subgrade	Excavation of Soils and Stockpiling On-Site	m^3	0	$ 5.25	$ -
4	Subgrade	Rough and Finish Grading	hectare	1.61	$ 5,000.00	$ 8,050
5	Subgrade	Construct Perimeter Soil Berms, Channel, and Access Road	m^3	0	$ 2.60	$ -
6	Liner System	60.96-cm Compacted Low Permeability Soil Liner (using on-site excavated soils - Permeability ≤ 1.0 x 10^{-7} cm/sec)	m^3	9,815	$ 4.15	$ 40,730
7	Liner System	Geosynthetics Anchor Trench Material and Installation	meter	200	$ 36.00	$ 7,200
8	Liner System	Furnish Protective Soil Cover from Off-Site Source (Permeability ≥ 1.0 x 10^{-3} cm/sec)	m^3	4,830	$ 18.50	$ 89,355
9	Liner System	30-cm Protective Soil Cover Installation	m^3	4,830	$ 3.25	$ 15,698
GEOSYNTHETICS						
10	Mobilization/Demobilization	Installer Mobilization and Demobilization	EA	1	$ 2,000.00	$ 2,000
11	Geomembrane	Supply and Install 60-mil HDPE Textured Liner	m^2	16,100	$ 4.60	$ 74,060
STORMWATER MANAGEMENT						
12	Stormwater Control	Drop Inlets and Culvert Pipes	LS	0	$ 12,500.00	$ -
13	Stormwater Control	Seeding	hectare	0.0	$ 950.00	$ -
14	E&S Control	Stormwater Storage Basin	EA	0	$ 25,000.00	$ -
LEACHATE MANAGEMENT						
15	Leachate Collection	250 mm HDPE Perforated and Solid Pipe and Fittings includes Stone and Geotextile Fabric	meter	150	$ 170.00	$ 25,500
16	Leachate Collection	630 mm HDPE Leachate Sideslope Riser Perforated and Solid Pipe and Fittings	meter	55	$ 225.00	$ 12,375
17	Leachate Collection	Leachate Pump and Controls	EA	1	$ 30,000.00	$ 30,000
18	Leachate Collection	140 mm HDPE Leachate Forcemain (Dual Containment Pipe)	meter	0	$ 110.00	$ -
19	Leachate Storage	Aboveground Storage Tanks with Secondary Containment (1,893 m^3 Total Capacity)	EA	0	$ 500,000.00	$ -
20	Leachate Treatment	Leachate Evaporator	EA	0	$ 400,000.00	$ -
MISCELLANEOUS						
20	General Condition	Bonds and Insurance (3%)	EA	1	$ 24,479.39	$ 24,479
21	Engineering and Bidding	Engineering and Bidding	EA	1	$ 40,000.00	$ 40,000
22	Construction Quality Assurance	Construction Quality Assurance	EA	1	$ 100,000.00	$ 100,000
23	Surveying	Construction and CQA Surveying	EA	1	$ 12,000.00	$ 12,000
24	Electrical	Electrical Service for Leachate Pumps and Controls	EA	1	$ 5,000.00	$ 5,000
25	One Scale and 230 m^2 Administration Buil	One Scale and 230 m^2 Administration Building	LS	0	$ 648,700.00	$ -
26	Gravel Covered Perimeter Road	Gravel Covered Perimeter Road including Woven Geotextile Fabric Underlayment	m^2	0	$ 12.54	$ -
					SUBTOTAL	**$992,459**
					5% CONTINGENCY	**$49,623**
					TOTAL CONSTRUCTION COST	**$1,042,082**

Construction Cost Estimate

Phase III

Landfill Cell 4

San Cristobal Landfill

Landfill Area (square meters) = 30,300 **3.03 hectares**

AREA OF WORK		TYPE	UNIT	CONSTRUCTION ESTIMATE These costs are in U.S. dollars, based on average costs in the southeastern U.S.		
				ESTIMATED QUANTITY	ESTIMATED PRICE PER UNIT ($)	EXTENDED COST($)
EARTHWORK						
1	Mobilization/Demobilization	GC Mobilization (5%)	LS	1	$ 66,929.98	$ 66,930
2	Subgrade	Waste Relocation	m^3	165,864	$ 5.25	$ 870,786
3	Subgrade	Excavation of Soils and Stockpiling On-Site	m^3	0	$ 5.25	$ -
4	Subgrade	Rough and Finish Grading	hectare	3.03	$ 5,000.00	$ 15,150
5	Subgrade	Construct Perimeter Soil Berms, Channel, and Access Road	m^3	0	$ 2.60	$ -
6	Liner System	60.96-cm Compacted Low Permeability Soil Liner (using on-site excavated soils - Permeability ≤ 1.0 x 10^{-7} cm/sec)	m^3	18,471	$ 4.15	$ 76,654
7	Liner System	Geosynthetics Anchor Trench Material and Installation	meter	192	$ 36.00	$ 6,912
8	Liner System	Furnish Protective Soil Cover from Off-Site Source (Permeability ≥ 1.0 x 10^{-3} cm/sec)	m^3	9,090	$ 18.50	$ 168,165
9	Liner System	30-cm Protective Soil Cover Installation	m^3	9,090	$ 3.25	$ 29,543
GEOSYNTHETICS						
10	Mobilization/Demobilization	Installer Mobilization and Demobilization	EA	1	$ 2,000.00	$ 2,000
11	Geomembrane	Supply and Install 60-mil HDPE Textured Liner	m^2	30,300	$ 4.60	$ 139,380
STORMWATER MANAGEMENT						
12	Stormwater Control	Drop Inlets and Culvert Pipes	LS	1	$ 12,500.00	$ 12,500
13	Stormwater Control	Seeding	hectare	0.0	$ 950.00	$ -
14	E&S Control	Stormwater Storage Basin	EA	0	$ 25,000.00	$ -
LEACHATE MANAGEMENT						
15	Leachate Collection	250 mm HDPE Perforated and Solid Pipe and Fittings includes Stone and Geotextile Fabric	meter	103	$ 170.00	$ 17,510
16	Leachate Collection	630 mm HDPE Leachate Sideslope Riser Perforated and Solid Pipe and Fittings	meter	0	$ 225.00	$ -
17	Leachate Collection	Leachate Pump and Controls	EA	0	$ 30,000.00	$ -
18	Leachate Collection	140 mm HDPE Leachate Forcemain (Dual Containment Pipe)	meter	0	$ 110.00	$ -
19	Leachate Storage	Aboveground Storage Tanks with Secondary Containment (1,893 m^3 Total Capacity)	EA	0	$ 500,000.00	$ -
20	Leachate Treatment	Leachate Evaporator	EA	0	$ 400,000.00	$ -
MISCELLANEOUS						
20	General Condition	Bonds and Insurance (3%)	EA	1	$ 42,165.89	$ 42,166
21	Engineering and Bidding	Engineering and Bidding	EA	1	$ 40,000.00	$ 40,000
22	Construction Quality Assurance	Construction Quality Assurance	EA	1	$ 100,000.00	$ 100,000
23	Surveying	Construction and CQA Surveying	EA	1	$ 12,000.00	$ 12,000
24	Electrical	Electrical Service for Leachate Pumps and Controls	EA	0	$ 5,000.00	$ -
25	One Scale and 230 m^2 Administration Buil	One Scale and 230 m^2 Administration Building	LS	0	$ 648,700.00	$ -
26	Gravel Covered Perimeter Road	Gravel Covered Perimeter Road including Woven Geotextile Fabric Underlayment	m^2	0	$ 12.54	$ -
					SUBTOTAL	**$1,599,696**
					5% CONTINGENCY	**$79,985**
					TOTAL CONSTRUCTION COST	**$1,679,680**

Construction Cost Estimate
Phase IV
Landfill Cell 5
San Cristobal Landfill

Landfill Area (square meters) = 20,700 **2.07 hectares**

	AREA OF WORK	TYPE	UNIT	CONSTRUCTION ESTIMATE These costs are in U.S. dollars, based on average costs in the southeastern U.S.		
				ESTIMATED QUANTITY	ESTIMATED PRICE PER UNIT ($)	EXTENDED COST($)
EARTHWORK						
1	Mobilization/Demobilization	GC Mobilization (5%)	LS	1	$ 37,852.26	$ 37,852
2	Subgrade	Waste Relocation	m^3	0	$ 5.25	$ -
3	Subgrade	Excavation of Soils and Stockpiling On-Site	m^3	52,532	$ 5.25	$ 275,793
4	Subgrade	Rough and Finish Grading	hectare	2.07	$ 5,000.00	$ 10,350
5	Subgrade	Construct Perimeter Soil Berms, Channel, and Access Road	m^3	8,609	$ 2.60	$ 22,383
6	Liner System	60.96-cm Compacted Low Permeability Soil Liner (using on-site excavated soils - Permeability ≤ 1.0 x 10^{-7} cm/sec)	m^3	12,619	$ 4.15	$ 52,368
7	Liner System	Geosynthetics Anchor Trench Material and Installation	meter	295	$ 36.00	$ 10,620
8	Liner System	Furnish Protective Soil Cover from Off-Site Source (Permeability ≥ 1.0 x 10^{-3} cm/sec)	m^3	6,210	$ 18.50	$ 114,885
9	Liner System	30-cm Protective Soil Cover Installation	m^3	6,210	$ 3.25	$ 20,183
GEOSYNTHETICS						
10	Mobilization/Demobilization	Installer Mobilization and Demobilization	EA	1	$ 2,000.00	$ 2,000
11	Geomembrane	Supply and Install 60-mil HDPE Textured Liner	m^2	20,700	$ 4.60	$ 95,220
STORMWATER MANAGEMENT						
12	Stormwater Control	Drop Inlets and Culvert Pipes	LS	0	$ 12,500.00	$ -
13	Stormwater Control	Seeding	hectare	0.6	$ 950.00	$ 570
14	E&S Control	Stormwater Storage Basin	EA	0	$ 25,000.00	$ -
LEACHATE MANAGEMENT						
15	Leachate Collection	250 mm HDPE Perforated and Solid Pipe and Fittings includes Stone and Geotextile Fabric	meter	308	$ 170.00	$ 52,360
16	Leachate Collection	630 mm HDPE Leachate Sideslope Riser Perforated and Solid Pipe and Fittings	meter	55	$ 225.00	$ 12,375
17	Leachate Collection	Leachate Pump and Controls	EA	1	$ 30,000.00	$ 30,000
18	Leachate Collection	140 mm HDPE Leachate Forcemain (Dual Containment Pipe)	meter	300	$ 110.00	$ 33,000
19	Leachate Storage	Aboveground Storage Tanks with Secondary Containment (1,893 m^3 Total Capacity)	EA	0	$ 500,000.00	$ -
20	Leachate Treatment	Leachate Evaporator	EA	0	$ 400,000.00	$ -
MISCELLANEOUS						
20	General Condition	Bonds and Insurance (3%)	EA	1	$ 23,846.92	$ 23,847
21	Engineering and Bidding	Engineering and Bidding	EA	1	$ 40,000.00	$ 40,000
22	Construction Quality Assurance	Construction Quality Assurance	EA	1	$ 100,000.00	$ 100,000
23	Surveying	Construction and CQA Surveying	EA	1	$ 12,000.00	$ 12,000
24	Electrical	Electrical Service for Leachate Pumps and Controls	EA	1	$ 5,000.00	$ 5,000
25	One Scale and 230 m^2 Administration Buil	One Scale and 230 m^2 Administration Building	LS	0	$ 648,700.00	$ -
26	Gravel Covered Perimeter Road	Gravel Covered Perimeter Road including Woven Geotextile Fabric Underlayment	m^2	1,590	$ 12.54	$ 19,939
					SUBTOTAL	**$970,744**
					5% CONTINGENCY	**$48,537**
					TOTAL CONSTRUCTION COST	**$1,019,282**

Construction Cost Estimate

Total

Landfill Cells 1 thru 5

San Cristobal Landfill

Landfill Area (square meters) = 92,400 9.24 hectares

	AREA OF WORK	TYPE	UNIT	CONSTRUCTION ESTIMATE These costs are in U.S. dollars, based on average costs in the southeastern U.S. ESTIMATED QUANTITY	ESTIMATED PRICE PER UNIT ($)	EXTENDED COST($)
EARTHWORK						
1	Mobilization/Demobilization	GC Mobilization (5%)	LS	1	$ 236,273	$ 236,273
2	Subgrade	Waste Relocation	m^3	303,839	$ 5.25	$ 1,595,155
3	Subgrade	Excavation of Soils and Stockpiling On-Site	m^3	103,212	$ 5.25	$ 541,863
4	Subgrade	Rough and Finish Grading	hectare	9.24	$ 5,000.00	$ 46,200
5	Subgrade	Construct Perimeter Soil Berms, Channel, and Access Road	m^3	34,609	$ 2.60	$ 89,983
6	Liner System	60.96-cm Compacted Low Permeability Soil Liner (using on-site excavated soils - Permeability ≤ 1.0 x 10^{-7} cm/sec)	m^3	56,327	$ 4.15	$ 233,757
7	Liner System	Geosynthetics Anchor Trench Material and Installation	meter	1,234	$ 36.00	$ 44,424
8	Liner System	Furnish Protective Soil Cover from Off-Site Source (Permeability ≥ 1.0 x 10^{-3} cm/sec)	m^3	27,720	$ 18.50	$ 512,820
9	Liner System	30-cm Protective Soil Cover Installation	m^3	27,720	$ 3.25	$ 90,090
GEOSYNTHETICS						
10	Mobilization/Demobilization	Installer Mobilization and Demobilization	EA	5	$ 2,000.00	$ 10,000
11	Geomembrane	Supply and Install 60-mil HDPE Textured Liner	m^2	92,400	$ 4.60	$ 425,040
STORMWATER MANAGEMENT						
12	Stormwater Control	Drop Inlets and Culvert Pipes	LS	2	$ 12,500.00	$ 25,000
13	Stormwater Control	Seeding	hectare	3.60	$ 950.00	$ 3,420
14	E&S Control	Stormwater Storage Basin	EA	1	$ 25,000.00	$ 25,000
LEACHATE MANAGEMENT						
15	Leachate Collection	250 mm HDPE Perforated and Solid Pipe and Fittings includes Stone and Geotextile Fabric	meter	830	$ 170.00	$ 141,100
16	Leachate Collection	630 mm HDPE Leachate Sideslope Riser Perforated and Solid Pipe and Fittings	meter	220	$ 225.00	$ 49,500
17	Leachate Collection	Leachate Pump and Controls	EA	4	$ 30,000.00	$ 120,000
18	Leachate Collection	140 mm HDPE Leachate Forcemain (Dual Containment Pipe)	meter	1,400	$ 110.00	$ 154,000
19	Leachate Storage	Aboveground Storage Tanks with Secondary Containment (1,893 m^3 Total Capacity)	EA	1	$ 500,000.00	$ 500,000
20	Leachate Treatment	Leachate Evaporator	EA	1	$ 400,000.00	$ 400,000
MISCELLANEOUS						
21	General Condition	Bonds and Insurance (3%)	EA	1	$ 168,313.16	$ 168,313
22	Engineering and Bidding	Engineering and Bidding	EA	5	$ 40,000.00	$ 200,000
23	Construction Quality Assurance	Construction Quality Assurance	EA	5	$ 100,000.00	$ 500,000
24	Surveying	Construction and CQA Surveying	EA	5	$ 12,000.00	$ 60,000
25	Electrical	Electrical Service for Leachate Pumps and Controls	EA	4	$ 5,000.00	$ 20,000
26	One Scale and 230 m^2 Administration Buil	One Scale and 230 m^2 Administration Building	LS	1	$ 648,700.00	$ 648,700
27	Gravel Covered Perimeter Road	Gravel Covered Perimeter Road including Woven Geotextile Fabric Underlayment	m^2	7,824	$ 12.54	$ 98,113
					SUBTOTAL	**$6,938,752**
					5% CONTINGENCY	**$346,938**
					TOTAL CONSTRUCTION COST	**$7,285,689**
					COST PER HECTARE	**$788,495**

Closure Cost Estimate

Landfill Cells 1-5

San Cristobal Landfill

2D Area (square meters) = 92,400 **9.24 hectares**

3D Surface Area (square meters) = 94,646 **9.46 hectares**

	AREA OF WORK	TYPE	UNIT	CLOSURE ESTIMATE These costs are in U.S. dollars, based on average costs in the southeastern U.S.		
				ESTIMATED QUANTITY	ESTIMATED PRICE PER UNIT ($)	EXTENDED COST($)
EARTHWORK						
1	Mobilization/Demobilization	GC Mobilization (5%)	LS	1	$ 127,361.90	$ 127,362
2	Final Grade Preparation	Surface Grading and Soil Filling	hectare	9.46	$ 3,500.00	$ 33,110
3	Soil Cap	Excavation and Soil Hauling from Soil Stockpile/Borrow (30% increase for compaction and swell)	m^3	36,912	$ 2.48	$ 91,542
4	Soil Cap	Compacted 30-cm Intermediate Soil Cover Installation	m^3	28,394	$ 6.12	$ 173,770
5	Geosynthetic Cap	Anchor Trench Material and Installation	meter	1,234	$ 36.00	$ 44,424
6	Geosynthetic Cap	Toe Drain Installation	meter	1,234	$ 100.00	$ 123,400
7	Soil Cap	Excavation and Soil Hauling from Borrow (15% increase for compaction and swell)	m^3	50,068	$ 2.48	$ 124,168
8	Soil Cap	46-cm Protective Soil Cover Installation	m^3	43,537	$ 3.82	$ 166,312
GEOSYNTHETICS						
9	Mobilization/Demobilization	Installer Mobilization and Demobilization	LS	1	$ 10,000.00	$ 10,000
10	Geosynthetic Cap	Supply and Install 40-mil LLDPE Textured Liner	m^2	94,646	$ 5.70	$ 539,482
11	Geosynthetic Cap	Supply and Install Drainage Geocomposite	m^2	94,646	$ 7.75	$ 733,507
STORMWATER MANAGEMENT						
12	Cap Stormwater Control	Sideslope Channel/Berms	meter	3,450	$ 35.00	$ 120,750
13	Cap Stormwater Control	Downslope Pipe	meter	330	$ 120.00	$ 39,600
14	Cap Stormwater Control	Sideslope Pipe Inlets	EA	13	$ 5,500.00	$ 71,500
15	Cap Stormwater Control	Seeding	hectare	9.46	$ 10,400.00	$ 98,432
16	Cap Stormwater Control	Erosion Matting for Sideslope Berms	m^2	17,250	$ 1.90	$ 32,775
17	Cap Stormwater Control	Sideslope Pipe Outlets and Riprap Protection	EA	3	$ 2,500.00	$ 7,500
18	Perimeter Stormwater Control	Regrade Perimeter Ditch, Install Erosion Matting and Seeding	meter	1,234	$ 55.65	$ 68,672
19	E&S Control	Cleanout Stormwater Storage Basin	EA	1	$ 15,000.00	$ 15,000
GAS COLLECTION AND CONTROL SYSTEM						
20	Gas Collection and Control System	New Collection Wells with Wellhead	EA		$ 6,270.00	$ -
21	Gas Collection and Control System	Collection Piping and Fittings	meter		$ 135.00	$ -
22	Gas Collection and Control System	Condensate Sumps and/or Traps	EA		$ 30,000.00	$ -
23	Gas Collection and Control System	LLDPE Boot for Wells, Condensate Sumps/Traps & Valves	EA		$ 523.00	$ -
MISCELLANEOUS						
24	General Condition	Bonds and Insurance (3%)	EA	1	$ 80,238.00	$ 80,238
25	Engineering and Bidding	Engineering and Bidding	EA	1	$ 40,000.00	$ 40,000
26	Construction Quality Assurance	Construction Quality Assurance	EA	1	$ 200,000.00	$ 200,000
27	Surveying	Construction and CQA Surveying	LS	1	$ 20,000.00	$ 20,000
28	Reclamation of Soil Stockpile or Borrow A	Rough Grading and Seeding	LS	1	$ 25,000.00	$ 25,000
29	Permanent Edge of Liner Marker Posts	Supply and Install Landfill Extents Marker Posts (Anchor Trench)	EA	50	$ 285.00	$ 14,250
30	Gravel Covered Access Road	Gravel Covered Access Road Including Woven Geotextile Fabric Underlayment	m^2	1,120	$ 12.54	$ 14,045
					CONSTRUCTION COST SUBTOTAL	**$3,014,838**
					5% CONTINGENCY	**$150,742**
					TOTAL CONSTRUCTION COST	**$3,165,580**
					COST PER HECTARE	**$342,595**

GCCS Cost Estimate

San Cristobal Landfill

GCCS Element	Unit Cost	Quantity			Estimated Cost		
		Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
Engineering	$ 35,000	1	1	1	$ 35,000	$ 35,000	$ 35,000
Moblilization	$ 6,500	1	1	1	$ 6,500	$ 6,500	$ 6,500
Vertical Extraction Well	$ 10,640	32	20	15	$ 340,480	$ 212,800	$ 159,600
Header Piping (m) 300mm Ø	$ 121	800	380	365	$ 96,432	$ 45,805	$ 43,997
Lateral Piping (m) 12mm Ø	$ 42	1000	430	550	$ 42,189	$ 18,141	$ 23,204
Condensate Sump	$ 20,475	3	1	0	$ 61,425	$ 20,475	$ -
Isolation Valve	$ 3,938	5	2	0	$ 19,688	$ 7,875	$ -
Blind Frange	$ 500	2	2	0	$ 1,000	$ 1,000	$ -
Road Crossing	$ 900	2	1	0	$ 1,800	$ 900	$ -
Blower/Flare Station	$ 356,000	1	0	0	$ 356,000	$ -	$ -
				Subtotal	$ 960,514	$ 348,496	$ 268,301
				Contingency 5%	$ 48,026	$ 17,425	$ 13,415
				Total	$ 1,008,539	$ 365,921	$ 281,716

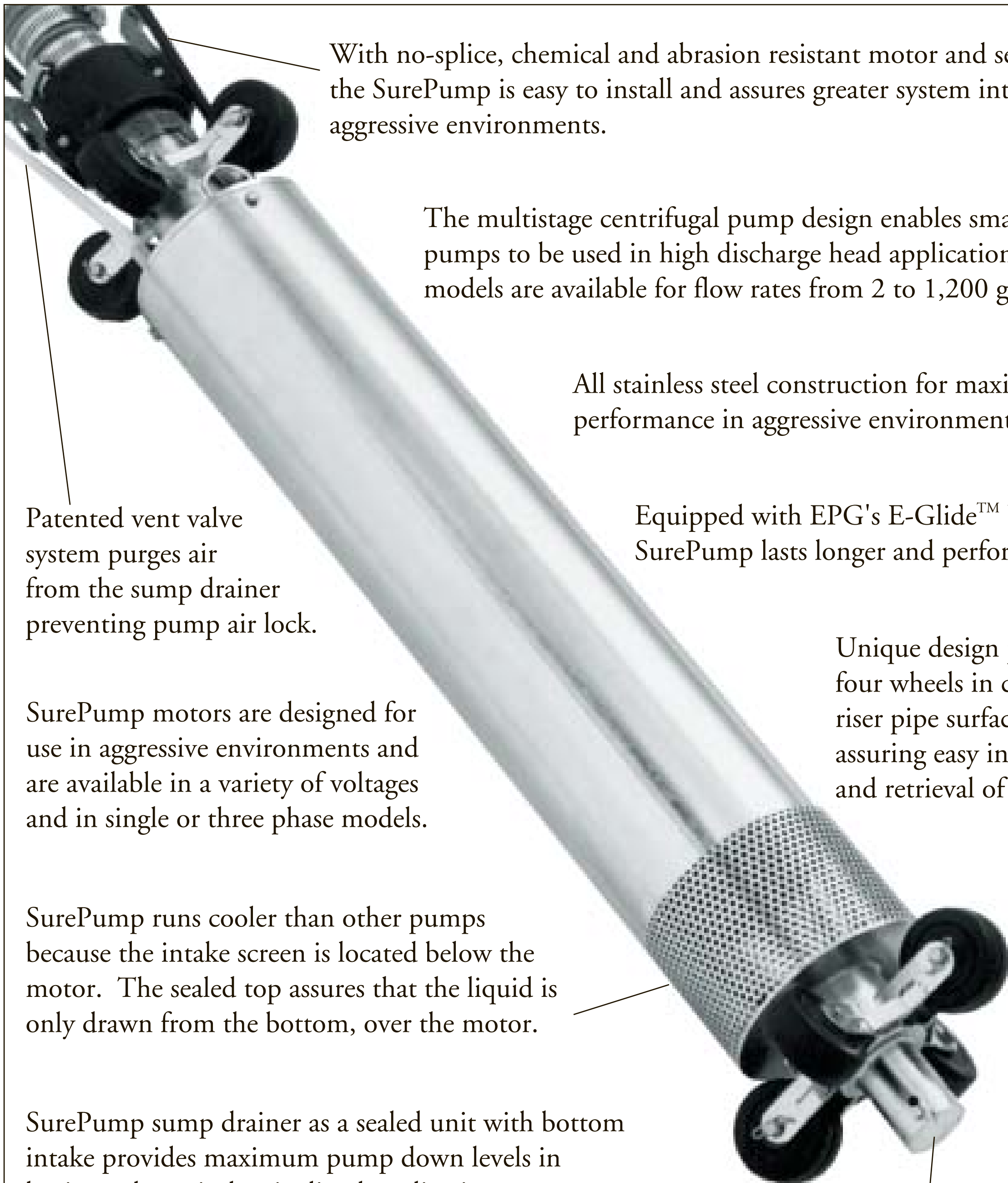
Typical Landfill Post-Closure Care Items
(30-year Post-Closure Period)
San Cristobal Landfill

ITEM		QUANTITY	UNIT	UNIT COST	ANNUAL COST	30 YEAR COST
1	**Administration and Recordkeeping**	1	Each	$ 5,000	$ 5,000	$ 150,000
2	**Groundwater Monitoring**					
	(Estimated 6 Groundwater Wells) x (2 Sample Events per Year) =	12	Each	$ 1,200	$ 14,400	$ 432,000
3	**Methane Gas Monitoring**					
	(Estimated 6 Gas Probes) x (4 Sample Events per Year) =	24	Each	$ 35	$ 840	$ 25,200
4	**Mowing**	9.5	Hectare	$ 45	$ 428	$ 12,825
5	**Final Cover (Cap) Maintenance**					
	(5% of 9.5 Hectares) =	0.5	Hectare	$ 1,100	$ 523	$ 15,675
6	**Stormwater Basin Sediment Cleanout**					
	(Labor and Equipment) x (Once every 5 Years) =	0.2	Each	$ 1,500	$ 300	$ 9,000
7	**Leachate Collection and Removal System Maintenance**	1	Each	$ 7,500	$ 7,500	$ 225,000
8	**Leachate Disposal**					
	(500 liters per hectare after closure) x (9.24 ha) =	4,620	Liter	$ 0.19	$ 878	$ 26,334
9	**Landfill Gas Collection and Control System Monitoring**					
	(Labor and Equipment) x (Once per Month) =	12	Month	$ 1,500	$ 18,000	$ 540,000
10	**Landfill Gas Collection and Control System Maintenance**					
(Maintenance and/or Replacement Wells & Piping) x (Once every 3 Years) =		0.3	Each	$ 30,000	$ 9,000	$ 270,000
11	**Replace LFG Blower/Flare Equipment**					
	(Once in 30 Years)	1	LS	$ 350,000	$ 11,667	$ 350,000
12	**Landfill Inspections**					
	(Quarterly) =	4	Each	$ 2,500	$ 10,000	$ 300,000
				Annual Cost:	**$ 78,536**	
				30 Year Post-Closure Care Cost:		**$ 2,356,034**

Appendix F: Examples of Submersible Electric Pumping Systems

Horizontal Wheeled Sump Drainer

More details at www.epgco.com



With no-splice, chemical and abrasion resistant motor and sensor leads, the SurePump is easy to install and assures greater system integrity in aggressive environments.

The multistage centrifugal pump design enables smaller diameter pumps to be used in high discharge head applications. SurePump models are available for flow rates from 2 to 1,200 gpm.

All stainless steel construction for maximum performance in aggressive environments.

Patented vent valve system purges air from the sump drainer preventing pump air lock.

Equipped with EPG's E-Glide™ bearings, the SurePump lasts longer and performs better.

Unique design places at least four wheels in contact with riser pipe surface at all times assuring easy installation and retrieval of the pump.

SurePump motors are designed for use in aggressive environments and are available in a variety of voltages and in single or three phase models.

SurePump runs cooler than other pumps because the intake screen is located below the motor. The sealed top assures that the liquid is only drawn from the bottom, over the motor.

SurePump sump drainer as a sealed unit with bottom intake provides maximum pump down levels in horizontal, vertical or inclined applications.

The patented submersible level sensor is mounted along the central axis of the sump drainer, is removable from the bottom and assures accurate, repeatable level control.

Why EPG Pumps are Suitable for Class I, Division 1 & 2 Applications

Before a pump can be considered suitable to be used in a Class I, Division 1 hazardous (classified) locations, it must first meet at least one of the four criteria established in paragraph (a) of the National Electric Code (NEC), Article 501-8 Motors and Generators. Condition (4) states:

> "Of a type designed to be submerged in a liquid that is flammable only when vaporized and mixed with air, or in a gas or vapor at a pressure greater than atmospheric and that is flammable only when mixed with air; and the machine is arranged so to prevent energizing it until it has been purged with the liquid or gas to exclude air, and also arranged to automatically de-energize the equipment when the supply of liquid or gas or vapor fails or the pressure is reduced to atmospheric."

EPG pumps meet the intent of NEC 501-8, condition 4 in the following way:

The motors used in EPG pumps are filled with a mixture of glycol and water. During normal operation, this fluid lubricates the internal sleeve bearings. If motor temperature increases beyond normal operating temperature, the internal fluid boils out and the motor temperature starts to rise. At 225^{O} F, internal insulation of the motor fails causing a winding-to-winding internal short, (sealed between inter and outer stainless steel shells surrounded by non-hydroscopic insulation). When this phase-to-phase short occurs, the motor will be automatically de-energized. Without an ignition source, there can be no explosion.

Paragrapg (b) Class I, Division 2 of the National Electric Code (NEC), Article 501.8 Motors and Generators, states:

> "The installation of open or nonexplosionproof enclosed motors, such as squirrel-cage induction motors without brushes, switching mechanisms, or similar arc-producing devices, shall be permitted."

EPG pumps also meet this criteria since they contain no arc-producing devices. In fact, the same motor design of EPG pumps is used in almost every underground gasoline storage tank pump application throughout the US.

EPG pumps have been time-tested (over 20 years) and field-proven (over 6,000 installations) to be suitable for service in over 800 landfills worldwide. EPG pump motors have also been tested under a dozen or more failure modes and found to have a maximum surface temperature at failure of 225^{O} F. In addition, the power cable used with EPG pumps are made from the same material used in off-shore drilling rig applications. This material was selected when designing the power cables because it is extremely chemical resistant, waterproof, and more cut/abrasive resistant than extra heavy-duty service cable and it does not sustain combustion.

Based on meeting NEC criteria, manufacturing design and service/performance record, EPG pumps have been proven to be suitable for Class I, Division 1 & 2 locations.

EPG PUMPS

- Meet NEC criteria for Class I, Division 1 & 2 locations
- Field proven with over 6,000 installations in more than 800 landfills
- Time tested with over 20 years of dependable service
- Motors contain no arc-producing device
- All internal parts are dissimilar and not a source of energy release
- Extremely chemical resistant, waterproof and abrasive resistant
- Maximum surface temperature of 225^{O} F - can not sustain combustion
- Power cable used is more abrasive resistant than extra heavy-duty service cable
- Motor stator windings are hermetically sealed

