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Permit Application

Volume 3
Part 1 of 3

STATE OF NEW MEXICO
DIRECTOR OF OIL CONSERVATION DIVISION

IN THE MATTER OF THE APPLICATION OF SUNDANCE WEST, INC. FOR A SURFACE WASTE MANAGEMENT FACILITY PERMIT

APPLICATION FOR PERMIT
SUNDANCE WEST

AUGUST 2016

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS

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1.0 INTRODUCTION

Sundance West (Sundance West Facility) is a proposed Surface Waste Management Facility for oil field waste processing and disposal services. The proposed Sundance West Facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD). The Facility has been designed in compliance with 19.15.36 NMAC, and will be constructed and operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned by, and will be constructed and operated by, Sundance West, Inc.

1.1 Description

The Sundance West site is comprised of a 320-acre ± tract of land located approximately 3 miles east of Eunice, 18 miles south of Hobbs, and approximately 1.5 miles west of the Texas/New Mexico state line in the South ½ of Section 30, Township 21 South, Range 38 East Lea County, New Mexico (NM). Site access will be provided via NM 18 and Wallach Lane. The Sundance West Facility will include two main components; a liquid oil field waste Processing Area (80 acres ±), and an oil field waste Landfill (120 acres ±). Oil field wastes are anticipated to be delivered to the Sundance West Facility from oil and gas exploration and production operations in southeastern NM and west Texas. The Site Development Plan provided in the **Permit Plans, Attachment III.1.A**, identifies the locations of the Processing Area and Landfill facilities.

2.0 DESIGN CRITERIA

This Section, "Engineering Design" is provided as a summary of the engineering design elements for the Sundance West Landfill and Processing Facility. The Engineering Design has been developed in accordance with the Oil and Gas Rules. More specifically, 19.15.36.17.A NMAC requires an "Engineering Design Plan" for evaporation, storage, treatment and skimmer ponds. In addition, the construction standards for these facilities are also addressed in compliance with 19.15.36.17.B NMAC. Engineering requirements specific to landfills as referenced in 19.15.36.14.C-F NMAC, including landfill design standards, liner specifications, requirements for the soil component of composite liners, and the leachate collection and removal system are addressed herein. The Engineering Design also addresses the requirements of 19.15.36.13.M NMAC pertaining to the control of run-on and runoff from the 25-year, 24-hour design storm (**Volume III.4** and **Permit Plans, Attachment III.1.A**).

Compliance with the design standards is demonstrated on the **Permit Plans** listed in **Table III.1.1**, which are sealed by Mr. I. Keith Gordon, P.E., of Gordon Environmental, Inc., a New Mexico Professional Engineer with extensive experience in geotechnical engineering and waste containment design employing geosynthetics. The **Permit Plans** are provided for reference in **Attachment III.1.A** as 11 x 17 inch (in.) plots and are also submitted as "D" size sealed plots (i.e., 24 x 36 in.) as part of this Application for Permit.

Table III.1.1
List of Permit Plans
Sundance West

Sheet	Title
1	Cover Sheet and Drawing Index
2	Existing Site Conditions
3	Site Development Plan
4	Base Grading Plan
5	Final Grading Plan
6	East Phase Development Base Grading Plan
7	East Phase Development Intermediate and Final Grading Plan
8	Landfill Completion Drainage Plan
9	East Phase Development Drainage Plan
10	Drainage Channel Profiles and Typical Sections
11	Landfill Cross Sections
12	Liner System and Cover System
13	Leachate Collection System Details
14	Stormwater Drainage Details
15	Evaporation Pond Layout
16	Evaporation Pond Details
17	Evaporation Pond Cross Sections
18	Process Layout
19	Process Layout Cross Sections

3.0 LANDFILL DESIGN STANDARDS

The proposed Sundance West Landfill will be located within the 320 ± acre facility boundary as shown on the **Permit Plans,** (**Attachment III.1.A**). The landfill footprint will be approximately 126 ± acres in size with a depth from the top of the 10-foot (ft) perimeter berm to the base grades of approximately 20 feet (ft) on the east end and 60 ft on the west end. The base grades of the landfill are in excess of 100 ft from groundwater. The landfill consists of three independent units (Units 1, 2, and 3) each having a leachate collection system and collection sump located at the west end (**Permit Plans, Attachment III.1.A**).

3.1 Liner System

A double liner and leak detection system design is proposed for the Sundance West Landfill. An alternate liner system is being proposed that meets the requirements of 19.15.36.14.C NMAC demonstrated as equivalent in the United States Environmental Protection Agency (USEPA) Hydrologic Evaluation of Landfill Performance (HELP) Model (**Volume III.4)** and has a demonstrated track record for long-term waste containment performance. The liner system consists of, from top to bottom:

- 24-in. protective soil layer (on-site soils with permeability ≥ 10^{-4} cm/sec)
- 200-mil HDPE geonet drainage layer
- 60-mil HDPE primary liner
- 200-mil HDPE geonet leak detection layer
- 60-mil HDPE secondary liner
- Geosynthetic Clay Liner (GCL)
- 6-in. soil compacted subgrade

The liner system is designed to meet the performance requirement of no more than one foot of leachate on the primary liner as required in 19.15.36.14.F NMAC and demonstrated in the HELP Model (**Volume III.4**).

HDPE material is proposed for the leachate collection layer, leak detection layer and liners as HDPE has proven to be the preferred material for waste containment facilities due to its durability and resistance to degradation by waste constituents. **Volume III.6** provides documentation regarding HDPE material compatibility in compliance with 19.15.36.14.D.(2)(a) NMAC.

3.2 Leachate Collection and Leak Detection System

The leachate collection system designed for the Landfill consists of an alternate 2-ft protective soil layer consisting of "SM" soil material with a permeability of $\geq 10^{-4}$ centimeters per second (cm/sec) covering a 200-mil geonet drainage layer. The leak detection system layer will incorporate a 200-mil geonet specifically prescribed for this application (**Permit Plans, Attachment III.1.A)**. With a design transmissivity of 1×10^{-3} square meters per second (m^2/sec), the geonet will provide fluid flow potential superior to the prescriptive soil leak detection layer of 2 ft of pervious soils (19.15.36.14.C.(3) NMAC and 19.15.36.14.C.(5) NMAC). This fact has been demonstrated in the HELP Model (**Volume III.4**).

The leachate collection layer slopes at 2.8% to a 6-in. diameter standard dimension ratio (SDR) 11 high density polyethylene (HDPE) perforated leachate collection pipe to the center of the units and is directed at a 2% slope to the leachate collection sumps on the west end of the Landfill (**Permit Plans, Attachment III.1.A)**. The leak detection geonet slopes at 2.8% to the center of the units and is directed at a 2% slope to each of the nine leak detection sumps located on the west end of the Landfill (**Permit Plans, Sheet 4**). Each of the sumps is approximately 2 ft deep and contains ¾-in. to 2.0-in. diameter pre-qualified select aggregate installed on and wrapped in a geotextile cushion placed over the HDPE liners. Classification criteria for the aggregate are specified in the Liner Construction Quality Assurance (CQA) Plan (**Volume II.7**), which state that it not be angular (i.e., sharp edges which could damage the liners) or calcareous (which could degrade over time).

The fluids collected in the leachate collection and leak detection sumps will be monitored and collected by separate 12-in. diameter sidewall riser pipes, that do not penetrate the liners, in compliance with 19.15.36.14.C.(10) NMAC. The piping is demonstrated to resist degradation by the waste constituents as documented in the Geosynthetic Application and Compatibility Documentation (**Volume III.6**).

The leachate collection system pipe will consist of a minimum 6-in. diameter perforated SDR 11 HDPE. The leachate collection and leak detection sump riser pipes will consist of a 12-in. diameter, SDR 11 HDPE; and will be perforated or slotted for the bottom 2 ft depth within the sump (i.e., 8 ft length at 4:1 slope). HDPE piping has shown superior characteristics for waste containment applications vs. the polyvinylchloride specified in the Oil and Gas Rules (**Table III.1.2**). The piping is demonstrated to resist degradation by the waste constituents as documented in the Geosynthetic Application and Compatibility Documentation (**Volume III.6**).

TABLE III.1.2
HDPE Leachate Collection Pipe
Sundance West

Characteristic	**6-in. Diameter Leachate Collection Pipe**	**12-in. Diameter Leachate and Leak Detection Riser Pipes**
	SDR 11 HDPE	**SDR 11 HDPE**
Dimension Ratio	11.0	11.0
Method of Joining	Welded	Welded
Manning’s Number (n)	0.010	0.010
Outside Diameter (in.)	6.625[2]	12.75[2]
Min. Wall Thickness (in.)	0.602[2]	1.159[2]
Tensile Strength (psi)	5,000	5,000
Modulus of Elasticity (psi)	130,000	130,000
Flexural Strength (psi)	135,000	135,000

Notes:
[1]*PolyPipe, A-4 (**Attachment III.1.G**)*

The details in the **Permit Plans**, **Attachment III.1.A** reflect the deployment of SDR 11 HDPE piping for the leachate collection pipe and leak detection sump riser pipes. HDPE flat stock or four layers of geonet will be placed beneath the beveled edge of the perforated risers in the sumps to prevent potential liner damage (**Permit Plans**). Solid-wall HDPE piping will extend from above the sumps to the permanent wellheads shown on the **Permit Plans**.

The entire leachate collection system will be covered by 2 ft of protective soil with a hydraulic conductivity greater than or equal to 10^{-4} cm/sec. The HELP Model, provided in **Volume III.4**, confirms that the design meets the requirements of 19.15.36.14.F NMAC.

The leachate collection system and protective soil cover on the top of the liner system in the Landfill will protect the floor and sidewall liner by providing ballast and blocking sunlight (i.e., UV rays), with the upper sections of sidewall liner secured by the anchor trench as depicted on the **Permit Plans**.

3.3 Landfill Final Cover System

The final cover for the top and sideslopes will utilize an alternative cover system consisting of the following:

- 24-in. erosion layer
- 6-in. infiltration layer
- Oil Field Waste and soil compacted to estimated average 80% Standard Proctor

On-site soils will be used to construct the final cover, and the cap will be placed as the Landfill reaches final grades. The Landfill will have 4:1 design sideslopes with drainage benches spaced at a vertical distance of approximately 30-ft; and a top slope of 5%. The final cover was modeled using the HELP Model (**Volume III.4**), and results indicate that percolation through the cover will not exceed that of the bottom liner as required in 19.15.36.14.C.(9) NMAC.

4.0 LANDFILL CONSTRUCTION

Construction of the Landfill will be accomplished by constructing individual cells within the units. Detailed Construction Plans and Technical Specifications will be prepared for the proposed Sundance West Landfill cells and submitted to several pre-qualified Liner Installation Contractors for quotes. The cell excavation, construction, floor grading/compaction, and geosynthetics installation will be subject to the rigorous CQA standards specified in the Liner CQA Plan (**Volume II.7**).

OCD will be provided a major milestone schedule in advance of construction; and will be notified via e-mail or phone at least 3 working days prior to the installation of the primary liner. An Engineering Certification Report, sealed by a Professional Engineer with expertise in geotechnical engineering, will be submitted to OCD documenting compliance of completed construction with the Permit, regulatory requirements, industry standards, and the plans and specification.

The Engineering Design, as demonstrated by the Volumetric Calculations (**Volume III.2**) deliberately provides a "sustainable" configuration that does not require the import of off-site soils. The materials equation provides an excess of soils excavated (i.e., cut) and fill for the cover and perimeter berms. The in-situ and on-site fill soil will be pre-qualified in accordance with the CQA Plan (**Volume II.7**). At least one Standard Proctor Density test will be conducted in the laboratory for each 5,000 cubic yards of subgrade soils, fill material or a change in subgrade material. These tests will be the basis for field density measurements during construction (i.e., 90% standard Proctor dry density) conducted at a minimum frequency of 4 tests/acre/lift.

Fill for the berms will be placed in horizontal compacted lifts that do not exceed 12-in. in thickness. The subgrade surface will be inspected to confirm the absence of any deleterious materials, abrupt changes in slope, evidence of erosion, etc. The compliance of the completed subgrade construction will be confirmed prior to secondary liner installation, and documented in the Engineering Certification Report.

The 60-mil HDPE and geosynthetic clay secondary liner will be installed for the proposed Cells in direct contact with the prepared and certified subgrade liner in accordance with the CQA Plan (**Volume II.7**). Installation of the geonet; geotextile, aggregate and riser pipes in the sumps will follow. The installation of all soil and geosynthetic components will meet or exceed the requirements of 19.15.36.14.C NMAC, as detailed in the CQA Plan. Finally, the primary liner will be constructed, and liner/leak detection/leachate collection system elements (i.e., secondary, geonet, primary, geonet) will be secured in the common anchor trench at the top of the Landfill sideslope**.** The anchor trench will be carefully backfilled with select on-site soils compacted to 90% of standard Proctor dry density by mechanical and/or hand-tamping devices as required by the CQA Plan. Documentation will be provided in the Engineering Certification Report submitted to OCD upon completion of construction.

5.0 POND DESIGN STANDARDS

The designs for the Ponds are identical, except that Pond elevations are different depending on their site location (**Permit Plans, Attachment III.1.A**). Each pond is approximately 420 ft east-west by 200 ft north-south as measured at the top of the surrounding berms, for a footprint of 2.0 ± acres each. The floor of the ponds is designed with a 2.8% slope to facilitate drainage in the leak detection system to the two sumps in each basin situated on the interior sidewall.

Because the berms have a uniform top elevation, the 2.8% floor slope creates a pond depth that ranges from a maximum of 12 ft to a minimum of just less than 8 ft. The maximum water depth occurs at the sump locations and does not exceed 8.5 ft. Maintaining a high water elevation of 3,415 ft and 3,411 ft in the east Ponds; and 3,407 ft and 3,405 ft in the west Ponds; will provide a minimum freeboard of 3 ft in each of the ponds. This 3 ft minimum freeboard meets the standard; while also accommodating the minimal impact potential of rainfall or wave action (**Volume III.12**). The resultant capacity of each pond is approximately 9.5 acre-ft, not including freeboard, below the maximum 10 acre-ft volume prescribed by 19.15.36.17.B(12) NMAC. The normal water surface is marked in each pond to define the available freeboard. **Attachment III.1.F** provides pond capacity calculations.

Section 5.0 (Pond Construction) below and the CQA Plan (**Volume II.7**) provide documentation on the installation of berms, soil subgrade, and geosynthetics. Exceeding the standards specified in 19.15.36.17.B(5) NMAC, both the exterior and interior sidewalls of all of the Ponds have design slopes of 3:1. The top platform of the berms surrounding the Ponds has a minimum design width of 15 ft to provide adequate room for inspection and maintenance, which is more than adequate for the 2 ft anchor trench shown on the **Permit Plans**; and to accommodate pipe risers.

5.1 Liner System

A double liner and leak detection system design is proposed for each pond. An alternate liner system is being proposed that meets the requirements of 19.15.36.17.B(9) NMAC and has a demonstrated track record for long-term waste containment performance. The pond liner system consists of, from top to bottom:

- 60-mil HDPE primary liner
- 200-mil HDPE geonet leak detection layer
- 60-mil HDPE secondary liner
- GCL under the leak detection sumps
- 6-in. compacted soil subgrade

HDPE material is proposed for the liners and leak detection layer as HDPE has proven to be the preferred material for waste containment facilities due to its durability and resistance to degradation by waste constituents. **Volume III.6** provides documentation regarding HDPE material compatibility in compliance with 19.15.36.17.B(3) NMAC

5.2 Leak Detection System

The leak detection system layer designed for the ponds consists of a 200-mil geonet specifically prescribed for these applications (**Permit Plans**). With a design transmissivity of 1 x 10^{-3} m^2/sec, the geonet will provide fluid flow potential superior to the prescriptive leak detection layer of 2 ft of pervious soils (19.15.36.17.B(9) NMAC).

The underlying 60-mil HDPE secondary liner, the 200-mil geonet leak detection layer, and the overlaying 60-mil HDPE primary liner, will slope at 2% to the 2 leak detection sumps located in each pond (**Permit Plans**). Fluids collected in the leak detection layer, which encompasses the entire footprint for each pond, are directed with the 2% slope to the leak detection sumps. Each of the sumps will be approximately 2 ft deep, as measured from the secondary liner to the primary liner. The sumps will contain ¾-in. to 2.0-in. diameter pre-qualified select aggregate installed on a geotextile cushion placed over the secondary liner. Classification criteria for the aggregate are specified in the CQA Plan (**Volume II.7**), which state that it not be angular (i.e., sharp edges which could damage the liners) or calcareous (which could degrade over time).

The fluids collected in the leak detection sumps will be monitored and removed through a 6-in. diameter, SDR 11 HDPE sidewall riser pipes that do not penetrate the liners. The leak detection sump riser pipes will be perforated or slotted for the bottom 2 ft depth within the sump (i.e., 6 ft length at 3:1 slope). HDPE piping has shown superior characteristics for waste containment applications (**Table III.1.3**). The piping is demonstrated to resist degradation by the waste constituents as documented in **Volume III.6**.

TABLE III.1.3
HDPE Sump Riser Pipe
Sundance West

Characteristic	**6-in. Diameter Leak Detection Riser Pipes**
	SDR 11 HDPE
Dimension Ratio	11.0
Method of Joining	Welded
Manning's Number (n)	0.010
Outside Diameter (in.)	6.625[2]
Min. Wall Thickness (in.)	0.602[2]
Tensile Strength (psi)	5,000
Modulus of Elasticity (psi)	130,000
Flexural Strength (psi)	135,000

Notes:
*[1]PolyPipe, A-4 (**Attachment III.1.G**)*

The details in the **Permit Plans** reflect the deployment of SDR 11 HDPE piping for the leak detection sump riser pipes. HDPE flat stock or four layers of geonet will be placed beneath the beveled edge of the perforated risers in the sumps to prevent potential liner damage (**Permit Plans**). Solid-wall HDPE piping will extend from above the sumps to the permanent wellheads shown on **Permit Plans**. The sidewall liners and leak detection geonet will be secured by the anchor trench as depicted on the **Permit Plans.**

6.0 POND CONSTRUCTION

Detailed Construction Plans and Technical Specifications will be prepared for the proposed Ponds, and submitted to several pre-qualified Liner Installation Contractors for quotes. The berm construction, floor grading/compaction, and geosynthetics installation will be subject to the rigorous CQA standards specified in **Volume II.7**.

OCD will be provided a major milestone schedule in advance of construction; and notified via email or phone at least 3 working days prior to the installation of the primary liner in compliance with 19.15.36.17.B(10) NMAC. An Engineering Certification Report, sealed by a Professional Engineer with expertise in geotechnical engineering, will be submitted to OCD documenting compliance of completed construction with the Permit, regulatory requirements, industry standards, and the plans and specification.

The Engineering Design presented on the **Permit Plans** (**Attachment III.1.A**) deliberately provides a "sustainable" configuration that does not require import of off-site soils. The materials equation provides a balance between soils excavation (i.e., pond) and fill for the sidewalls. The in-situ and on-site fill soil will be pre-qualified in accordance with the CQA Plan (**Volume II.7**). At least one standard Proctor dry density test will be conducted in the laboratory for each pond footprint, 5,000 cubic yards (cy) of fill material for berms, or change in subgrade material. These tests will be the basis for field density measurements during construction (i.e., 90% standard Proctor dry density) conducted at a minimum frequency of 4 tests/acre/lift.

Fill for the berms will be placed in horizontal compacted lifts that do not exceed 12 in. in thickness. The subgrade surface will be inspected to confirm the absence of any deleterious materials, abrupt changes in slope, evidence of erosion, etc. The compliance of the completed subgrade construction shall be confirmed prior to secondary liner installation, and documented in the Engineering Certification Report.

The double liner and leak detection system design, planned for the ponds, consists of proven technology with a demonstrated track record of long-term waste containment performance. The secondary liner proposed for the ponds, consists of a smooth 60-mil HDPE geomembrane placed in direct contact with a prepared and compacted soil subgrade, certified in accordance with the CQA Plan (**Volume II.7**). The same HDPE material will be used for the primary liner and the geonet for the leak detection layer. HDPE has proven to be the preferred material for waste containment facilities due to its durability and resistance to attack by waste constituents.

Volume III.6 provides documentation regarding liner and leak detection material compatibility in compliance with 19.15.36.17.B(3) NMAC. An additional layer of 60-mil HDPE (22.5 ft x 40 ft ±) will be welded above the primary Pond liner where active wastewater discharge will occur (**Permit Plans**). This will protect the Pond liner from excessive hydrostatic force or mechanical damage. External discharge lines and leak detection system discharge lines will not penetrate the liner. The CQA Plan (**Volume II.7**) provides the most current technical specifications for the geosynthetics.

Fluid in the Ponds will protect the floor and lower sidewall liner by providing ballast and deflecting sunlight (i.e., UV rays). The upper sections of pond sidewall liner will be secured by the anchor trench. The anchor trench will be carefully backfilled with select on-site soils compacted to 90% of standard Proctor dry density by mechanical and/or hand-tamping devices (per the CQA Plan). Documentation will be provided in the Engineering Certification Report submitted to OCD upon completion of construction.

Although the freeboard zone of the pond sidewall liner will be exposed to the elements, recent research indicates that exposed HDPE in similar environments has a functional longevity in excess of 25 years (**Attachment III.1.B**). GEI has inspected several similar water storage ponds in New Mexico and has found exposed geomembrane liners to be functionally intact after over 25 years.

7.0 POND OPERATION

Detailed plans for the operation of the Ponds are prescribed in the Operations, Maintenance, and Inspection Plan (**Volume II.1**). Essentially, it is anticipated that some fluids will accumulate in the leak detection sumps as a result of condensation, construction water, etc. As described in **Volume II.1**, the leak detection sumps will be monitored at least monthly for the presence of fluids, which will be extracted and tested when the level in the sump(s) exceeds 24 in. A reduced monitoring frequency may be proposed to OCD dependent upon historical results. The design of the Ponds allows for isolation of potential leaks into isolated drainage basins, facilitating necessary evaluation or repair by allowing each pond to be emptied.

8.0 PROCESS AREA TANK CONTAINMENT

As proposed in this Application, produced water tanks and the crude oil receiving tanks depicted in **Attachment III.1.C;** and oil sales tanks as depicted in **Attachment III.1.D** will be installed in the excavated tank farm as shown on the **Permit Plans**. Detailed operations of the tanks are described in the Operations, Maintenance, and Inspection Plan (**Volume II.1**), and a schematic of the process area is provided in **Attachment III.1.E**. The tanks will be constructed with an underlying, continuous, system which is designed to capture any fluids within the watershed of the tank farm.

The secondary containment liner in the tank area is a 30-mil polyester liner (XR-5 8130 Reinforced Geomembrane). The use of the XR-5 8130 Reinforced Geomembrane in the tank area is primarily based on the chemical compatibility and puncture resistance of the material compared to either PVC or HDPE material. The chemical resistance of the XR-5 material exceeds the chemical compatibility of either PVC or HDPE to hydrocarbon products (see Chemical Resistance Chart, Page 13, "Technical Data and Specifications for XR-5", **Attachment III.1.H**). Since PVC material has limited chemical resistance in a hydrocarbon environment, physical properties of the XR-5 geomembrane (**Attachment III.1.H**) are compared to 60-mil HDPE geomembrane (**Attachment III.1.I**) as shown in **Table III.1.4**:

TABLE III.1.4
Physical Properties: XR-5 8130 Reinforced Geomembrane
and 60-mil HDPE Geomembrane
Sundance West

Property	XR-5 8130	60-mil HDPE
Thickness	30-mil	60-mil
Tear Strength	40 lbs	42 lbs
Puncture Resistance	275 lbs	108 lbs
Break Strength	400 lbs/in.	228 lbs/in.
Break Elongation	25%	700%
Hydrostatic Resistance	800 psi	> 450 psi
Hydraulic Conductivity	1 x 10^{-12} cm/sec	2 x 10^{-13} cm/sec
Seam Properties		
Shear Strength	500 lbs	120 lbs/in.
Peel Strength	40 lbs/2 in.	91 lbs/in.

The necessary storage capacity for the interconnected tank/containment system will be sufficiently managed by the proposed lined volume of the Ponds. In the unlikely event of a total catastrophic failure of all affected storage units, the contents of the tanks will flow into the ponds, which have a lined storage capacity of 736,994 ± barrels (bbl) (excluding freeboard). When the freeboard is included, the storage capacity of the ponds is over 1,222,640 bbl, which results in a net surplus of over 485,646 bbl. The entire volume of the proposed receiving tanks will be 50,000 bbl, providing a net excess capacity of over 435,646 bbl. Thus, the Ponds will hold the entire volume of the receiving/settling tanks within the required permanent freeboard of 3 ft.

The maximum proposed number of interconnected tanks is five 1,000 bbl tanks for a total of 5,000 bbl. Allowing for an additional 30% capacity will require a minimum of 6,500 bbl of bermed capacity in the tank farm. The containment area is conservatively sized to surround the entire tank farm, which results in a holding capacity of 7,836 bbl, and is 6,836 bbl greater than the capacity of the largest tank (1,000 bbl) and 1,336 bbl greater that the combined connected tank volume, including a 30% volume, factor of safety within the containment area. Therefore the containment area surrounding the receiving/settling tanks is more than sufficient. Included in this Section is a spreadsheet (**Attachment III.1.F**) that identifies all of the proposed tanks and Evaporation Ponds in this Application.

9.0 STABILIZATION AND SOLIDIFICATION AREA

The design for the stabilization and solidification (S&S) area relies on many of the Pond design characteristics, except that the S&S area is designed to allow dump trucks and tanker trucks delivering materials that require stabilization and/or solidification to discharge directly into the S&S area from a concrete unloading pad. (**Permit Plans, Attachment III.1.A**). The S&S area covers approximately 5-acres and measures 660 ft east-west by 330 ft north-south at the top of the surrounding berms. The floor of this area is designed with a 2% slope to facilitate drainage on the liner and in the leak detection system to collect in a sump situated along the east sidewall of the area.

Because the three perimeter berms have a uniform top elevation, the 2% floor slope creates a pond depth that ranges from a minimum of 5 ft at the unloading pad to a maximum of 20 ft at the sump along the eastern perimeter berm. The bottom liner slope allows for a 5-ft-thick protective and operational cover on the liner. This slope also provides operation capacity for the S&S function proposed for this area while providing the capacity to meet the 3 ft minimum freeboard standard and accommodating the minimal impact potential of rainfall. The resultant capacity of the S&S area is approximately 5.6 acre-ft, not including freeboard, well below the maximum 10 acre-ft volume prescribed by 19.15.36.17.B(12) NMAC.

Section 5.0 (Pond Construction) and the CQA Plan (**Volume II.7**) provide documentation on the installation of berms, soil subgrade, and geosynthetics. Exceeding the standards specified in 19.15.36.17.B(5) NMAC, both the exterior and interior sidewalls of S&S area have design slopes of 3:1. The top platform of the berms surrounding the S&S area has a minimum design width of 15 ft, which is more than adequate for the 2 ft anchor trench.

9.1 Liner System

As with the Ponds, the S&S area is designed with a double liner and leak detection system proposing the same alternate liner system that meets the requirements of 19.15.36.17.B(9) NMAC and has a demonstrated track record for long-term waste containment performance. The S&S Area liner system consists of, from top to bottom:

- 3 ft operational layer
- 1 ft chipped tire warning zone
- 1 ft protective soil layer
- 200-mil HDPE geonet liquid collection layer
- 60-mil HDPE primary liner
- 200-mil HDPE geonet leak detection layer
- 60-mil HDPE secondary liner
- GCL under the leak detection sumps
- 6-in. compacted soil subgrade

HDPE material is proposed for the liners and leak detection layer as HDPE has proven to be the preferred material for waste containment facilities due to its durability and resistance to attack by waste constituents. **Volume III.6** provides documentation regarding HDPE material compatibility in compliance with 19.15.36.17.B(3) NMAC

9.2 Leak Detection System

The leak detection system layer designed for the S&S area consists of a 200-mil geonet specifically prescribed for these applications. With a design transmissivity of 1×10^{-3} m^2/sec, the geonet will provide fluid flow potential superior to the prescriptive leak detection layer of 2 ft of pervious soils (19.15.36.17.B(9) NMAC).

The underlying 60-mil HDPE secondary liner, the 200-mil geonet leak detection layer, and the overlaying 60-mil HDPE primary liner, will slope at 2% to the leak detection sump located on the eastern berm of the S&S area. Fluids collected in the leak detection layer, which encompasses the entire footprint of the S&S area, are directed with the 2% slope to the leak detection sump. This sump will be approximately 2 ft deep, as measured from the secondary liner to the primary liner. The sump will contain ¾-in. to 2.0-in. diameter pre-qualified select aggregate installed on a geotextile cushion placed over the secondary liner. Classification criteria for the aggregate are specified in the CQA Plan (**Volume II.7**), which state that it not be angular (i.e., sharp edges which could damage the liners) or calcareous (which could degrade over time).

The fluids collected in the leak detection sump will be monitored and removed through a 12-in. diameter, SDR 11 HDPE sidewall riser pipe that does not penetrate the liners. The leak detection sump riser pipe will be perforated or slotted for the bottom 2 ft depth within the sump (i.e., 6 ft length at 3:1 slope). HDPE piping has shown superior characteristics for waste containment applications (**Table III.1.3**). The piping is demonstrated to resist degradation by the waste constituents as documented in **Volume III.6**. The details in the **Permit Plans** reflect the deployment of SDR 11 HDPE piping for the leak detection sump riser pipe.

HDPE flat stock or four layers of geonet will be placed beneath the beveled edge of the perforated riser in the sump to prevent potential liner damage. Solid-wall HDPE piping will extend from above the sump to the permanent wellhead shown on the **Permit Plans**. The sidewall liners and leak detection geonet will be secured by the anchor trench as depicted on the **Permit Plans**.

9.3 Stabilization & Solidification Area Construction

Detailed Construction Plans and Technical Specifications will be prepared for the proposed S&S area, and submitted to several pre-qualified Liner Installation Contractors for quotes. The berm construction, floor grading/compaction, and geosynthetics installation will be subject to the rigorous CQA standards specified in **Volume II.7**.

OCD will be provided a major milestone schedule in advance of construction; and notified via email or phone at least 3 working days prior to the installation of the primary liner in compliance with 19.15.36.17.B(10) NMAC. An Engineering Certification Report, sealed by a Professional Engineer with expertise in geotechnical engineering, will be submitted to OCD documenting compliance of completed construction with the Permit, regulatory requirements, industry standards, and the plans and specification.

The Engineering Design presented on the **Permit Plans** (**Attachment III.1.A**) deliberately provides a "sustainable" configuration that does not require import of off-site soils. The materials equation provides a balance between soils excavation (i.e., S&S area) and fill for the sidewalls. The in-situ and on-site fill soil will be pre-qualified in accordance with the CQA Plan (**Volume II.7**). At least one standard Proctor dry density test will be conducted in the laboratory for the S&S area footprint, 5,000 cubic yard (cy) of fill material for berms, or change in subgrade material. These tests will be the basis for field density measurements during construction (i.e., 90% standard Proctor dry density) conducted at a minimum frequency of 4 tests/acre/lift.

Fill for the berms will be placed in horizontal compacted lifts that do not exceed 12 in. in thickness. The subgrade surface will be inspected to confirm the absence of any deleterious materials, abrupt changes in slope, evidence of erosion, etc. The compliance of the completed subgrade construction shall be confirmed prior to secondary liner installation, and documented in the Engineering Certification Report.

The double liner and leak detection system design planned for the S&S area consists of proven technology with a demonstrated track record of long-term waste containment performance. The secondary liner proposed for the area, consists of a smooth 60-mil HDPE geomembrane placed in direct contact with a prepared and compacted soil subgrade, certified in accordance with the CQA Plan (**Volume II.7**). The same HDPE material will be used for the primary liner and the geonet for the leak detection layer. HDPE has proven to be the preferred material for waste containment facilities due to its durability and resistance to attack by waste constituents. **Volume III.6** provides documentation regarding liner and leak detection material compatibility in compliance with 19.15.36.17.B(3) NMAC. Leak detection system discharge lines will not penetrate the liner. The CQA Plan (**Volume II.7**) provides the most current technical specifications for the geosynthetics.

Protective cover and tire chip layers in the S&S area will protect the floor and lower sidewall liner by providing ballast and deflecting sunlight (i.e., UV rays). The upper sections of S&S area sidewall liner will be secured by the anchor trench (**Permit Plans**). The anchor trench will be carefully backfilled with select on-site soils compacted to 90% of standard Proctor dry density by mechanical and/or hand-tamping devices (per the CQA Plan). Documentation will be provided in the Engineering Certification Report submitted to OCD upon completion of construction.

Although the freeboard zone of the S&S area sidewall liner will be exposed to the elements, recent research indicates that exposed HDPE in similar environments has a functional longevity in excess of 25 years (**Attachment III.1.B**). GEI has inspected similar applications in New Mexico and has found exposed geomembrane liners to be functionally intact after over 25 years.

9.4 Stabilization and Solidification Area Operation

Detailed plans for the operation of the S&S area are prescribed in the Operations, Maintenance, and Inspection Plan (**Volume II.1**). To ensure compliance with the capacity limits imposed on the operation of this area, volumes in and out of this area will be tracked to document the volume in processing at any time. Equipment operating within the S&S area may be equipped with Global Positioning System (GPS) equipment (see **Attachment III.1.J** for information on the Computer Aided Earthmoving System provided by Caterpillar) to monitor the location of the equipment relative to the liner system. This system may be implemented to maintain adequate separation of equipment and the liner system during the stabilization and solidification operation. Material that has completed the S&S operation will be relocated to the Landfill for disposal. Solidification material will be excavated from borrow sources within the solid waste management facility or selectively diverted from the incoming solid waste stream.

10. FACILITY DRAINAGE DESIGN

The **Permit Plans**, **Attachment III.1.A,** show the stormwater management systems that will be employed to manage both run-on and runoff for the Sundance West Landfill and Processing Facilities. The design event, pursuant to 19.15.36.13.M NMAC (i.e., 25-year, 24-hour storm) will be managed by a series of drainageways that surround the proposed Ponds, Processes, and Landfill and capture stormwater from other on-site areas.

Stormwater detention basins are planned for installation as shown on the **Permit Plans**; and the Stormwater Management Plan is included in **Volume III.3** that demonstrates the efficacy of the proposed system.

The berms surrounding the Landfill and processing area have a maximum exterior slope of 3:1, and an average height of less than 10 ft, minimizing the potential for soil erosion. The drainageways and detention basins will be regularly inspected and cleaned out, as necessary.

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.A

PERMIT PLANS

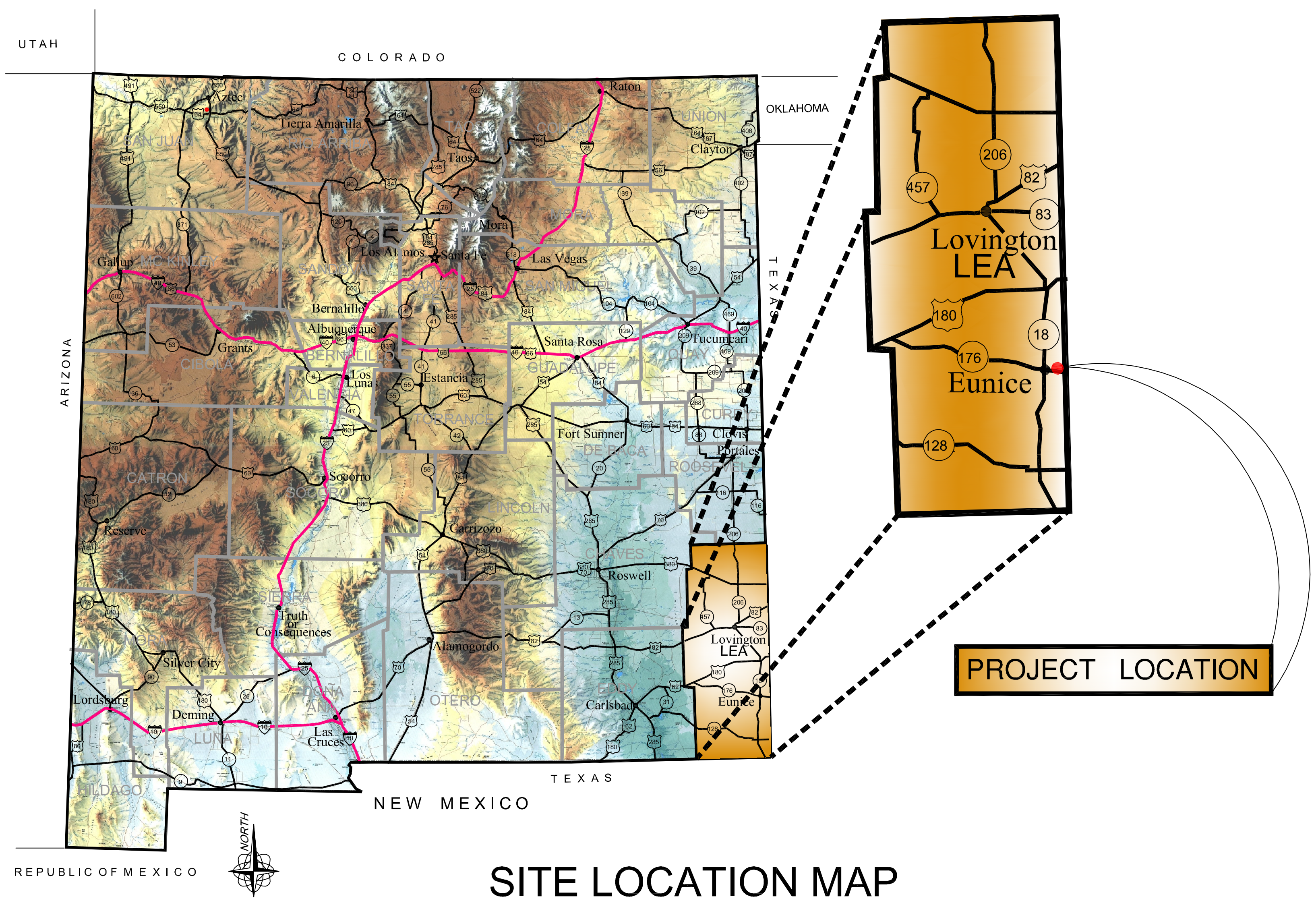
Sheet	Title
1	Cover Sheet and Drawing Index
2	Existing Site Conditions
3	Site Development Plan
4	Base Grading Plan
5	Final Grading Plan
6	East Phase Development Base Grading Plan
7	East Phase Development Intermediate and Final Grading Plan
8	Landfill Completion Drainage Plan
9	East Phase Development Drainage Plan
10	Drainage Channel Profiles and Typical Sections
11	Landfill Cross Sections
12	Liner System and Cover System
13	Leachate Collection System Details
14	Stormwater Drainage Details
15	Evaporation Pond Layout
16	Evaporation Pond Details
17	Evaporation Pond Cross Sections
18	Process Layout
19	Process Layout Cross Sections

ENGINEERING DRAWINGS

FOR

SUNDANCE WEST SURFACE WASTE MANAGEMENT FACILITY

LEA COUNTY, NEW MEXICO



SITE LOCATION MAP

SHEET		TITLE
01 COVER.DWG	1	COVER SHEET AND DRAWING INDEX
02 EXISTING.DWG	2	EXISTING SITE CONDITIONS
03 SITE DEV.DWG	3	SITE DEVELOPMENT PLAN
04 BASE GRADES.DWG	4	LANDFILL BASE GRADING PLAN
05 FINAL GRADES.DWG	5	LANDFILL FINAL GRADING PLAN
06 DRAINAGE PLAN.DWG	6	LANDFILL COMPLETION DRAINAGE PLAN
07 EAST DEV BG.DWG	7	EAST PHASE DEVELOPMENT BASE GRADING PLAN
08 EAST INT. FG.DWG	8	EAST PHASE DEVELOPMENT INTERMEDIATE GRADING PLAN
09 EAST DRAINAGE.DWG	9	EAST PHASE DEVELOPMENT DRAINAGE PLAN
10 CHANNEL PROFILES.DWG	10	DRAINAGE CHANNEL PROFILES & TYPICAL SECTIONS
11 X SECTIONS.DWG	11	LANDFILL CROSS SECTIONS
12 LINER DET.DWG	12	LINER SYSTEM AND COVER SYSTEM DETAILS
13 LEACH DET.DWG	13	LEACHATE COLLECTION SYSTEM DETAILS
14 STORM DET.DWG	14	STORMWATER DRAINAGE DETAILS
15 EVAP POND LAYOUT.DWG	15	EVAPORATION POND LAYOUT
16 EVAP POND DET.DWG	16	EVAPORATION POND DETAILS
17 EVAP POND X SECTIONS.DWG	17	EVAPORATION POND CROSS SECTIONS
18 PROCESS AREA.DWG	18	PROCESS AREA LAYOUT
19 PROCESS AREA X SECTIONS.DWG	19	PROCESS AREA CROSS SECTIONS

UPDATED: AUGUST, 2016

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

COVER SHEET AND DRAWING INDEX
SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
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Fax: 505-867-6991

DATE: 08/02/2016	CAD: 01 COVER.dwg	PROJECT #: 530.01.01
DRAWN BY: GEI	REVIEWED BY: CWF	SHEET 1 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

NOT FOR CONSTRUCTION
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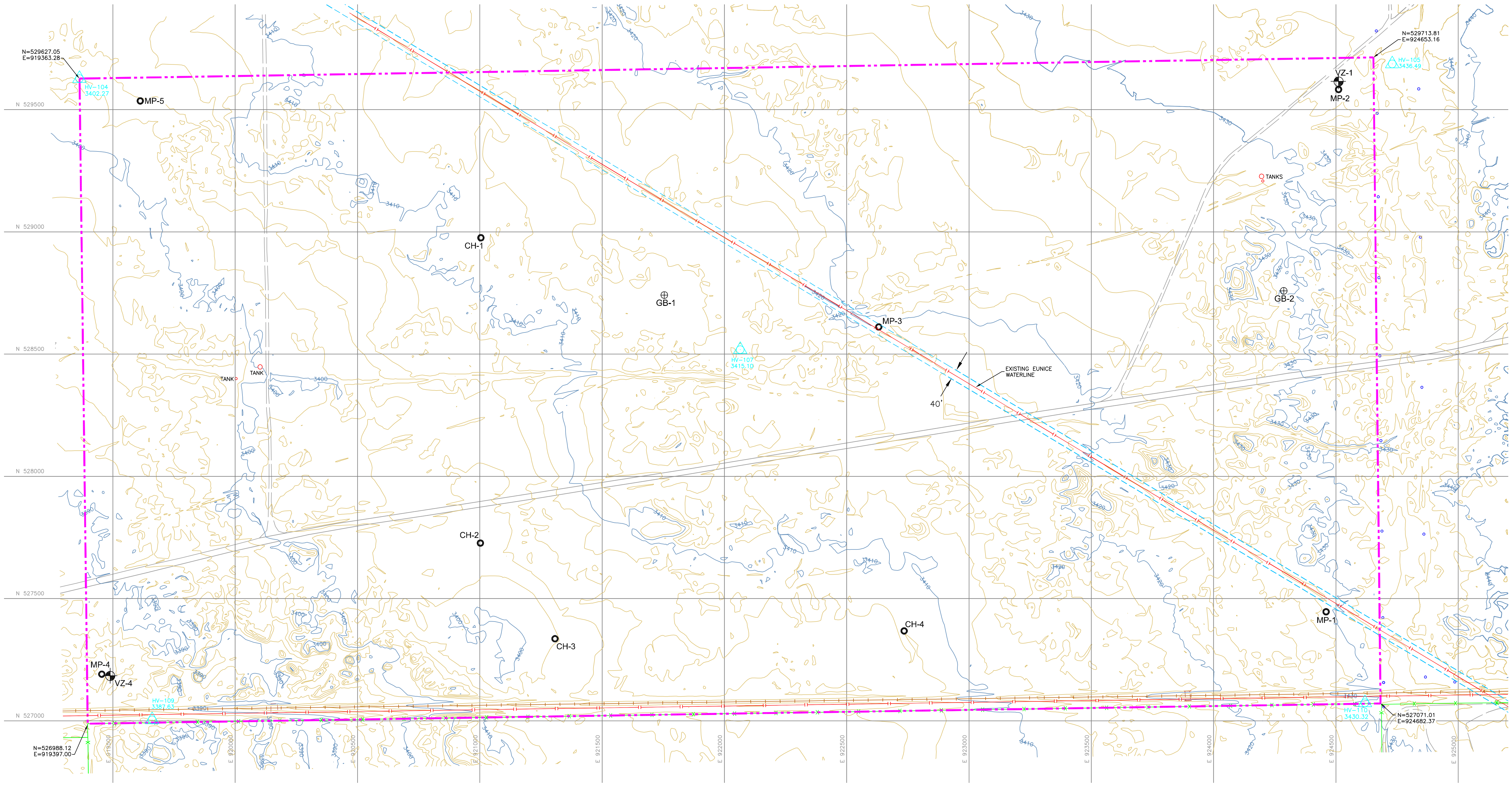

LEGEND

	FACILITY BOUNDARY	GB-1	GEOTECHNICAL BOREHOLE
3420	10' CONTOUR (EXISTING)	CH-3	COREHOLE BORING
	2' CONTOUR (EXISTING)		POWER POLE
	FENCE		OIL STORAGE TANK
	EXISTING PAVED ROAD		EXISTING BOX CULVERT
	EXISTING UNPAVED ROAD	HV-105 3436.49	SURVEY CONTROL POINT
	RAILROAD TRACKS	N 527500 / E 922000	SITE GRID
	EXISTING EUNICE WATERLINE		
	PIPELINE EASEMENT		
VZ-4	VADOSE ZONE MONITORING WELL (EXISTING)		
MP-2	SOIL BORING		

NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

NORTH

0 200' 400'

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\02 EXISTING.dwg
Date/Time:Aug, 03, 2016-13:37:19

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

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UPDATED: AUGUST, 2016

EXISTING SITE CONDITIONS

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

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Bernalillo, New Mexico, USA
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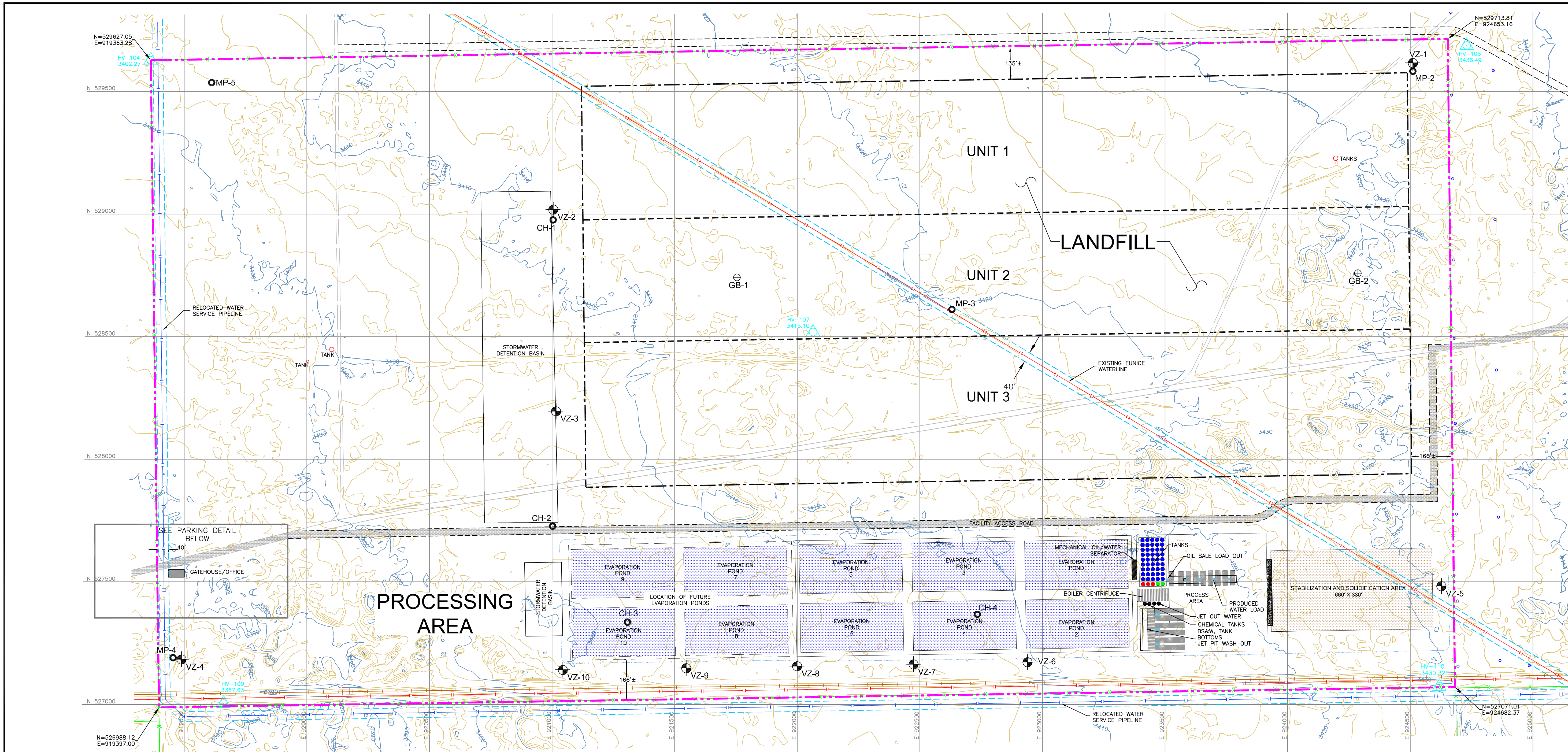
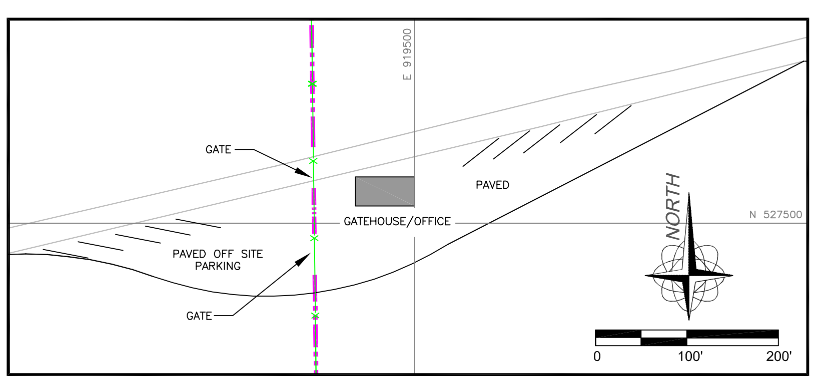
DATE: 08/02/2016	CAD: 02 EXISTING.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 2 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	





PARKING DETAIL

LEGEND

- FACILITY BOUNDARY
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- FENCE
- EXISTING PAVED ROAD
- EXISTING UNPAVED ROAD
- NEW UNPAVED ROAD
- NEW PAVED ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- VZ-4 VADOSE ZONE MONITORING WELL
- MP-2 SOIL BORING
- GB-1 GEOTECHNICAL BOREHOLE
- CH-3 COREHOLE BORING
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- HV-105 3436.49 SURVEY CONTROL POINT
- N 527500 E 922000 SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

NORTH

0 200' 400'

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: AUGUST, 2016

SITE DEVELOPMENT PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

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DATE: 08/02/2016	CAD: 03 SITE DEV.dwg	PROJECT #: 530.01.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 3 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

NOT FOR CONSTRUCTION
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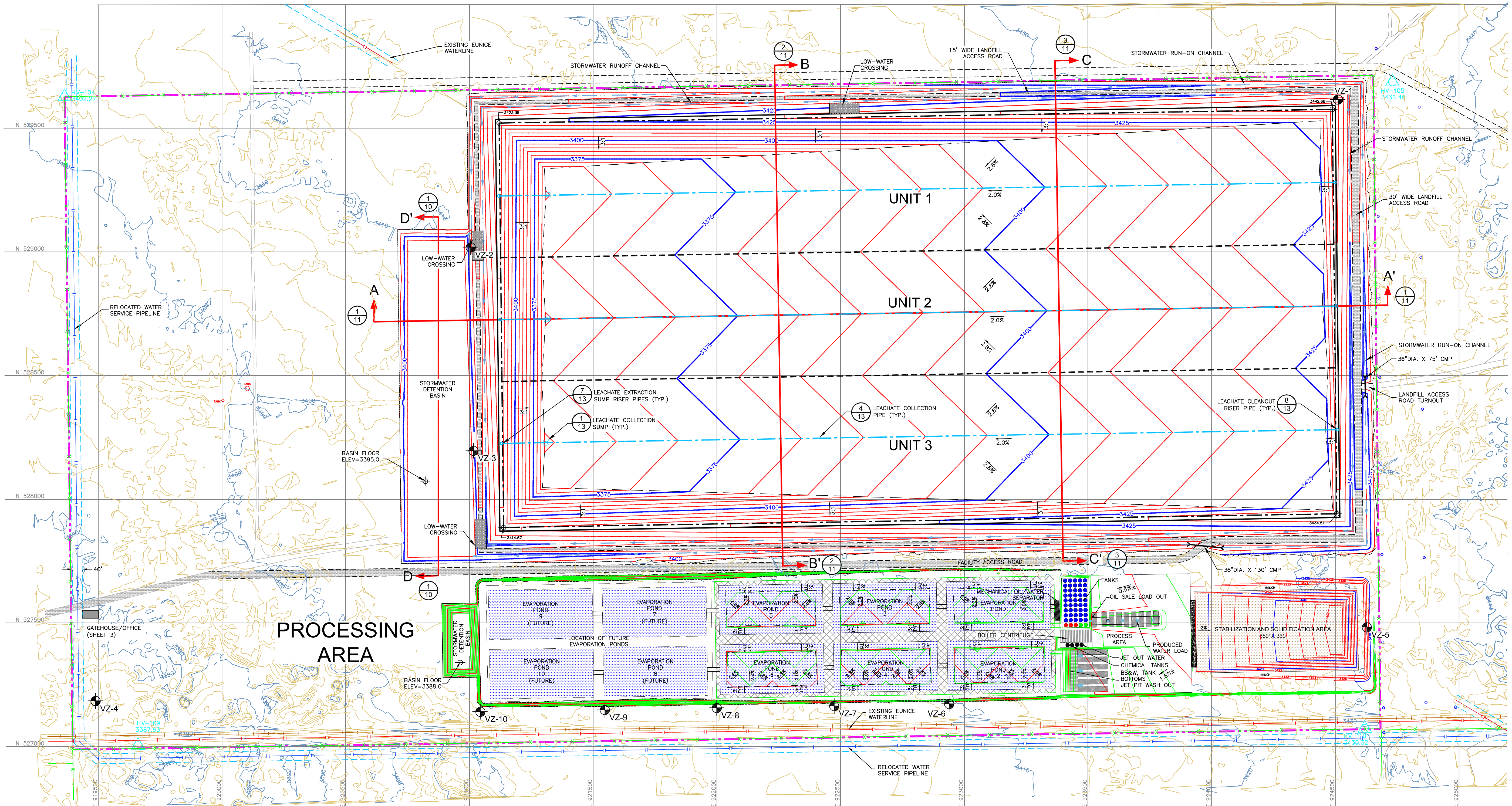

NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- TOP OF LANDFILL BERM
- TOE OF SLOPE
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- CUT AND FILL DAYLIGHT LINE
- DRAINAGE CHANNEL FLOW LINE
- LEACHATE COLLECTION PIPE AND RISERS
- FENCE
- EXISTING UNPAVED ROAD
- EXISTING PAVED ROAD
- NEW UNPAVED ROAD
- PAVED LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- NEW CULVERT
- DETAIL NUMBER / SHEET NUMBER
- CROSS SECTION LOCATION
- VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- SPOT ELEVATION
- SURVEY CONTROL POINT
- SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NORTH

0 200' 400'

UPDATED: AUGUST, 2016

LANDFILL BASE GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

I, KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

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DATE: 08/02/2016	CAD: 04 BASE GRADES.dwg
DRAWN BY: DMI	REVIEWED BY: CWF
APPROVED BY: IKG	gei@gordonenvironmental.com
PROJECT #: 530.06.01	SHEET 4 of 19

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\04 BASE GRADES.dwg
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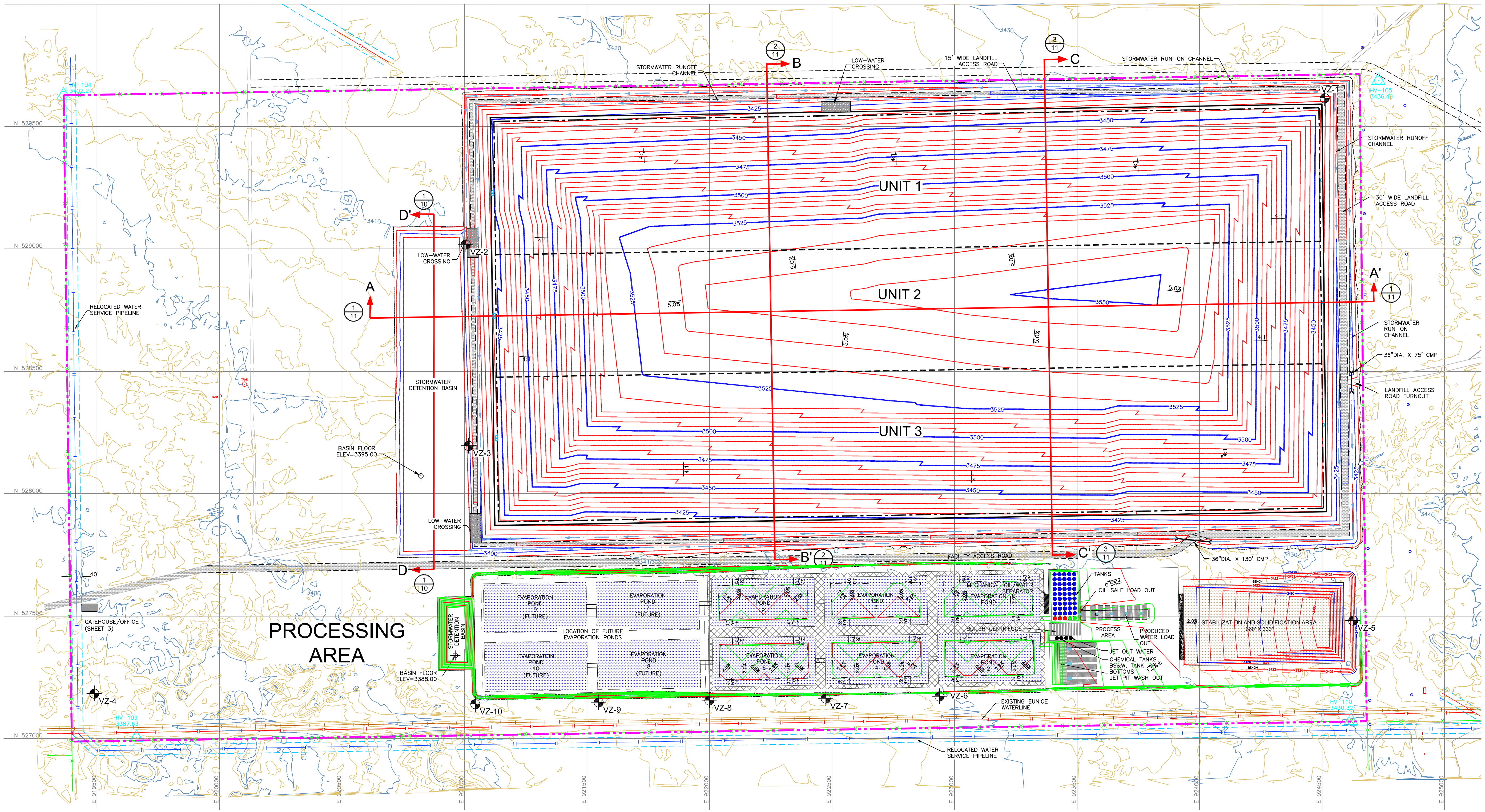

NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- TOP OF LANDFILL BERM
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- CUT AND FILL DAYLIGHT LINE
- DRAINAGE CHANNEL FLOW LINE
- FENCE
- LEACHATE COLLECTION RISER PIPES
- EXISTING UNPAVED ROAD
- EXISTING PAVED ROAD
- NEW UNPAVED ROAD
- PAVED LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- NEW CULVERT
- DETAIL NUMBER / SHEET NUMBER
- CROSS SECTION LOCATION
- VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- SPOT ELEVATION
- SURVEY CONTROL POINT
- SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NOT FOR CONSTRUCTION
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Date/Time:Aug. 03, 2016-13:43:38

NORTH

0 200' 400'

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: AUGUST 2016

LANDFILL FINAL GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
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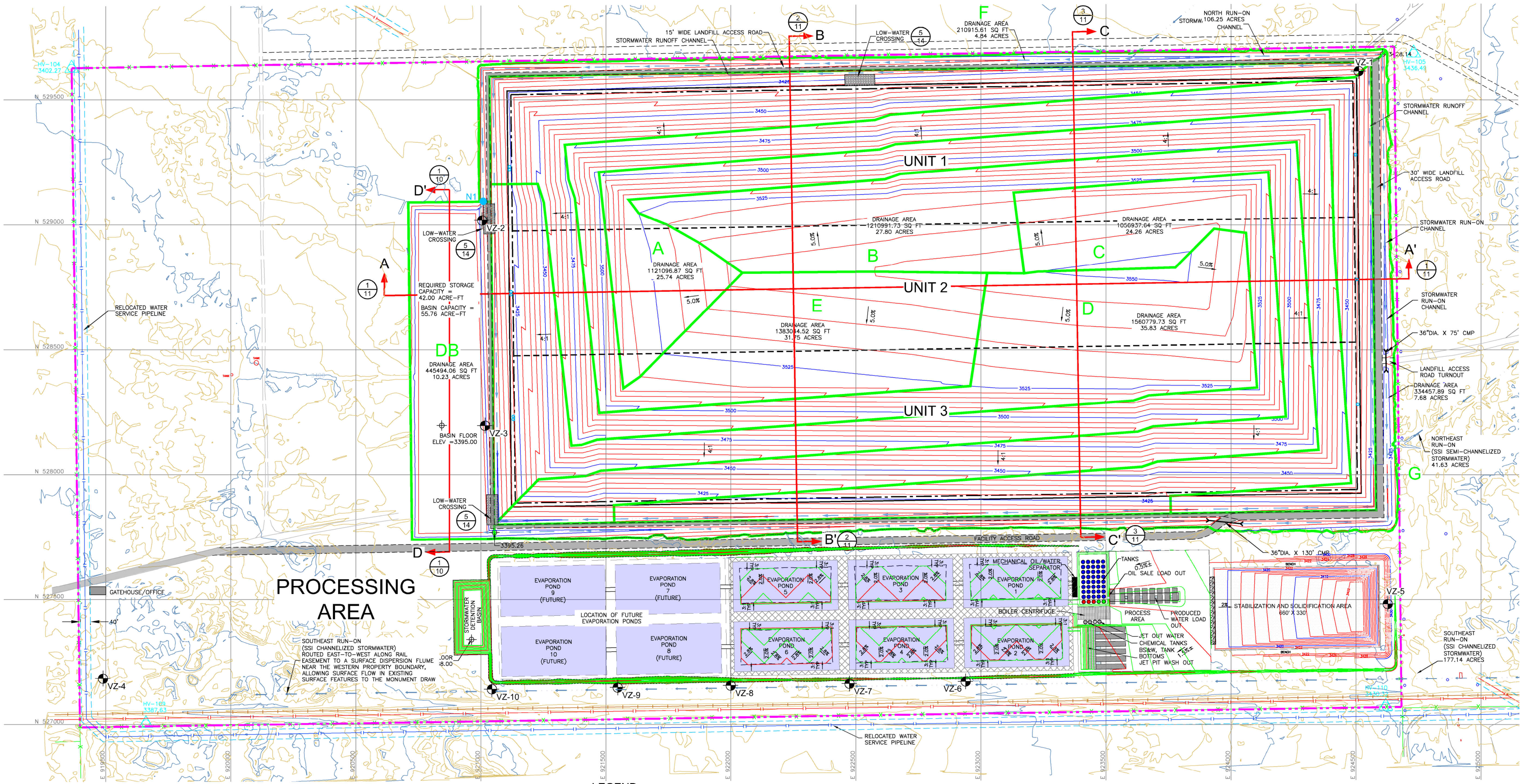
Fax: 505-867-6991

DATE: 08/02/2016	CAD: 05 FINAL GRADES.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 5 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



Final Phase Basin Summary			
	Drainage Area	Volume (ac-ft)	Discharge
Total Runoff	212.29	430.14	0
Total Retained Run-on	153.57	306.71	0
Total Run-on to Flume	177.14	181.30	0

Final Phase Drainage Subbasins

Sub-Basin ID	Area (acres)	Curve Number (CN)	Peak Discharge (cfs)	Volume (acre-ft)	Discharge To
Subbasin A	25.67	77.00	5.49	8.86	DB
Subbasin B	27.73	77.00	5.93	11.22	DB
Subbasin C	24.20	77.00	5.17	10.75	DB
Subbasin D	35.74	77.00	7.64	12.86	DB
Subbasin E	31.67	77.00	6.77	8.63	DB
Subbasin F	4.83	77.00	1.03	12.62	DB
Subbasin G	7.91	77.00	1.69	16.78	DB
Subbasin DB	10.20	77.00	2.18	63.72	(self-contained)
NorthRun-On	111.94	72.00	20.00	199.92	DB
ProcessingArea_'etc'	14.07	77.00	3.01	29.18	ProcAreaBasin
StabilizationArea	5.83	77.00	1.25	24.18	(self-contained)
Treatment_Ponds	24.42	100.00	10.03	231.34	(self-contained)
SSI-SouthCatchment-DrainsWest	177.14	72.00	31.65	181.30	West Flume
SSI-NorthWestCatchment-DrainsWest	41.63	72.00	7.44	106.79	DB

NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\06 DRAINAGE PLAN.dwg
Date/Time:Aug. 03, 2016-13:51:20

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- TOP OF LANDFILL BERM
- FENCE
- EXISTING PAVED ROAD
- EXISTING UNPAVED ROAD
- NEW UNPAVED ROAD
- PAVED LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- DRAINAGE CHANNEL FLOW LINE
- LEACHATE COLLECTION RISER PIPES
- NEW CULVERT
- VZ-4 VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- 3414.57 SPOT ELEVATION
- D DRAINAGE AREA & IDENTIFICATION
- 2 / 11 DETAIL NUMBER / SHEET NUMBER
- B B' CROSS SECTION LOCATION
- HV-105 3436.49 SURVEY CONTROL POINT
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK
- N 527500 / E 922000 SITE GRID

NORTH

0 200 400

UPDATED: AUGUST, 2016

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

LANDFILL COMPLETION DRAINAGE PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
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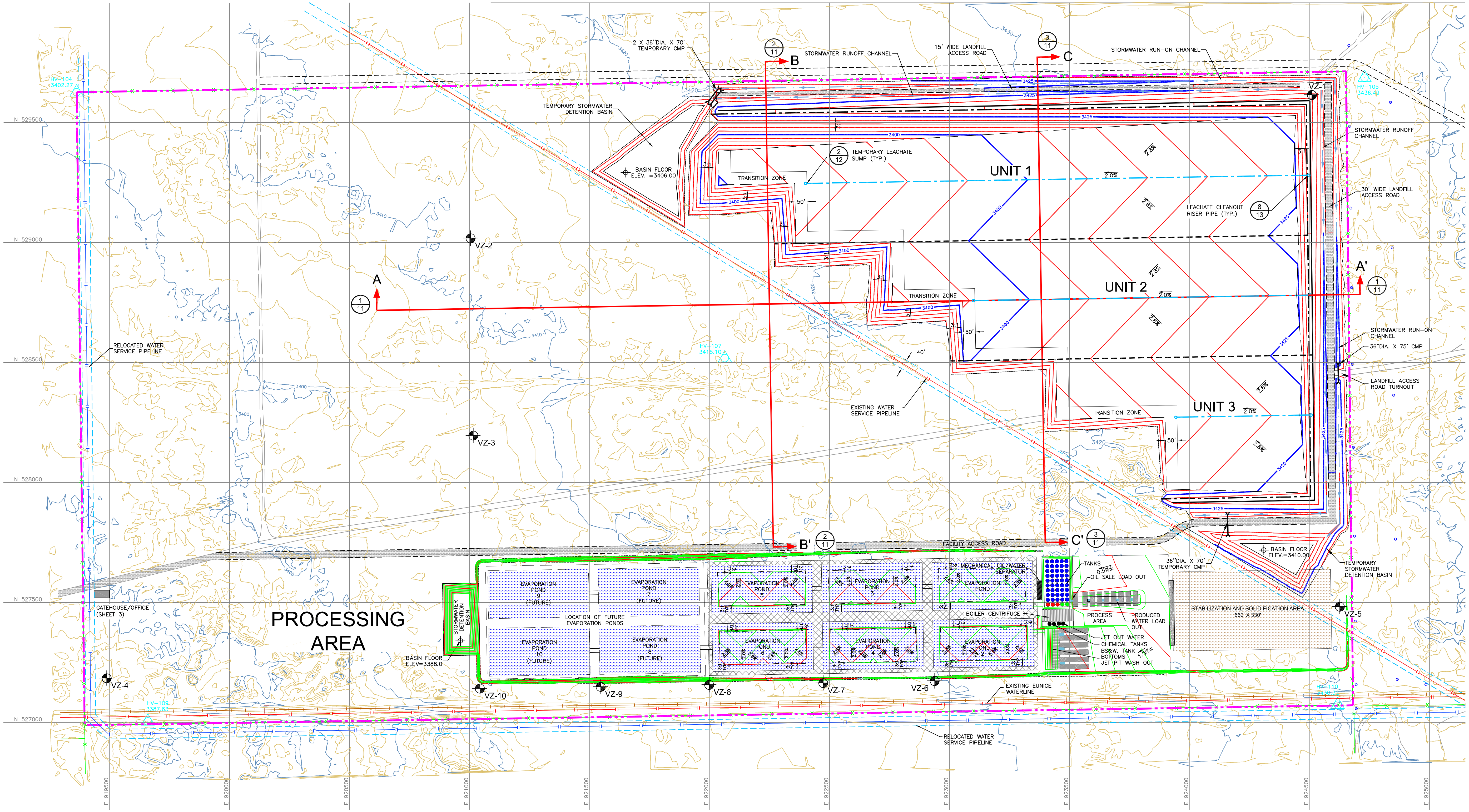
DATE: 08/02/2016	CAD: 06 DRAINAGE PLAN.dwg	PROJECT #: 530.01.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 6 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\07 EAST DEV BG.dwg
Date/Time:Aug. 03, 2016-13:54:02

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- TOP OF LANDFILL BERM
- TOE OF SLOPE
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- CUT AND FILL DAYLIGHT LINE
- DRAINAGE CHANNEL FLOW LINE
- LEACHATE COLLECTION PIPE AND RISERS
- FENCE
- EXISTING UNPAVED ROAD
- EXISTING PAVED ROAD
- NEW UNPAVED ROAD
- LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- NEW CULVERT
- DETAIL NUMBER / SHEET NUMBER
- A A' CROSS SECTION LOCATION
- VZ-4 VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- 3388.0 SPOT ELEVATION
- HV-105 3436.49 SURVEY CONTROL POINT
- N 527500 / E 922000 SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NORTH

0 200' 400'

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

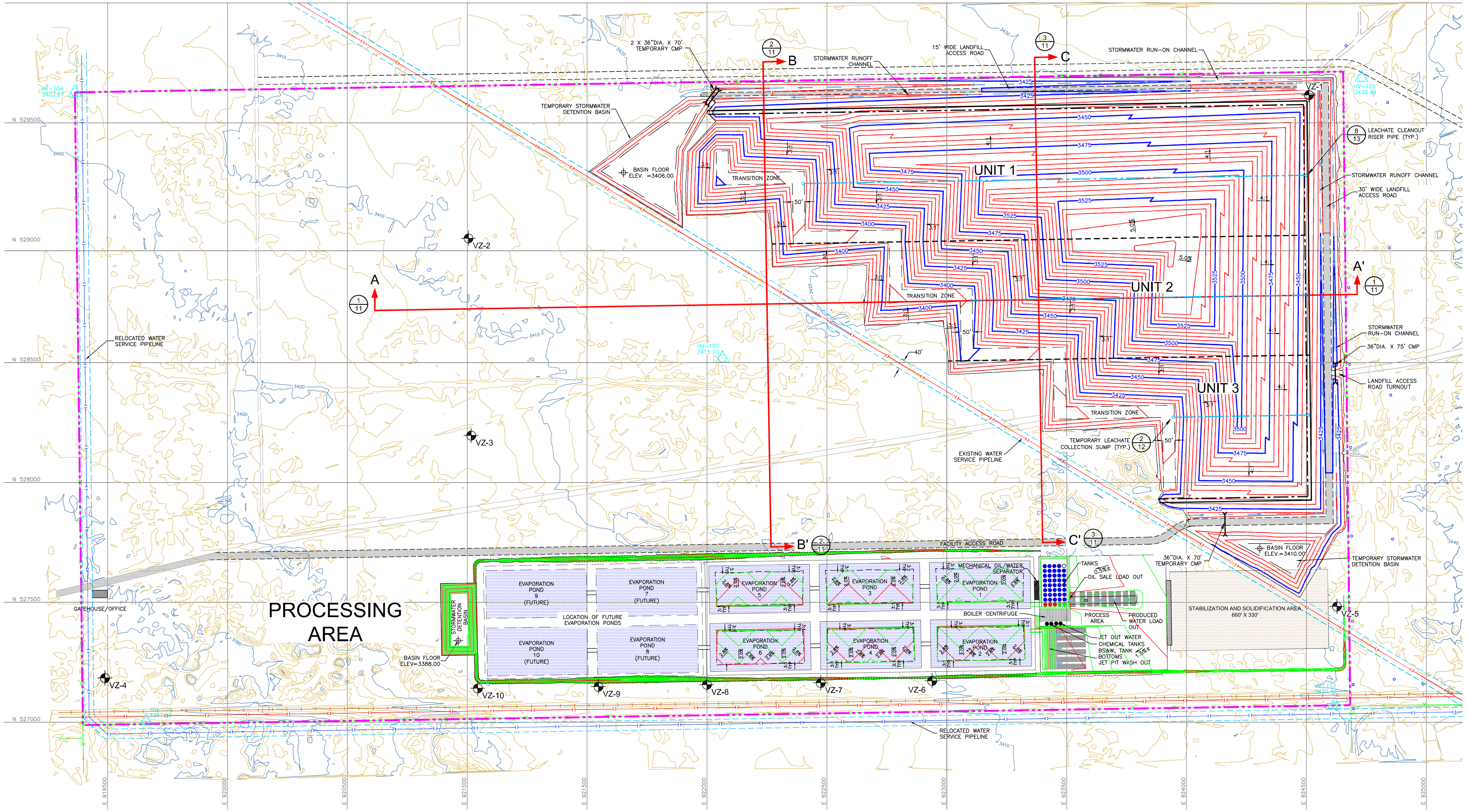
UPDATED: AUGUST 2016

EAST PHASE DEVELOPMENT BASE GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 08/02/2016	CAD: 07 EAST DEV BG.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 7 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

LEGEND

FACILITY BOUNDARY
LIMIT OF WASTE
UNIT BOUNDARY
TOP OF LANDFILL BERM
10' CONTOUR (EXISTING)
2' CONTOUR (EXISTING)
25' CONTOUR (DESIGN)
5' CONTOUR (DESIGN)
1' CONTOUR (DESIGN)
CUT AND FILL DAYLIGHT LINE
DRAINAGE CHANNEL FLOW LINE
FENCE
LEACHATE COLLECTION RISER PIPES

EXISTING UNPAVED ROAD
EXISTING PAVED ROAD
NEW UNPAVED ROAD
PAVED LANDFILL ACCESS ROAD
RAILROAD TRACKS
RELOCATED WATER SERVICE PIPELINE
EXISTING EUNICE WATERLINE
PIPELINE EASEMENT
NEW CULVERT
DETAIL NUMBER
SHEET NUMBER
CROSS SECTION LOCATION

VADOSE ZONE MONITORING WELL
POWER POLE
OIL STORAGE TANK
EXISTING BOX CULVERT
SPOT ELEVATION
SURVEY CONTROL POINT
SITE GRID

PRODUCED WATER TANK
CRUDE OIL RECOVERY TANK
OIL SALES TANK

NORTH

0 200' 400'

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\08 EAST INT FG.dwg
Date/Time:Aug. 03, 2016-13:55:33

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

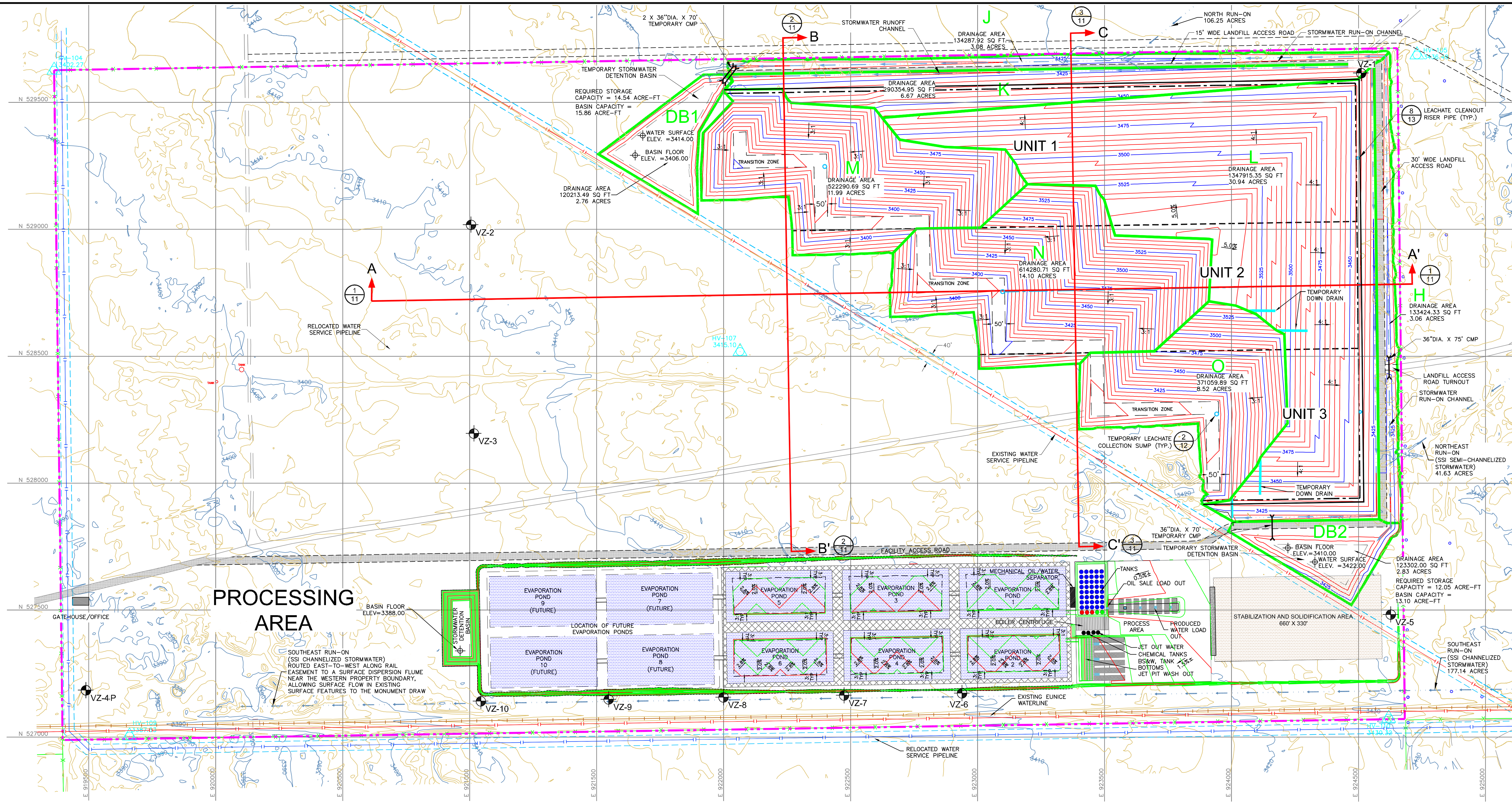
UPDATED: AUGUST, 2016

EAST PHASE DEVELOPMENT INTERMEDIATE GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 08/02/2016	CAD: 08 EAST INT FG.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 8 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- TOP OF LANDFILL BERM
- FENCE
- EXISTING PAVED ROAD
- EXISTING UNPAVED ROAD
- NEW UNPAVED ROAD
- PAVED LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- DRAINAGE CHANNEL FLOW LINE
- LEACHATE COLLECTION RISER PIPES
- NEW CULVERT
- VZ-4 VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- 3414.57 SPOT ELEVATION
- D DRAINAGE AREA & IDENTIFICATION
- 2/11 DETAIL NUMBER SHEET NUMBER
- B B' CROSS SECTION LOCATION
- HV-105 3436.49 SURVEY CONTROL POINT
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK
- N 527500 E 922000 SITE GRID

East Phase Basin Summary			
	Drainage Area	Volume (ac-ft)	Discharge
Total Runoff	84.01	264.09	0.00
Total Retained Run-on	147.88	333.29	0.00
Total Run-on to Flume	177.14	181.30	0.00

East Phase Drainage Subbasins					
Sub-Basin ID	**Area (acres)**	**Curve Number (CN)**	**Peak Discharge (cfs)**	**Volume (acre-ft)**	**Discharge To**
Subbasin DB1 (NW)	2.76	77	0.59	17.23	DB1 (NW)
Subbasin DB2 (SE)	2.82	77	0.60	17.63	DB2 (SE)
Subbasin H	3.06	77	0.65	8.91	DB2 (SE)
Subbasin J	3.08	77	0.66	7.06	DB1 (NW)
Subbasin K	6.65	77	1.42	14.91	DB1 (NW)
Subbasin L	30.89	77	6.60	15.20	DB2 (SE)
Subbasin M	12.20	77	2.61	58.43	TransZone
Subbasin N	14.07	77	3.01	74.77	TransZone
Subbasin O	8.50	77	1.82	49.95	TransZone
SSI-NorthWestCatchment-DrainsWest	41.63	72	7.44	106.79	DB1 (NW)
SSI-SouthCatchment-DrainsWest	177.14	72	31.65	181.30	West Flume
NorthRun-On	106.25	77	22.71	226.50	DB2 (SE)

NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\09 EAST DRAINAGE.dwg
Date/Time:Aug. 03, 2016-13:56:53

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

NORTH

0 200 400

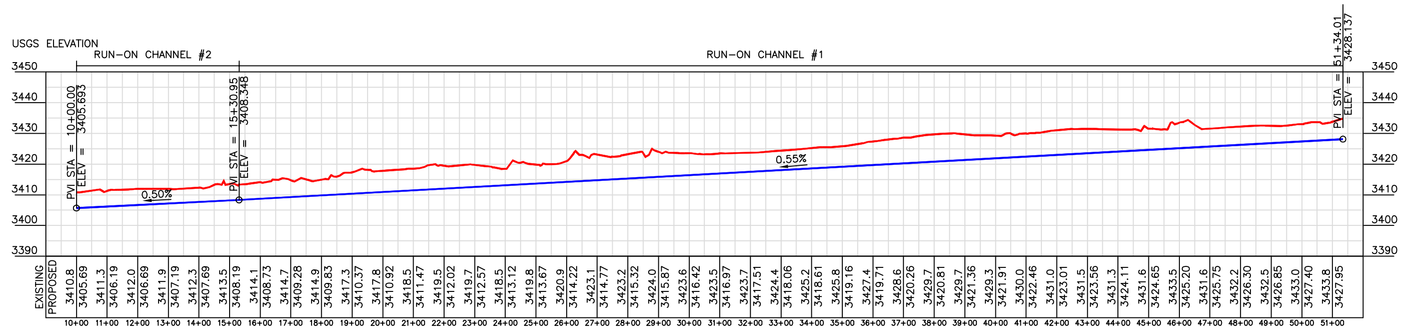
UPDATED: AUGUST, 2016

EAST PHASE DEVELOPMENT DRAINAGE PLAN

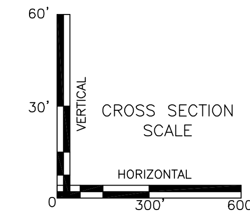
SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

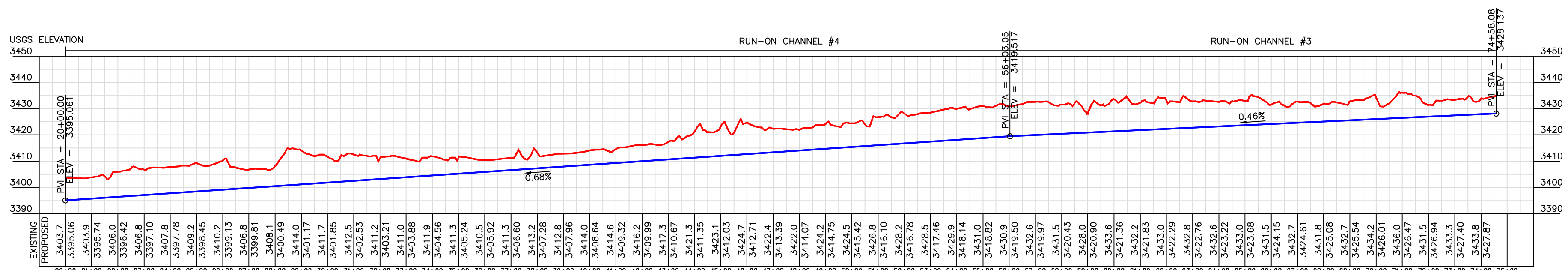
Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 08/02/2016	CAD: 09 EAST DRAINAGE.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 9 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

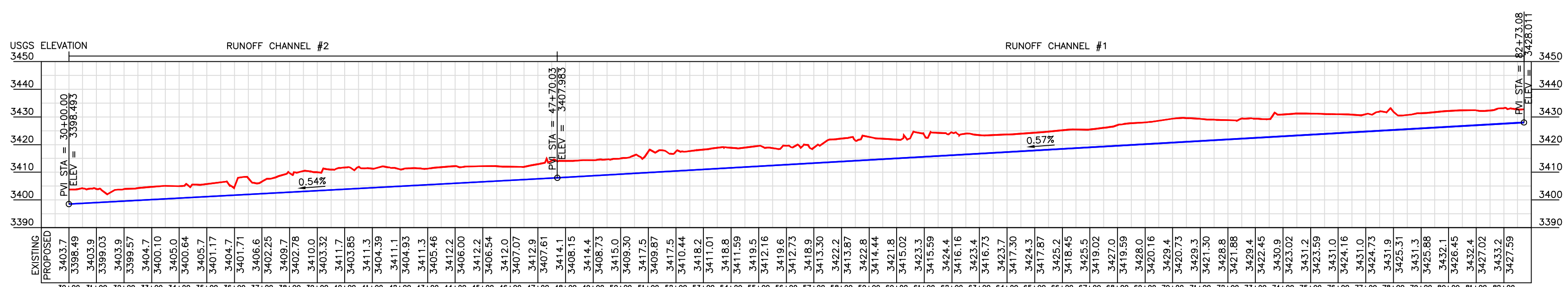


RUN-ON CHANNELS #1 & #2 PROFILE

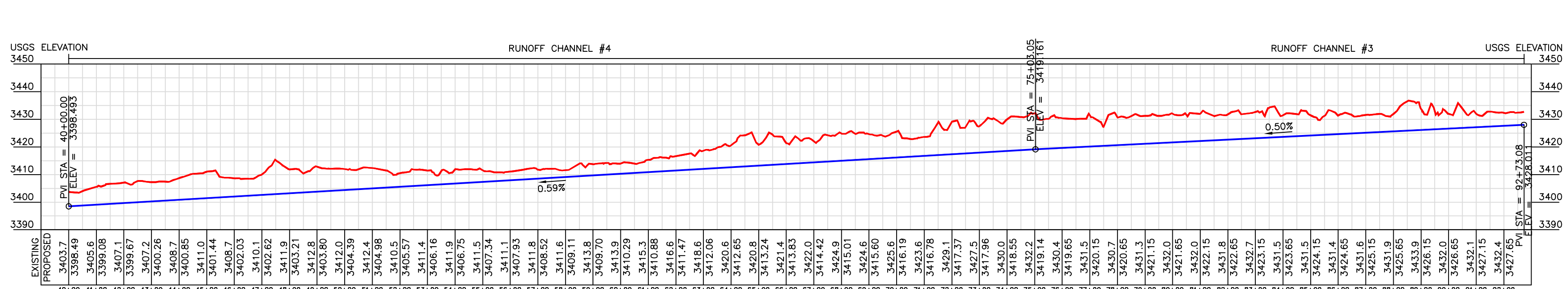




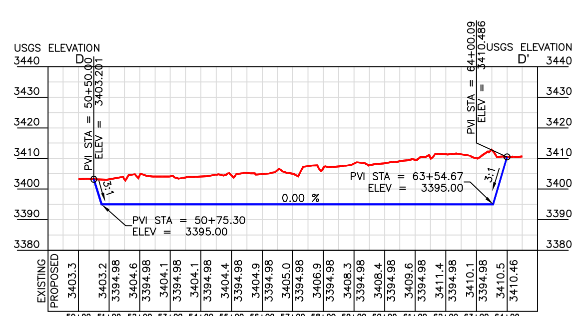
RUN-ON CHANNELS #3 & #4 PROFILE



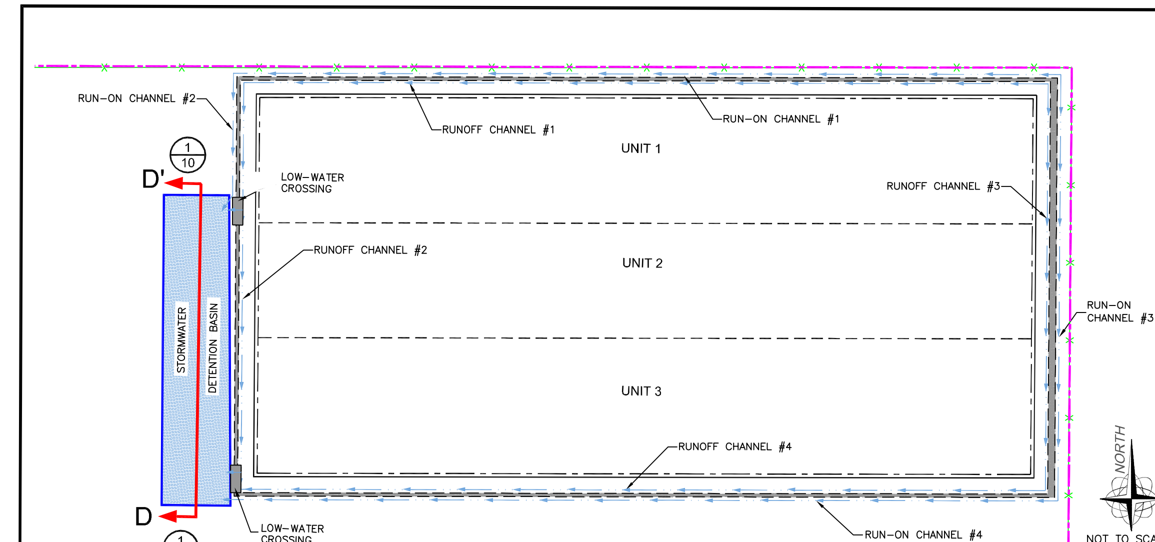
RUNOFF CHANNELS #1 & #2 PROFILE



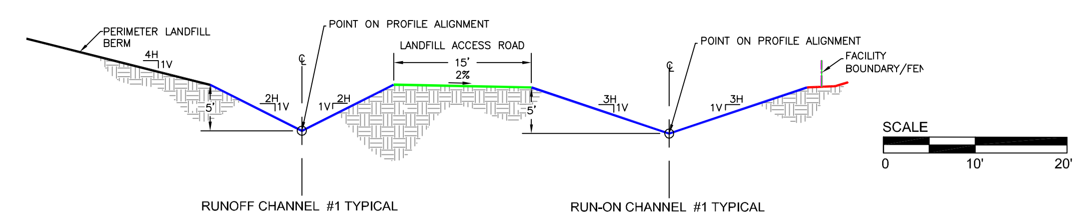
RUNOFF CHANNELS #3 & #4 PROFILE



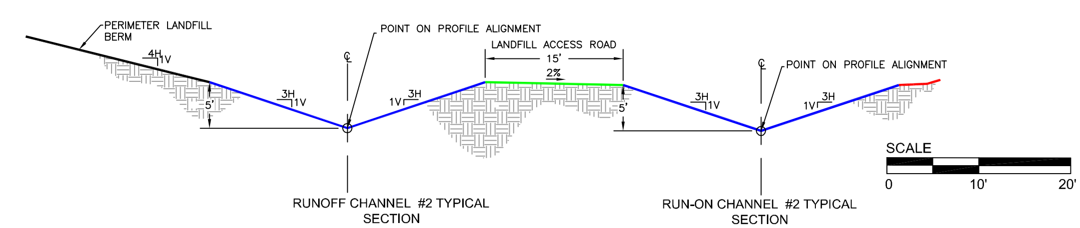
1/10 STORMWATER DETENTION BASIN SECTION D-D'



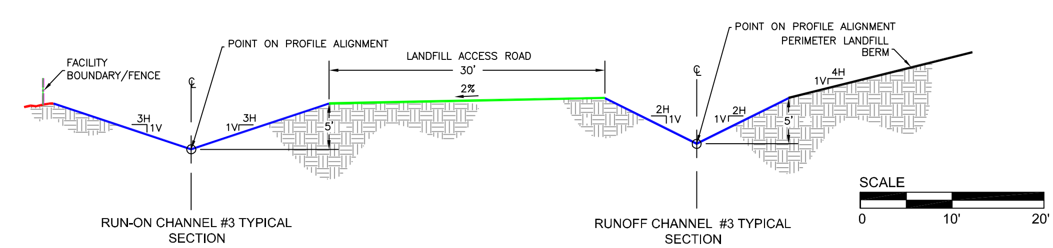
KEY MAP



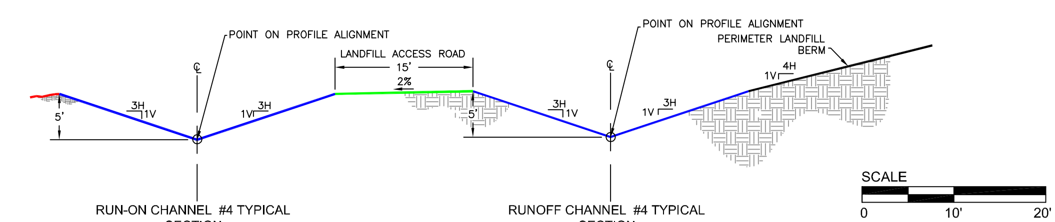
NORTH PERIMETER CHANNELS



WEST PERIMETER CHANNELS



EAST PERIMETER CHANNELS



SOUTH PERIMETER CHANNELS

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- TOP OF LANDFILL BERM
- CHANNEL DESIGN GRADE
- EXISTING GRADE
- ROAD DESIGN GRADE
- PERIMETER BERM DESIGN GRADE
- DRAINAGE CHANNEL FLOW LINE ALIGNMENT
- LANDFILL ACCESS ROAD
- FENCE
- 1/10 DETAIL NUMBER / SHEET NUMBER
- D D' CROSS SECTION LOCATION
- STORMWATER DETENTION BASIN

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\10 CHANNEL PROFILES.dwg
Date/Time:Aug. 03, 2016-13:58:03

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: AUGUST, 2016

DRAINAGE CHANNEL PROFILES & TYPICAL SECTIONS

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
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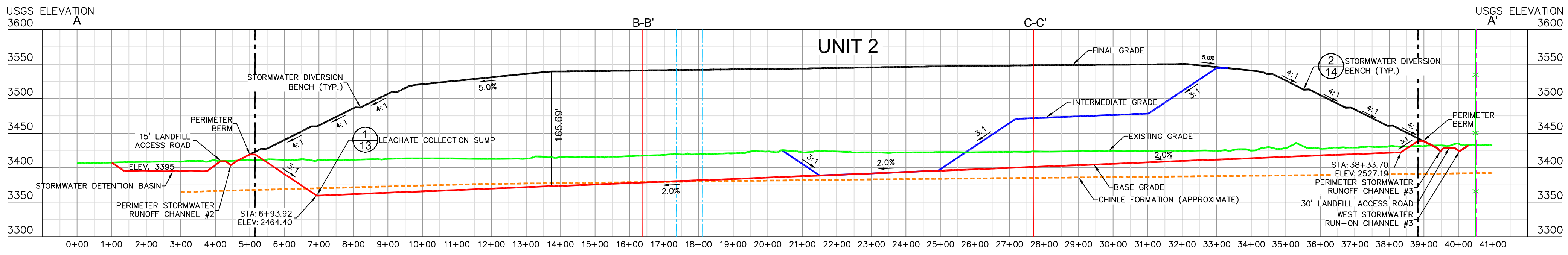
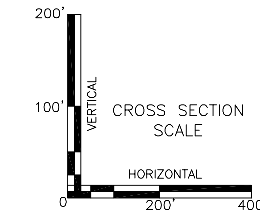
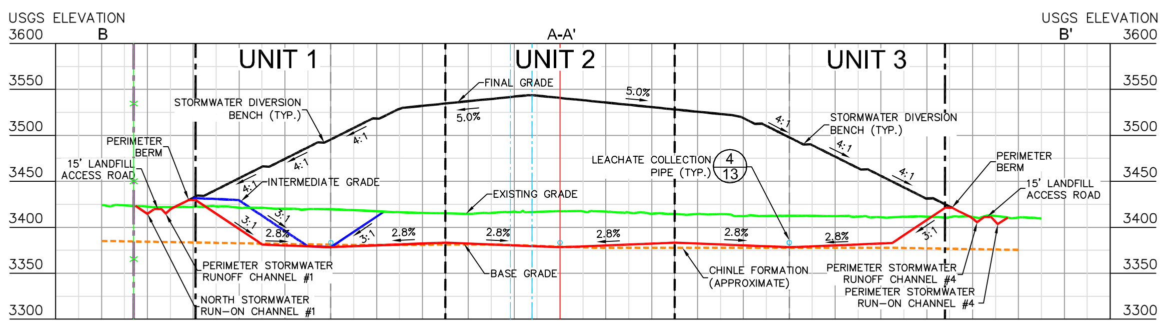
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 08/02/2016	CAD: 07 CHANNEL PROFILES.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 10 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

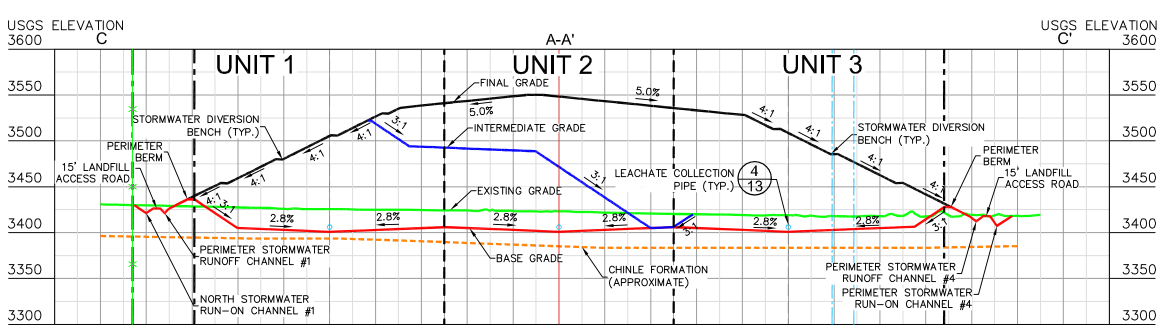


CROSS SECTION A-A'

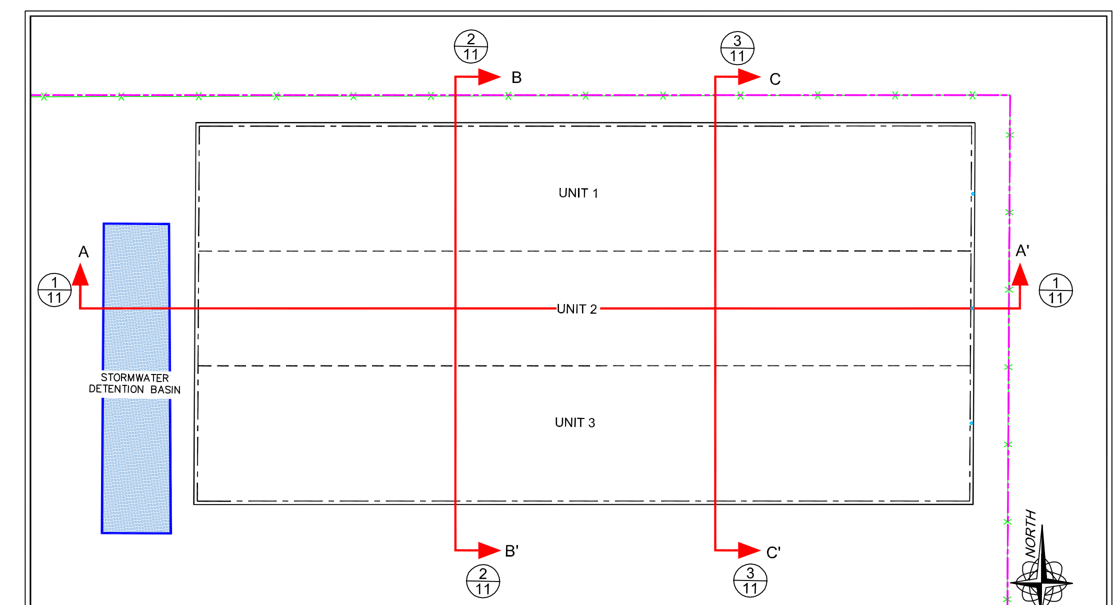




CROSS SECTION B-B'



CROSS SECTION C-C'



KEY MAP

LEGEND

- FACILITY BOUNDARY
- FENCE
- UNIT BOUNDARY
- LIMIT OF WASTE
- FINAL GRADE
- INTERMEDIATE GRADE (EAST PHASE DEVELOPMENT)
- EXISTING GRADE
- BASE GRADE
- CHINLE FORMATION (APPROXIMATE)
- EXISTING WATER SERVICE PIPELINE
- PIPELINE EASEMENT
- LEACHATE COLLECTION PIPE
- DETAIL NUMBER / DETAIL LOCATED ON SHEET NUMBER
- CROSS SECTION LOCATION
- STORMWATER DETENTION BASIN

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\11 X SECTIONS.dwg
Date/Time:Aug. 03, 2016-14:00:11

I, KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: AUGUST, 2016

LANDFILL CROSS SECTIONS

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
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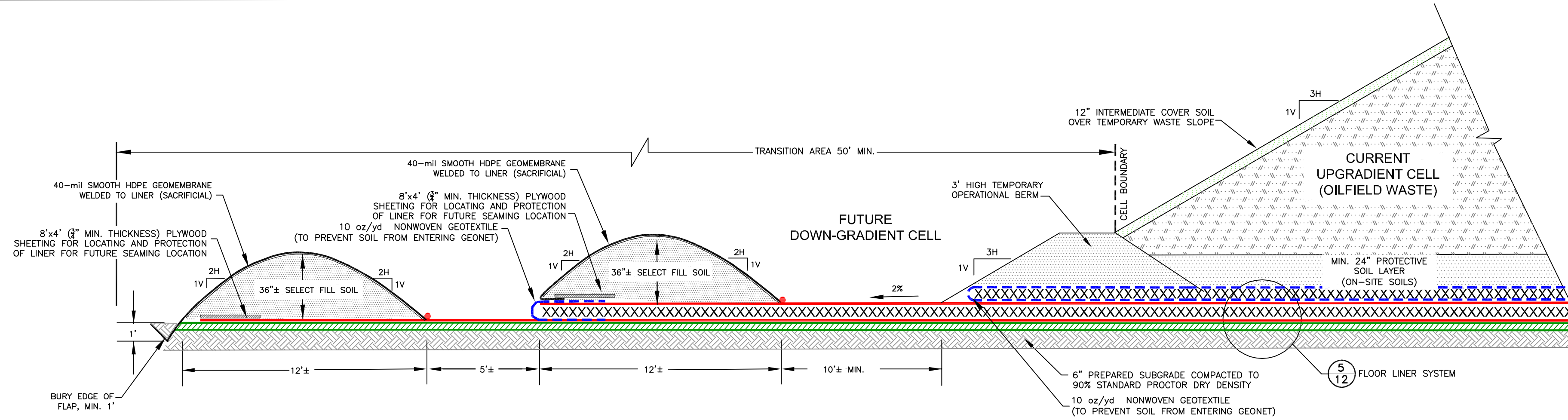
Fax: 505-867-6991

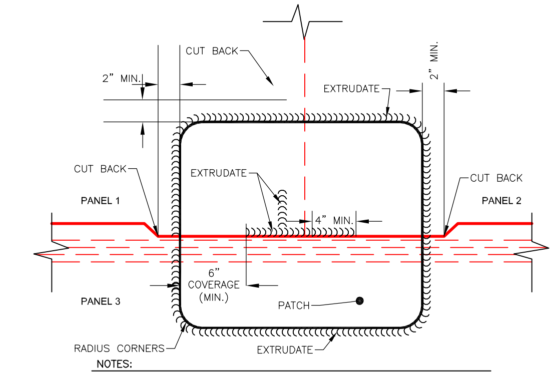
DATE: 08/02/2016	CAD: 11 X SECTIONS.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 11 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



TEMPORARY INSTALLATION AT BOUNDARY BETWEEN EXISTING UPGRADIENT CELL AND ADJACENT DOWNGRADIENT FUTURE CELL

1/12 TYPICAL CELL TRANSITION AREA

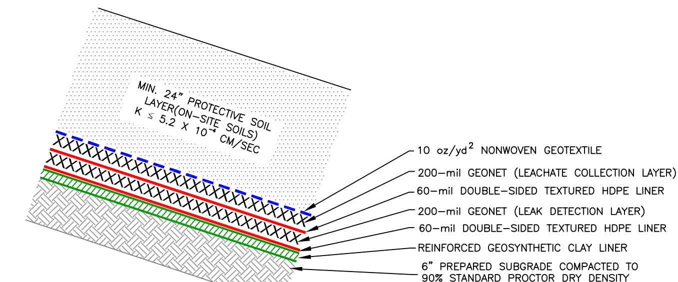
NOT TO SCALE



NOTES:
1. ALL EXTRUSION WELDS SHALL BE VACUUM TESTED
2. ALL DOUBLE TRACK FUSION WELDS SHALL BE AIR PRESSURE TESTED
3. PANELS SHALL BE OVERLAPPED IN NUMERICAL ORDER – HIGHEST ON TOP

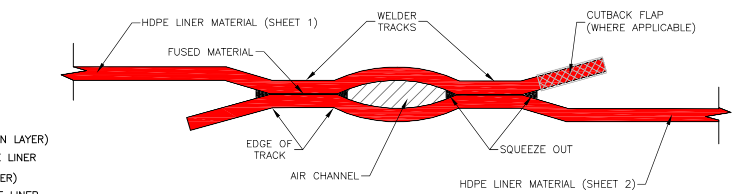
8/12 TYPICAL "T" AT BUTT SEAM

PLAN VIEW NOT TO SCALE



4/12 SIDEWALL LINER SYSTEM

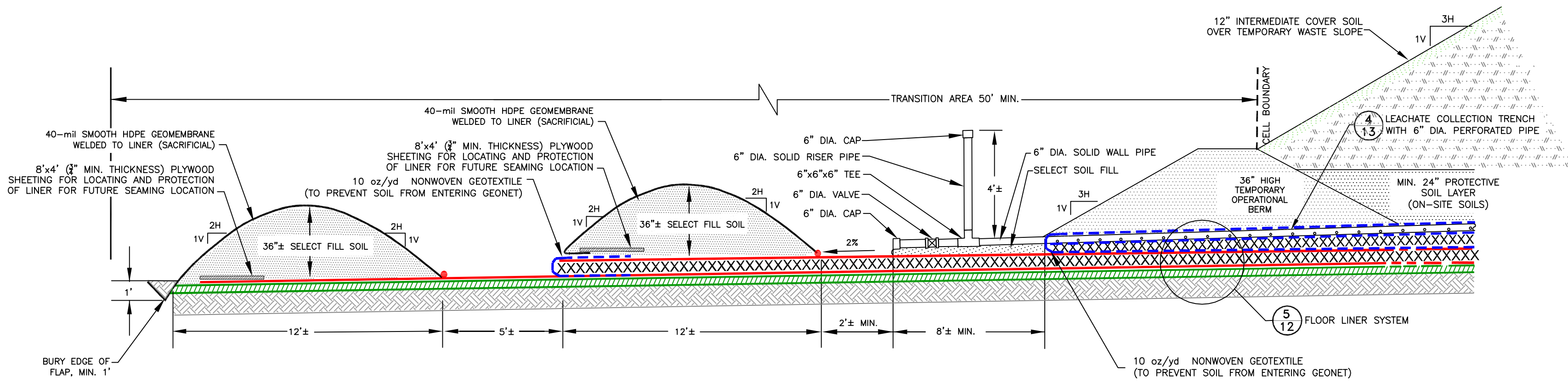
NOT TO SCALE



NOTES:
1. BOTH AREAS OF FUSED MATERIAL SHOULD BE VOID OF ANY SEAM LINES
2. EDGE OF TRACKS NOT TO CUT THE LINER
3. AIR CHANNEL SHOULD BE CLEAR
4. BOTH WELDER TRACKS SHALL BE EQUAL WIDTHS
5. SQUEEZE OUT SHOULD BE JUST BARELY VISIBLE IN ALL FOUR (4) LOCATIONS WHEN VIEWED IN THE TEST CROSS-SECTION
6. ALL DOUBLE TRACK FUSION WELDS SHALL BE AIR PRESSURE TESTED

9/12 TYPICAL FUSION WELD

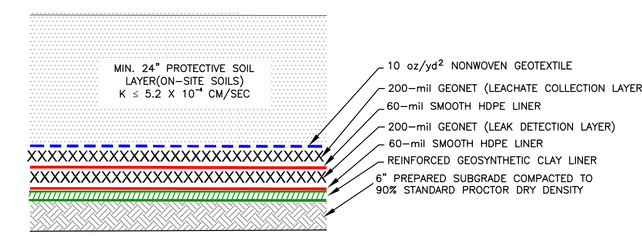
SECTION VIEW NOT TO SCALE



TEMPORARY LEACHATE SUMP INSTALLATION AT BOUNDARY BETWEEN UPGRADIENT CELL AND DOWNGRADIENT FUTURE CELL.

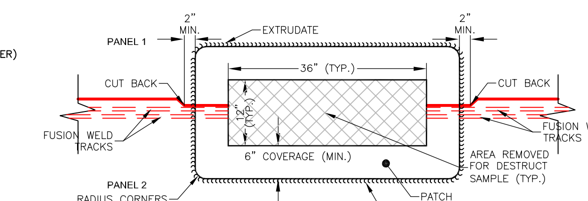
2/12 TEMPORARY SUMP DETAIL

NOT TO SCALE



5/12 FLOOR LINER SYSTEM

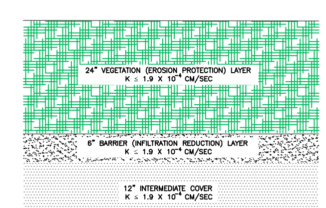
NOT TO SCALE



NOTES:
1. ALL EXTRUSION WELDS SHALL BE VACUUM TESTED
2. ALL DOUBLE TRACK FUSION WELDS SHALL BE AIR PRESSURE TESTED
3. PANELS SHALL BE OVERLAPPED IN NUMERICAL ORDER – HIGHEST ON TOP

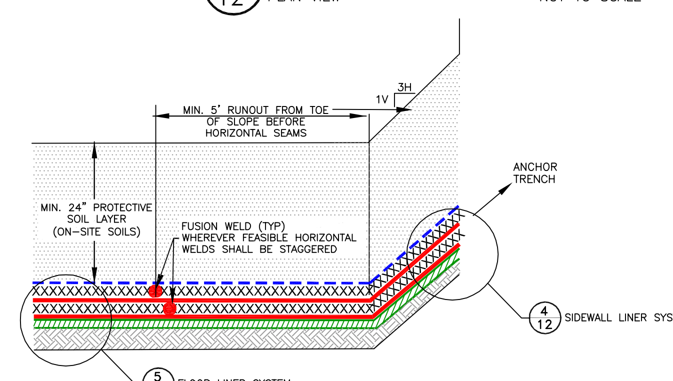
10/12 TYPICAL DESTRUCT SAMPLE PATCH 60-mil LINER

PLAN VIEW NOT TO SCALE



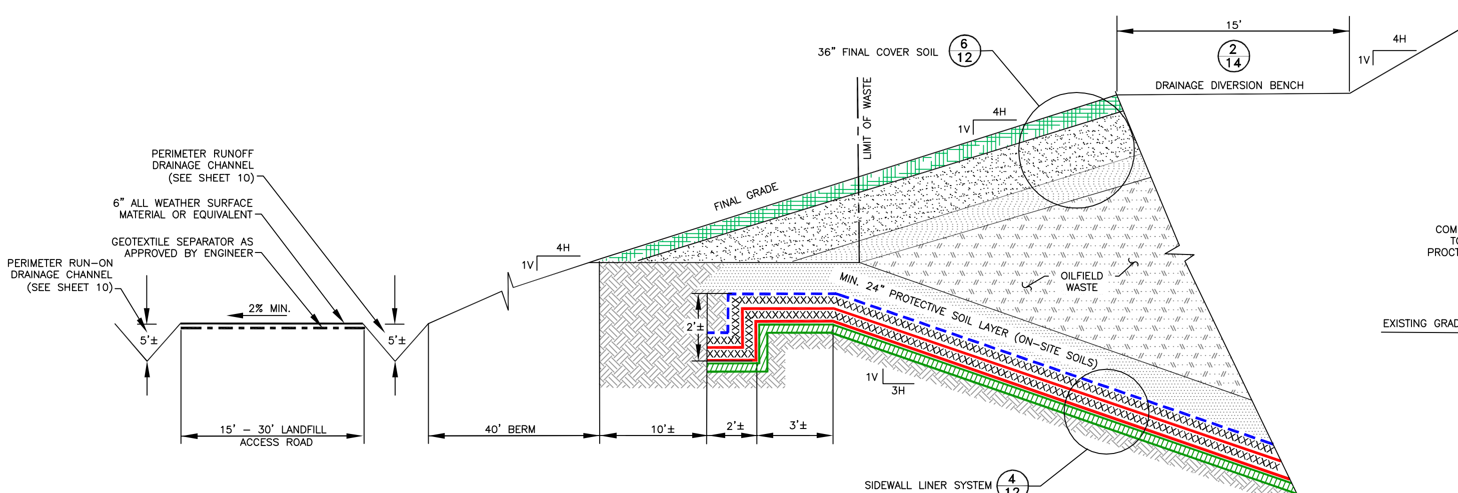
6/12 FINAL COVER DETAIL

NOT TO SCALE



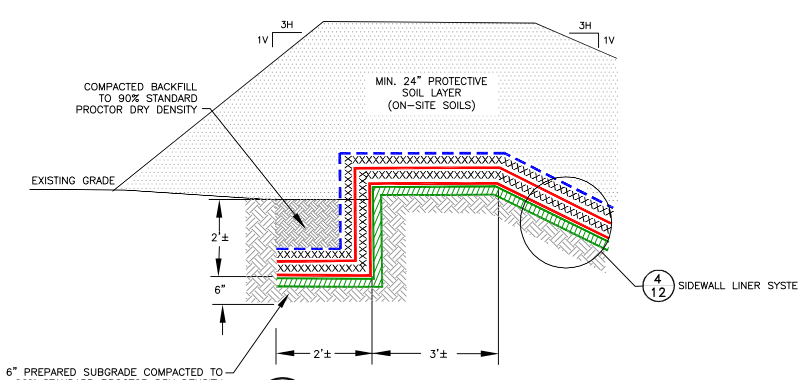
11/12 LINER RUNOUT ON LANDFILL FLOOR

NOT TO SCALE



3/12 FINAL COVER TIE-IN

NOT TO SCALE



7/12 PERMANENT ANCHOR TRENCH

NOT TO SCALE

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\12 LINER DET.dwg
Date/Time:Aug. 03, 2016-14:04:00

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: AUGUST, 2016

LINER SYSTEM AND COVER SYSTEM DETAILS

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

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213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
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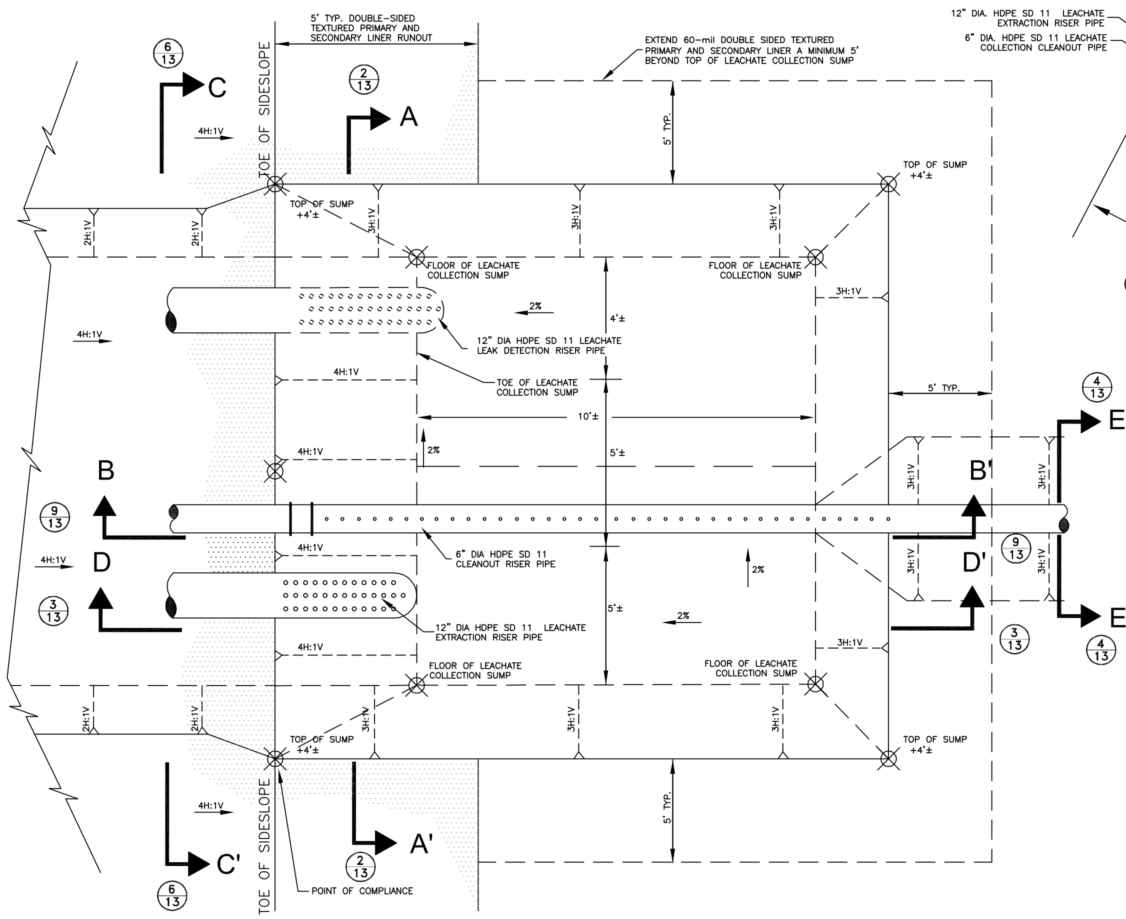
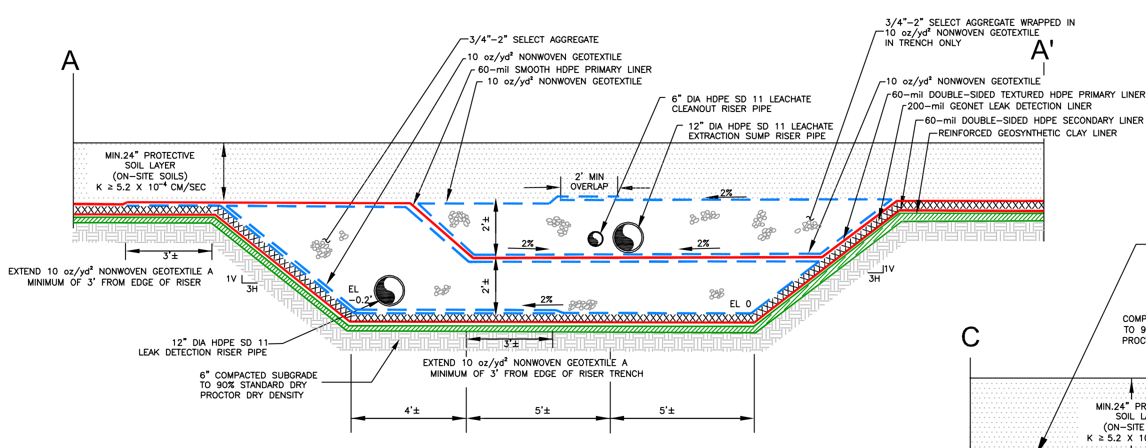
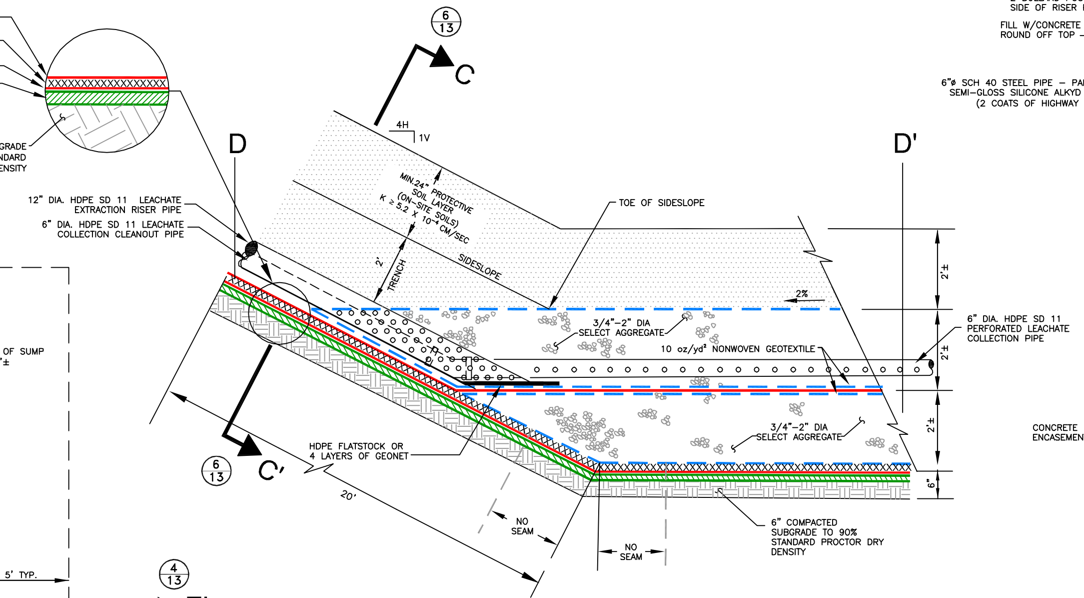
DATE: 08/02/2016	CAD: 12 LINER DET.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 12 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



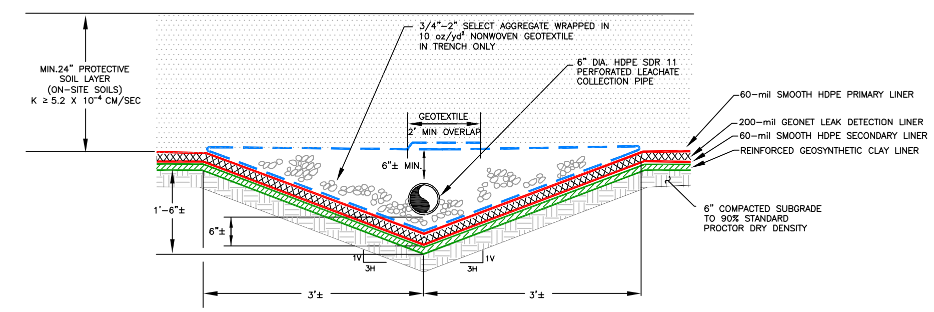
1/13 LEACHATE COLLECTION SUMP
PLAN VIEW NOT TO SCALE



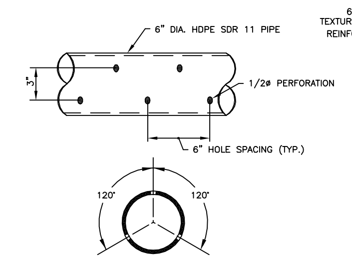
2/13 LEACHATE COLLECTION SUMP
SECTION A–A' NOT TO SCALE



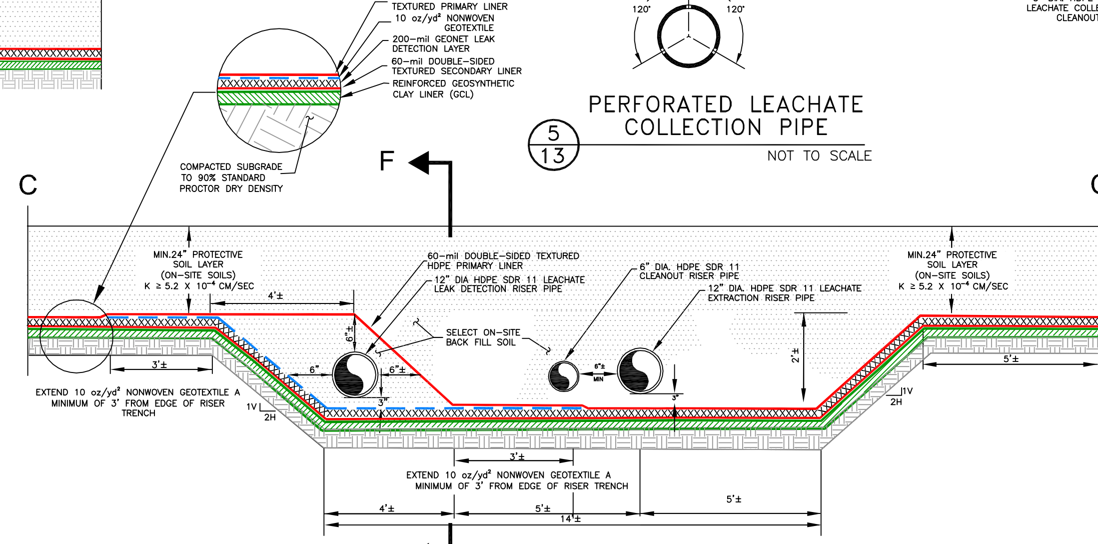
3/13 LEACHATE EXTRACTION RISER PIPE
SECTION D–D' NOT TO SCALE



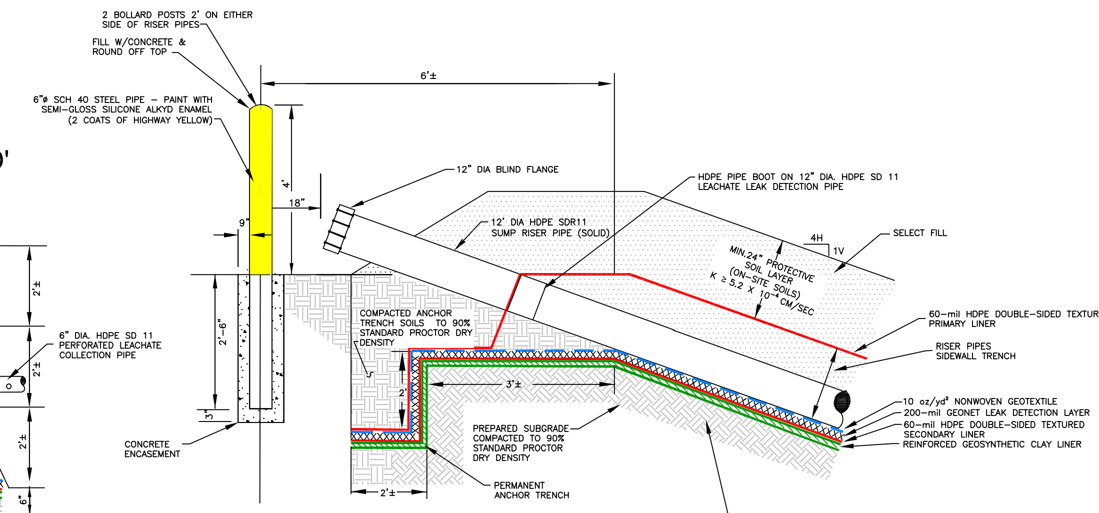
4/13 LEACHATE COLLECTION TRENCH AND PIPE
CROSS SECTION E–E' NOT TO SCALE



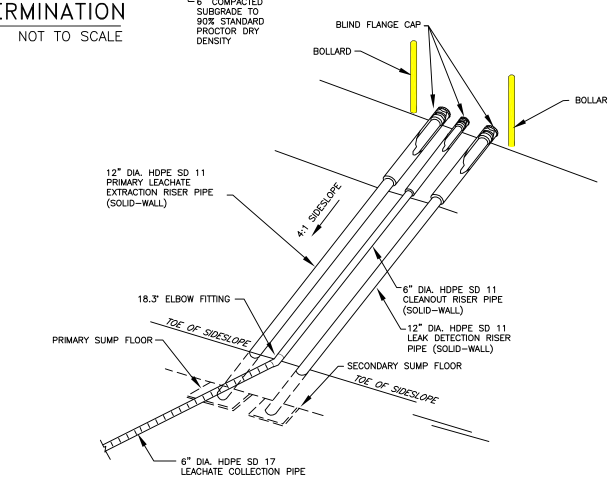
5/13 PERFORATED LEACHATE COLLECTION PIPE
NOT TO SCALE



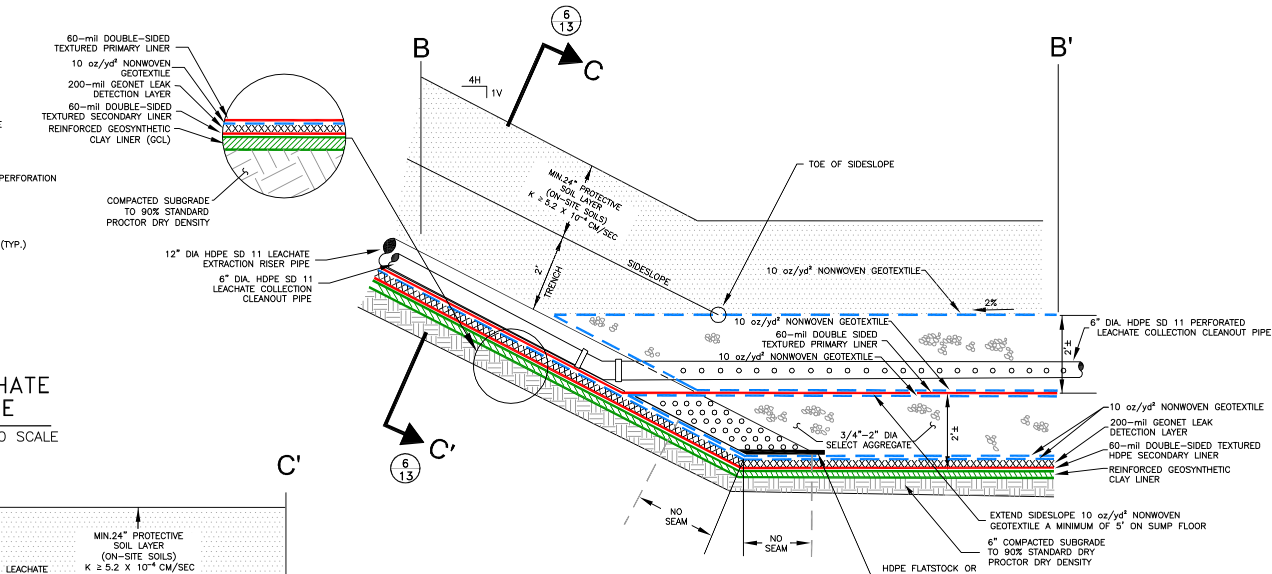
6/13 LEACHATE COLLECTION SUMP RISER TRENCH
SECTION C–C' NOT TO SCALE



7/13 RISER PIPE TERMINATION
SECTION F–F' NOT TO SCALE



8/13 SUMP CLEANOUT/RISER CONFIGURATION SCHEMATIC
NOT TO SCALE



9/13 LEAK DETECTION RISER PIPE
SECTION B–B' NOT TO SCALE

UPDATED: AUGUST, 2016

LEACHATE COLLECTION SYSTEM DETAILS

SUNDANCE WEST
SURFACE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

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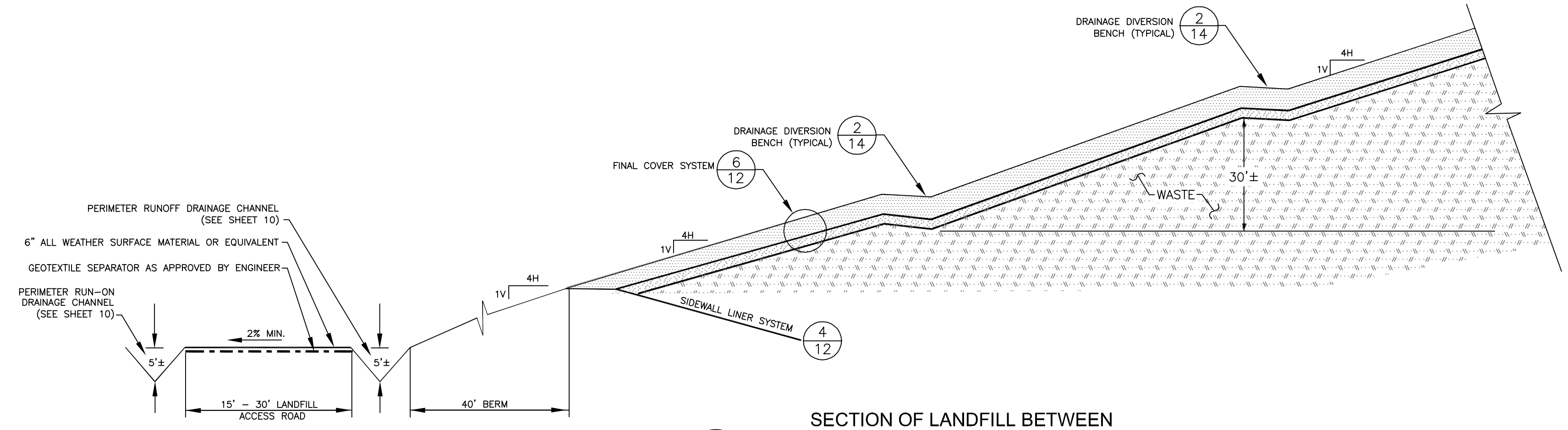
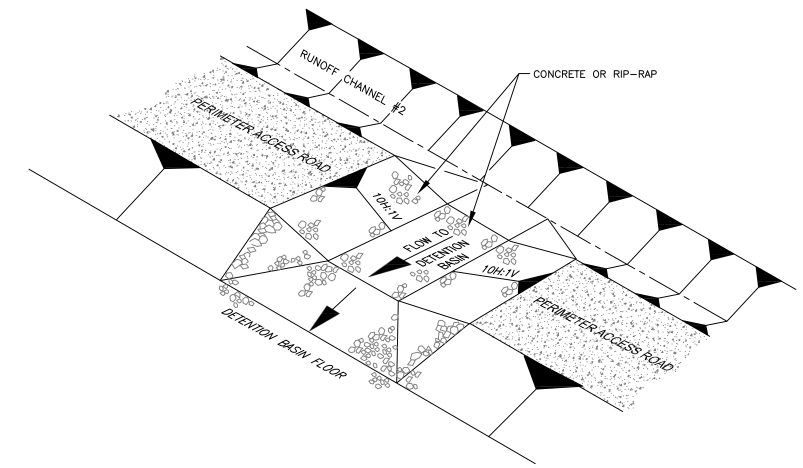
gei@gordonenvironmental.com

DATE: 08/02/2016	CAD: 13 LEACHATE DET.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 13 of 19
APPROVED BY: IKG		

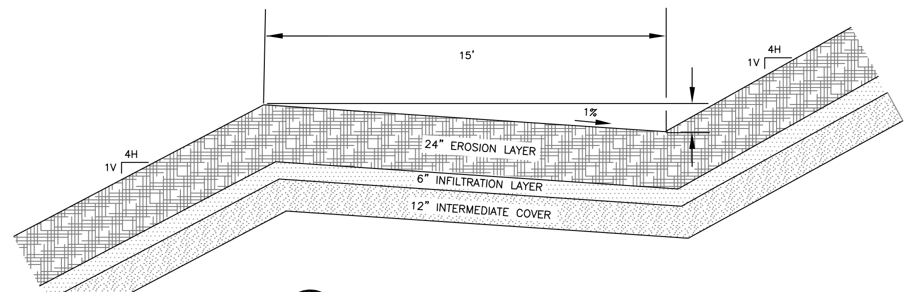
NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\13 LEACHATE DET.dwg
Date/Time:Aug. 03, 2016-14:05:10



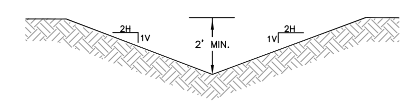
1/14 SECTION OF LANDFILL BETWEEN DRAINAGE DIVERSION BENCHES (TYPICAL)
NOT TO SCALE



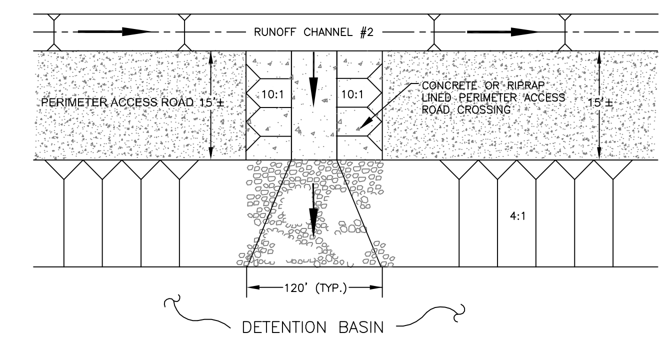
4/14 LOW FLOW CROSSING ISOMETRIC
NOT TO SCALE



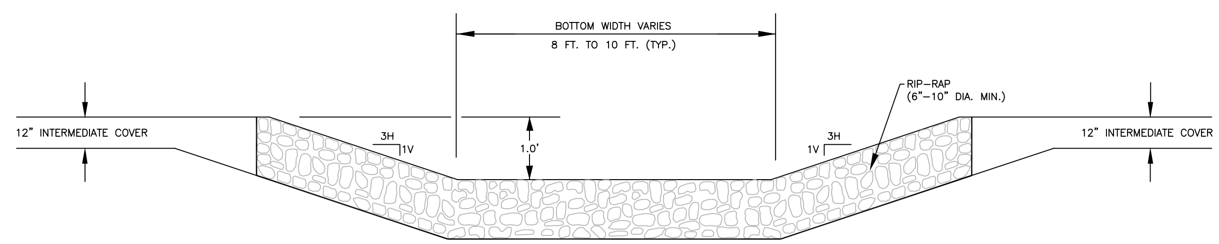
2/14 DRAINAGE DIVERSION BENCH
NOT TO SCALE



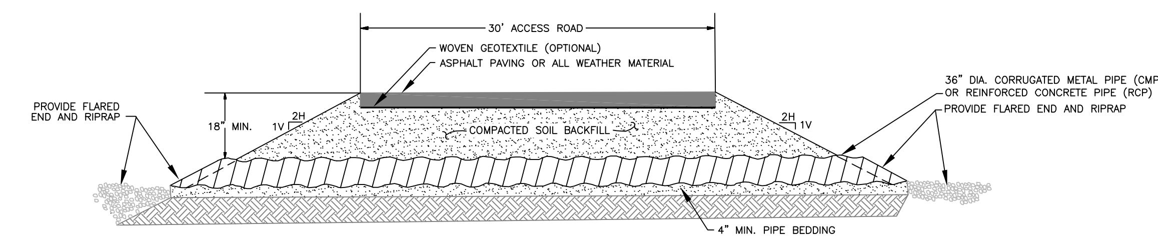
6/14 PROCESS AREA CHANNEL TYPICAL SECTION
NOT TO SCALE



5/14 TYPICAL LOW FLOW PERIMETER ROAD CROSSING
NOT TO SCALE



3/14 TYPICAL RIP-RAP LINED DOWN DRAIN (TEMPORARY)
CROSS SECTION
NOT TO SCALE



NOTES:
1. INVERT OF CORRUGATED METAL PIPE TO BE DETERMINED DURING INSTALLATION.
2. PROVIDE RIPRAP OR EQUIVALENT EROSION PROTECTION AT INLET AND OUTLET OF CULVERT.
3. PROVIDE FLARED END SECTION AT INLET AND OUTLET OF CULVERT TO PROVIDE A SMOOTH TRANSITION OF FLOW.

7/14 TYPICAL CULVERT INSTALLATION
NOT TO SCALE

UPDATED: AUGUST, 2016

STORMWATER DRAINAGE DETAILS

SUNDANCE WEST
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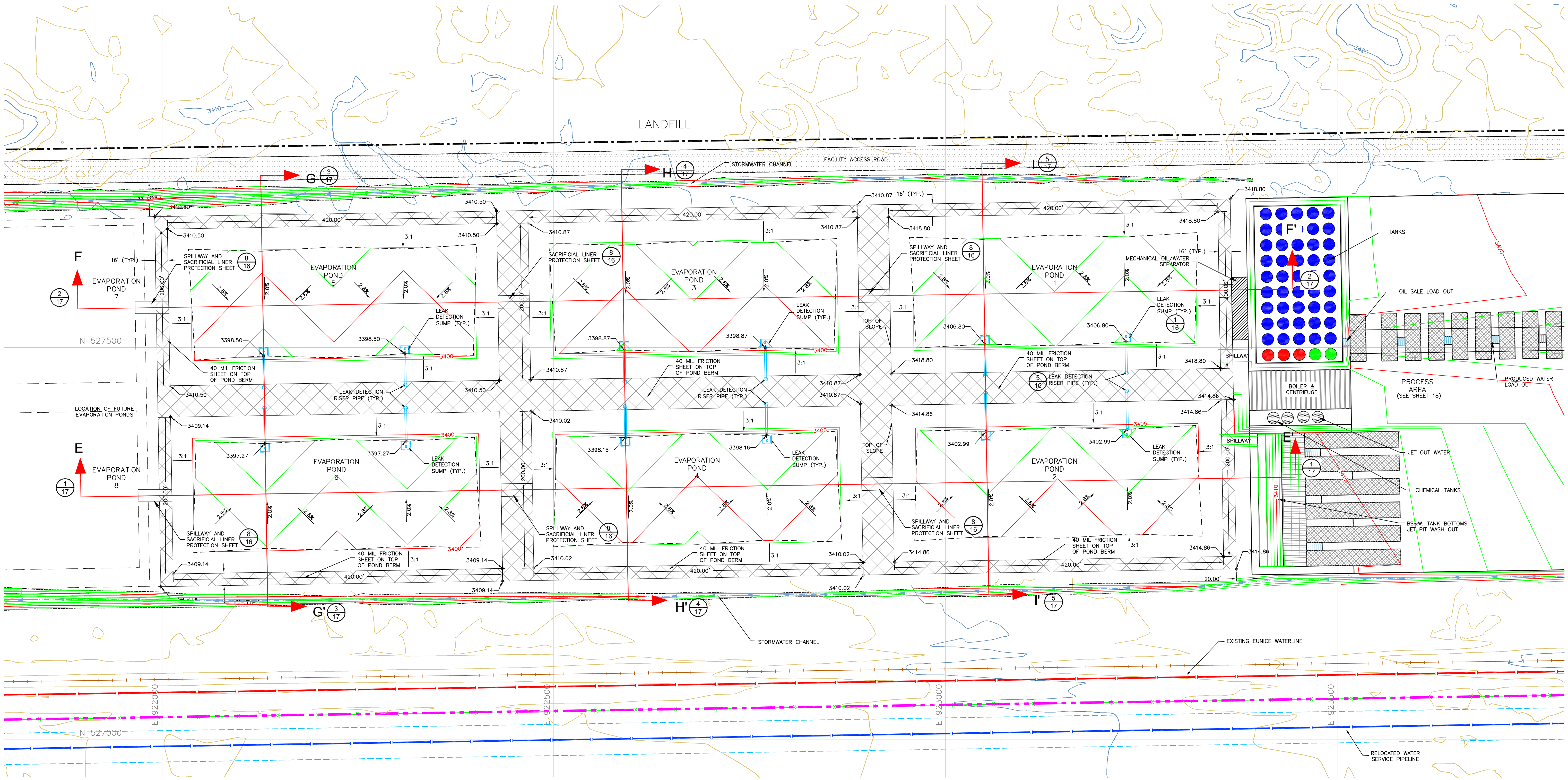
DATE: 08/02/2016	CAD: 14 STORM DET.dwg	PROJECT #: 530.01.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 14 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\14 STORM DET.dwg
Date/Time:Aug. 03, 2016-14:06:16



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

LEGEND

- FACILITY BOUNDARY
- LIMIT OF LANDFILL
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 5' AND 10' EVAPORATION POND CONTOUR
- 1' EVAPORATION POND CONTOUR
- TOP OF SLOPE
- TOE OF SLOPE
- CUT/FILL LINE
- NEW UNPAVED ROAD
- PAVED LANDFILL ACCESS ROAD
- FENCE
- RAILROAD TRACKS
- EXISTING EUNICE WATERLINE
- RELOCATED WATER SERVICE PIPELINE
- PIPELINE EASEMENT
- STORMWATER CHANNEL FLOW LINE
- 3410.02 SPOT ELEVATION
- DETAIL NUMBER / SHEET NUMBER
- H H' SECTION LOCATION
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK
- N 527500 E 922000 SITE GRID

NORTH

0 60' 120'

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\15 EVAP POND LAYOUT.dwg
Date/Time:Aug. 03, 2016-14:09:52

I. KEITH GORDON, P.E.
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UPDATED: AUGUST, 2016

EVAPORATION POND LAYOUT

SUNDANCE WEST
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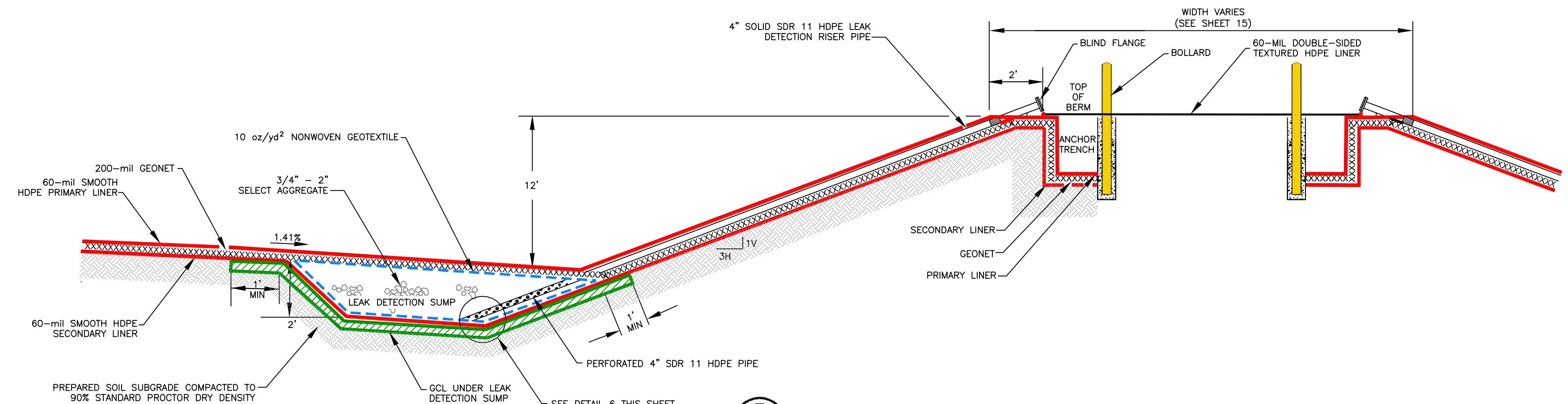
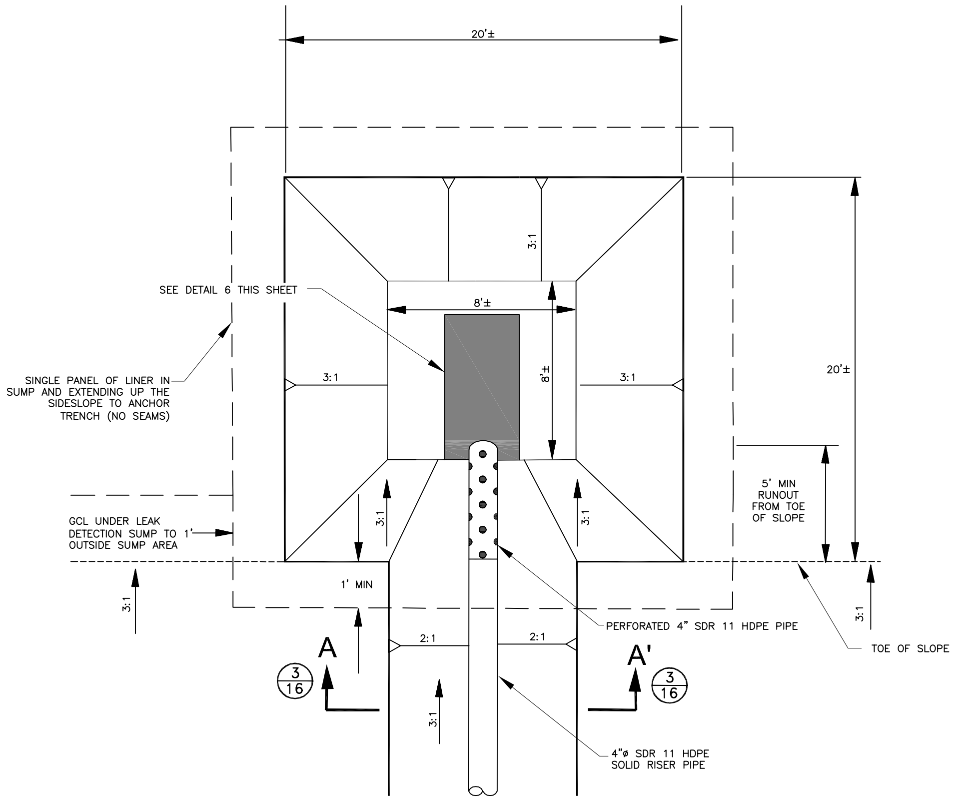
DATE: 08/02/2016	CAD: 15 EVAP POND LAYOUT.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 15 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



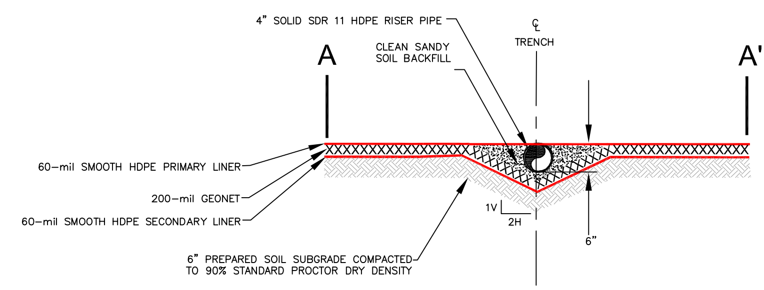
5/16 CROSS-SECTION AT LEAK DETECTION SUMP

NOT TO SCALE



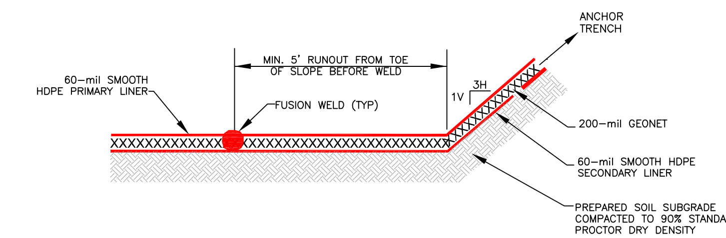
1/16 LEAK DETECTION SUMP

NOT TO SCALE



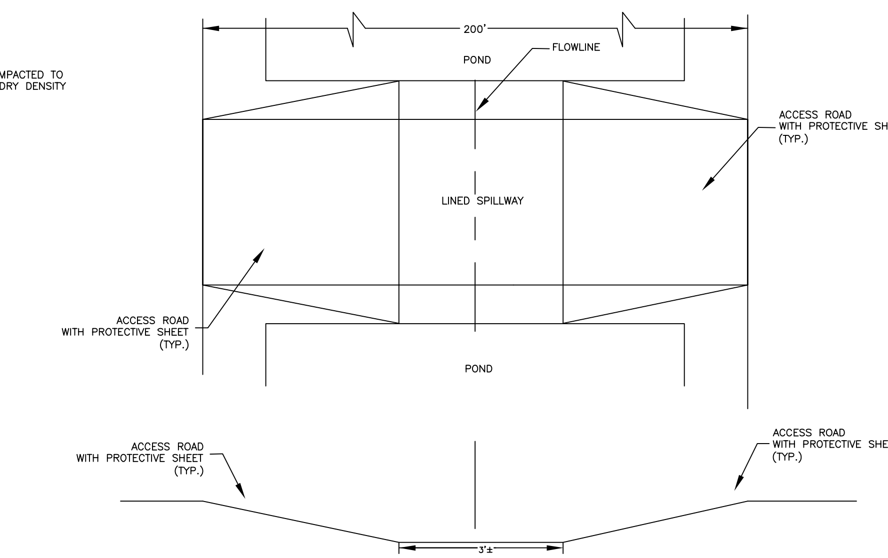
3/16 LEAK DETECTION SUMP RISER PIPE CROSS SECTION A-A'

NOT TO SCALE



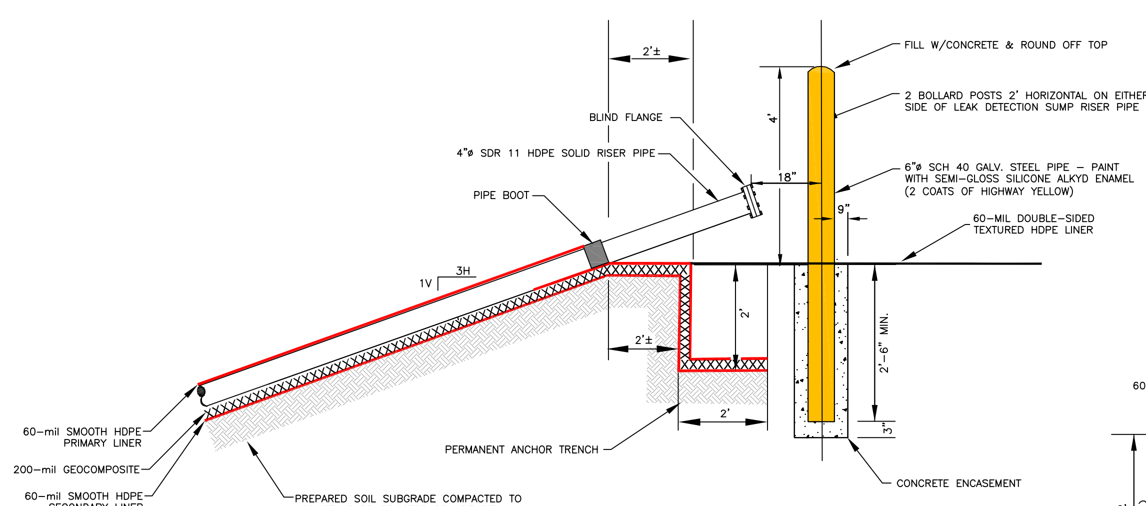
7/16 LINER RUNOUT ON POND FLOOR

NOT TO SCALE



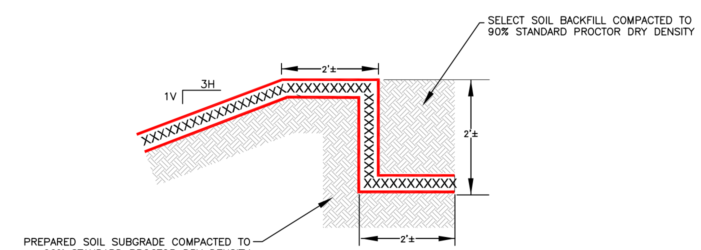
8/16 SPILLWAY PLAN PROFILE

NOT TO SCALE



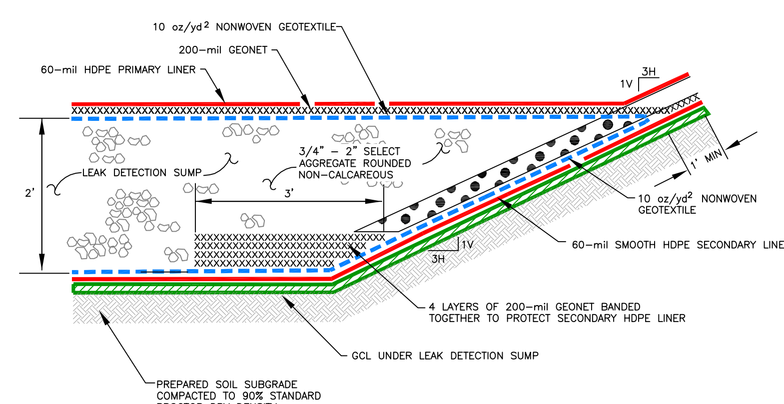
2/16 LEAK DETECTION SUMP RISER PIPE

SECTION VIEW NOT TO SCALE



4/16 ANCHOR TRENCH DETAIL

NOT TO SCALE



6/16 SUMP FLOOR DETAIL

NOT TO SCALE

UPDATED: AUGUST, 2016

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

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EVAPORATION POND DETAILS

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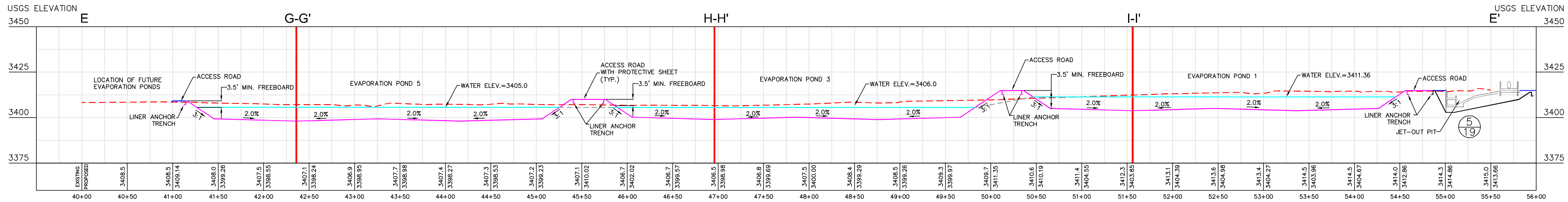
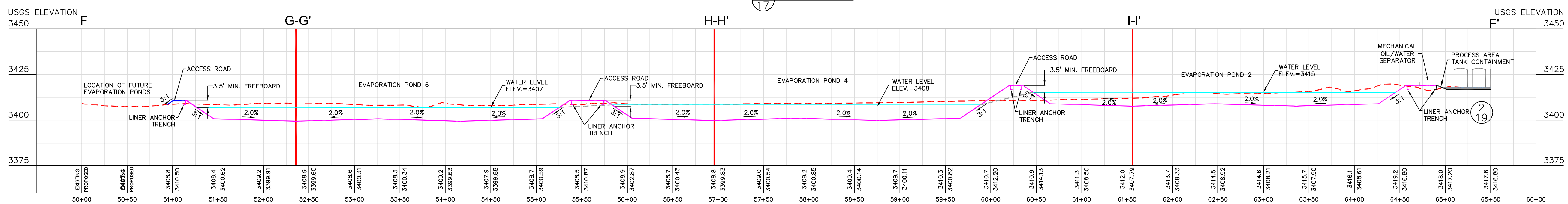
DATE: 08/02/2016	CAD: 16 EVAP POND DET.dwg	PROJECT #: 530,06,01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 16 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

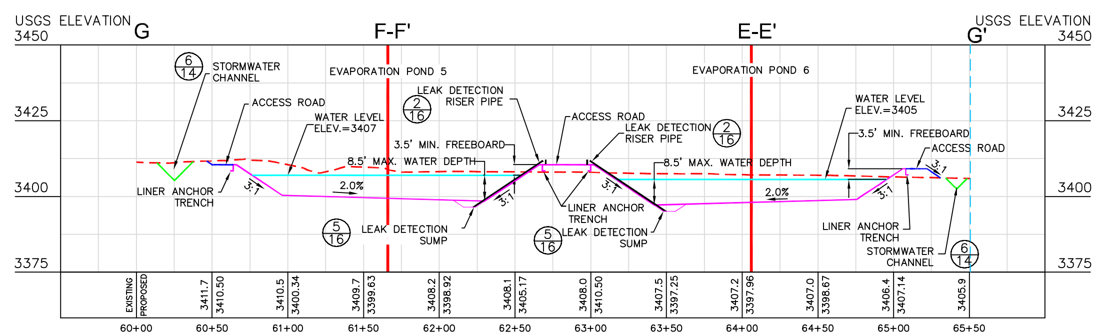
NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\16 EVAP POND DET.dwg
Date/Time:Aug. 03, 2016-14:11:01



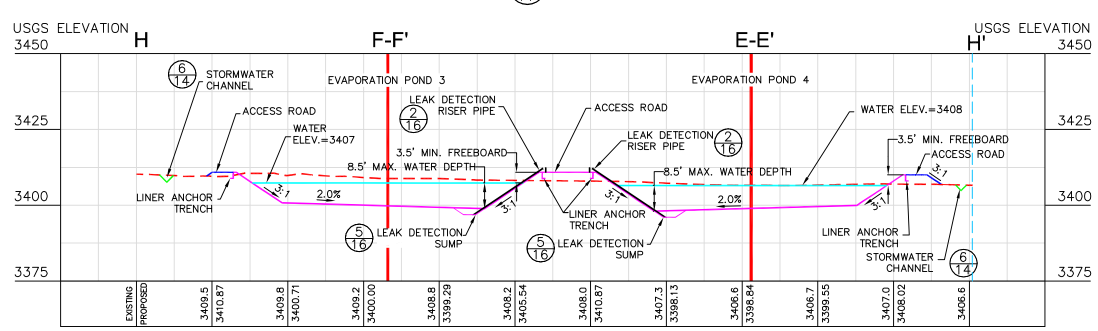
1 / 17 CROSS SECTION E-E'



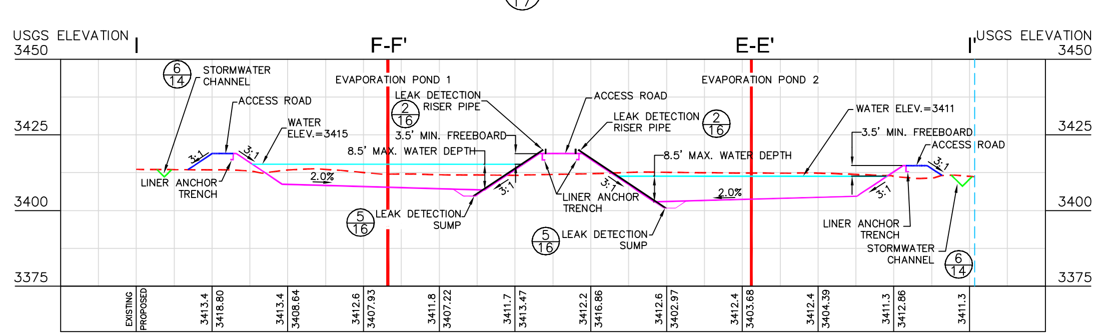
2 / 17 CROSS SECTION F-F'



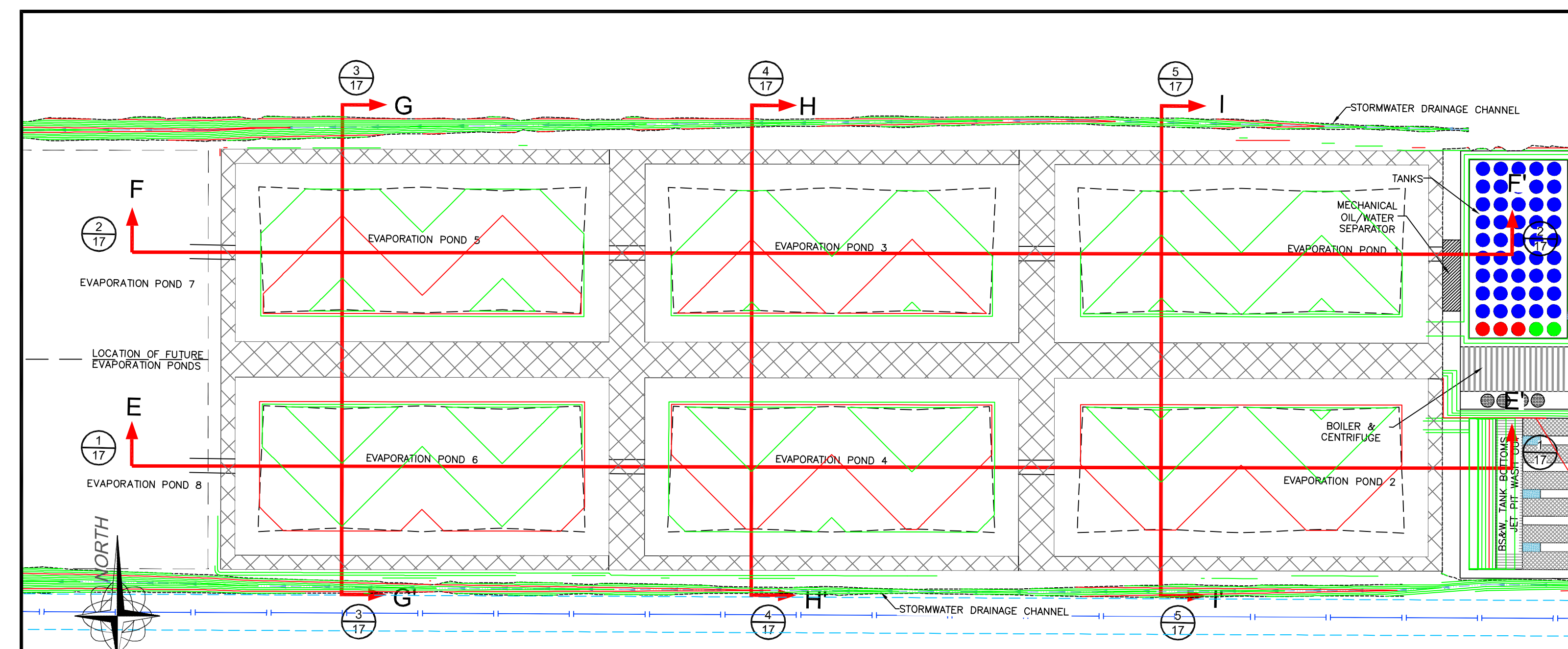
3 / 17 CROSS SECTION G-G'



4 / 17 CROSS SECTION H-H'



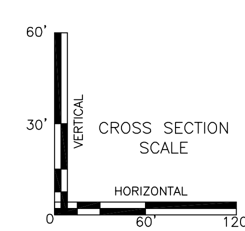
5 / 17 CROSS SECTION I-I'



KEY MAP

LEGEND

FINISHED GRADE	PRODUCED WATER TANK
EXISTING GRADE	CRUDE OIL RECOVERY TANK
SPILLWAY	OIL SALES TANK
5' AND 10' CONTOUR	
1' CONTOUR	
60-MIL HDPE LINER	
30-MIL POLYESTER LINER	
WATER LEVEL	
RELOCATED WATER SERVICE PIPELINE	
PIPELINE EASEMENT	
STORMWATER CHANNEL FLOW LINE	
DETAIL NUMBER / DETAIL LOCATED ON SHEET NUMBER	
SECTION LOCATION	



CROSS SECTION SCALE

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\17 EVAP POND X SECTIONS.dwg
Date/Time:Aug. 03, 2016-14:12:21

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UPDATED: AUGUST, 2016

EVAPORATION POND CROSS SECTIONS

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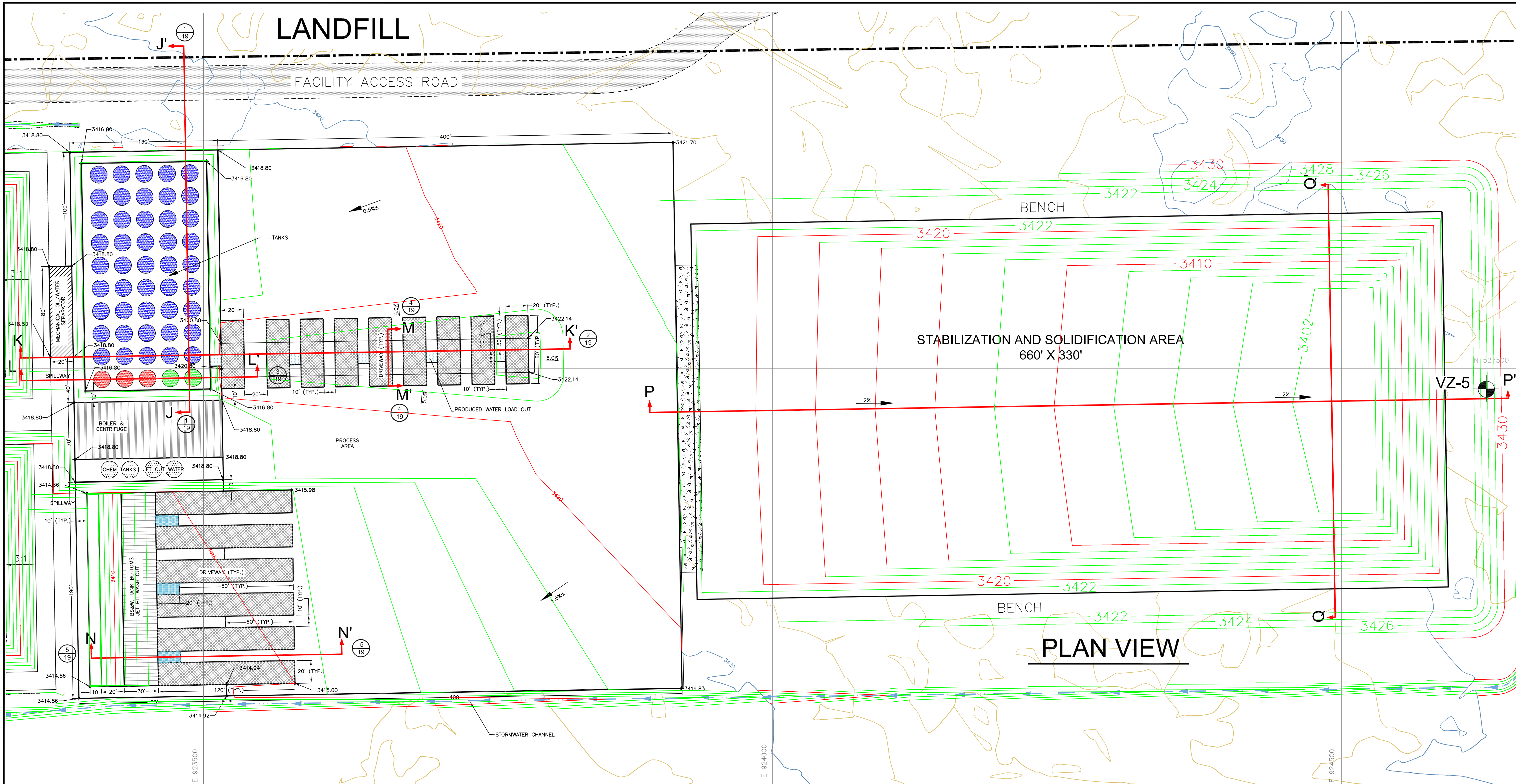
gei@gordonenvironmental.com

DATE: 08/02/2016	CAD: 17 EVAP POND X SECTIONS.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 17 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

LEGEND

- LIMIT OF LANDFILL
- 3410 — 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 3410 — 5' AND 10' PROCESS AREA CONTOUR
- 1' PROCESS AREA CONTOUR
- FENCE
- STORMWATER DRAINAGE CHANNEL FLOW LINE
- 3415.98 — DESIGN SPOT ELEVATION
- VZ-4 — VADOSE ZONE MONITORING WELL
- 1/19 — DETAIL NUMBER / SHEET NUMBER
- J J' — SECTION LOCATION
- N 527500 / E 922000 — SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NORTH

0 40' 80'

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UPDATED: AUGUST, 2016

PROCESS AREA LAYOUT

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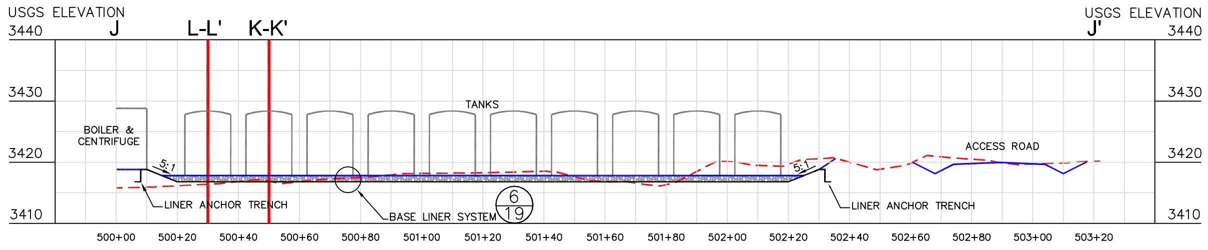
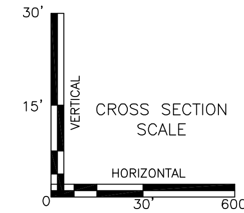
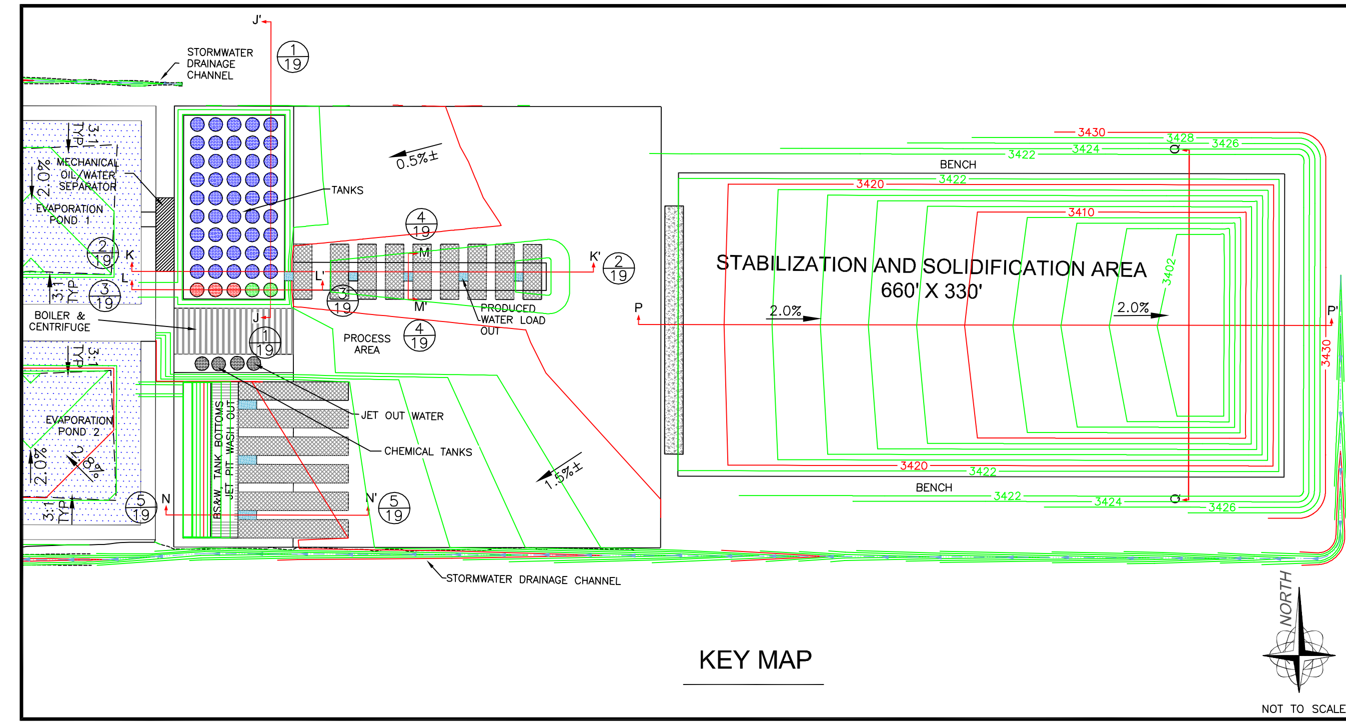
DATE: 08/02/2016	CAD: 18 PROCESS AREA.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: MRH	SHEET 18 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

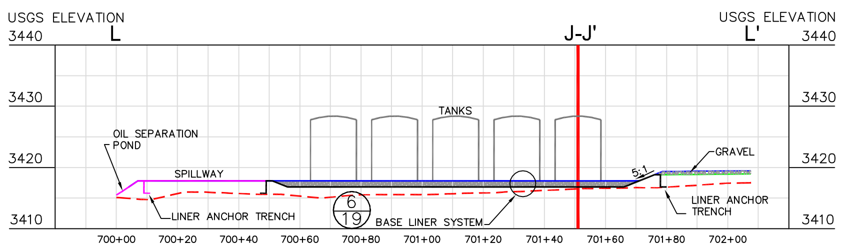
NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\18 PROCESS AREA.dwg
Date/Time:Aug. 03, 2016-14:14:06



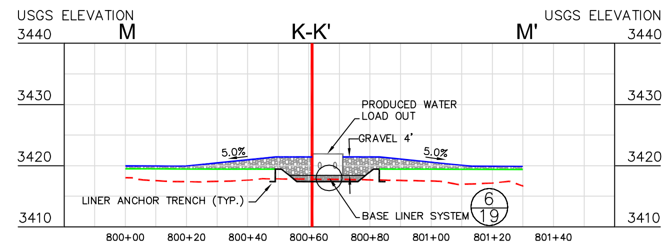
1/19 CROSS SECTION J-J'



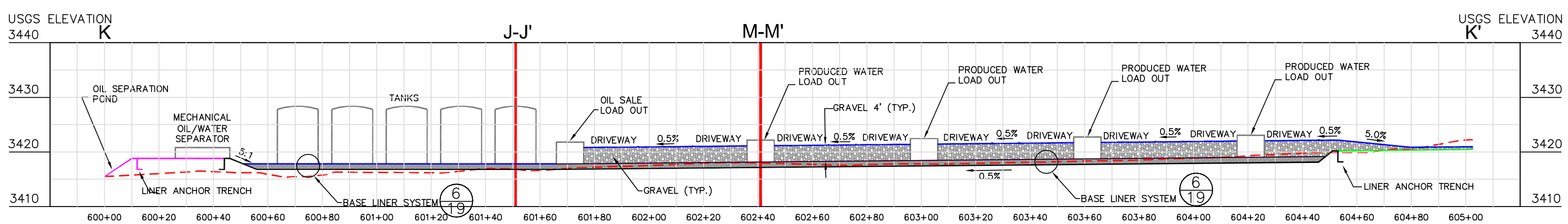




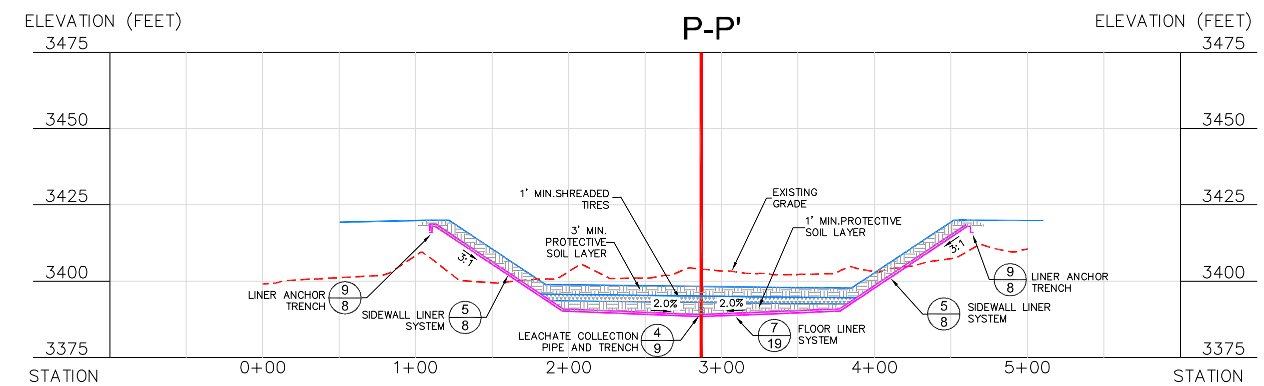
3/19 CROSS SECTION L-L'



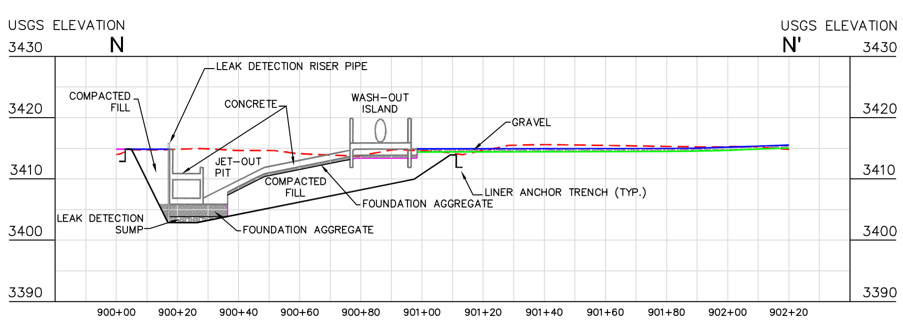
4/19 CROSS SECTION M-M'



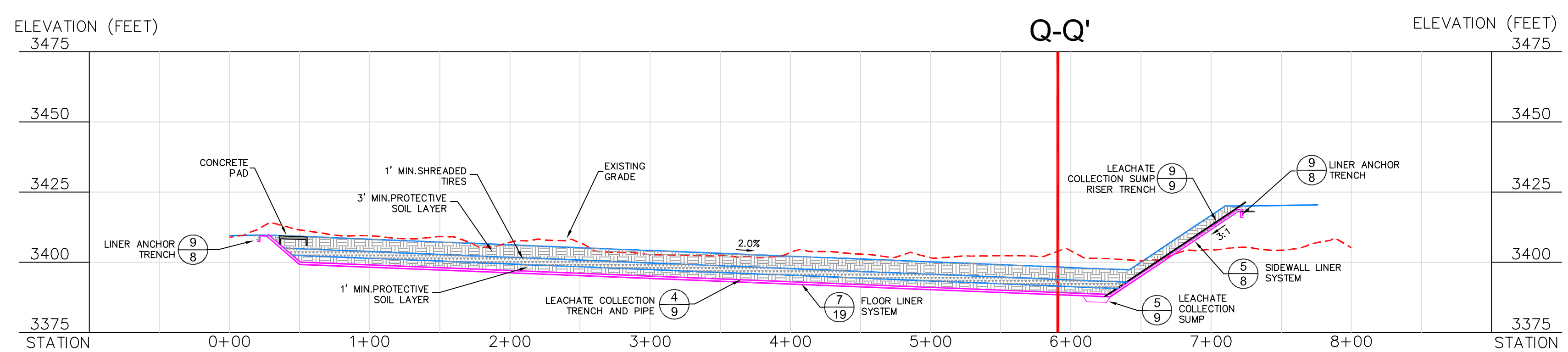
2/19 CROSS SECTION K-K'



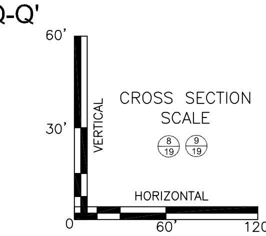
8/19 STABILIZATION AND SOLIDIFICATION AREA
SECTION Q-Q'

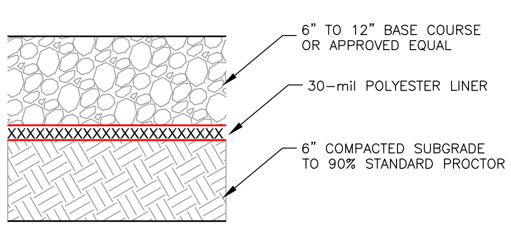


5/19 CROSS SECTION N-N'

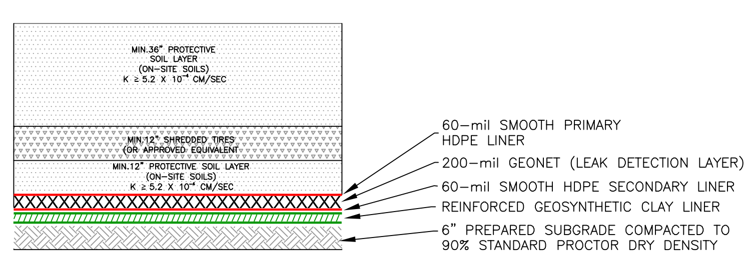


9/19 STABILIZATION AND SOLIDIFICATION AREA
SECTION P-P'





6/19 BASE LINER SYSTEM
NOT TO SCALE



7/19 FLOOR LINER SYSTEM
NOT TO SCALE

LEGEND

- FINISHED GRADES
- EXISTING GRADE
- SUBGRADE
- 30-MIL POLYESTER LINER
- 60-MIL HDPE LINER
- 1/19 DETAIL NUMBER / DETAIL LOCATED ON SHEET NUMBER
- K – K' CROSS SECTION LOCATION

NOT FOR CONSTRUCTION
Drawing: P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\19 PROCESS AREA X SECTIONS.dwg
Date/Time: Aug. 03, 2016-14:16:03

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: AUGUST, 2016

PROCESS AREA CROSS SECTIONS

SUNDANCE WEST
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DATE: 08/02/2016	CAD: 19 PROCESS AREA X SECTIONS.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	SHEET 19 of 19
APPROVED BY: IKG	gei@gordonenvironmental.com	

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.B

LINER LONGEVITY ARTICLE:

GEOSYNTHETICS MAGAZINE, OCT/NOV 2008

How long will my liner last?

| What is the remaining service life of my HDPE geomembrane?

By Ian D. Peggs, P.E., P.Eng., Ph.D.

Introduction

In his keynote lecture at the GeoAmericas-2008 conference last March, Dr. Robert Koerner (et al., 2008) of the Geosynthetic Institute (GSI) reported the ongoing Geosynthetic Research Institute (GRI) work to make the first real stab at assessing the service lives of high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), reinforced PE, ethylene propylene diene terpolymer (EPDM), and flexible polypropylene (fPP) exposed geomembranes.

The selected environment simulated that of Texas, USA, in sunny ambient temperatures between ~7°C (45°F) and 35°C (95°F). Of course, an exposed black HDPE geomembrane in the sun will achieve much higher temperatures, probably in excess of 80°C (176°F).

I do not know what the temperature would be at 150-300mm above the liner (for those still specifying this parameter), but it is quite immaterial. The only temperature of concern is the actual geomembrane temperature.

The lifetimes are shown in **Table 1**, but it must be recognized that these data are for specific manufactured products with specific formulations. The "greater than" notation indicates that laboratory exposures (incubations) are still on-going, not that some samples have failed after the indicated time period. The PE-R-1 material is a thin LLDPE, so it might be expected to be the first to reach the defined end of life; the half-life—the time to loss of 50% of uniaxial tensile properties.

It is interesting to note that HDPE-1 and LLDPE-1 are proceeding apace, but it would be expected that the LLDPE-1 would reach its half-life earlier than HDPE-1. However, this does not automatically follow. With adequate additive formulations, perhaps LLDPE could be left exposed and demonstrate more weathering resistance than some HDPEs. This demonstrates the fact that all PEs, whether HD or LLD, are not identical—they can have different long-term performances dependent on the PE resin used and the formulation of the stabilizer package. However, such differences are not evident in the conventional mechanical properties such as tensile strength/elongation, puncture and tear resistances, and so on.

The two fPPs are performing well. However, there had also been an fPP-1, one of the first PP geomembranes that did not perform well. This was due to a totally inappropriate stabilizer formulation. That particular product lasted 1.5 years in service. In

Final Inspection continued on page 44

Type	Specification	Predicted Lifetime in Texas, USA
HDPE-1	GRI-GM13	>28 years (Incubation ongoing)
LLDPEE-1	GRI-GM17	>28 years (Incubation ongoing)
EPDM-1	GRI-GM21	>20 years (Incubation ongoing)
PE-R-1	GRI-GM22	≈17 years (reached halflife)
fPP-2	GRI-GM18 (temp. susp.)	>27 years (Incubation ongoing)
fPP-3	GRI-GM18 (temp. susp.)	>17 years (Incubation ongoing)

Table 1 | Estimated exposed geomembrane lifetimes

| Ian Peggs is president of I-CORP International Inc. and is a member of *Geosynthetics* magazine's Editorial Advisory Committee.

Final Inspection continued from page 56

the QUV weatherometer, it lasted 1,800 light hours at 70°C (158°F). Therefore, the lab/field correlation is that 1,000 QUV light hours is equivalent to a 0.83yr service life under those specific environmental conditions.

At another location in Texas, Koerner/GRI found 1,000hr of QUV exposure was equivalent to 1.1 year actual field exposure. Consequently, for Texas exposures GRI is using a correlation of 1000hr QUV exposure as equivalent to lyr of in-service exposure. Clearly, the correlation would be different in less sunny and colder environments.

The failed fPP-1 liner was replaced with a correctly stabilized fPP that, subsequently, performed well.

While estimated correlations might be made for other locations using historical weather station sunshine and temperature data, there is no question that the best remaining lifetime assessments will be obtained using samples removed from the field installation of interest.

A lifetime in excess of 28yr, demonstrated for a recently-made HDPE geomembrane, is comparable to the present actual service periods of as long as 30-35yr. However, actual lifetimes of as low as ~15yr have also been experienced.

Do service lifetimes now exceeding 30yr mean that we might expect to see another round of stress cracking failures as exposed liners finally oxidize sufficiently on the surface to initiate stress cracking?

This would be frustrating after resolving the early 1980s problems with stress cracking failures at welds and stone protrusions when the liners contracted at low temperatures, but it is the way end-of-life will become apparent. And will that be soon or in another 5-20 years? It would be useful to know.

So how can we evaluate the condition of our exposed liners in a simple and practical manner to ensure they will continue to provide adequate service lifetimes and to get sufficient warning of impending expiration?

For each installation, a baseline needs to be established, and changes from that baseline need to be monitored.

A liner lifetime evaluation program

Rather than be taken by surprise when a liner fails or simply expires, it should be possible to monitor the condition of the liner to obtain a few years of notice for impending expiration. One can then plan for a timely replacement without the potential for accidental environmental damage and undesirable publicity. A program of periodic liner-condition assessment is proposed.

... it should be possible to monitor the condition of the liner to obtain a few years of notice for impending expiration.

For baseline data, it would be useful to have some archive material to test, but that is not usually available. Manufacturers often discard retained samples after about 5 years. Perhaps facility owners should be encouraged to keep retained samples at room temperature and out of sunlight. The next best thing is to use material from the anchor trench or elsewhere that has not experienced extremes in temperature and that has not been exposed to UV radiation or to expansion/contraction stresses.

Less satisfactory options are to use the original NSF 54 specifications, the manufacturer's specifications, or the GRI-GM13 specifications at the appropriate time of liner manufacturing. The concern with using these specifications is that while aged material may meet them, there is no indication of whether the measured values have significantly decreased from the actual as-manufactured values that generally significantly exceed the specification.

A final option for the baseline would be to use the values at the time of the first liner assessment.

The first liner condition assessment would consist of a site visit during which a general visual examination would be done together with a mechanical probing of the edges of welds. A visual examination would include the black/gray shades of different panels that might indicate low carbon contents.

A closer examination should be done using a loupe (small magnifier) on suspect areas such as wrinkle peaks, the tops and edges of multiple extrusion weld beads, and the apex-down creases of round die-manufactured sheet.

The last detail is significant because the combination of oxidizing surface and exposed surface tension when the liner contracts at low temperatures and the crease is pulled flat can be one of the first locations to crack. The apex-up creases do not fail at the same time because the oxidized exposed surface is under compression (or less tension) when the crease is flattened out.

Appropriate samples for detailed laboratory testing will be removed.

It may be appropriate to do a water lance electrical integrity survey on the exposed sideslopes, but this would only be effective on single liners, and on double liners with a composite primary liner, a conductive geomembrane, or a geocomposite with a conductive geotextile on top.

A sampling and testing regime

A liner lifetime evaluation program should be simple, meaningful, and cost-effective.

While it will initially require expert polymer materials science/engineering input to analyze the test data and to define the critical parameters, it should ultimately be possible to use an expert system to automatically make predictions using the input test data.

Small samples will be taken from deep in the anchor trench and from appropriate

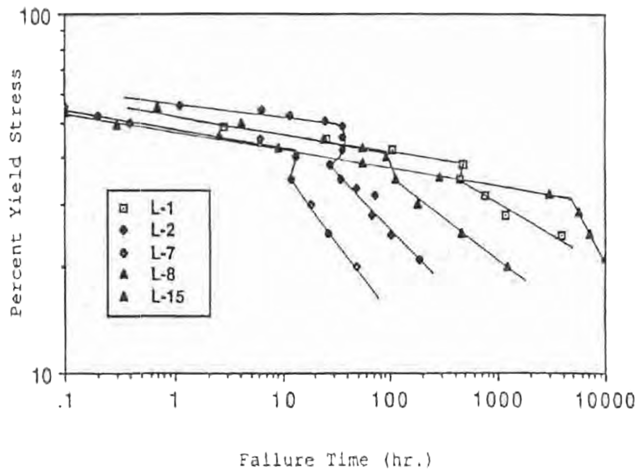

Figure 1 | Standard stress rupture curves for five HDPE geomembranes (Hsuan, et al. 1992)

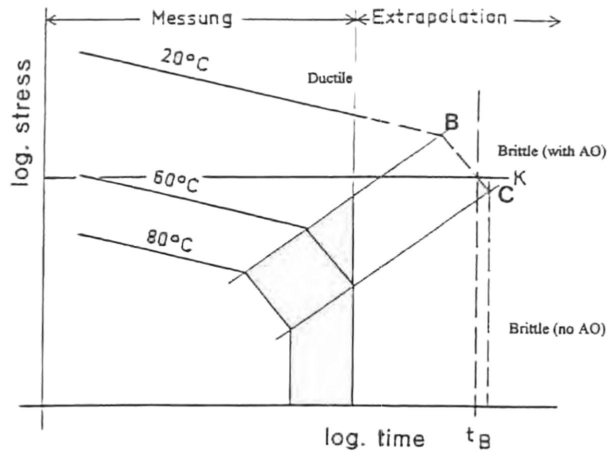

Figure 2 | Stress rupture curves showing third stage (Brittle no AO) oxidized limit. (Gaube, et al. 1985)

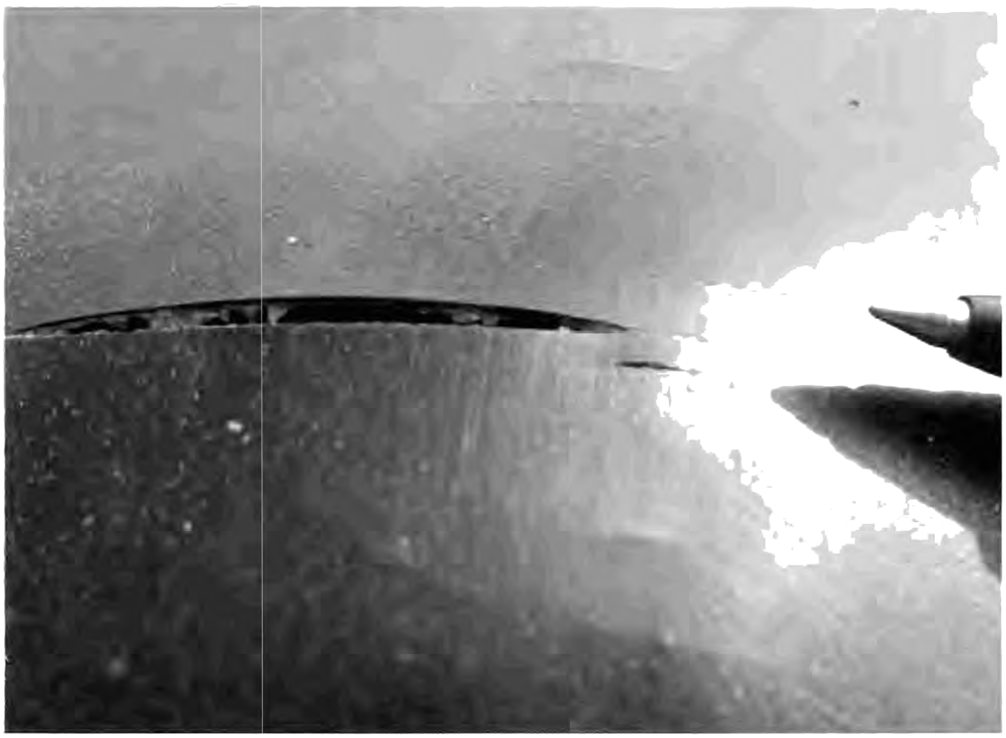

Figure 3 | Stress crack initiated by extruder die line at stone protrusion

exposed locations. Potential sites for future sample removal by the facility owner for future testing will be identified and marked by the expert during the first site visit.

The baseline sample(s) will be tested as follows:

- Single-point stress cracking resistance (SCR) on a molded plaque by ASTM D5397
- High-pressure oxidative induction time (HP-OIT) by ASTM D5885
- Fourier transform infrared spectroscopy (FTIR-ATR) on upper surface to determine carbonyl index (CI) on nonarchive samples only
- Oven aging/HP-OIT (GRI-GM13)
- UV resistance/HP-OIT (GRI-GM13)

The exposed samples will be tested as follows:

- Carbon content (ASTM D1603)
- Carbon dispersion (ASTM D5596)
- Single-point SCR on molded plaque (ASTM D5397)
- Light microscopy of exposed surface, through-thickness cross sections, and thin microsections (~15 µm thick) as necessary
- HP-OIT on 0.5-mm-thick exposed surface layers from basic sheet and from sheet at edge of extruded weld bead (ASTM D5885), preferably at a double-weld bead
- FTIR-ATR on exposed surface to determine CI
- Oven aging/HP-OIT on 0.5mm surface layer (GRI-GM13)
- UV resistance/HP-OIT on 0.5 mm surface layer (GRI-GM13)

Carbon content is done to ensure adequate basic UV protection. Carbon dispersion is done to ensure uniform surface UV protection and to evaluate agglomerates that might act as initiation sites for stress cracking.

HP-OIT is used to assess the remaining amount of stabilizer additives, both in the liner panels and in the sheet adjacent to an extrusion weld. Most stress cracking is observed at the edges of extrusion weld beads in the lower sheet, so it is important to monitor this location.

While standard OIT (ASTM D3895 at 200°C) better assesses the relevant stabilizers effective at processing (melting) and welding temperatures, the relevant changes in effective stabilizer content during continued service, including in the weld zone, will be provided by measurement of HP-OIT. There will be no future high temperature transient where knowledge of S-OIT will be useful. It is expected that the liner adjacent to the weld bead will be more deficient in stabilizer than the panel itself. Therefore, S-OIT is not considered in this program.

Note that HP-OIT is measured on a thin surface layer because the surface layer may be oxidized while the body of the geomembrane may not. If material from the full thickness of the geomembrane is used it could show a significant value of OIT, implying that there is still stabilizer present and that oxidation is far from occurring. However, the surface layer could be fully oxidized with stress cracks already initiated and propagating. A crack will then propagate more easily through unoxidized material than would initiation and propagation occur in unoxidized material.

The fact that the HP-OIT meets a certain specification value in the as-manufactured condition provides no guarantee that thermo- and photo-oxidation protection will be provided for a long time. Stabilizers might be consumed quickly or slowly while providing protection. They may also be consumed quickly to begin with, then more slowly, or vice versa.

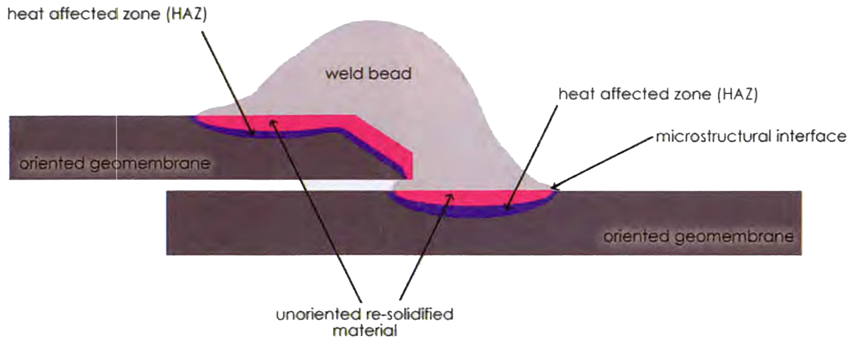

Figure 4 | Schematic of microstructure at extrusion weld

Hence, the need for continuing oven (thermal) aging and UV resistance tests. These two parameters, assessed by measuring retained HP- OIT, are critical to the assessment of remaining service life.

Oven (thermal) aging and UV resistance tests performed in this program will provide an extremely valuable data base that relates laboratory testing to in-service performance and that will further aid in more accurately projecting in-service performance from laboratory testing results.

Special considerations

Because we do not know, by OIT measurements alone, whether the surface layer is or is not oxidized (unless OIT is zero), and since we do not yet know at what level of OIT loss there might be an oxidized surface layer (the database has not yet been generated), FTIR directly on the surface of the geomembrane is performed using the attenuated total reflectance (ATR) technique to deny or confirm the presence of oxidation products (carbonyl groups).

Following the practice of Broutman, et al. (1989) and Duvall (2002) on HDPE pipes, if the ratio of the carbonyl peak at wave number 1760 cm-1 and the C-H stretching (PE) peak at wave number 1410 cm -1 is more than 0.10, there is a sufficiently oxidized surface layer that stress cracking might be initiated. For those familiar with the two slope stress rupture curve (**Figure 1**) where the brittle stress cracking region is the steeper segment below the knee, there is a third vertical part of the curve (**Figure 2**) where the material is fully oxidized and fracture occurs at the slightest stress. This is what will happen at the end of service life. But first note the times to initiation of stress cracking (the knees in the curves) in **Figure 1**—they range from ~10/hr to ~5,000/hr—clearly confirming that all HDPEs are not the same. Some are far more durable than others.

At the end of service life, at some level of OIT, there will be a critically oxidized surface layer that when stressed, such as at low temperatures by an upwards protruding stone, or by flexing due to wind uplift, will initiate a stress crack on the surface that will propagate downward through the geomembrane, as shown by the crack in **Figure 3**.

This crack, initiated at a stress concentrating surface die mark, occurred when the liner contracted at low temperatures, and tightened over an upwardly protruding stone. The straight morphology of the crack, and the ductile break at the bottom surface as the stress in the remaining ligament rose above the knee in the stress rupture curve, are typical of a stress crack. Note the shorter stress cracks initiated along other nearby die marks.

Stress cracks are preferentially initiated along the edges of welds because the adjacent geomembrane has been more depleted of stabilizers during the high temperature welding process. Thus, under further oxidizing service conditions, it will become the first location to

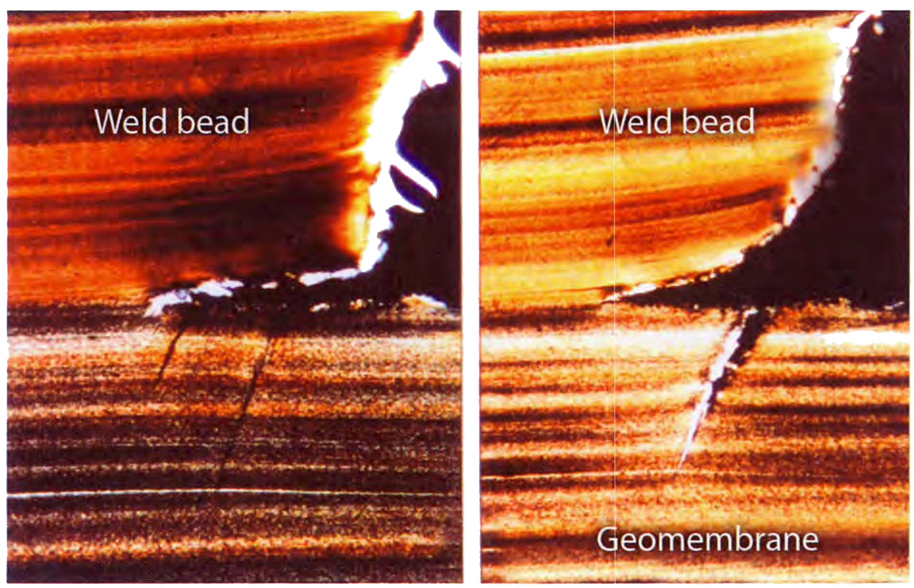

Figure 5 | Typical off-normal angle of precursor crazes (left) and stress crack (right) at edge of extrusion weld.

Type	Specification	Predicted Lifetime in Texas, USA
Side wall exposed	54	5
Side wall concrete side	81	71
Lower launder exposed	16	3
Lower launder concrete side	145	1

Table 2 | S-OIT values on solution and concrete liner surfaces (Peggs, 2008).

be oxidized to the critical level at which stress cracks will be initiated under any applied stress. In addition, the geometrical notches at grinding gouges and at the edges of the bead increase local stresses to critical levels for SC to occur.

I also believe that an internal microstructural flaw exists between the originally oriented geomembrane structure and the pool of more isotropic melted and resolidified material at the edge of the weld zone, as shown schematically in **Figure 4**. Most stress cracks occur at an off-normal angle at the edge of the weld bead that may be related to the angle of this molten-pool to oriented-structure interface (**Figure 5**). It is also known that stress increases the extraction of stabilizers from polyolefin materials.

With all of these agencies acting synergistically, it is not surprising that stress cracking often first occurs adjacent to extrusion welds.

Looking ahead

With the first field assessment test results available to us, and the extent of changes from the baseline sample known, removal of a second set of samples by the facility owner (at locations previously identified and marked by the initial surveyor), will be planned for a future time, probably in 2 or 3 years.

Why 2 or 3 years? In an extreme chemical environment, extensive reductions in S-OIT of studded HDPE concrete protection liners in mine solvent extraction facilities using kerosene/aromatic hydrocarbon/sulfuric acid process solutions at 55°C (131°F) have been observed on the solution and concrete sides of the liner (**Table 2**) within 1 year (Peggs 2008). But it is unlikely that such rapid decreases will be observed in air-exposed material.

With this second set of field samples, and with three sets of data points, practically reliable extrapolations of remaining lifetime can start to be made.

It is expected that a few years of notice for impending failures will be possible.

The key point to note in making these condition assessments is that, while all HDPE geomembranes have very similar conventional index properties, they can have widely variable photo-oxidation, thermal-oxidation, and stress-cracking resistances. Therefore, some HDPEs are more durable than others.

Thus, while one HDPE geomembrane manufactured in 1990 failed after 15 years in 2005, another HDPE geomembrane made in 1990 from a different HDPE resin (or more correctly a medium-density polyethylene [MDPE] resin), and with a better stabilizer additive package, could still have a remaining lifetime of 5, 20, or 30 years.

So, keep a close eye on those exposed liners and we'll learn a great deal more about liner performance and get notice of the end of service lifetime. And if owners can retain some archive material from new installations, so much the better.

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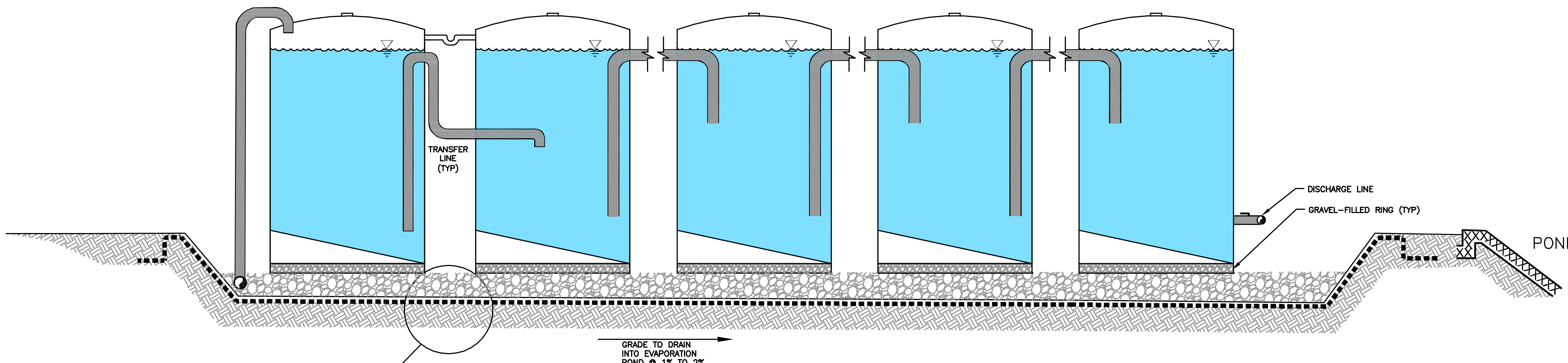
APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.C

TYPICAL RECEIVING TANK INSTALLATION DETAILS



ELEVATION - SECTION A-A'

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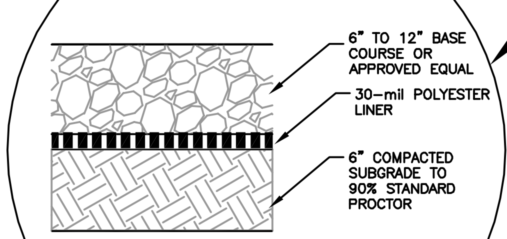

BASE LINER SYSTEM

NOT TO SCALE

TYPICAL RECEIVING TANK INSTALLATION DETAILS

SUNDANCE WEST
SURFACE WASTEMANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers

213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 01/05/2015	CAD: TANK ELEV.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: DRT	ATTACHMENT III.I.C
APPROVED BY: IKG	gei@gordonenvironmental.com	

Drawing:P:\acad 2003\530.06.01\PERMIT FIGURES\TANK ELEV.dwg
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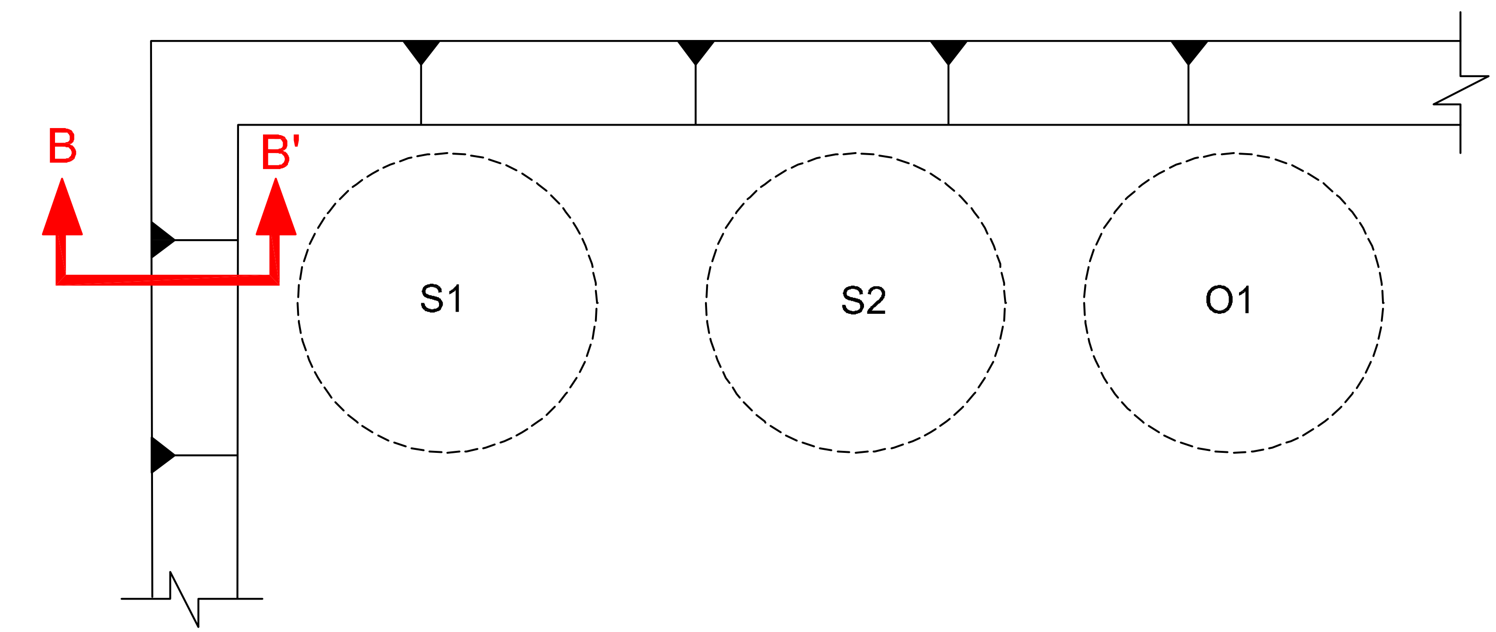
APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.D

TYPICAL SALES TANK INSTALLATION DETAILS



PLAN VIEW
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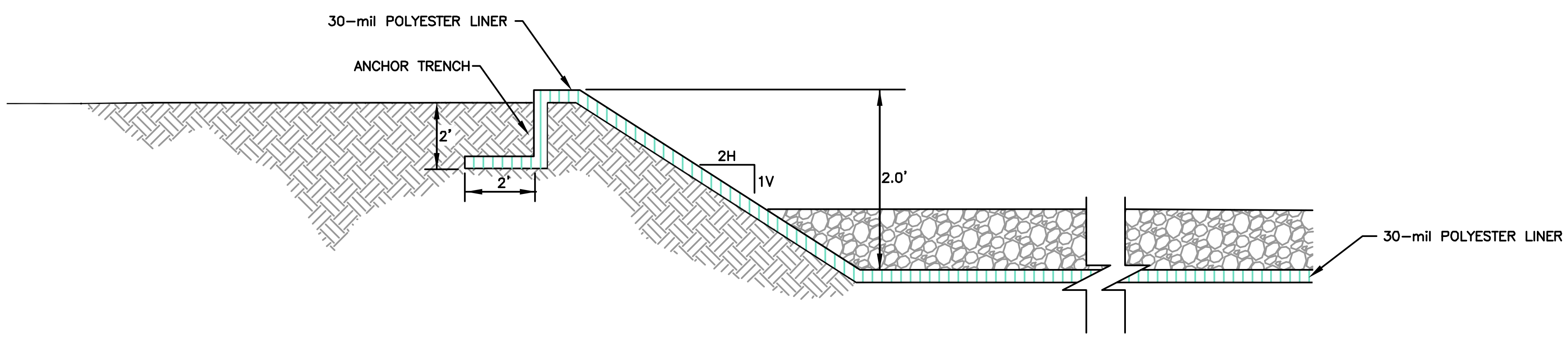

CROSS SECTION B-B'
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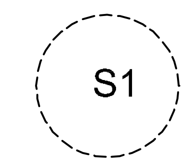
LEGEND



PROPOSED TANK

TYPICAL SALES TANK INSTALLATION DETAILS

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
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DATE: 01/05/2015	CAD: TYP TANK.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: MRH	ATTACHMENT III.I.D
APPROVED BY: IKG	gei@gordonenvironmental.com	

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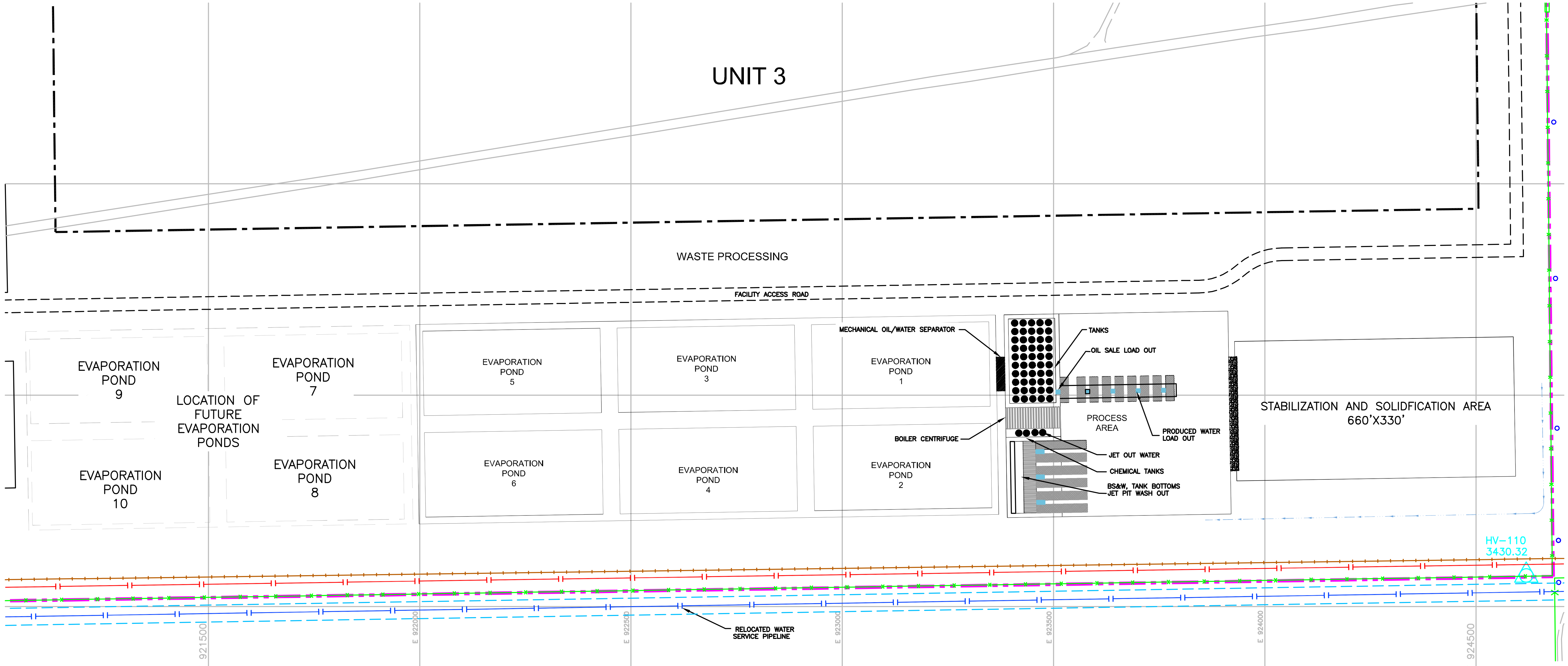
APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.E

SITE SCHEMATIC



LEGEND

	FACILITY BOUNDARY
	LIMIT OF WASTE BOUNDARY
	DELIVERY VEHICLE ROUTE
	NEW UNPAVED ROAD
	RAILROAD TRACK
	EXISTING EUNICE WATERLINE
	RELOCATED WATER SERVICE PIPELINE
	WATER SERVICE PIPELINE RIGHT-OF-WAY

NORTH

NOT TO SCALE

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SITE SCHEMATIC

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
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DATE: 07/27/2016	CAD: SCHEMATIC.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	ATTACHMENT III.I E
APPROVED BY: IKG	gei@gordonenvironmental.com	

APPLICATION FOR PERMIT
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VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.F

TANK AND POND CAPACITY CALCULATIONS

Attachment III.1.F
Sundance West
Tank and Pond Capacity Calculations

Sundance West is a surface waste management facility.

A. Produced Water is delivered by trucking companies into one of nine proposed Produced Water Receiving Tanks (metal) located within a bermed, lined containment area:

Proposed Tank No.	Volume	Permitted
R-1	1000 bbls	Permitted under this Application
R-2	1000 bbls	Permitted under this Application
R-3	1000 bbls	Permitted under this Application
R-4	1000 bbls	Permitted under this Application
R-5	1000 bbls	Permitted under this Application
R-6	1000 bbls	Permitted under this Application
R-7	1000 bbls	Permitted under this Application
R-8	1000 bbls	Permitted under this Application
R-9	1000 bbls	Permitted under this Application

i. The Receiving tanks serve to gravity separate solids and oil from the water. Solids collect in the bottoms and oil floats to the tops of the receiving tanks.
ii. The Receiving Tanks bottoms are solidified and taken to the OCD permitted Landfill.
iii. The Receiving Tanks are set on gravel or sand pads on top of a lined bermed impermeable pad that drains into the evaporation pond.

B. Water from each Receiving Tanks flows in series through four additional Settling Tanks (metal) to remove oil prior to discharge in the mechanical oil water separator:

Proposed Tank No.	Volume	Permitted
S-1A	1000 bbls	Permitted under this Application
S-1B	1000 bbls	Permitted under this Application
S-1C	1000 bbls	Permitted under this Application
S-1D	1000 bbls	Permitted under this Application
S-2A	1000 bbls	Permitted under this Application
S-2B	1000 bbls	Permitted under this Application
S-2C	1000 bbls	Permitted under this Application
S-2D	1000 bbls	Permitted under this Application
S-3A	1000 bbls	Permitted under this Application
S-3B	1000 bbls	Permitted under this Application
S-3C	1000 bbls	Permitted under this Application
S-3D	1000 bbls	Permitted under this Application
S-4A	1000 bbls	Permitted under this Application
S-4B	1000 bbls	Permitted under this Application
S-4C	1000 bbls	Permitted under this Application
S-4D	1000 bbls	Permitted under this Application
S-5A	1000 bbls	Permitted under this Application
S-5B	1000 bbls	Permitted under this Application
S-5C	1000 bbls	Permitted under this Application
S-5D	1000 bbls	Permitted under this Application
S-6A	1000 bbls	Permitted under this Application
S-6B	1000 bbls	Permitted under this Application
S-6C	1000 bbls	Permitted under this Application
S-6D	1000 bbls	Permitted under this Application
S-7A	1000 bbls	Permitted under this Application
S-7B	1000 bbls	Permitted under this Application
S-7C	1000 bbls	Permitted under this Application

S-7C	1000 bbls	Permitted under this Application
S-7D	1000 bbls	Permitted under this Application
S-8A	1000 bbls	Permitted under this Application
S-8B	1000 bbls	Permitted under this Application
S-8C	1000 bbls	Permitted under this Application
S-8D	1000 bbls	Permitted under this Application
S-9A	1000 bbls	Permitted under this Application
S-9B	1000 bbls	Permitted under this Application
S-9C	1000 bbls	Permitted under this Application
S-9D	1000 bbls	Permitted under this Application

i. The Settling Tanks increase the detention time available to provide additional gravity separation of oil from the water,
ii. The Settling Tank bottoms are taken to the OCD permitted Landfill.
iii. The Settling Tanks are set on gravel or sand pads on top of a lined bermed impermeable pad that drains into the evaporation pond.

C. The separated oil flows into one of three heated Crude Oil Receiving Tanks (metal):

Proposed Tank No.	Volume	Permitted
C-1	1000 bbls	Permitted under this Application
C-2	1000 bbls	Permitted under this Application
C-3	1000 bbls	Permitted under this Application

i. The Crude Oil Receiving Tanks are set inside the proposed lined containment berm.
ii. The Crude Oil Receiving Tanks are interconnected at the top of the tanks for oil removal.

D. The water from the Settling Tanks is discharged through one of up to two Dissolved Air Floatation (DAF) Units(metal).

Proposed Tank No.	Volume	Permitted
D-1	10 bbls	Permitted under this Application
D-2	10 bbls	Permitted under this Application

i. The DAF Units are situated on the lined Evaporation Pond berm in a location where any leakage would drain into
ii. The DAF use air bubbles to lift any remaining oil from the water prior to discharge into one of two Ponds.
iii. The oil containing foam generated by the DAF is collected and discharged into the Crude Oil Receiving Tanks for further processing.

E. The water from the Dissolved Air Floatation (DAF) Units flows into the proposed double lined Ponds (P-1 & 2) equipped with a leak detection system.

Proposed Pond No.	Storage Volume	Permitted
P-1	73,700 bbls	Permitted under this Application
P-2	73,700 bbls	Permitted under this Application
P-3	73,700 bbls	Permitted under this Application
P-4	73,700 bbls	Permitted under this Application
P-5	73,700 bbls	Permitted under this Application
P-6	73,700 bbls	Permitted under this Application
P-7	73,700 bbls	Permitted under this Application
P-8	73,700 bbls	Permitted under this Application
P-9	73,700 bbls	Permitted under this Application
P-10	73,700 bbls	Permitted under this Application

i. Surface aeration and bleach are used to maintain water chemistry parameters:
:O_2 at or above 0.5 ppm one foot off the bottom of the pond.

:pH above 8
ii. H2S monitors are placed around the pond covering the four major points on the compass.
iii. The H2S monitors continually monitor the ambient air.
iv. Two chlorine monitors are placed around the ponds covering the North and West borders.
v. Treatment capacity of each Pond is <73,700 bbls (~9.5 acre feet)
vi. 3 Feet of Freeboard is proposed, storage volume does not include freeboard due to spillway elevation limits.
vii. Volume including freeboard is 77.583 bbls (10 acre-feet)for ponds 9 and 10.
viii. Inside grade shall be no steeper than 3H:1V
ix. Levees shall have an outside grade no steeper than 3H:1V

x. Levees' tops shall be wide enough to install an anchor trench and provide adequate room for inspection/maintenance.
xi. Liner seams shall be minimized and oriented up and down, not across a slope
Each pond shall have a:
:primary liner (60-mil HDPE liner, UV resistant)
:secondary liner (60-mil HDPE liner, UV resistant)
xii. Slope shall be ≥2% (2 ft V for 100 ft H)
xiii. A mechanical evaporation system shall be installed in each pond to enhance evaporation.
xiv. Approximate size of each pond is 200 x 420 feet x 8 feet deep

F. Bleach for H2S management is stored in two proposed chemical tanks (fiberglass or plastic):

Proposed Tank No.	Volume	Permitted
B-1	60 bbls	Permitted under this Application
B-2	60 bbls	Permitted under this Application

i. The Chemical Tanks are set on a bermed concrete pad that drains into the pond.
ii. The Bleach is pumped through lines to discharge points in each of the ponds.

G. Water from Pond 1 (P-1) is:
i. Pumped through lines to floating evaporators in Ponds 2, 3, and 4 (P-2, P-3, P-4).
ii. Three or more floating evaporators are situated in each Pond.
iii. Water that does not evaporate from Ponds 2, 3, or 4 is pumped to floating evaporators in Ponds 5 and 6.
iv. Water that does not evaporate from Ponds 5 and 6 is pumped to floating evaporators in Ponds 7 and 8.
v. Water that does not evaporate from Ponds 7 and 8 is pumped to floating evaporators in Ponds 9 and 10.

H. The Jet-Out Pit (concrete)receives discharges from tankers bringing oil contaminated drilling mud, BS&W, tank bottoms and washout from tank cleanings.

Proposed Pit No.	Volume	Permitted
J-1	1000 bbls	Permitted under this Application

Proposed Tank No.	Volume	Permitted
WW-1	1000 bbls	Permitted under this Application
FW-1	1000 bbls	Permitted under this Application

i. Wash-Water for the Jet-Out Pit is recycled through a line from Pond-10 to WW-1. A pump connected to WW-1 pumps the water through a line to one of six wash-out stations for use cleaning the tankers.
ii. Fresh-Water for the Jet-Out Pit is discharged from the city line through an air gap into FW-1. A pump connected to FW-1 pumps the water through a line to one of six wash-out stations for use cleaning the tanks.
ii. Oil from the Jet-Out Pit is transferred through a line to the Crude Oil Receiving Tanks for further Processing..
iii. Water from the Jet-Out Pit is transferred through a line to the Produced Water Receiving Tanks for processing.
iv. Sludges and sediments from the Jet Out Pits is removed with a bucket loader and transferred for stabilization, solidification and disposal.

I. Oil from the Crude Oil Receiving Tanks (metal) C1-C3 is dewatered through the Centrifuge with the finished product transferred to the Oil Sales Tanks.

Proposed Tank No.	Volume	Permitted
S-1	1000 bbls	Permitted under this Application
S-2	1000 bbls	Permitted under this Application

i. The proposed Oil Sales Tanks are set inside the lined berm next to the Crude Oil Receiving Tanks.
ii. Oil is removed from the Oil Sales tank to a tanker at the Oil Sales Load-Out
iii. Water recovered from the centrifuge is redirected to the Produced Water Receiving Tanks.
iv. Sludges recovered from the Centrifuge are stabilized, solidified and sent to the landfill for disposal.

J. Pond Capacity Calculations:

Truncated Rectangular Pyramid Volume		
Dimension	Freeboard	Pond Volume
a	420	402
b	200	182
c	402	363

d	182	143
h	3	6.5
Volume (GAL)	1,762,291	3,028,410
Acre-FT	5.41	9.29
Barrels		72,075

i. Calculated using: http://www.aqua-calc.com/calculate/volume-truncated-pyramid

ii. Truncated pyramid or frustum of a pyramid is a pyramid whose vertex is cut away by a plane parallel to the base. The distance between the bottom and the top bases is the truncated pyramid height h.

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SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.G

PIPE WALL THICKNESS INFORMATION

Table A-2 (cont'd)
PIPE WEIGHTS AND DIMENSIONS *(IPS)*
PE3608 *(BLACK)*

OD			SDR	Nominal ID		Minimum Wall		Weight	
Nominal in.	Actual in.	Actual mm.		in.	mm.	in.	mm.	lb. per foot	kg. per meter
			7	2.44	61.98	0.500	12.70	2.047	3.047
			7.3	2.48	63.08	0.479	12.18	1.978	2.943
			9	2.68	67.96	0.389	9.88	1.656	2.464
			9.3	2.70	68.63	0.376	9.56	1.609	2.395
			11	2.83	71.77	0.318	8.08	1.387	2.065
3	3.500	88.90	11.5	2.85	72.51	0.304	7.73	1.333	1.984
			13.5	2.95	74.94	0.259	6.59	1.153	1.716
			15.5	3.02	76.74	0.226	5.74	1.015	1.511
			17	3.06	77.81	0.206	5.23	0.932	1.386
			21	3.15	79.93	0.167	4.23	0.764	1.136
			26	3.21	81.65	0.135	3.42	0.623	0.927
			7	3.14	79.68	0.643	16.33	3.384	5.037
			7.3	3.19	81.11	0.616	15.66	3.269	4.865
			9	3.44	87.38	0.500	12.70	2.737	4.073
			9.3	3.47	88.24	0.484	12.29	2.660	3.958
			11	3.63	92.27	0.409	10.39	2.294	3.413
4	4.500	114.30	11.5	3.67	93.23	0.391	9.94	2.204	3.280
			13.5	3.79	96.35	0.333	8.47	1.906	2.836
			15.5	3.88	98.67	0.290	7.37	1.678	2.497
			17	3.94	100.05	0.265	6.72	1.540	2.292
			21	4.05	102.76	0.214	5.44	1.262	1.879
			26	4.13	104.98	0.173	4.40	1.030	1.533
			32.5	4.21	106.84	0.138	3.52	0.831	1.237
			7	3.88	98.51	0.795	20.19	5.172	7.697
			7.3	3.95	100.27	0.762	19.36	4.996	7.435
			9	4.25	108.02	0.618	15.70	4.182	6.224
			9.3	4.29	109.09	0.598	15.19	4.065	6.049
			11	4.49	114.07	0.506	12.85	3.505	5.216
5	5.563	141.30	11.5	4.54	115.25	0.484	12.29	3.368	5.012
			13.5	4.69	119.11	0.412	10.47	2.912	4.334
			15.5	4.80	121.97	0.359	9.12	2.564	3.816
			17	4.87	123.68	0.327	8.31	2.353	3.502
			21	5.00	127.04	0.265	6.73	1.929	2.871
			26	5.11	129.78	0.214	5.43	1.574	2.343
			32.5	5.20	132.08	0.171	4.35	1.270	1.890
			7	4.62	117.31	0.946	24.04	7.336	10.917
			7.3	4.70	119.41	0.908	23.05	7.086	10.545
			9	5.06	128.64	0.736	18.70	5.932	8.827
			9.3	5.11	129.92	0.712	18.09	5.765	8.579
			11	5.35	135.84	0.602	15.30	4.971	7.398
6	6.625	168.28	11.5	5.40	137.25	0.576	14.63	4.777	7.109
			13.5	5.58	141.85	0.491	12.46	4.130	6.147
			15.5	5.72	145.26	0.427	10.86	3.637	5.413
			17	5.80	147.29	0.390	9.90	3.338	4.967
			21	5.96	151.29	0.315	8.01	2.736	4.072
			26	6.08	154.55	0.255	6.47	2.233	3.322
			32.5	6.19	157.30	0.204	5.18	1.801	2.680

See ASTM D3035, F714 and AWWA C-901/906 for OD and wall thickness tolerances.
Weights are calculated in accordance with PPI TR-7.

Table A-2 (cont'd)
PIPE WEIGHTS AND DIMENSIONS *(IPS)*
PE3608 *(BLACK)*

OD			SDR	Nominal ID		Minimum Wall		Weight	
Nominal	Actual							lb. per	kg. per
in.	in.	mm.		in.	mm.	in.	mm.	foot	meter
			7	6.01	152.73	1.232	31.30	12.433	18.503
			7.3	6.12	155.45	1.182	30.01	12.010	17.872
			9	6.59	167.47	0.958	24.34	10.054	14.962
			9.3	6.66	169.14	0.927	23.56	9.771	14.541
			11	6.96	176.85	0.784	19.92	8.425	12.538
8	8.625	219.08	11.5	7.04	178.69	0.750	19.05	8.096	12.049
			13.5	7.27	184.67	0.639	16.23	7.001	10.418
			15.5	7.45	189.11	0.556	14.13	6.164	9.174
			17	7.55	191.76	0.507	12.89	5.657	8.418
			21	7.75	196.96	0.411	10.43	4.637	6.901
			26	7.92	201.21	0.332	8.43	3.784	5.631
			7	7.49	190.35	1.536	39.01	19.314	28.743
			7.3	7.63	193.75	1.473	37.40	18.656	27.764
			9	8.22	208.73	1.194	30.34	15.618	23.242
			9.3	8.30	210.81	1.156	29.36	15.179	22.589
			11	8.68	220.43	0.977	24.82	13.089	19.478
10	10.750	273.05	11.5	8.77	222.71	0.935	23.74	12.578	18.717
			13.5	9.06	230.17	0.796	20.23	10.875	16.184
			15.5	9.28	235.70	0.694	17.62	9.576	14.251
			17	9.41	239.00	0.632	16.06	8.788	13.078
			21	9.66	245.48	0.512	13.00	7.204	10.721
			26	9.87	250.79	0.413	10.50	5.878	8.748
			32.5	10.05	255.24	0.331	8.40	4.742	7.058
			7	8.89	225.77	1.821	46.26	27.170	40.433
			7.3	9.05	229.80	1.747	44.36	26.244	39.056
			9	9.75	247.57	1.417	35.98	21.970	32.695
			9.3	9.84	250.03	1.371	34.82	21.353	31.777
			11	10.29	261.44	1.159	29.44	18.412	27.400
12	12.750	323.85	11.5	10.40	264.15	1.109	28.16	17.693	26.330
			13.5	10.75	272.99	0.944	23.99	15.298	22.767
			15.5	11.01	279.56	0.823	20.89	13.471	20.047
			17	11.16	283.46	0.750	19.05	12.362	18.397
			21	11.46	291.16	0.607	15.42	10.134	15.081
			26	11.71	297.44	0.490	12.46	8.269	12.305
			32.5	11.92	302.73	0.392	9.96	6.671	9.928
			7	9.76	247.90	2.000	50.80	32.758	48.750
			7.3	9.93	252.33	1.918	48.71	31.642	47.089
			9	10.70	271.84	1.556	39.51	26.489	39.420
			9.3	10.81	274.54	1.505	38.24	25.745	38.313
			11	11.30	287.07	1.273	32.33	22.199	33.036
14	14.000	355.60	11.5	11.42	290.05	1.217	30.92	21.332	31.746
			13.5	11.80	299.76	1.037	26.34	18.445	27.449
			15.5	12.09	306.96	0.903	22.94	16.242	24.170
			17	12.25	311.25	0.824	20.92	14.905	22.181
			21	12.59	319.70	0.667	16.93	12.218	18.183
			26	12.86	326.60	0.538	13.68	9.970	14.836
			32.5	13.09	332.40	0.431	10.94	8.044	11.970

See ASTM D3035, F714 and AWWA C-901/906 for OD and wall thickness tolerances.
Weights are calculated in accordance with PPI TR-7.

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VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.H

TECHNICAL DATA AND SPECIFICATIONS FOR XR GEOMEMBRANES

Technical Data and Specifications for

XR® Geomembranes

XR-3®
XR-5®
XR-3® PW

Industrial, Municipal and Potable Water Grade Geomembranes

Seaman Corporation
1000 Venture Blvd.
Wooster, Ohio 44691
(330) 262-1111
www.xr-5.com

Seaman Corp. XR Geomembranes

Section 1 - Product Overview/Applications

- All XR Geomembrane products are classified as an Ethylene Interpolymer Alloy (EIA)
- XR-5 grade is high strength and chemically resistant for maximum resistance to high temperature, and broad chemical resistance, including acids, oils and methane
- XR-3 grade for moderate chemical resistant requirement applications such as stormwater and domestic wastewater
- NSF 61 approved XR-3 PW grade for potable water contact
- Heat weldable-thermal weldable for seams as strong as the membrane. Factory panels over 15,000 square feet (1400 sq meters) for less field seaming
- Stability is excellent, with low thermal expansion-contraction properties
- 30+ year application history

Product Application Chart

	XR-5			XR-3	XR-3 PW
	8130	**8138**	**6730**	**8228**	**8130**
High Puncture Resistance	X	X	X		X
UV Resistance	X	X	X	X	X
High Strength Applications	X	X	X		X
Floating Covers (Nonpotable)	X	X	X	X	
Diesel/Jet Fuel Containment	X	X	X		
Industrial Wastewater	X	X	X		
Stormwater	X	X	X	X	
Municipal/Domestic Wastewater	X	X	X	X	
Floating Diversion Baffles/Curtains	X		X		X
Potable Water					X
<-65 Deg F Applications	Contact Seaman Corp.				
Chemically Resistant Applications	X	X	X		

Section 2 - Physical Properties

Part 1- Material Specifications

Property	Test Method	8130 XR-5	8138 XR-5	6730 XR-5
Base Fabric Type Base Fabric Weight	ASTM D 751	Polyester 6.5 oz/yd^2 nominal (220 g/m^2 nominal)	Polyester 6.5 oz/yd^2 nominal (220 g/m^2 nominal)	Polyester 7 oz/yd^2 nominal (235 g/m^2 nominal)
Thickness	ASTM D 751	30 mils min. (0.76 mm min.)	40 mils nom. (1.0 mm nom.)	30 mils min. (0.76 mm min.)
Weight	ASTM D 751	30.0 +- 2 oz/sq yd (1017 +- 2 g/m^2)	38.0 +- 2 oz/sq yd (1288 +- 70 g/m^2)	30.0 +- 2 oz/sq yd (1017 +- 70 g/m^2)
Tear Strength	ASTM D 751 Trap Tear	40/55 lbs. min. (175/245 N min.)	40/55 lbs. min. (175/245 N min.)	
Breaking Yield Strength	ASTM D 751 Grab Tensile	550/550 lbs. min. (2,447/2,447 N min.)	550/550 lbs. min. (2,447/2,447 N min.)	600/550 lbs. min. (2,670/2,447 N min.)
Low Temperature Resistance	ASTM D 2136 4 hrs-1/8" Mandrel	Pass @ -30° F Pass @ -35° C	Pass @ -30° F Pass @ -35° C	Pass @ -30° F Pass @ -35° C
Dimensional Stability	ASTM D 1204 100° C-1 Hr.	0.5% max. each direction	0.5% max. each direction	0.5% max. each direction
Hydrostatic Resistance	ASTM D 751 Procedure A	800 psi min. (5.51 MPa min.)	800 psi min. (5.51 MPa min.)	800 psi min. (5.51 MPa min.)
Blocking Resistance	ASTM D 751 180° F	#2 Rating max.	#2 Rating max.	#2 Rating max.
Adhesion-Ply	ASTM D 413 Type A	15 lbs./in. min. or film tearing bond (13 daN/5 cm min. or FTB)	15 lbs./in. min. or film tearing bond (13 daN/5 cm min. or FTB)	15 lbs./in. min. or film tearing bond (13 daN/5 cm min. or FTB)
Adhesion (minimum) Heat Welded Seam	ASTM D 751 Dielectric Weld	40 lbs./2in. RF weld min. (17.5 daN/5 cm min.)	40 lbs./2in. RF weld min. (17.5 daN/5 cm min.)	15 lbs./in. RF weld min. (15 daN/5 cm min.)
Dead Load Seam Strength	ASTM D 751, 4-Hour Test	Pass 220 lbs/in @ 70° F (Pass 980 N/2.54 cm @ 21° C) Pass 120 lbs/in @ 160° F (Pass 534 N/2.54 cm @ 70° C)	Pass 220 lbs/in @ 70° F (Pass 980 N/2.54 cm @ 21° C) Pass 120 lbs/in @ 160° F (Pass 534 N/2.54 cm @ 70° C)	
Bonded Seam Strength	ASTM D 751 Procedure A, Grab Test Method	550 lbs. min. (2,450 N min.)	550 lbs. min. (2,450 N min.)	550 lbs. min. (2,560 N min.)

Abrasion Resistance	ASTM D 3389 H-18 Wheel 1 kg Load	2,000 cycles min. before fabric exposure, 50 mg/100 cycles max. weight loss	2,000 cycles min. before fabric exposure, 50 mg/100 cycles max. weight loss	2,000 cycles min. before fabric exposure, 50 mg/100 cycles max. weight loss
Weathering Resistance	Carbon-Arc ASTM G 153	8,000 hours min. with no appreciable changes or stiffening or cracking of coating	8000 hours min. with no appreciable change or stiffening or cracking of coating	8000 hours min. with no appreciable change or stiffening or cracking of coating
Water Absorption	ASTM D 471, Section 12 7 Days	0.025 kg/m^2 max. @70° F/21° C 0.14 kg/m^2 max at 212° F/100° C	0.025 kg/m^2 max. @70° F/21° C 0.14 kg/m^2 max at 212° F/100° C	0.025 kg/m^2 max. @70° F/21° C 0.14 kg/m^2 max at 212° F/100° C
Wicking	ASTM D 751	1/8" max (0.3 cm max)	1/8" max. (0.3 cm max.)	1/8" max. (0.3 cm max.)
Bursting Strength	ASTM D 751 Ball Tip	750 lbs. min. (3,330 N min.)	750 lbs. min. (3,330 N min.)	750 lbs. min. (3,330 N min.)
Puncture Resistance	ASTM D 4833	275 lbs. min. 1,200 N min.	275 lbs. min. 1,200 N min.	275 lbs. min. 1,200 N min.
Coefficient of Thermal Expansion/ Contraction	ASTM D 696	8 x 10^{-6} in/in/° F max. (1.4 x 10^{-5} cm/cm/° C max.)	8 x 10^{-6} in/in/° F max. (1.4 x 10^{-5} cm/cm/° C max.)	8 x 10^{-6} in/in/° F max. (1.4 x 10^{-5} cm/cm/° C max.)
Environmental/Chemical Resistant Properties		See Chemical Resistance Table, Page 8	See Chemical Resistance Table, Page 8	See Chemical Resistance Table, Page 8
Puncture Resistance	FED-STD-101C Method 2031	350 lbs. (approx.)	350 lbs. (approx.)	
Cold Crack	ASTM D 2136 4 Hrs, 1/8" Mandrel	Pass at -30° F/-34° C	Pass @ -30° F/-34° C	Pass @ -30° F/-34° C

Section 2 - Physical Properties

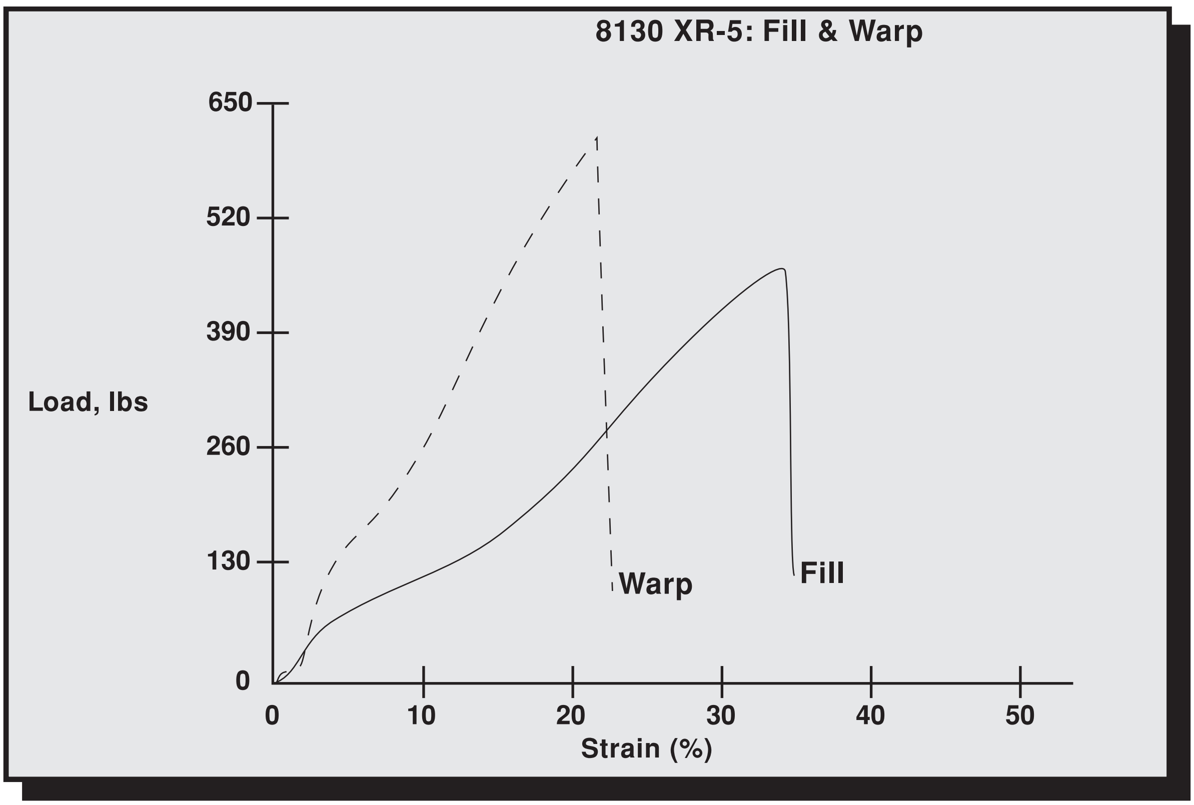
Part 1- Material Specifications (cont.)

Property	Test Method	8130 XR-3 PW	8228 XR-3
Base Fabric Type Base Fabric Weight	ASTM D 751	Polyester 6.5 oz/yd^2 nominal (220 g/m^2 nominal)	Polyester 3.0 oz/yd^2 nominal (100 g/m^2 nominal)
Thickness	ASTM D 751	30 mils min. (0.76 mm min.)	30 mils min. (0.76 mm min.)
Weight	ASTM D 751	30.0 +- 2 oz./sq. yd. (1017 +- 70 g/sq. m)	28.0 +- 2 oz./sq. yd. (950 +- 70 g/sq. m)
Tear Strength	ASTM D 751 Trap Tear	40/55 lbs. min. (175/245 N min.)	30/30 lbs. nom. (133/133 N nom.)
Breaking Yield Strength	ASTM D 751 Grab Tensile	550/550 lbs. min. (2,447/2447 N min.)	250/200 lbs. min. (1,110/890 N min.)
Low Temperature Resistance	ASTM D 2136 4hrs-1/8" Mandrel	Pass @ -30° F (Pass @ -35° C)	Pass @ -25° F (Pass @ -32° C)
Dimensional Stability	ASTM D 1204 100° C-1 hr.	0.5% max. each direction	5% max. each direction
Hydrostatic Resistance	ASTM D 751 Method A	800 psi min. (5.51 MPa min.)	300 psi min. (2.07 MPa min.)
Blocking Resistance	ASTM D 751 180° F	#2 Rating max.	#2 Rating max.
Adhesion-Ply	ASTM D 413 Type A	15 lbs./in. min. or film tearing bond (13 daN/5 cm min. or FTB)	12 lbs./in. (approx.) (10 daN/5 cm approx.)
Adhesion- Heat Welded Seam	ASTM D 751 Dielectrc Weld	40 lbs./2in. min. (17.5 daN/5 cm min.)	10 lbs./in min. (9 daN/5 cm min.)
Dead Load Seam Strength	ASTM D 751, 4-Hour Test	Pass 220 lbs/in. @ 70° F (Pass 980 N/2.54 cm @ 21° C) Pass 120 lbs/in. @ 160° F (Pass 534 N/2.54 cm @ 70° C)	Pass 100 lbs/in @ 70° F (Pass 445 N @ 21° C) Pass 50 lb @ 160° F (Pass 220 N @ 70° C)
Bonded Seam Strength	ASTM D 751 Procedure A, Grab Test Method	550 lbs. min. (2,450 N min.)	250 lbs. (approx.) (1,112 N min.)

Abrasion Resistance	ASTM D 3389 H-18 Wheel 1 kg Load	2000 cycles min. before fabric exposure, 50 mg/100 cycles max. weight loss	2000 cycles min.
Weathering Resistance	ASTM G 153	8000 hours min. with no appreciable change or stiffening or cracking of coating	8000 hours min.
Water Absorption	ASTM D 471, Section 12 7 Days	0.025 kg/m^2 max. @ 70° F/21° C 0.14 kg/m^2 max @ 212° F/100° C	0.05 kg/m^2 max. @ 70° F/21° C (approx.) 0.28 kg/m^2 max. @ 212° F/100° C (approx.)
Wicking	ASTM D 751	1/8" max. (0.3 cm max.)	1/8" max (0.3 cm max.)
Bursting Strength	ASTM D 751 Ball Tip	750 lbs. min. (3330 N min.)	350 lbs. (approx.) (1557 N min.)
Puncture Resistance	ASTM D 4833	275 lbs. min. 1200 N min.	50 lb typ. (225 N typ.)
Coefficient of Thermal Expansion/ Contraction	ASTM D 696	8 x 10^{-6} in/in/° F max. (1.4 x 10^{-5} cm/cm/° C max.)	8 x 10^{-6} in/in/° F max. (approx.) (1.4 x 10^{-5} cm/cm/° C max. approx.)
Environmental/Chemical Resistant Properties	ASTM D 741 7-Day Total Immersion With Exposed Edges	NSF 61 approved for potable water	Crude oil 5% max. weight gain Diesel fuel 5% max. weight gain
Puncture Resistance	FTMS 101C Method 2031	350 lbs. (approx.)	205 lbs. (approx.)
Tongue Tear	ASTM D 751		50 lbs. (approx.)

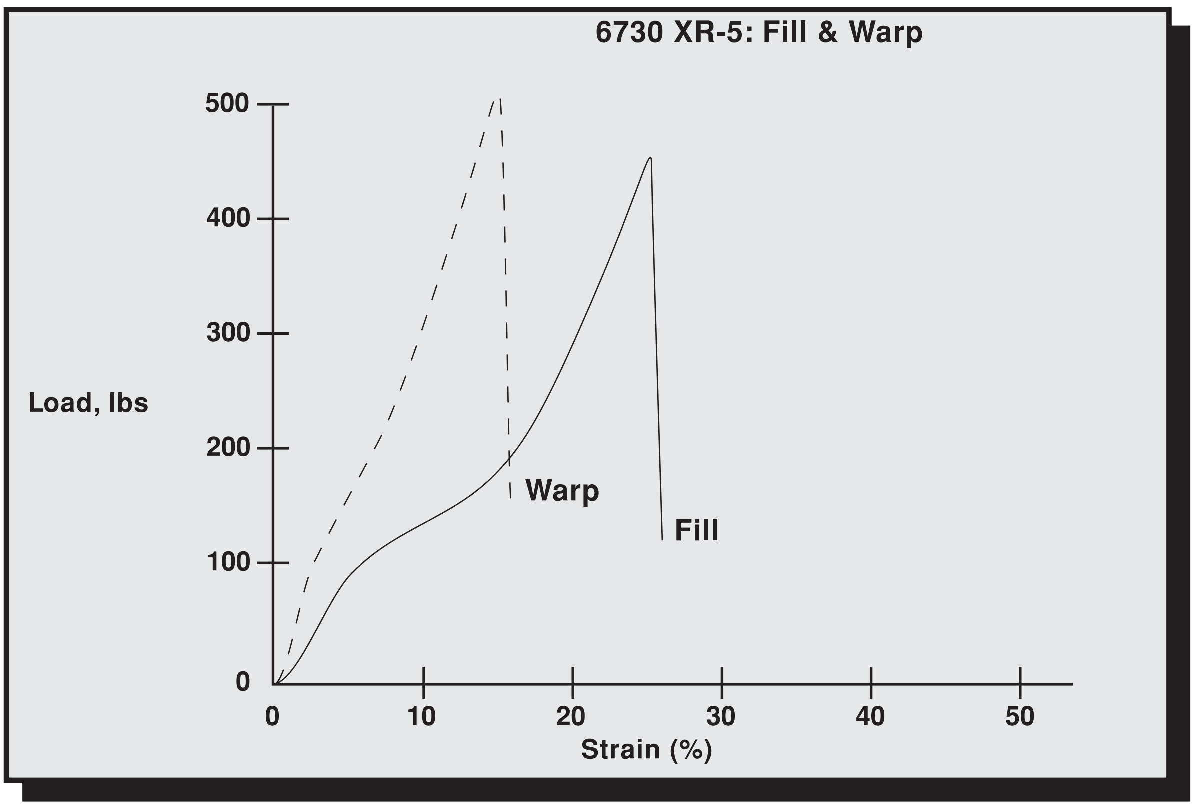
Part 2 - Elongation Properties Test

8130 XR-5



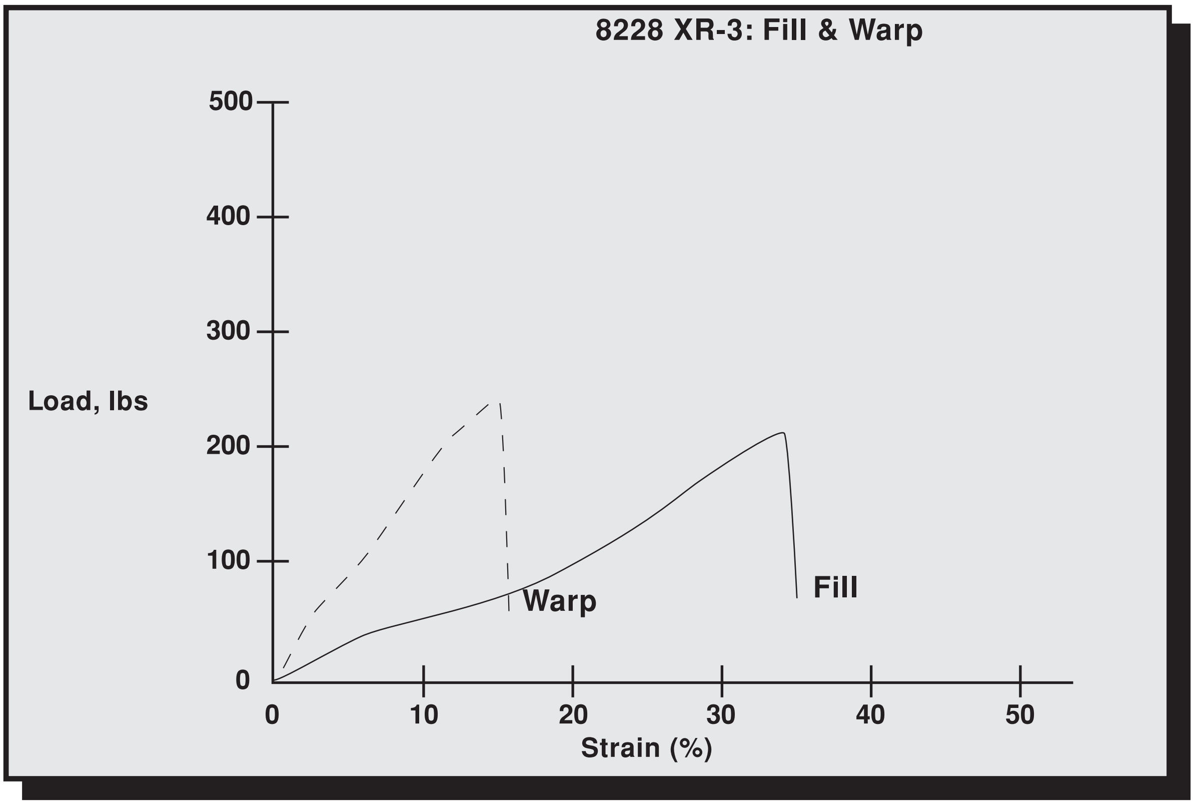
Part 2 - Elongation Properties Test

6730 XR-5



Part 2 - Elongation Properties Test

8228 XR-3



Section 3 - Chemical/Environmental Resistance

Part 1 - XR-5® Fluid Resistance Guidelines

The data below is the result of laboratory tests and is intended to serve only as a guide. No performance warranty is intended or implied. The degree of chemical attack on any material is governed by the conditions under which it is exposed. Exposure time, temperature, and size of the area of exposure usually varies considerably in application, therefore, this table is given and accepted at the user's risk. Confirmation of the validity and suitability in specific cases should be obtained. Contact a Seaman Corporation Representative for recommendation on specific applications.

When considering XR-5 for specific applications, it is suggested that a sample be tested in actual service before specification. Where impractical, tests should be devised which simulate actual service conditions as closely as possible.

EXPOSURE	RATING	EXPOSURE	RATING
AFFF	A	JP-4 Jet Fuel	A
Acetic Acid (5%)	B	JP-5 Jet Fuel	A
Acetic Acid (50%)	C	JP-8 Jet Fuel	A
Ammonium Phosphate	T	Kerosene	A
Ammonium Sulfate	T	Magnesium Chloride	T
Antifreeze (Ethylene Glycol)	A	Magnesium Hydroxide	T
Animal Oil	A	Methanol	A
Aqua Regia	X	Methyl Alcohol	A
ASTM Fuel A (100% Iso-Octane)	A	Methyl Ethyl Ketone	X
ASTM Oil #2 (Flash Pt. 240° C)	A	Mineral Spirits	A
ASTM Oil #3	A	Naphtha	A
Benzene	X	Nitric Acid (5%)	B
Calcium Chloride Solutions	T	Nitric Acid (50%)	C
Calcium Hydroxide	T	Perchloroethylene	C
20% Chlorine Solution	A	Phenol	X
Clorox	A	Phenol Formaldehyde	B
Conc. Ammonium Hydroxide	A	Phosphoric Acid (50%)	A
Corn Oil	A	Phosphoric Acid (100%)	C
Crude Oil	A	Phthalate Plasticizer	C
Diesel Fuel	A	Potassium Chloride	T
Ethanol	A	Potassium Sulphate	T
Ethyl Acetate	C	Raw Linseed Oil	A
Ethyl Alcohol	A	SAE-30 Oil	A
Fertilizer Solution	A	Salt Water (25%)	B
#2 Fuel Oil	A	Sea Water	A
#6 Fuel Oil	A	Sodium Acetate Solution	T
Furfural	X	Sodium Bisulfite Solution	T
Gasoline	B	Sodium Hydroxide (60%)	A
Glycerin	A	Sodium Phosphate	T
Hydraulic Fluid- Petroleum Based	A	Sulphuric Acid (50%)	A
Hydraulic Fluid- Phosphate Ester Based	C	Tanic Acid (50%)	A
Hydrocarbon Type II (40% Aromatic)	C	Toluene	C
Hydrochloric Acid (50%)	A	Transformer Oil	A
Hydrofluoric Acid (5%)	A	Turpentine	A
Hydrofluoric Acid (50%)	A	Urea Formaldehyde	A
Hydrofluosilicic Acid (30%)	A	UAN	A
Isopropyl Alcohol	T	Vegetable Oil	A
Ivory Soap	A	Water (200°F)	A
Jet A	A	Xylene	X
		Zinc Chloride	T

Ratings are based on visual and physical examination of samples after removal from the test chemical after the samples of Black XR-5 were immersed for 28 days at room temperature. Results represent ability of material to retain its performance properties when in contact with the indicated chemical.

Rating Key:
A – Fluid has little or no effect
B – Fluid has minor to moderate effect
C – Fluid has severe effect
T – No data - likely to be acceptable
X – No data - not likely to be acceptable

Vapor Transmission Data

Tested according to ASTM D814-55 Inverted Cup Method

Perhaps a more meaningful test is determination of the diffusion rate of the liquid through the membrane. The vapor transmission rate of Style 8130 XR-5® to various chemicals was determined by the ASTM D814-55 inverted cup method. All tests were run at room temperature and results are shown in the table.

Chemical	8130 XR-5 Black g/hr/m2
Water	0.11
#2 Diesel Fuel	0.03
Jet A	0.11
Kerosene	0.15
Hi-Test Gas	1.78
Ohio Crude Oil	0.03
Low-Test Gas	5.25
Raw Linseed Oil	0.01
Ethyl Alcohol	0.23
Naphtha	0.33
Perchlorethylene	38.58
Hydraulic Fluid	0.006
100% Phosphoric Acid	7.78
50% Phosphoric Acid	0.43
Ethanol (E-96)	0.65
Transformer Oil	0.005
Isopropyl Alcohol	0.44
JP4 (E-96)	0.81
JP8 (E-96)	0.42
Fuel B (E-96)	6.28
Fuel C (E-96)	7.87

Note: The tabulated values are measured Vapor Transmission Rates (VTR). Normal soil testing methods to determine permeability are impractical for synthetic membranes. An "equivalent hydraulic" permeability coefficient can be calculated but is not a direct units conversion. Contact Seaman Corporation for additional technical information.

Seam Strength

Style 8130 XR-5 Black Seam Strength After Immersion

Two pieces of Style 8130 were heat sealed together (seam width 1 inch overlap) and formed into a bag. Various oils and chemicals were placed in the bags so that the seam area was entirely covered. After 28 days at room temperature, the chemicals were removed and one inch strips were cut across the seam and the breaking strength immediately determined. Results are listed below.

Chemical	Seam Strength
None	340 Lbs. Fabric Break- No Seam Failure
Kerosene	355 Lbs. Fabric Break- No Seam Failure
Ohio Crude Oil	320 Lbs. Fabric Break- No Seam Failure
Hydraulic Fluid- Petroleum Based	385 Lbs. Fabric Break- No Seam Failure
Toluene	0 Lbs. Adhesion Failure
Naphtha	380 Lbs. Fabric Break- No Seam Failure
Perchloroethylene	390 Lbs. Fabric Break- No Seam Failure

Even though 1-inch overlap seams are used in the tests to study the accelerated effects, it is recommended that XR-5 be used with a 2-inch nominal overlap seam in actual application. In some cases where temperatures exceed 160ºF and the application demands extremely high seam load, it may be necessary to use a wider width seam.

Long Term Seam Adhesion

11 Years Immersion
ASTM D 751
Lbs./In.

Seam samples of 8130 XR-5® were dielectrically welded together and totally immersed in the liquids for 11 years. The samples were taken out, dried for 24 hours and visually observed for any signs of swelling, cracking, stiffening or degradation of the coating. The coating showed no appreciable degradation and no stiffening, swelling, cracking or peeling.

The adhesion, or resistance to separation of the coating from the base cloth, was then measured by ASTM D 751. Results show 8130 XR-5 maintains seam strength over this long period (11 years).

	Control	Crude Oil	JP-4 Jet Fuel	Diesel Fuel	Kerosene	Naphtha
8130 XR-5	20+	18	33	25	40	33*

Values in lbs./in.

*The naphtha sample was sticky.

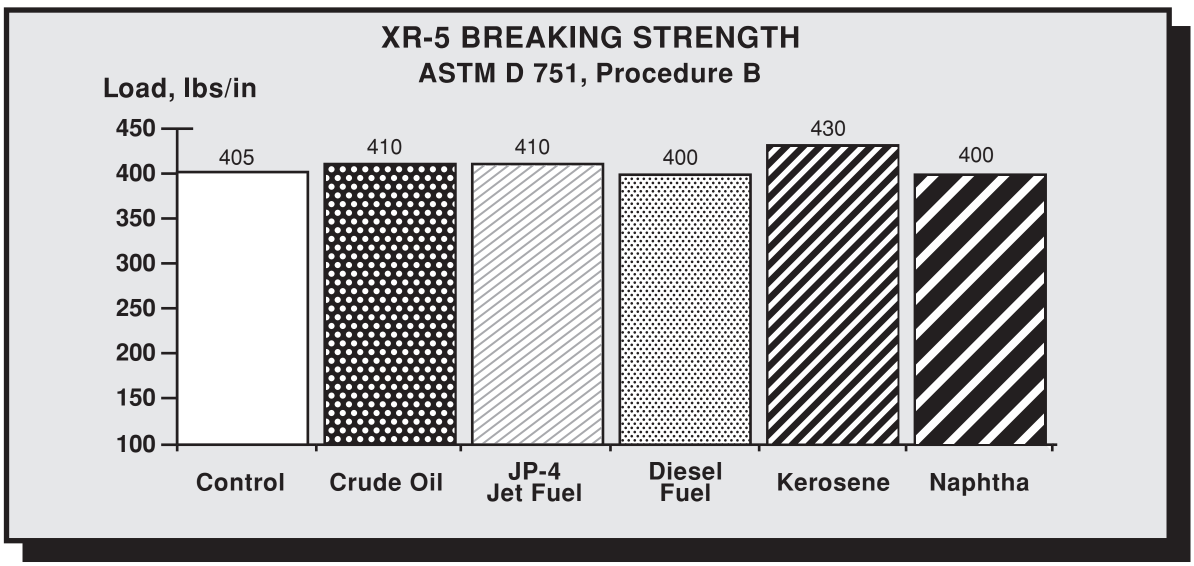
Fuel Compatibility - Long Term Immersion

Test: Samples of 8130 XR-5® Black were immersed in Diesel Fuel, JP-4 Jet Fuel, Crude Oil, Kerosene, and Naphtha for 6 1/2 years.

The samples were then taken out of the test chemicals, blotted and dried for 24 hours. The samples were observed for blistering, swelling, stiffening, cracking or delamination of the coating from the fiber.

Results: It was found in all cases that the 8130 XR-5, after immersion for six years, maintained its strength and there was no evidence of blistering, swelling, stiffening, cracking or delamination.

The strip tensile strength, or breaking strength, of the samples was measured after six years of immersion and the following are the results.



XR-3 Chemical Resistance Statement (Summary)

XR-3® is recommended for moderate chemical resistant applications such as stormwater and municipal wastewater and is not recommended for prolonged contact with pure solutions. XR-3 PW® membranes are recommended only for contact with drinking water and are resistant to low levels of chlorine found in drinking water. XR-5 has a broad range of chemical resistance which is detailed in this section.

Part 2: XR-5® Comparative Chemical Resistance

Chemical Resistance Chart

Comparative Chemical Resistance

	XR-5	HDPE	PVC	Hypalon	Polypropylene
Kerosene	A	B	C	C	C
Diesel Fuel	A	A	C	C	C
Acids (General)	A	A	A	B	A
Naphtha	A	A	C	B	C
Jet Fuels	A	A	C	B	C
Saltwater, 160° F	A	A	C	B	A
Crude Oil	A	B	C	B	C
Gasoline	B	B	C	C	C

A= Excellent **B= Moderate** **C= Poor**

Source: Manufacturer's Literature

XR-5 data based on conditions detailed in Section 3, Part 1.

Part 3: Weathering Resistance

Accelerated Weathering Test

XR-5 has been tested in the carbon arc weatherometer for over 10,000 hours of exposure and in the Xenon weatherometer for over 12,000 hours of exposure. The sample showed no loss in flexibility and no significant color change. Based on field experience of Seaman Corporation products and similar weatherometer exposure tests, XR-5 should have an outdoor weathering life significantly longer than competitive geomembranes, particularly in tropical or subtropical applications.

EMMAQUA Testing: ASTM E-838-81 was performed on a modified form of XR-5, FiberTite, used in the single-ply roofing industry. After 3 million Langleys in Arizona, no signs of degradation were noted with no evidence of cracking, blistering, swelling or adhesion delamination failure of the coating.

Natural Exposure

After over 17 years as a holding basin at a large oil company in the Texas desert, XR-5 showed no signs of environmental stress cracking, thermal expansion/contraction, or low yield strength problems. Temperature ranges from near zero to over 100° F.

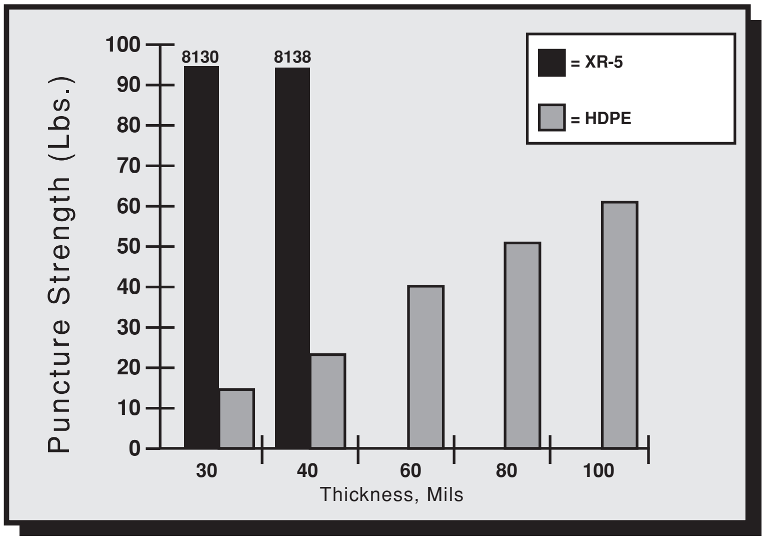
In service approximately 17 years in a solar pond application at a research facility in Ohio, UV exposed samples, as well as immersed samples, retained over 90% of the tensile strength. Examination of the material determined there was little effect on the coating compound. The solar pond was exposed to temperatures from below zero to over 100° F.

XR5 was exposed for 12½ years in Sarasota, Florida, on a weathering rack, facing the southern direction at 45°. No significant color loss, cracking, crazing, blistering, or adhesion delamination failure of the coating was noted.

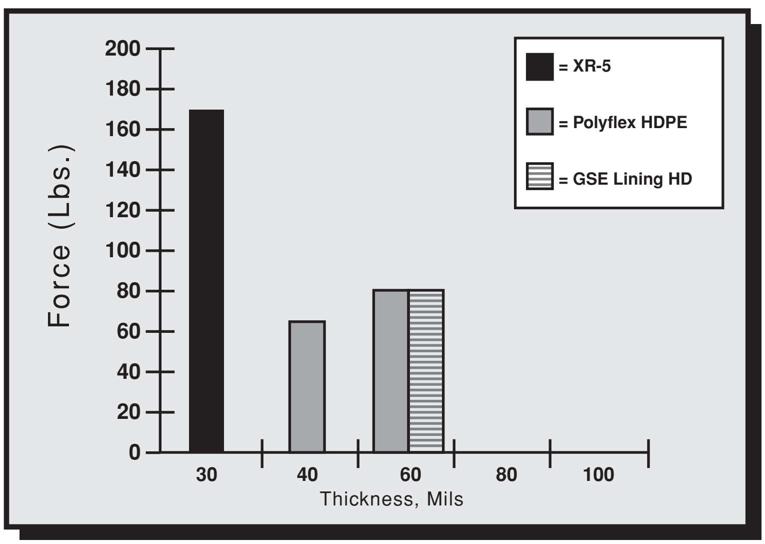
Section 4 - Comparative Physical Properties

XR-5/HDPE Comparative Properties

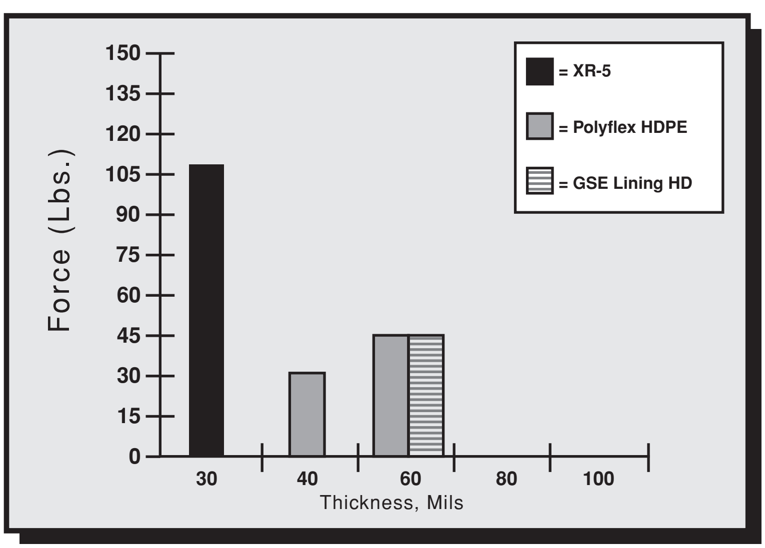
Puncture Resistance



1. ASTM D 751, Screwdriver Tip, 45° Angle (Room Temperature) Puncture Resistance, XR5 vs. HDPE



2. FED-STD-101C Method 2065 (Room Temperature)*



3. FED-STD-101C Method 2065 (70°C)*

* Data provided by E.I. DuPont de Nemours & Co. Wilmington, Delaware

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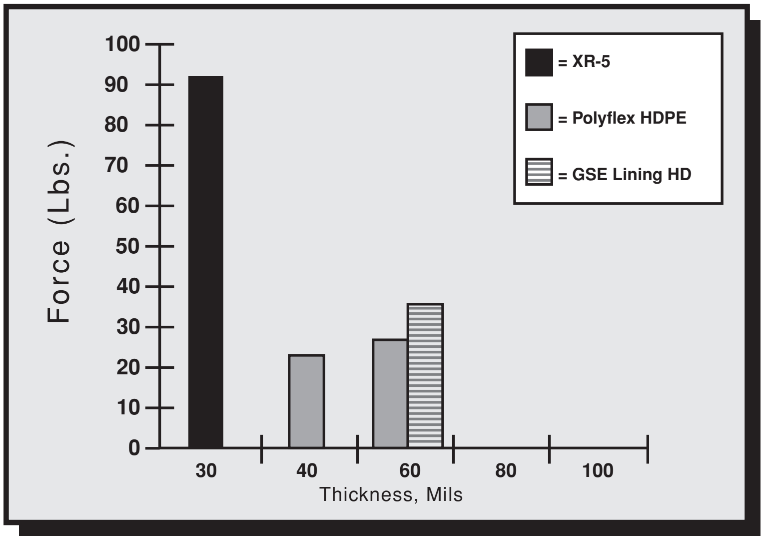
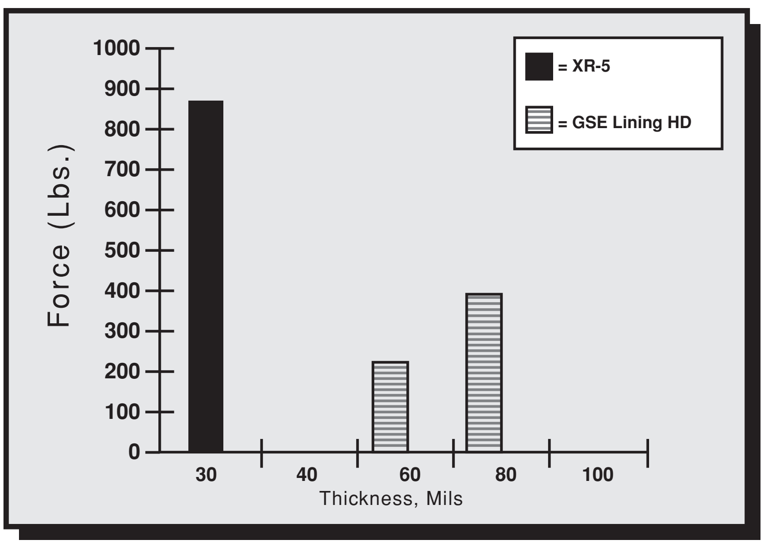
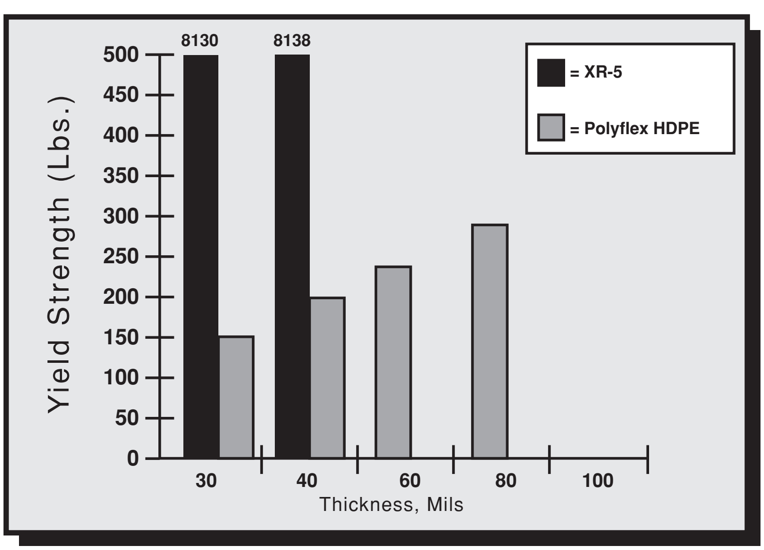


4. FED-STD-101C Method 2065 (100°C)*



5. ASTM D 751 Ball Burst Puncture

Yield Strength



1. Yield Strength, XR-5 vs. HDPE

Test Method: Grab Tensile, ASTM D 751, 70° C

* Data provided by E.I. DuPont de Nemours & Co. Wilmington, Delaware

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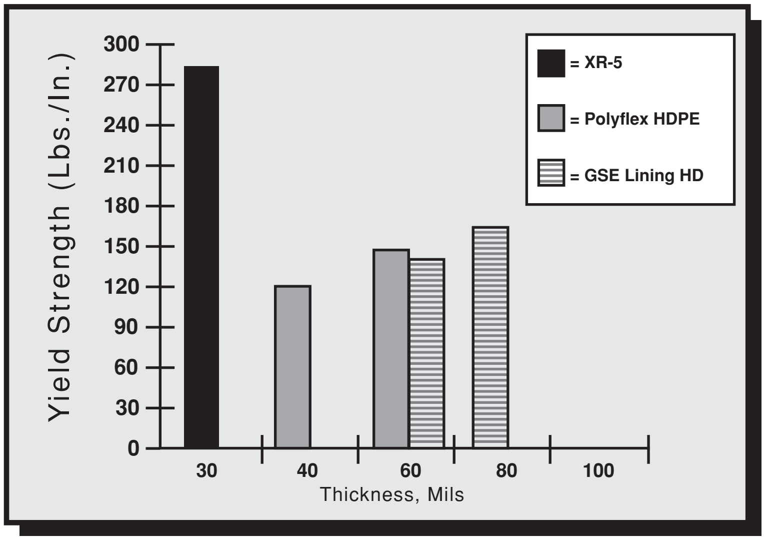
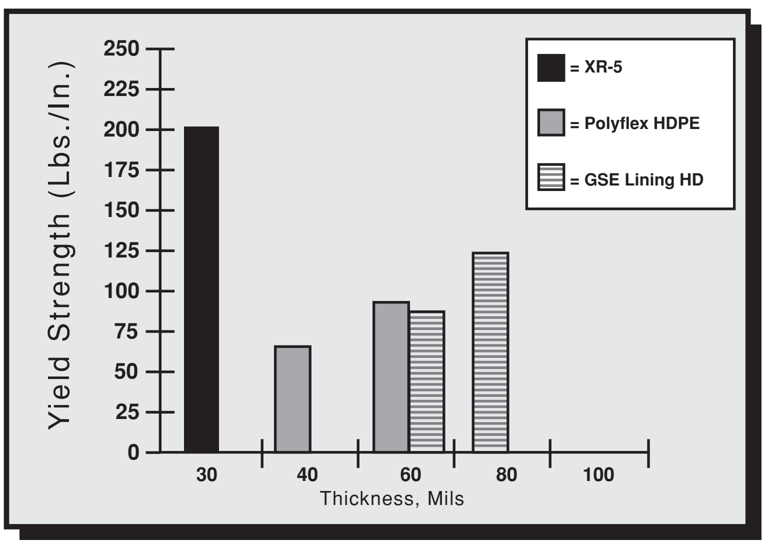
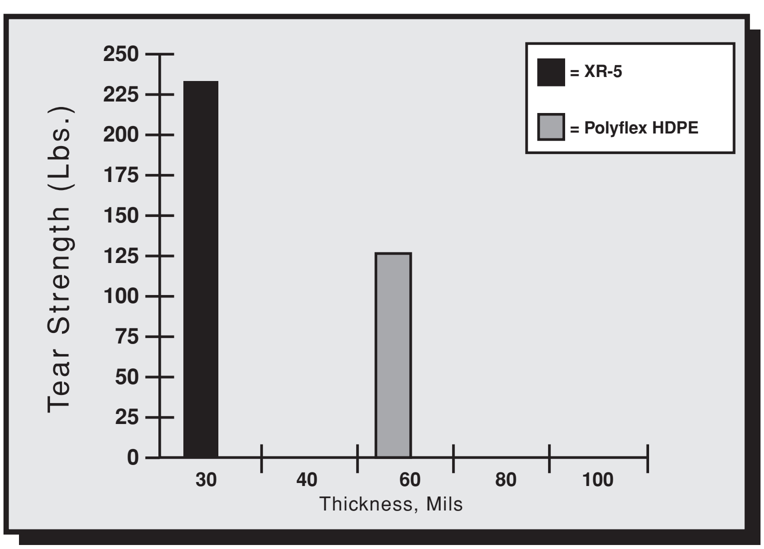


2. Strip Tensile, ASTM D 751, Room Temperature*



3. Strip tensile, ASTM D 751, 70°C*

Tear Strength



1. Tongue Tear (8" x 10" Specimens), ASTM D 751, Room Temperature*

* Data provided by E.I. DuPont de Nemours & Co. Wilmington, Delaware

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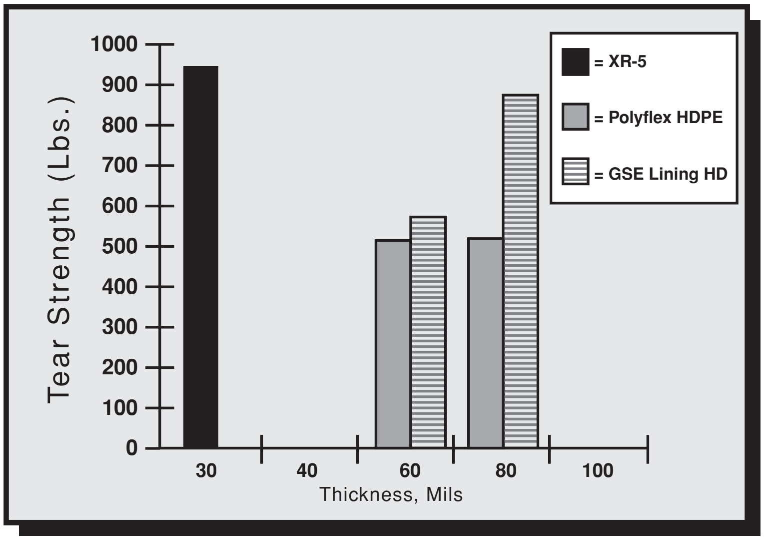
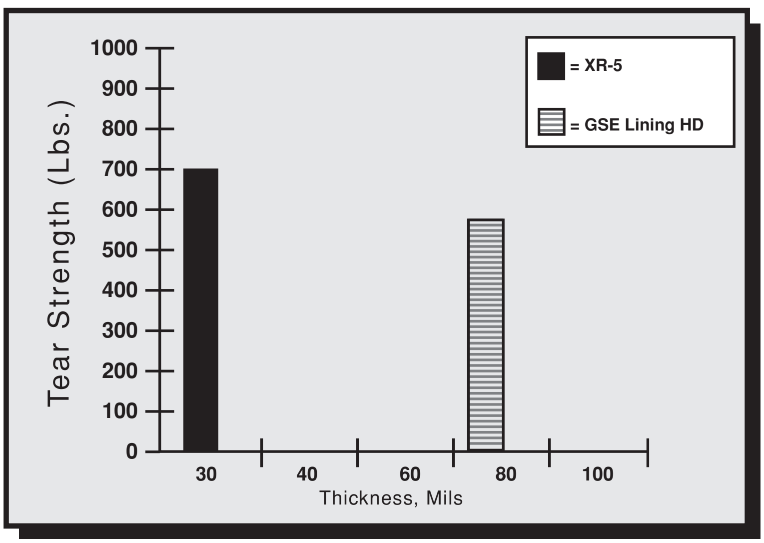


1. Graves Tear, ASTM D 624, Die C, Room Temperature*

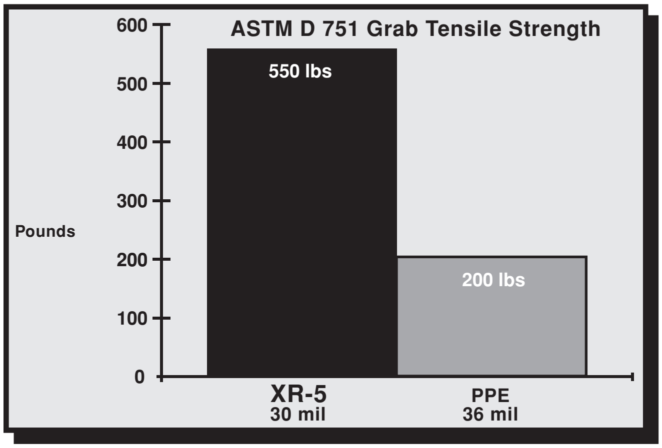


2. Graves Tear, ASTM D 624, Die C, 70°C*

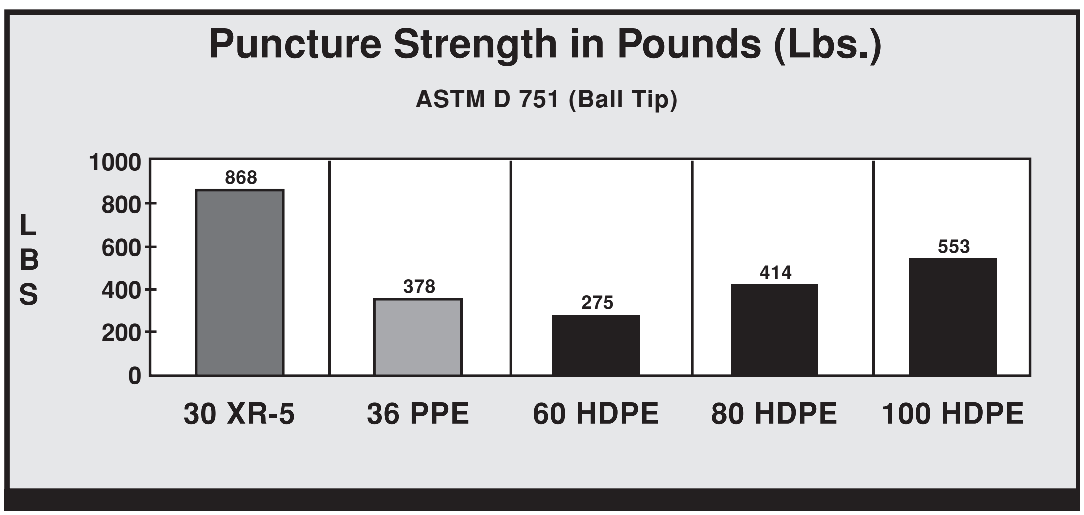
* Data provided by E.I. DuPont de Nemours & Co. Wilmington, Delaware

GSE is a registered trademark of GSE Lining Technology, Inc.

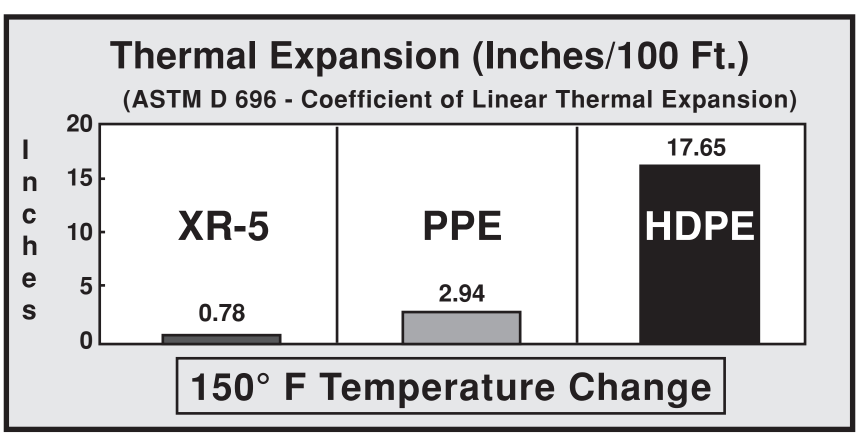
Grab Strength – XR-5® vs. Polypropylene Tensile



Puncture Strength Comparison



Coated Fabric Thermal Stability



Specification For Geomembrane Liner

(Sample specification: 8130 XR-5®. For other product specifications, go to www.xr-5.com)

General

1.01 Scope Of Work
Furnish and install flexible membrane lining in the areas shown on the drawings. All work shall be done in strict accordance with the project drawings, these specifications and membrane lining fabricator's approved shop drawings.

Geomembrane panels will be supplied sufficient to cover all areas, including appurtenances, as required in the project, and shown on the drawings. The fabricator/installer of the liner shall allow for shrinkage and wrinkling of the field panels.

1.02 Products
The lining material shall be 8130 XR-5 as manufactured by Seaman Corporation (1000 Venture Boulevard, Wooster, OH 44691; 330-262-1111), with the following physical specifications:

Base- (Type)	Polyester
Fabric Weight (ASTM D 751)	6.5 oz./sq. yd.
Finished Coated Weight (ASTM D 751)	30 ± 2 oz./sq. yd.
Trapezoid Tear (ASTM D 751)	40/55 lbs. min.
Grab Yield Tensile (ASTM D 751, Grab Method Procedure A)	550/550 lbs. min.
Elongation @ Yield (%)	20% min.
Adhesion- Heat Seam (ASTM D 751, Dielectric Weld)	40 lbs./2in. weld min.
Adhesion- Ply (ASTM D 413, Type A)	15 lbs./in. or film tearing bond
Hydrostatic Resistance (ASTM D 751, Method A)	800 psi min.
Puncture Resistance (ASTM D 4833)	275 lbs. min.
Bursting Strength (ASTM D 751 Ball Tip)	750 lbs. min.
Dead Load (ASTM D 751) Room Temperature	220 lbs. min.
(2" overlap seam, 4 hours) 160°F	120 lbs. min.
Bonded Seam Strength (ASTM D 751 Grab Test Method, Procedure A)	575 lbs. min.
Low Temperature (ASTM D 2136, 4 hours- 1/8" Mandrel)	Pass @ -30°F
Weathering Resistance ASTM G 153 Carbon Arc	8,000 hours min. With no appreciable changes or stiffening or cracking of coating
Dimensional Stability (ASTM D 1204, 212°F 1 Hour, Each Direction)	0.5% max.
Water Absorption (ASTM D 471, 7 Days)	0.025 kg/m^2 max. @ 70°F 0.14 kg/m^2 max. @ 212°F
Abrasion Resistance ASTM D 3389,	2000 cycles before fabric exposure;
H-18 Wheel, 1000 g load	50 mg/100 cycles max. wgt. Loss
Coefficient of Thermal Expansion/Contraction (ASTM D 696)	8 x 10^{-6} in/in/° F max.

1.03 Submittals
The fabricator of panels used in this work shall prepare shop drawings with a proposed panel layout to cover the liner area shown in the project plans. Shop drawings shall indicate the direction of factory seams and shall show panel sizes consistent with the material quantity requirements of 1.01.

Details shall be included to show the termination of the panels at the perimeter of lined areas, the methods of sealing around penetrations, and methods of anchoring.

Placement of the lining shall not commence until the shop drawings and details have been approved by the owner, or his representative.

1.04 Factory Fabrication

The individual XR-5® liner widths shall be factory fabricated into large sheets custom designed for this project so as to minimize field seaming. The number of factory seams must exceed the number of field seams by a factor of at least 10.

A two-inch overlap seam done by heat or RF welding is recommended. The surface of the welded areas must be dry and clean. Pressure must be applied to the full width of the seam on the top and bottom surface while the welded area is still in a melt-type condition. The bottom welding surface must be flat to insure that the entire seam is welded properly. Enough heat shall be applied in the welding process that a visible bead is extruded from both edges being welded. The bead insures that the material is in a melt condition and a successful chemical bond between the two surfaces is accomplished.

Two-inch overlapped seams must withstand a minimum of 240 pounds per inch width dead load at 70° F. and 120 pounds per inch width at 160° F. as outlined in ASTM D 751. All seams must exceed 550 lbs. bonded seam strength per ASTM D 751 Bonded Seam Strength Grab Test Method, Procedure A.

1.05 Inspection And Testing Of Factory Seams

The fabricator shall monitor each linear foot of seam as it is produced. Upon discovery of any defective seam, the fabricator shall stop production of panels used in this work and shall repair the seam, and determine and rectify the cause of the defect prior to continuation of the seaming process.

The fabricator must provide a Quality Control procedure to the owner or his representative which details his method of visual inspection and periodic system checks to ensure leak-proof factory fabrication.

1.06 Certification and Test Reports

Prior to installation of the panels, the fabricator shall provide the owner, or his representative, with written certification that the factory seams were inspected in accordance with Section 1.05.

1.07 Panel Packaging and Storage

Factory fabricated panels shall be accordian-folded, or rolled, onto a sturdy wooden pallet designed to be moved by a forklift or similar equipment. Each factory fabricated panel shall be prominently and indelibly marked with the panel size. Panels shall be protected as necessary to prevent damage to the panel during shipment.

Panels which have been delivered to the project site shall be stored in a dry area.

1.08 Qualifications of Suppliers

The fabricator of the lining shall be experienced in the installation of flexible membrane lining, and shall provide the owner or his representative with a list of not less than five (5) projects and not less than 500,000 square feet of successfully installed XR-5 synthetic lining. The project list shall show the name, address, and telephone number of an appropriate party to contact in each case. The manufacturer of the sheet goods shall provide similar documentation with a 10 million square foot minimum, with at least 5 projects demonstrating 10+ years service life.

The installer shall provide similar documentation to that required by the fabricator.

1.09 Subgrade Preparation By Others

Lining installation shall not begin until a proper base has been prepared to accept the membrane lining. Base material shall be free from angular rocks, roots, grass and vegetation. Foreign materials and protrusions shall be removed, and all cracks and voids shall be filled and the surface made level, or uniformly sloping as indicated on the drawings. The prepared surface shall be free from loose earth, rocks, rubble and other foreign matter. Generally, no rock or other object larger than USCS sand (SP) should remain on the subgrade in order to provide an adequate safety factor against puncture. Geotextiles may be used to compensate for irregular subgrades. The subgrade shall be uniformly compacted to ensure against settlement. The surface on which the lining is to be placed shall be maintained in a firm, clean, dry and smooth condition during lining installation.

1.10 Lining Installation
Prior to placement of the liner, the installer will indicate in writing to the owner or his representative that he believes the subgrade to be adequately prepared for the liner placement.

The lining shall be placed over the prepared surface in such a manner as to assure minimum handling. The sheets shall be of such lengths and widths and shall be placed in such a manner as to minimize field seaming.

In areas where wind is prevalent, lining installation should be started at the upwind side of the project and proceed downwind. The leading edge of the liner shall be secured at all times with sandbags or other means sufficient to hold it down during high winds.

Sandbags or rubber tires may be used as required to hold down the lining in position during installation. Materials, equipment or other items shall not be dragged across the surface of the liner, or be allowed to slide down slopes on the lining. All parties walking or working upon the lining material shall wear soft-sole shoes.

Lining sheets shall be closely fit and sealed around inlets, outlets and other projections through the lining. Lining to concrete seals shall be made with a mechanical anchor, or as shown on the drawings. All piping, structures and other projections through the lining shall be sealed with approved sealing methods.

1.11 XR-5 Field Seaming
All requirements of Section 1.04 and 1.05 apply. A visible bead should be extruded from the hot air welding process.

Field fabrication of lining material will not be allowed.

1.12 Inspection
All field seams will be tested using the Air Lance Method. A compressed air source will deliver 55 psi minimum to a 3/16 inch nozzle. The nozzle will be directed to the lip of the field seam in a near perpendicular direction to the length of the field seam. The nozzle will be held 4 inches maximum from the seam and travel at a rate not to exceed 40 feet per minute. Any loose flaps of 1/8" or greater will require a repair.

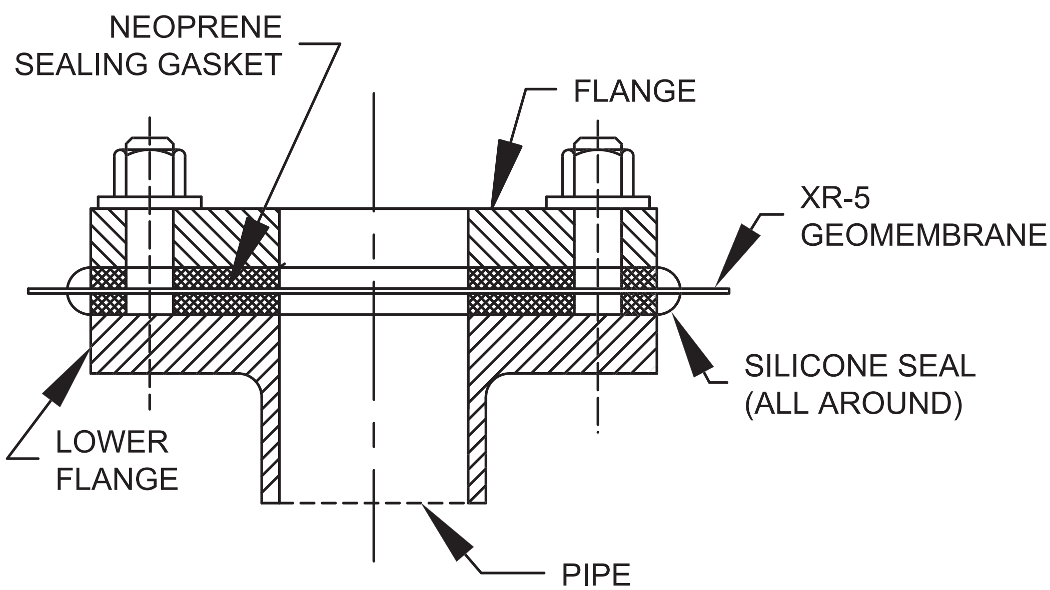
Alternatively all field seams should also be inspected utilizing the Vacuum Box Technique as described in Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber (ASTM D 5641-94 (2006)), using a 3 to 5 psi vacuum pressure. All leaks shall be repaired and tested.

All joints, on completion of work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade, shall as directed by the owner or his representative be replaced or covered, and sealed with an additional layer of lining of the proper size, in accordance with the patching procedure.

1.13 Patching
Any repairs to the lining shall be patched with the lining material. The patch material shall have rounded corners and shall extend a minimum of four inches (4") in each direction from the damaged area.

Seam repairs or seams which are questionable should be cap stripped with a 1" wide (min.) strip of the liner material. The requirements of Section 1.11 apply to this cap stripping.

1.14 Warranty
The lining material shall be warranted on a pro-rated basis for 10 years against both weathering and chemical compatibility in accordance with Seaman Corporation warranty for XR-5® Style 8130. A test immersion will be performed by the owner and the samples evaluated by the manufacturer. Workmanship of installation shall be warranted for one year on a 100% basis.



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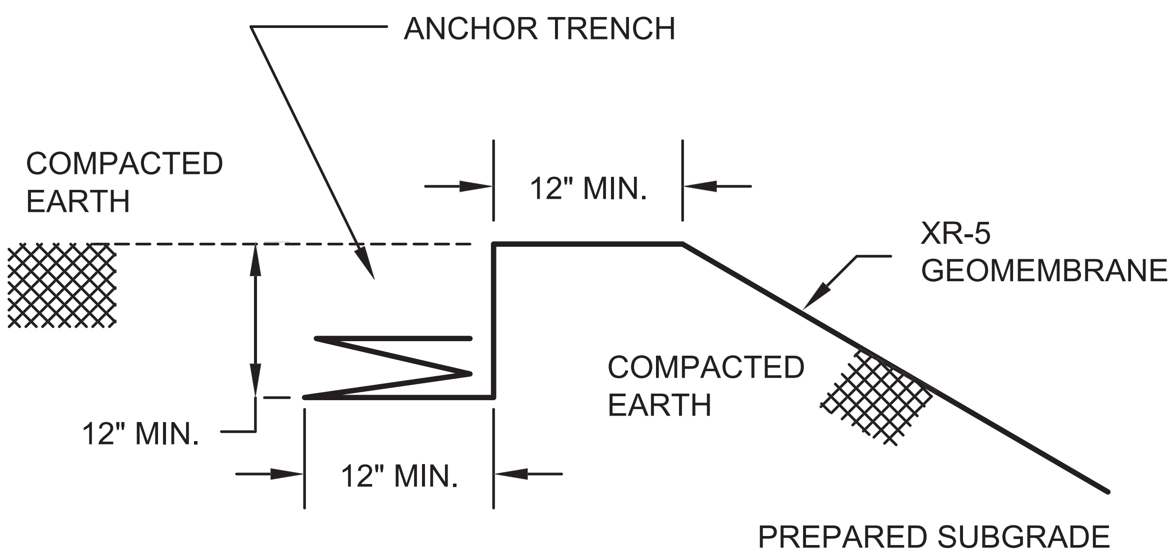
FLANGE CONNECTION
TO
PIPE SECTION

SCALE: NONE	
SHEET 1 of 1	DRAW NO. XRD-019



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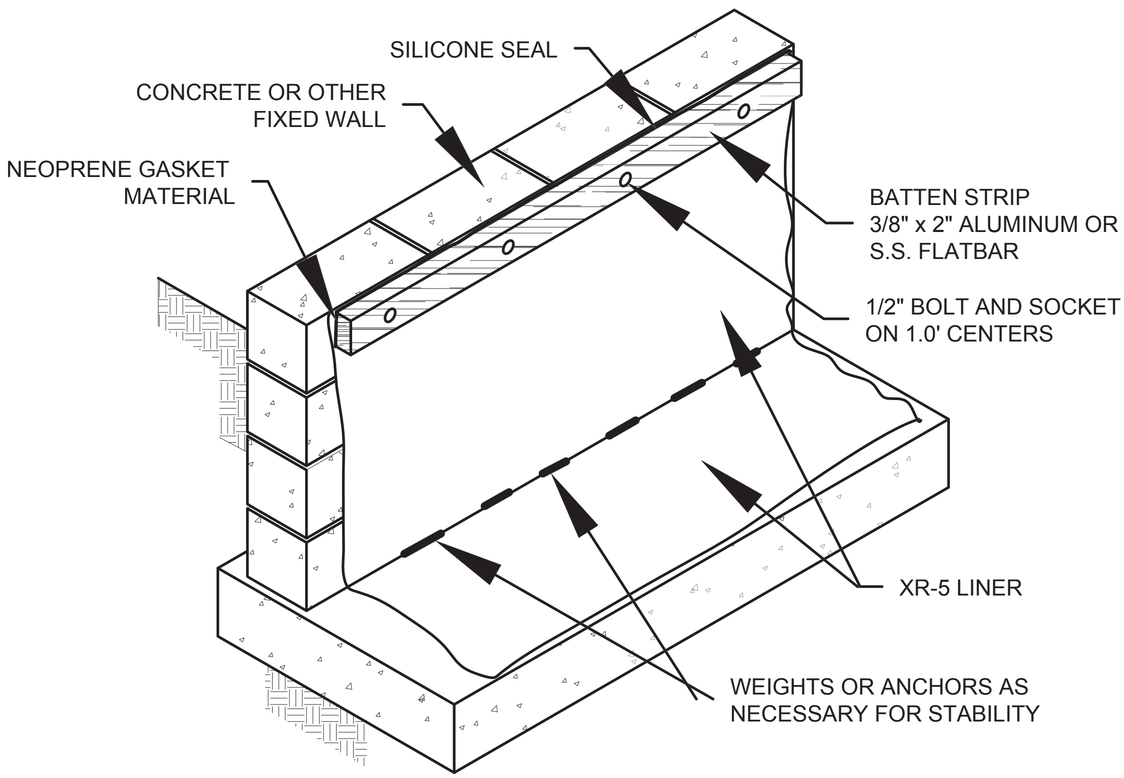
1000 Venture Blvd.,Wooster, Ohio 44691

ELEVATION VIEW
TYPICAL ANCHOR DETAILS
XR-5 LINER

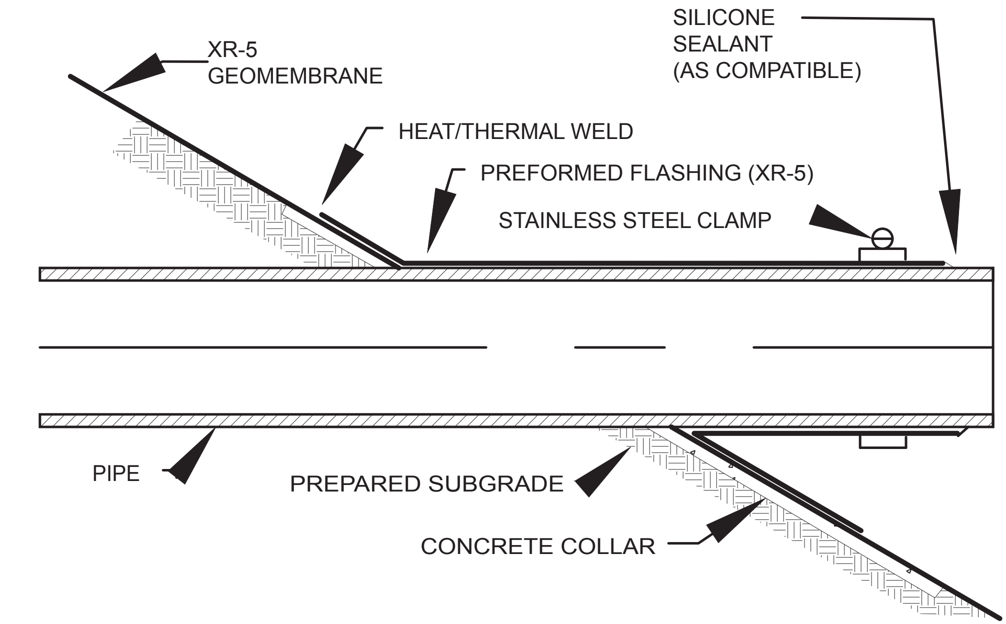
SCALE: NONE

SHEET 1 of 1

DRAW NO. XRD-001



Seaman Corporation ENGINEERED PRODUCTS GROUP 1000 Venture Blvd.,Wooster, Ohio 44691	
ANCHORING DETAIL *XR-5 LINER TO FIXED WALL*	
SCALE: NONE	
SHEET 1 of 1	DRAW NO. XRD-023



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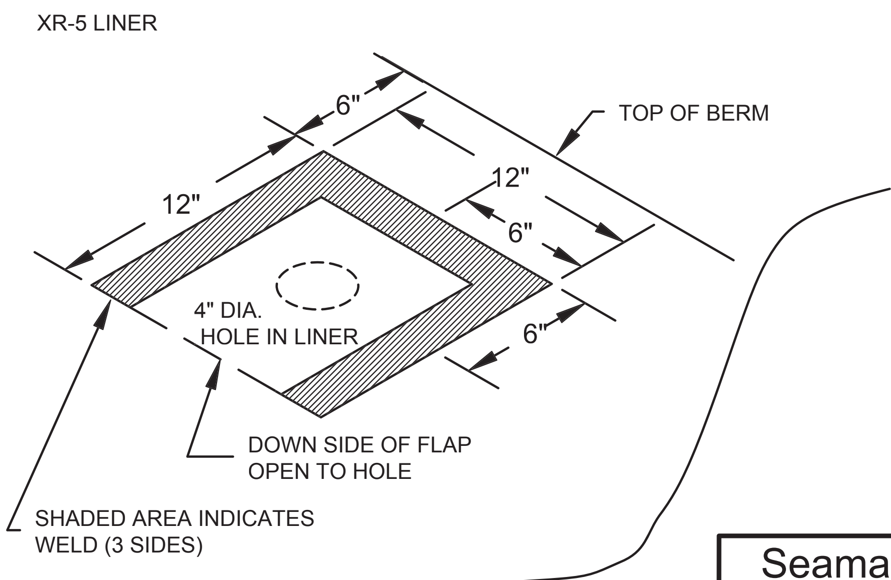
ELEVATION VIEW
TYPICAL PIPE PUNCTURE
SEAL DETAIL XR-5 LINER

SCALE: NONE	
SHEET 1 of 1	DRAW NO. XRD-018



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PLAN VIEW
FLAP VENT DETAIL
XR-5 LINER

SCALE: NONE	
SHEET 1 of 1	DRAW NO. XRD-012

Section 6 - Warranty Information

Warranty

XR-5® is offered with Seaman Corporation standard warranty which addresses weathering and chemical compatibility for a 10-year period. A test immersion is required with subsequent testing and approval by Seaman Corporation.

Instructions for XR-5 Test Immersions and Warranty Requests

1. Completely immerse six Style 8130 XR-5 samples (8-1/2" x 11" size) in the liquid to be contained.
2. At the end of approximately thirty days, retrieve three of the samples. The samples should be rinsed with fresh water and dried.
3. Send the three samples to:
   Attn: Geomembrane Department
   Seaman Corporation
   1000 Venture Blvd.
   Wooster, OH 44691
4. Keep the other three samples immersed until further notice in case longer immersion data is required.
5. Complete and return the information form on the liner application.

8228 XR-3® and all PW Geomembranes are offered with a standard 10-year warranty for weathering. The attached information form should be completed.

XR® Membrane Application and Utilization Form

Installation Owner and Address:

Physical Location of Installation:

Expected Date of Installation:

Expected Beginning Date of Service:

Description of Application:
(Example: impoundment used to contain brine on an emergency basis.)

Physical Features of Application:
(Example: 1.3 million gallon earthen impoundment with overall top dimensions of 160' x 160' with 3:1 slopes and 10' deep.)

Description of Liquid:

(Describe content of liquid including pollutants and expected temperature extremes in basin and at application point. Attach analysis of liquid chemistry, composition taken on a representative basis.)

Operational Characteristics:

(Describe the operation of the facility such as filling schedules, fluctuating liquid levels, operating temperatures, etc.)

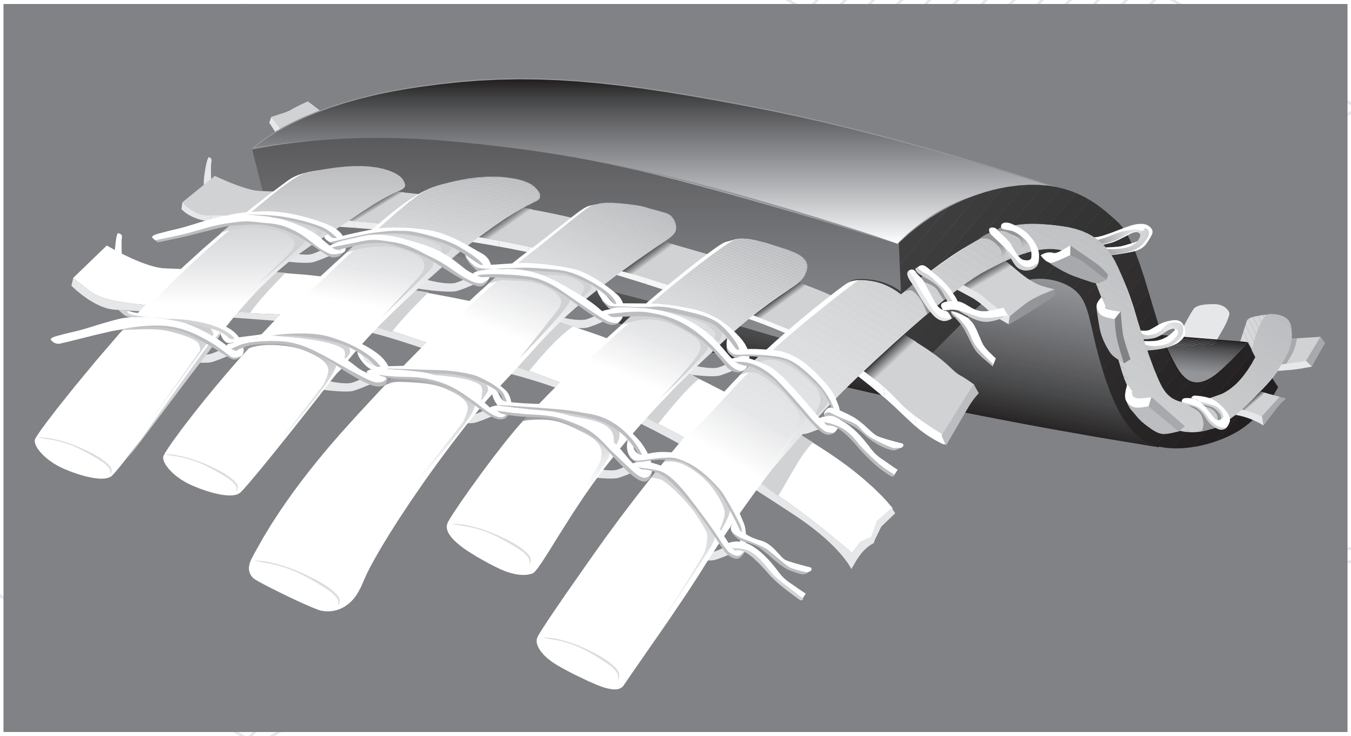
Performance Requirements, Etc:

(State any other requirements, such as rate of permeability required.)

Owner represents the information herein is complete and accurate, and understands and agrees that issuance of Seaman Corporation Warranty for XR products are conditioned upon such completeness and accuracy.

OWNER'S SIGNATURE

Reference Materials:



XR-5®: High Performance Composite Geomembrane

Seaman Corporation
1000 Venture Blvd.
Wooster, Ohio 44691
(330) 262-1111
www.xr-5.com

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.I

SMOOTH HDPE GEOMEMBRANE

SMOOTH HDPE GEOMEMBRANE
ENGLISH UNITS

Property	Test Method	Minimum Average Values 30 mil	40 mil	60 mil	80 mil	100 mil
Thickness, mils	ASTM D 5199					
minimum average		30	40	60	80	100
lowest individual reading		27	36	54	72	90
Sheet Density, g/cc	ASTM D 1505/D 792	0.940	0.940	0.940	0.940	0.940
Tensile Properties[1]	ASTM D 6693					
1. Yield Strength, lb/in		63	84	126	168	210
2. Break Strength, lb/in		114	152	228	304	380
3. Yield Elongation, %		12	12	12	12	12
4. Break Elongation, %		700	700	700	700	700
Tear Resistance, lb	ASTM D 1004	21	28	42	56	70
Puncture Resistance, lb	ASTM D 4833	54	72	108	144	180
Stress Crack Resistance[2], hrs	ASTM D 5397 (App.)	300	300	300	300	300
Carbon Black Content[3], %	ASTM D 1603	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Carbon Black Dispersion	ASTM D 5596			--Note 4--		
Oxidative Induction Time (OIT)						
Standard OIT, minutes	ASTM D 3895	100	100	100	100	100
Oven Aging at 85°C	ASTM D 5721					
High Pressure OIT - % retained after 90 days	ASTM D 5885	60	60	60	60	60
UV Resistance[5]	GRI GM11					
High Pressure OIT[6] - % retained after 1600 hrs	ASTM D 5885	50	50	50	50	50
Seam Properties	ASTM D 6392 (@ 2 in/min)					
1. Shear Strength, lb/in		57	80	120	160	200
2. Peel Strength, lb/in - Hot Wedge		45	60	91	121	151
- Extrusion Fillet		39	52	78	104	130
Roll Dimensions						
1. Width (feet):		23	23	23	23	23
2. Length (feet)		1000	750	500	375	300
3. Area (square feet):		23,000	17,250	11,500	8,625	6,900
4. Gross weight (pounds, approx.)		3,470	3,470	3,470	3,470	3,470

1 Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction. Yield elongation is calculated using a gauge length of 1.3 inches; Break elongation is calculated using a gauge length of 2.0 inches.
2 The yield stress used to calculate the applied load for the SP-NCTL test should be the mean value via MQC testing.
3 Other methods such as ASTM D 4218 or microwave methods are acceptable if an appropriate correlation can be established.
4 Carbon black dispersion for 10 different views: Nine in Categories 1 and 2 with one allowed in Category 3.
5 The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.
6 UV resistance is based on percent retained value regardless of the original HP-OIT value.

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: ENGINEERING DESIGN AND CALCULATIONS
SECTION 1: ENGINEERING DESIGN

ATTACHMENT III.1.J

COMPUTER AIDED EARTHMOVING SYSTEM

Computer Aided Earthmoving System

CAES for Landfills

CAT®

Landfill Compactors
Track-Type Tractors
Wheel Tractor Scrapers
Motor Graders

System Components	
Communications Radio	TC900B
GPS Antenna	L1/L2
GPS Receiver	MS840
In-Cab Display	CAES Touch Screen Display
CAESoffice™/METSmanager	

Computer Aided Earthmoving System for Landfills

Advanced GPS technologies for earthmoving equipment improve machine efficiency, maximize air space utilization, and extend landfill life.

Caterpillar is helping customers revolutionize the way they compact trash, grade slopes and manage their operation with new technology solutions for landfills. Solutions that provide greater accuracy, higher productivity, lower operating costs, more profitability and longer landfill life.

The Computer Aided Earthmoving System (CAES) is a high technology earthmoving tool that allows machine operators to achieve maximum landfill compaction, desired grade/slope, and conserve and ensure even distribution of valuable cover soil with increased accuracy without the use of traditional survey stakes and crews. Using global positioning system (GPS) technology, machine-mounted components, a radio network, and office management software, this state-of-the-art machine control system delivers real-time elevation, compaction and grade control information to machine operators on an in-cab display. By monitoring grade and compaction progress, operators have the information they need to maximize the efficiency of the machine, resulting in proper drainage and optimum airspace utilization.

This advanced technology tool also aids in the identification of site-specific storage areas for hazardous, medical, industrial, and organic waste requiring special handling and placement records.

Applications

CAES is an ideal tool for landfill planning, engineering, surveying, grade control, and production monitoring applications in dump areas. CAES is specifically designed for use on landfill compactors, track-type tractors, wheel tractor scrapers, and motor graders.

On-Board Components

- CAES Touch Screen Display
- GPS Receiver
- GPS Antenna (L1/L2)
- Communications Radio

Off-Board Components

- GPS Reference Station
- Radio Network
- CAESoffice/METSmanager

Operation

CAES uses GPS technology, a wireless radio communications network, and office software to map landfills, create site plans, locate a machine's position, and track compaction and earthmoving progress with complete accuracy.

The receiver uses signals from GPS satellites to determine precise machine positioning. Two receivers are used to capture and collect satellite data – one located at a stationary spot on the landfill site, and another located on the machine. Signals from the ground-based reference station and on-board computer are used to remove errors in satellite measurements for centimeter accuracy.

The CAES-enabled machine is driven over the site to create a digital terrain design file. Using the radio network and office software, landfill terrain data is transmitted from the machine to the landfill office. Landfill managers can then send the work plan from the office to the in-cab display to show operators the work to be done.

The in-cab display provides the operator with an overhead and cross-sectional three-dimensional surface view of the color-coded work plan and precise machine location. The software continuously updates terrain and machine position information as the machine traverses the site.

CAES gives the operator the ability to control grade by monitoring progress on the in-cab display, which shows a graphical representation of lift thickness and compaction density. Cut/fill numbers are displayed in real-time as the machine moves across the site, which allows the operator to know precise elevation, material spread, compaction passes, and required cut or fill at any point on the job.

The *compactor* display shows colored grids representing the number of compaction passes the machine has made across each area. As the compactor wheel travels over an area, the screen changes color to acknowledge the pass. Green areas indicate when optimum compaction has been reached. The system also monitors thick lift information and visually displays when a lift exceeds maximum site parameters.

In *tractor, scraper and motor grader* applications, the color display graphically shows the operator cut, fill, and grade work to be done according to plan. As the machine works, the screen changes color. Green indicates when the operator has achieved plan grade.

By providing immediate feedback on the accuracy of each pass, CAES operators have the information and confidence they need to work more efficiently, productively and profitably.

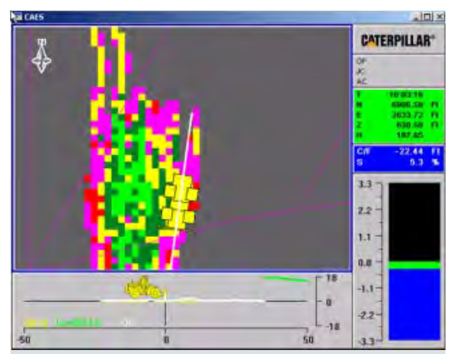
On-Board Components

Communications Radio. The rugged radio, mounted on the roof of the machine, is used for transmitting, repeating and receiving real-time data from GPS receivers. The radio broadcasts real-time, high-precision data for GPS applications. Under normal conditions, the 900 MHz radio broadcasts data up to 10 km (6.2 miles) line-of-sight. Coverage can be enhanced with a network of repeaters, which allows coverage over a broader area. Optimized for GPS with increased sensitivity and jamming immunity, the radio features error correction and high-speed data transfer, ensuring optimum performance. A 450 MHz radio solution is also available.

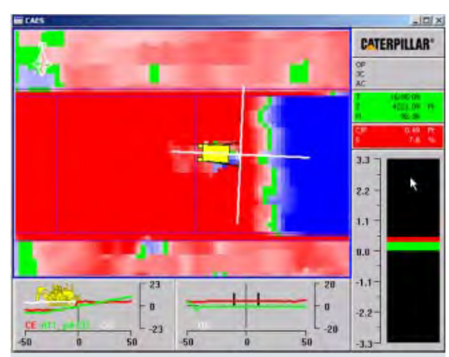
GPS Antenna (L1/L2). The dual frequency external antenna, mounted on the roof of the machine and reference station, is used to pick up the signals from the GPS satellites to determine the machine's position for high precision, real-time machine guidance and control. A low-noise amplifier provides sensitive performance in demanding applications. The compact, low profile design and sealed housing ensure reliable performance in harsh weather conditions.

GPS Receiver. The dual frequency real-time kinematic (RTK) GPS receiver is used to send and receive data simultaneously across the radio network. The system computes differential corrections for real-time positioning with centimeter accuracies, to ensure precise machine guidance and control.

CAES Touch Screen Display. The in-cab graphical display provides real-time operating information to the operator. Designed for simple operation, the 264 mm (10.4 in) custom configurable, integrated touch screen display allows operators to easily interface with the CAES system. The display utilizes the latest infrared touch and transflective backlight technology for superior viewing in bright light conditions and a broad-range dimmable backlight for viewing in low light conditions. Designed for reliable performance in extreme operating conditions, the unit is guarded against shock and sealed to keep out dust and moisture.



Compactor Screen



Dozer Screen

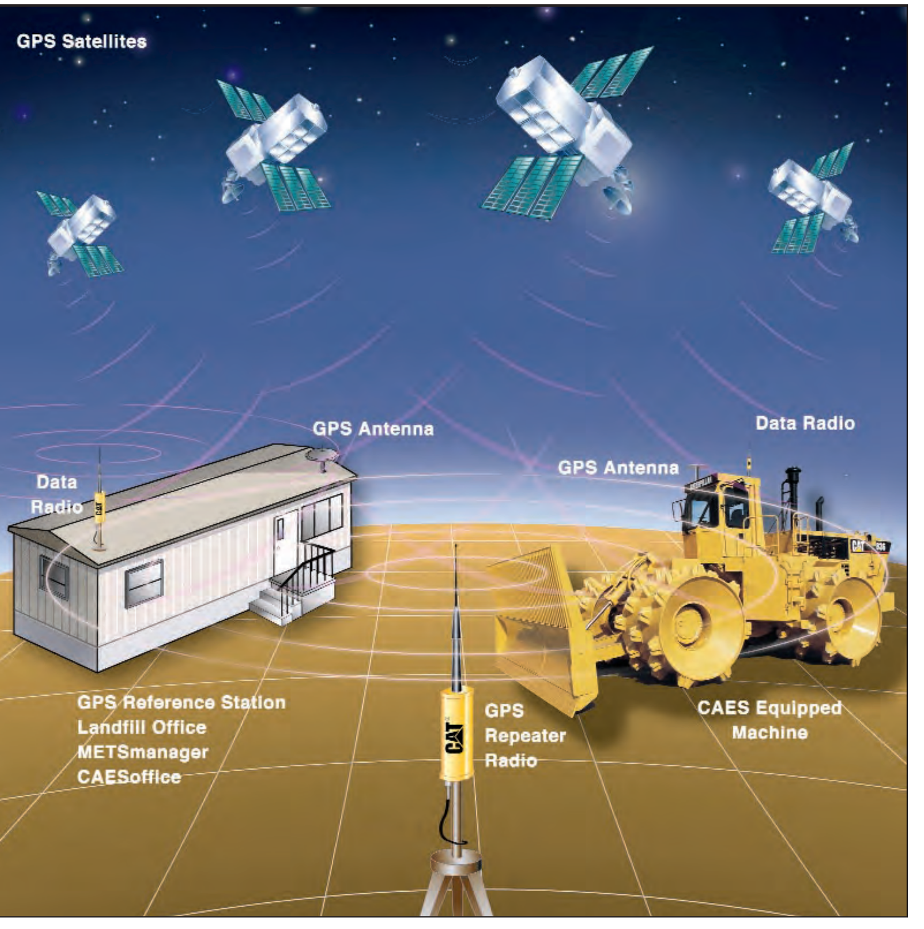
Off-Board Components

GPS Technology. Global Positioning System (GPS) technology uses 24+ satellites that orbit above the earth and constantly transmit their positions, identities and times of signal broadcasts to earth-based satellite sensors. The GPS receiver is an electronic box, which measures the distance to each visible satellite from an antenna on the ground. Through trilateralization, the receiver determines where the satellite is in respect to the center of the earth. The GPS receiver uses its own position and GPS satellite positions to calculate errors and corrections for computing exact location and precise positioning with centimeter accuracy.

GPS Reference Station. A GPS reference station is used to achieve the centimeter level accuracy needed in a landfill application. The reference station sends GPS information over a radio link to the GPS receiver on the CAES-enabled machine. The receiver combines the information with its own observations to compute precise positioning.

Radio Network. The radio network for CAES has two channels. GPS correction data is transmitted over one channel, while the other channel is used to send site planning and production data to the machine and from the machine back to the site office. By utilizing the same radio as a repeater the range can be extended to provide seamless coverage around local obstacles such as hills or large buildings. Up to four radio repeaters may be used to provide extended coverage.

Landfill Planning Software. Site planning and surveying begins with the landfill planning software. CAES is compatible with most third party CAD planning software packages. Data formats used between the CAES software and the planning software are industry standard .DXF and ASCII.



CAESoffice™. The powerful Caterpillar-designed CAESoffice software enables landfill management to monitor CAES-equipped machines and work progress throughout the site in near real-time. The data is stored in a database format for easy customized access, reporting and editing.

METSmanager. This software package allows for integration of the landfill planning system and the machine. It provides the user interface for CAES and controls all communications over the wireless radio network. METSmanager reads design files in standard .DXF formats, converts them to CAES format (.CAT), and sends the design files to the on-board display on the machine over the radio network. This program continually updates the site model by regularly requesting data transmissions from the machine to the office.

- **File Window.** Displays design files (.DXF) created using the site planning package, and holds application configuration files for GPS receivers and files converted from .DXF to the CAES on-board software format (.CAT).
- **Machines Window.** Shows icons of each machine equipped with CAES on-board software. Allows multiple machines to be monitored at the same time.
- **Messages Window.** Contains a list of recent error, warning, confirmation, or information messages generated by METSmanager.
- **Communications Queue Window.** Lists all file transmissions scheduled to occur over the radio network and displays transmission status for all files.

Specifications

TC900B Communications Radio
- Technology: Spread spectrum
- Modes: Base, repeater, rover
- Optimal Range: 10 km (6 miles), line-of-sight
- Typical Range: 3-5 km (2-3 miles) varies w/terrain and operating conditions. Repeaters may be used to extend range
- Frequency Range: 902-928 MHz
- Networks: Ten, user selectable
- Transmit Power: Meets FCC requirements, 1 watt max.
- License Free (U.S. and Canada)
- Wireless Data Rates: 128 Kbps[2]
- Operating Temperature: –40° C to 70° C (–40° F to 158° F)
- Storage Temperature: –40° C to 85° C (–40° F to 185° F)
- Humidity: 100%
- Sealing: Exceeds MIL-STD-810E, sealed to ±34.5 kPa (±5 psi), immersible to 1 m (39 in)
- Vibration: 8 gRMS, 20-2000 Hz
- Operational Shock: ±40 g, 10 msec
- Survival Shock: ±75 g, 6 msec
- Electrical Input: 10.5 to 20V DC
- Nominal Current: 250 mA (3 W)1
- Transmit Current: 1000 mA (12 W)1
- Protection: Reverse polarity
- Control Interface: SAE J1939 CAN
- Emissions and Susceptibility: CE compliant, exceeds ISO 13766
- Input Connector: 8-pin
- Network Connector: 8-pin
- Height: 250 mm (10 in)
- Width: 85 mm (3.4 in)
- Weight: 0.9 kg (2.0 lb)

Radios outside of U.S. and Canada operate on different frequencies. Please contact your Cat Dealer for specifics.

L1/L2 GPS Antenna
- Operating Temperature: –40° C to 70° C (–40° F to 158° F)
- Storage Temperature: –55° C to 85° C (–67° F to 185° F)
- Height: 151mm (6 in)
- Width: 330 mm (13 in)
- Depth: 72 mm (2.8 in)
- Weight: 1.695 kg (3.8 lb)

MS840 GPS Receiver
- Tracking: 9 channels L1 C/A code, L1/L2 full cycle carrier, fully operational during P-code encryption
- Signal Processing: Supertrak multibit technology, Everest multipath suppression
- Positioning Mode –
- Synchronized RTK: 1 cm + 2 ppm horizontal accuracy/2 cm + 2 ppm vertical accuracy, 300 ms latency, 5 Hz std. maximum rate
- Low Latency: 2 cm + 2 ppm horizontal accuracy/3 cm + 2 ppm vertical accuracy, <20 ms latency, 20 Hz maximum rate
- DPGS: <1m accuracy, <20 ms latency, 20 Hz maximum rate
- Range: Up to 20 km from base for RTK
- Communication: 3x RS-232 ports, baud rates up to 115,200
- Control Interface: SAE J1939 CAN
- Configuration: RS-232 Serial connection
- Operating Temperature: –20° C to 60° C (–4° F to 140° F)
- Storage Temperature: –30° C to 80° C (–22° F to 176° F)
- Humidity: 100%
- Operational Vibration: 3 gRMS
- Survival Vibration: 6.2 gRMS
- Operational Shock: ±40 g
- Survival Shock: ±75 g
- Electrical Input: 12/24V DC, 9 watts
- Height: 5.1 cm (2.0 in)
- Width: 14.5 cm (5.7 in)
- Depth: 23.9 cm (9.4 in)
- Weight: 1.0 kg (2.25 lb)

CAES Touch Screen Display
- LCD Display: 264 mm (10.4 in) 640 × 480 transflective color VGA
- Buttons: touch screen
- Touch Screen: 3.17 mm (0.125 in) resolution infrared high light rejection
- Back Light: 200 cd/m2, 200:1 dimming ratio
- Processor: Intel Pentium CPU
- Memory: 64 MB Ram
- Solid State Disk: Internal 128 MB, external compact flash
- Operating Environment: Embedded WinNT
- Operating Temperature: –20° C to 70° C (–4° F to 158° F)
- Storage Temperature: –50° C to 85° C (–58° F to 185° F)
- Sealing: IP68 sealed to ±5 psi
- Humidity: 100%
- Electrical Input: 9-32V DC
- Power Supply: 5 amp @ 40W load dump, reverse voltage, ESD, over voltage protection
- Connector: 70-pin
- Discrete I/O: 8 digital ports; 5 PMW inputs
- Mounting: bracket or panel
- Height: 261 mm (10.28 in)
- Width: 315 mm (12.4 in)
- Depth: 93 mm (3.66 in)
- Weight: 3.17 kg (8.5 lb)

CAESoffice/METSmanager PC Requirements
- Pentium II/III processor w/ 128 MB memory
- 21 in. monitor (SVGA color 1024 × 768 resolution) with 2MB video memory
- Windows NT 4.0 or higher with latest service pack
- Modem- internal or external (required for remote support)
- Required ports: serial (suggest 2 serial, 1 parallel)
- CD ROM drive
- 3.5 in disk drive
- Mouse or suitable pointing device
- Hard Drive Space: 200 MB min.

Customer Support. For over 25 years, Caterpillar has been providing electronic and electrical components and systems for the earthmoving industry – real world technology solutions that enhance the value of Cat products and make customers more productive and profitable. Your Cat Dealer is ready to assist you with matching machine systems to the application or obtaining responsible, knowledgeable support. For additional information, please contact us at LANDFILLGPS@CAT.com

Computer Aided Earthmoving System for Landfills

Landfill Compactors
Track-Type Tractors
Wheel Tractor Scrapers
Motor Graders

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CATERPILLAR®

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 2: VOLUMETRIC CALCULATIONS

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APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 2: VOLUMETRIC CALCULATIONS

1.0 INTRODUCTION

Sundance West (Sundance West Facility) is a proposed Surface Waste Management Facility for oil field waste processing and disposal services. The proposed Sundance West Facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD). The Facility has been designed in compliance with 19.15.36 NMAC, and will be constructed and operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned by, and will be constructed and operated by, Sundance West, Inc.

1.1 Description

The Sundance West site is comprised of a 320-acre ± tract of land located approximately 3 miles east of Eunice, 18 miles south of Hobbs, and approximately 1.5 miles west of the Texas/New Mexico state line in the South ½ of Section 30, Township 21 South, Range 38 East Lea County, New Mexico (NM). Site access will be provided via NM 18 and Wallach Lane. The Sundance West Facility will include two main components; a liquid oil field waste Processing Area (80 acres ±), and an oil field waste Landfill (120 acres ±). Oil field wastes are anticipated to be delivered to the Sundance West Facility from oil and gas exploration and production operations in southeastern NM and west Texas. The Site Development Plan provided in the **Permit Plans, Volume III.1**, identifies the locations of the Processing Area and Landfill facilities.

2.0 LANDFILL VOLUMETRIC CALCULATIONS

Landfill volumetric calculations were completed for the Sundance West (Sundance West Facility) corresponding to the design shown on the **Permit Plans**. Landfill volumetric calculations include waste capacity analysis and the soil material balance. Capacity analysis for the Sundance West landfill is presented in **Table III.2.1**. The gross airspace computed for Units 1 - 3 is approximately 20,575,000 cubic yards (yd^3); with approximately 17,382,300 yd^3 (17,382,300 tons assuming a waste density of 2,000 lbs/yd^3) of net airspace (i.e., waste capacity). The projected longevity is approximately 95.2 years assuming 500 tons per day (tpd) incoming waste volume; 47.6 years assuming 1,000 tpd incoming waste volume; and 19.0 years assuming 2,500 tpd incoming waste volume. A materials balance was completed for the landfill and is presented in **Table III.2.2**. Sundance West has more than sufficient soils from on-site excavations for the protective soil layer (PSL), daily, intermediate, and final cover for Units 1-3.

Landfill volumetric calculations were also completed for Sundance West corresponding to the East Phase Development (East Phase) design shown on the **Permit Plans**. Landfill volumetric calculations include a waste capacity analysis and a soil material balance. Capacity analysis for the East Phase is presented in **Table III.2.1**. The gross airspace computed for the East Phase is approximately 5,272,000 yd^3, with approximately 4,373,000 yd^3 (4,373,000 tons assuming a waste density of 2,000 lbs/yd^3) of net airspace (i.e., waste capacity). The projected longevity for the East Phase is approximately 24.0 years assuming 500 tons per day (tpd) incoming waste volume; 12.0 years assuming 1,000 tpd incoming waste volume; and 4.8 years assuming 2,500 tpd incoming waste volume. A materials balance was also completed for the East Phase and is presented in **Table III.2.2**. Sundance West has more than sufficient soils from on-site excavations for protective soil layer (PSL), daily, intermediate, and final cover for the East Phase.

Table III.2.1
Capacity Analysis

						Longevity Estimates		
Description	**Fill Area (acres)**	**Gross Airspace (yd^3)**	**Cover (yd^3)[1]**	**Waste Capacity Airspace (yd^3)**	**Waste Capacity Airspace (tons)**	**@ 500 tpd**	**@ 1,000 tpd**	**@ 2,500 tpd**
Landfill								
East Phase Development	55±	5,272,000	899,000	4,373,000	4,373,000	24.0 years	12.0 years	4.8 years
Units 1 - 3	126±	20,575,000	3,192,700	17,382,300	17,382,300	95.2 years	47.6 years	19.0 years
Landfill Total	**126±**	**20,575,000**	**3,192,700**	**17,382,300**	**17,382,300**	**95.2 years**	**47.6 years**	**19.0 years**

Notes:

1. Includes protective soil cover, daily cover, intermediate cover, and final cover.
2. 500 ton/day = 182,500 tons/yr based on landfill open 365 days/year.
3. 1,000 tons/day = 365,000 tons/yr based on landfill open 365 days/year.
4. 2,500 tons/day = 912,500 tons/yr based on landfill open 365 days/year.
5. Volume of final cover assumes 3.0-foot depth over final grades.
6. Volume of protective soil layer assumes 2.0 feet depth over liner.
7. Volume of intermediate cover assumes 1-foot depth over fill area acreage.
8. Volume of daily cover assumes 10% of net airspace.
9. Waste density assumed to be 2,000 lbs/cy.

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 2: VOLUMETRICS

Table III.2.2
Materials Balance

Description	Area (acres)	Soil Excavation (yd^3)[1]	Cover Required (yd^3)					Soil Surplus (yd^3)
			Perimeter Berm	Protective[2]	Daily[3]	Intermediate[4]	Final[5]	
Landfill								
East Phase Development	55.0±	1,719,400	59,100	177,500	484,700	88,800	148,000	761,300
Units 1 - 3	126±	5,130,000	146,000	406,600	1,954,000	203,300	628,800	1,791,300
Landfill Total	**126±**	**5,130,000**	**146,000**	**406,600**	**1,954,000**	**203,300**	**628,800**	**1,791,300**

Notes:
1. Includes soils excavated from drainage detention basins.
2. Protective soil volume assumes 2.0 foot soil depth over lined area.
3. Daily cover assumes soil usage @ 10% of waste volume.
4. Intermediate cover assumes 1-foot soil depth over fill area.
5. Final cover assumes 3.0-foot depth.

APPLICATION FOR PERMIT
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VOLUME III: LANDFILL ENGINEERING CALCULATIONS
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SUNDANCE WEST

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SECTION 3: DRAINAGE CALCULATIONS

LIST OF ATTACHMENTS

Attachment No.	**Title**
III.3.A	NEW MEXICO STATE HIGHWAY AND TRANSPORTATION DEPARTMENT DRAINAGE MANUAL, *DECEMBER 1995*
III.3.B	U.S. DEPT. OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NATIONAL WEATHER SERVICE OFFICE OF HYDROLOGIC DEVELOPMENT HYDROMETEOROLOGICAL DESIGN STUDIES CENTER, JUNE 2006, NOAA ATLAS 14, VOLUME 1, VERSION 5, POINT PRECIPITATION FREQUENCY ESTIMATES FOR LATITUDE: 32.4438°, LONGITUDE: -103.0864°, PDS-BASED POINT PRECIPITATION FREQUENCY ESTIMATES WITH 90% CONFIDENCE INTERVALS (IN INCHES)
III.3.C	AUTODESK,® INC, 2016, STORM AND SANITARY ANALYSIS, *EAST (INTERMEDIATE) PHASE* MODEL OUTPUT
III.3.D	AUTODESK,® INC, 2016, STORM AND SANITARY ANALYSIS, *FINAL PHASE* MODEL OUTPUT

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 3: DRAINAGE CALCULATIONS

1.0 INTRODUCTION

Sundance West (Sundance West Facility) is a proposed Surface Waste Management Facility for oil field waste processing and disposal services. The proposed Sundance West Facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD). The Facility has been designed in compliance with 19.15.36 NMAC, and will be constructed and operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned by, and will be constructed and operated by, Sundance West, Inc.

1.1 Description

The Sundance West site is comprised of a 320-acre ± tract of land located approximately 3 miles east of Eunice, 18 miles south of Hobbs, and approximately 1.5 miles west of the Texas/New Mexico state line in the South ½ of Section 30, Township 21 South, Range 38 East Lea County, New Mexico (NM). Site access will be provided via NM 18 and Wallach Lane. The Sundance West Facility will include two main components; a liquid oil field waste Processing Area (80 acres ±), and an oil field waste Landfill (120 acres ±). Oil field wastes are anticipated to be delivered to the Sundance West Facility from oil and gas exploration and production operations in southeastern NM and west Texas. The Site Development Plan provided in the **Permit Plans, Sheet 3**, identifies the locations of the Processing Area and Landfill facilities.

2.0 DESIGN CRITERIA

The stormwater management systems for the Sundance West (Sundance West Facility) are designed to meet the requirement of the regulatory standards identified in the New Mexico Oil Conservation Division (OCD) Rules 19.15.36 NMAC. More specifically, 19.15.36.13.M NMAC specifies:

Each operator shall have a plan to control run-on water onto the site and run-off water from the site, such that:

(1) the run-on and run-off control system shall prevent flow onto the surface waste management facility's active portion during the peak discharge from a 25-year storm; and

(2) run-off from the surface waste management facility's active portion shall not be allowed to discharge a pollutant to the waters of the state or United States that violates state water quality standards.

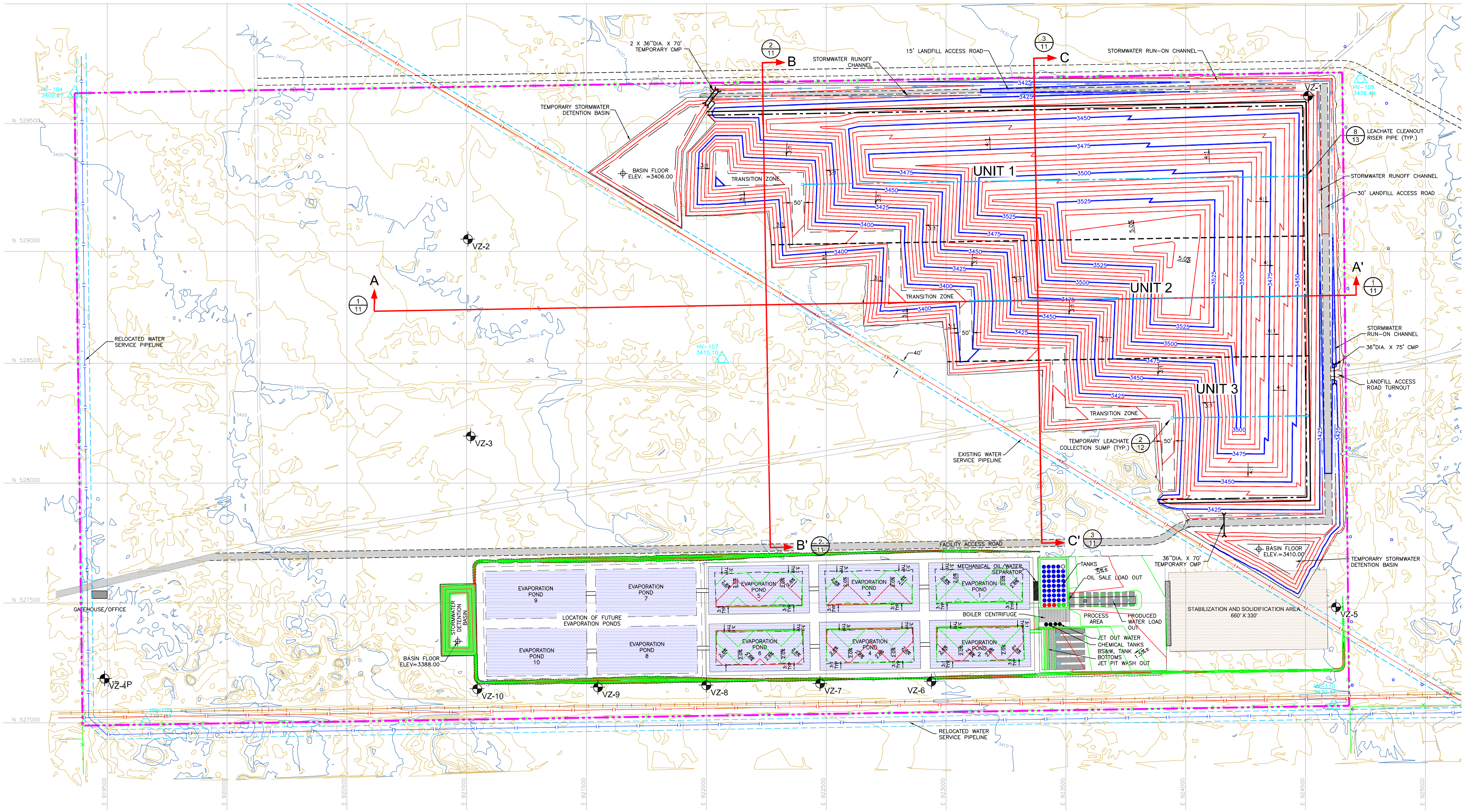
3.0 SITE CONDITIONS

The Sundance West site will be comprised of 320 ± acres, with a solid waste landfill footprint of 126 ± acres. The site is located in the South ½ Section 30 Township 21 South, Range 38 East, Lea County, New Mexico (NMPM).

Existing topography for the 320 ± acre site ranges from about 3,436 feet (ft) above mean sea level (amsl) to 3,386 ft amsl; and generally drains to the southwest at 0.8% to 1.7% slopes. The landfill boundaries of the site are contiguous with non-developed properties. The landfill will be completed in two phases. The first phase will be the East Phase Development which is located northeast of the existing water service pipeline easement (**Figure III.3.1**). On-site runoff and off-site run-on will be managed by the installation of two temporary stormwater detention basins located to the northwest of, and to the southeast of the East Phase Development. The second phase will be completion of the entire landfill after relocation of the water service pipeline (**Figure III.3.2**). On-site runoff and off-site run-on will be managed by the installation of a new stormwater detention basin located on the west side of the landfill. Site runoff from the completed landfill will be conveyed by perimeter channels which discharge into the stormwater detention basin.

4.0 METHODOLOGY

The methodology for the calculation of runoff stormwater flows is similar to that outlined by the New Mexico State Highway and Transportation Department (NMSHTD) Drainage Manual, Volume 1: Hydrology (Philips et al., 1995; **Attachment III.3.A**). The NMSHTD Drainage Manual specifies that the Simplified Peak Flow Method (NMSPFM) be used on drainage areas that are no larger than 5 square miles, and where land use is consistent



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

LEGEND

FACILITY BOUNDARY
LIMIT OF WASTE
UNIT BOUNDARY
TOP OF LANDFILL BERM
TOE OF SLOPE
10' CONTOUR (EXISTING)
2' CONTOUR (EXISTING)
25' CONTOUR (DESIGN)
5' CONTOUR (DESIGN)
1' CONTOUR (DESIGN)
CUT AND FILL DAYLIGHT LINE
DRAINAGE CHANNEL FLOW LINE
LEACHATE COLLECTION PIPE AND RISERS

FENCE
EXISTING UNPAVED ROAD
EXISTING PAVED ROAD
NEW UNPAVED ROAD
LANDFILL ACCESS ROAD
RAILROAD TRACKS
RELOCATED WATER SERVICE PIPELINE
EXISTING EUNICE WATERLINE
PIPELINE EASEMENT
NEW CULVERT
DETAIL NUMBER
SHEET NUMBER
CROSS SECTION LOCATION

VZ-4 VADOSE ZONE MONITORING WELL
POWER POLE
OIL STORAGE TANK
EXISTING BOX CULVERT
3414.57 SPOT ELEVATION
HV-105 3436.49 SURVEY CONTROL POINT
N 527500 E 922000 SITE GRID

PRODUCED WATER TANK
CRUDE OIL RECOVERY TANK
OIL SALES TANK

NORTH

0 200' 400'

I, KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

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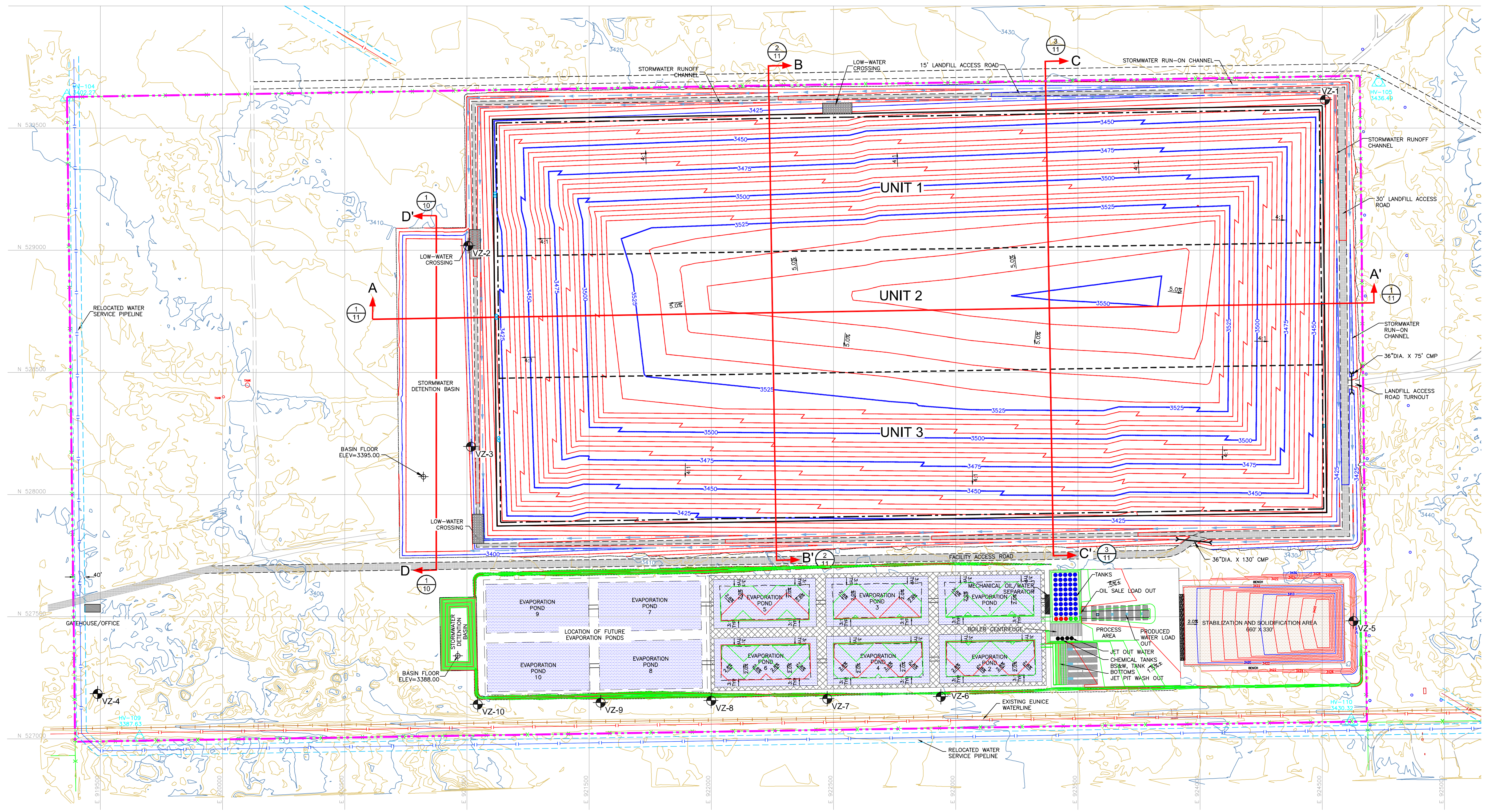
UPDATED: JULY, 2016

EAST PHASE DEVELOPMENT INTERMEDIATE & FINAL GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991
gei@gordonenvironmental.com

DATE: 07/21/2016	CAD: 07 EAST INT FG.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	FIGURE III.3.1
APPROVED BY: IKG		



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

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Date/Time:Aug. 01, 2016-10:58:09

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- TOP OF LANDFILL BERM
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- CUT AND FILL DAYLIGHT LINE
- DRAINAGE CHANNEL FLOW LINE
- FENCE
- LEACHATE COLLECTION RISER PIPES
- EXISTING PAVED ROAD
- EXISTING UNPAVED ROAD
- NEW UNPAVED ROAD
- LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- PIPELINE EASEMENT
- NEW CULVERT
- DETAIL NUMBER / SHEET NUMBER
- CROSS SECTION LOCATION
- VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- SPOT ELEVATION
- SURVEY CONTROL POINT
- SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NORTH

0 200' 400'

I. KEITH GORDON, P.E.
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UPDATED: JULY 20, 2016

FINAL GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 07/20/2016	CAD: 05 FINAL GRADES.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	FIGURE III.3.2
APPROVED BY: IKG	gei@gordonenvironmental.com	

throughout the watershed. The total enclosed drainage basin acreage for the East Phase project area is estimated to be approximately 0.36 square miles (**Figure III.3.1**). The total enclosed drainage basin acreage for the completed project area is estimated to be approximately 0.55 square miles (**Figure III.3.2**). The NMSHTD Drainage manual additionally allows "at the discretion of the designer, the Unit Hydrograph Method [a.k.a. the Soil Conservation Service (SCS) TR-55/TR-20] can be substituted for the Simplified Peak Flow method." Simplified Peak Flow Method is a specially simplified version of the SCS TR-20/TR-55 computerized rainfall modelling system which allows for calculations to be performed manually.

Calculation of runoff from the east-development phase and post-development phase of the landfill conditions was modeled according to the SCS TR-20 Method's hydrology model, and the SCS TR-55 time-of-concentration formulae using *Autodesk,® Inc.'s Storm and Sanitary Analysis* software package. The same method and model software package was used in an iterative process for projecting the effects and sizing of the run-on collection network including drainage channels and stormwater basins.

The TR-20 Method calculations used to determine stormwater runoff flows at Sundance West are presented in **Attachment III.3.C** and **III.3.D**. For these calculations, both East Phase and the Final Phase, the same calculation sequence is used:

- The model uses the 25-year, 24-hour rainfall event, obtained from **Attachment III.3.B** P_{24}= 4.93 inches
- For every drainage subbasin, the area, A, is calculated in acres
- Determine curve number "CN": From Table 3-1 "Runoff Curve Numbers for Arid and Semiarid Rangelands" in **Attachment III.3.A pg. 3-23**; for Desert shrub-mixture of grass, weeds, and low growing brush, with brush the minor element, Soil Group **B** (consisting of sandy soils, the predominate soils on-site) and 30-70% Vegetation Cover; Hydrologic Condition "poor"; **CN = 77**.

  (note that the SSI site, which is adjacent to the Sundance West site to the east, was modelled previously for closure / post-closure drainage, and has non-uniform curve numbers due to the intentional exposure of Soil Group D soils, further information is available in the SSI closure plan)
- Based on the final cover design, input the parameters describing the catchment for the electronic TR-55 Time of Concentration, $\mathbf{T_c}$ calculations. Catchments are described by one subarea, and information is located in **Attachment III.3.C pages 7-20** for the East Phase of site development, and **Attachment III.3.D pages 7-24** for the final site conditions. The calculations are based on Sheet Flow, using a Manning's Roughness

of 0.08 for Sparse Vegetation and the accepted maximum flow length of 100'; Shallow Concentrated Flow, using the remaining distance the water must travel to the nearest intentional channel; and Channel Flow, using a Manning's roughness of 0.03 for a vegetated earthen channel and the channel dimensions derived iteratively. TR-55's methodology yields a total Time of Concentration.

- The model then uses the Curve Number, rainfall data, and Time of Concentration to derive the Total Runoff (in depth, inches), Peak Runoff (in flow rate, CFS). From there, the system also calculates the Total Runoff Volume, as shown in the table in **Attachment III.3.C pg 2**, and summarized in **Tables III.3.1. and Table III.3.3**

5.0 EAST PHASE DEVELOPMENT SURFACE WATER SUMMARY

The East Phase consists of three retention basins; nine modelled subbasins contributing runoff to those basins; and three subbasins contributing run-on to two basins. The Transition Zone on the floor of the land disposal area makes up the only basin not expected to receive any run-on. The subbasins that comprise the east phase drainage model are summarized below in **Table III.3.1**.

TABLE III.3.1
East Phase Subbasin Summary
Sundance West

Sub-Basin ID	Area (acres)	Curve Number (CN)	Peak Discharge (cfs)	Volume (acre-ft)	Discharge To
Subbasin DB1 (NW)	2.76	77	0.59	17.23	DB1 (NW)
Subbasin DB2 (SE)	2.82	77	0.60	17.63	DB2 (SE)
Subbasin H	3.06	77	0.65	8.91	DB2 (SE)
Subbasin J	3.08	77	0.66	7.06	DB1 (NW)
Subbasin K	6.65	77	1.42	14.91	DB1 (NW)
Subbasin L	30.89	77	6.60	15.20	DB2 (SE)
Subbasin M	12.20	77	2.61	58.43	TransZone
Subbasin N	14.07	77	3.01	74.77	TransZone
Subbasin O	8.50	77	1.82	49.95	TransZone
SSI-NorthCentralCatchment-100%Retention	40.72	78	9.09	201.15	(offsite)
SSI-NorthEastCatchment-100%Retention	100.19	76	20.83	420.48	(offsite)
SSI-NorthWestCatchment-DrainsWest	41.63	72	7.44	106.79	DB1 (NW)
SSI-SouthCatchment-DrainsWest	177.14	72	31.65	181.30	West Flume
NorthRun-On	106.25	77	22.71	226.50	DB2 (SE)

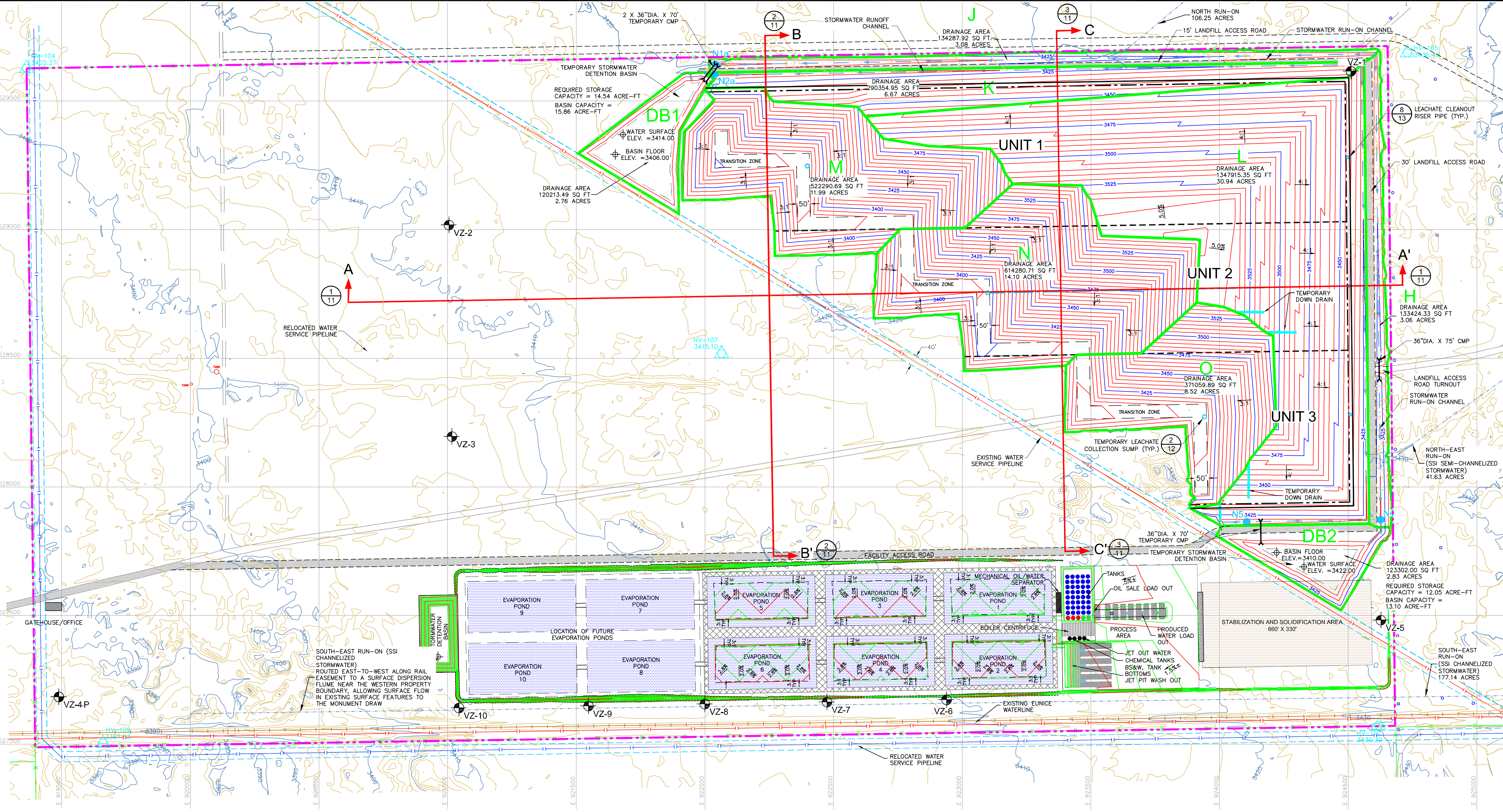
Using the Volume and Discharge information presented in **Attachment III.3.C** and summarized in **Table III.3.1**, calculations for the size of the Transition Zone Retention Basin, DB1 Retention Basin (to the North West) and DB2 Retention Basin (to the South East) can be completed. The basins were modeled conservatively, so as to include an inherent factor of safety. The relevant information is presented in **Attachment III.3.C Pg. 26-28**; note that pages 29-31 relate to stormwater management on the SSI site and relevant run-on and retained is addressed in the SSI closure plan. All three basins are modeled such that the extremely conservative, i.e., significantly smaller than the real design, and are modeled such that there is no outflow. This design ensures that there will be substantial freeboard for the design storm for the true basin design. **Figure III.3.3** depicts the East Phase Development Drainage Plan.

6.0 LANDFILL COMPLETION SURFACE WATER SUMMARY

The completed landfill design for Sundance West involves one retention basin, eight subbasins contributing runoff, and two subbasins contributing run-on. Note that the run-on from the North is from a greater area than for the intermediate design, so there is additional runoff in the North run-on subbasin. Also included in the Final design, is the retention basin for the processing area, and three subbasins that potentially contribute to it. The subbasins that make up the drainage model for the final design, as well as their drainage basins, are summarized in **Table III.3.2**.

TABLE III.3.2
Landfill Completion Subbasin Summary
Sundance West

Sub-Basin ID	Area (acres)	Curve Number (CN)	Peak Discharge (cfs)	Volume (acre-ft)	Discharge To
Subbasin A	25.67	77.00	5.49	8.86	DB
Subbasin B	27.73	77.00	5.93	11.22	DB
Subbasin C	24.20	77.00	5.17	10.75	DB
Subbasin D	35.74	77.00	7.64	12.86	DB
Subbasin E	31.67	77.00	6.77	8.63	DB
Subbasin F	4.83	77.00	1.03	12.62	DB
Subbasin G	7.91	77.00	1.69	16.78	DB
Subbasin DB	10.20	77.00	2.18	63.72	(self-contained)
NorthRun-On	111.94	72.00	20.00	199.92	DB
ProcessingArea_'etc'	14.07	77.00	3.01	29.18	ProcAreaBasin
StabilizationArea	5.83	77.00	1.25	24.18	(self-contained)
Treatment_Ponds	24.42	100.00	10.03	231.34	(self-contained)
SSI-SouthCatchment-DrainsWest	169.17	72.00	30.23	97.69	West Flume
SSI-NorthCentralCatchment-100%Retention	40.72	78.30	9.09	201.15	(offsite)
SSI-NorthEastCatchment-100%Retention	100.19	76.20	20.83	420.48	(offsite)
SSI-NorthWestCatchment-DrainsWest	41.63	72.00	7.44	106.79	(offsite)



LEGEND

FACILITY BOUNDARY	LEACHATE COLLECTION RISER PIPES
LIMIT OF WASTE	NEW CULVERT
UNIT BOUNDARY	VADOSE ZONE MONITORING WELL
10' CONTOUR (EXISTING)	POWER POLE
2' CONTOUR (EXISTING)	OIL STORAGE TANK
25' CONTOUR (DESIGN)	EXISTING BOX CULVERT
5' CONTOUR (DESIGN)	SPOT ELEVATION
1' CONTOUR (DESIGN)	DRAINAGE AREA & IDENTIFICATION
TOP OF LANDFILL BERM	DRAINAGE NODE
FENCE	DETAIL NUMBER SHEET NUMBER
EXISTING PAVED ROAD	CROSS SECTION LOCATION
EXISTING UNPAVED ROAD	SURVEY CONTROL POINT
NEW UNPAVED ROAD	PRODUCED WATER TANK
LANDFILL ACCESS ROAD	CRUDE OIL RECOVERY TANK
RAILROAD TRACKS	OIL SALES TANK
RELOCATED WATER SERVICE PIPELINE	SITE GRID
EXISTING EUNICE WATERLINE	
PIPELINE EASEMENT	
DRAINAGE CHANNEL FLOW LINE	

NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
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Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\09 EAST DRAINAGE.dwg
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NORTH

0 200' 400'

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UPDATED: JULY, 2016

EAST PHASE DEVELOPMENT DRAINAGE PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

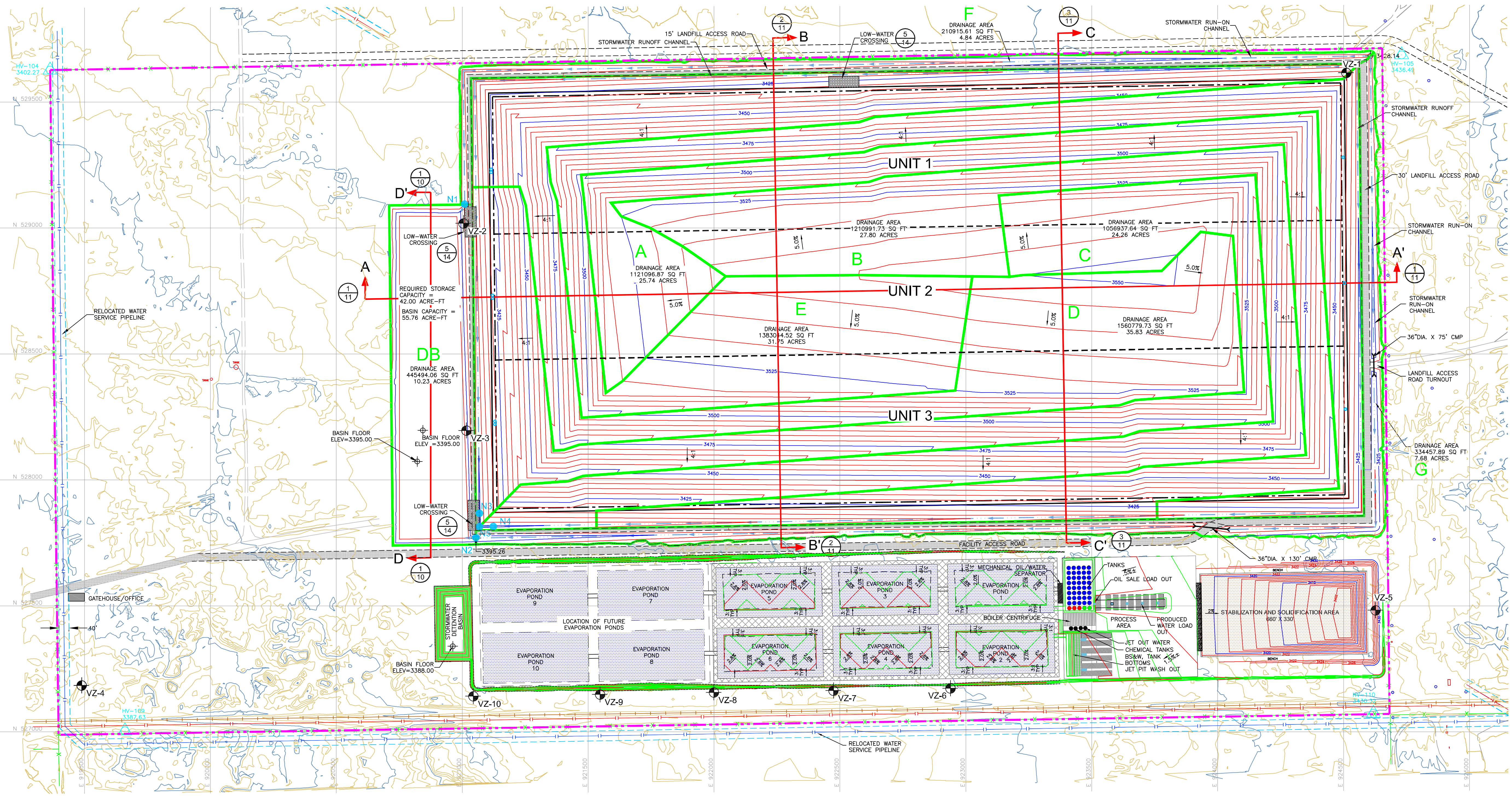
DATE: 07/26/2016	CAD: 09 EAST DRAINAGE.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	FIGURE III.3.3
APPROVED BY: IKG	gei@gordonenvironmental.com	

Using the Volume and Discharge information presented in **Attachment III.3.D** and summarized in **Table III.3.2**, calculations for the size of the storage basin DB can be executed. Additionally, calculations were performed to assess the necessary volume for the self-contained Stabilization Area Basin, the self-contained Evaporation Pond Basin, and the Processing Area Basin. The relevant information is presented in **Attachment III.3.D Pg. 28-30 & 34**; note that pages 31-33 relate to stormwater management on the SSI site and relevant run-on is addressed elsewhere. None of the basins that were assessed has any outflow for the design storm, i.e., each provides 100% retention for the Land Disposal, Processing Area and Evaporation Pond site areas. There is more than sufficient elevation change throughout the site to allow that stormwater conveyance channels can be designed at time of construction. **Figure III.3.4** depicts the Landfill Completion Drainage Plan.

7.0 CONCLUSION

For the 25-year 24-hour design storm, both the East (intermediate) and Final designs allow for 100% retention of runoff generated on the site, as well as sheet run-on from the north and northeast.

Since no landfill runoff from the 25-year 24-hour storm is discharged from the site, this design exceeds the aforementioned requirements set forth in 19.15.36.13.M NMAC in that: no run-on or runoff is directed onto any possible active portion; and no runoff from an active portion will discharge to the waters of the State or United States.



LEGEND

FACILITY BOUNDARY	LEACHATE COLLECTION RISER PIPES	PRODUCED WATER TANK	
LIMIT OF WASTE	NEW CULVERT	CRUDE OIL RECOVERY TANK	
UNIT BOUNDARY	VADOSE ZONE MONITORING WELL	OIL SALES TANK	
10' CONTOUR (EXISTING)	POWER POLE	SITE GRID	
2' CONTOUR (EXISTING)	OIL STORAGE TANK		
25' CONTOUR (DESIGN)	EXISTING BOX CULVERT		
5' CONTOUR (DESIGN)	SPOT ELEVATION		
1' CONTOUR (DESIGN)	DRAINAGE AREA & IDENTIFICATION		
TOP OF LANDFILL BERM	DRAINAGE NODE		
FENCE	DETAIL NUMBER SHEET NUMBER		
EXISTING PAVED ROAD	CROSS SECTION LOCATION		
EXISTING UNPAVED ROAD	SURVEY CONTROL POINT		
NEW UNPAVED ROAD			
LANDFILL ACCESS ROAD			
RAILROAD TRACKS			
RELOCATED WATER SERVICE PIPELINE			
EXISTING EUNICE WATERLINE			
PIPELINE EASEMENT			
DRAINAGE CHANNEL FLOW LINE			

NOTES

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N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: JULY 20, 2016

LANDFILL COMPLETION DRAINAGE PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 07/22/2016	CAD: 08 DRAINAGE PLAN.dwg	PROJECT #: 530.01.01
DRAWN BY: DMI	REVIEWED BY: CWF	FIGURE III.3.4
APPROVED BY: IKG	gei@gordonenvironmental.com	

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APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 3: DRAINAGE CALCULATIONS

ATTACHMENT III.3.A

NEW MEXICO STATE HIGHWAY AND TRANSPORATION DEPARTMENT DRAINAGE MANUAL

DECEMBER 1995

Drainage Manual

Volume 1, Hydrology

December, 1995

New Mexico State Highway
and Transportation Department
Preliminary Design Bureau/Drainage Section
P. O. Box 1149
Santa Fe, New Mexico 87504-1149

3.3.1.1 *Drainage Basin Delineation*

Drainage basins are usually defined graphically using topographic maps. USGS topographic maps at 1:24,000 scale provide adequate detail for NMSHTD projects and are available for most areas of New Mexico. Drainage structures crossing highways are usually located at low spots in the terrain, and are always provided where a stream channel exists. From the drainage structure location, drainage basin boundaries are drawn on the topographic map proceeding uphill such that the boundary encompasses all land which can drain to the crossing structure location. A simple test is to imagine a drop of rain falling on the ground, and to follow the path it takes as it runs downhill. Drainage basin boundary lines are generally drawn perpendicular to the topographic lines, following the ridgetops.

Once the overall drainage basin has been defined, the total drainage area should be measured. A planimeter is commonly used to measure areas from topographic maps. Drainage basin areas may also be measured electronically by digitizing map areas. Some USGS maps are now available in digital format. The historical grid method may also be used, where the basin map is overlaid with a transparent grid and grid rectangles are counted within the basin boundary lines.

Each drainage basin should be qualitatively assessed as follows:

- What hydrologic analysis method is required based on drainage basin size?
- Is one drainage basin okay for analysis purposes, or should we create sub–basins? Considerations might include: drastic changes in land slope, land use and development.
- Is the overall drainage basin shape somewhat consistent with implicit assumptions built into the analytical design methods? **Figure 3–3** shows the effects on hydrograph shape from different drainage basin shapes. The designer should consider subdividing drainage basins which are particularly elongated or short and wide.
- Will roads, diversions, ponds or other features within the drainage basin prevent it from behaving as a uniform, homogeneous watershed?
- In flat terrain, are there roads or other development features which act as drainage divides?

When these factors are accounted for, parameters such as Time of Concentration and Runoff Curve Number will more accurately portray the runoff response of the watershed.

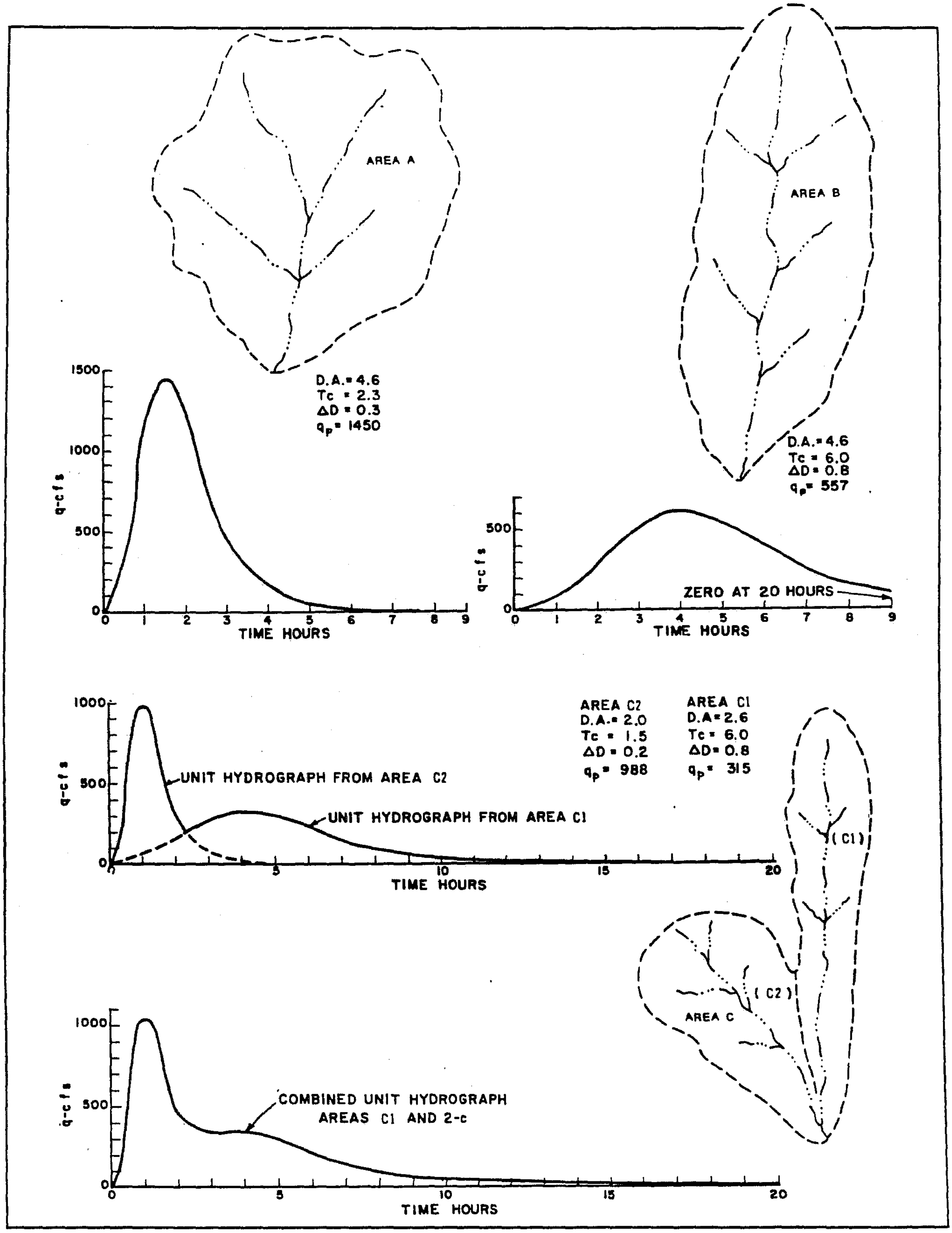


Figure 3-3
Effect of Drainage Basin Shape on Hydrograph Shape

Adapted from SCS, NEH-4, 1972

3.3.1.2 Rainfall

Rainfall data is a necessary input parameter for nearly all runoff computations performed on NMSHTD projects. The quantity of rainfall and the time distribution of the rainfall will both affect the resulting peak rate of runoff. Rainfall data is taken from the NOAA Precipitation – Frequency Atlas (Miller et al, 1973) or from updated NOAA maps when they become available. **Figures E–1 through E–12** in ***Appendix E*** of this manual provide the same NOAA data (1973) with a current (1995) State Highway map. Point precipitation values may be read from these **Figures** for the design rainfall event.

The designer must first determine the return frequency of the design flood to be used on a particular project or drainage structure. Design frequency floods are listed in a separate document, "**Drainage Design Criteria for NMSHTD Projects**," which may be obtained from the NMSHTD Drainage Section. Design frequencies are not included in this manual because the design criteria may change over time. **Designers should verify that they have the latest Drainage Design Criteria before proceeding with design on NMSHTD projects.**

For NMSHTD projects the assumption is made that rainfall frequencies produce equivalent flood frequencies, i.e. the 50–year rainfall event will produce the 50–year runoff event. This assumption is generally valid when all other factors remain constant (antecedent moisture, etc.), particularly for ephemeral stream systems. There are some situations where this assumption may not be correct. In regions of New Mexico where the seasonal snowpack is significant, the designer should evaluate both a rainfall event and a snowmelt/rainfall event as predicted by the USGS rural peak discharge regression equations.

3.3.1.2.1 Rainfall in the Rational Formula

Rainfall data must be transformed into an Intensity–Duration–Frequency (IDF) relationship for use in the Rational Formula. Rainfall intensity, i, has units of inches/hour, and changes with the Time of Concentration and design frequency. Specific IDF curves must be prepared for each NMSHTD project location. Generalized IDF curves should not be used. A manual procedure for preparing IDF curves is described below. A computer spreadsheet is used by the NMSHTD Drainage Section to expedite these calculations.

on the runoff response of the watershed. For these areas the designer must estimate ground cover type and density at the time of year when large runoff events are most likely to occur. **Figure 3–7** shows how to estimate ground cover density.

Hydrologic Condition – a "poor" hydrologic condition indicates impaired infiltration and therefore increased runoff. A "good" hydrologic condition indicates factors which encourage infiltration. For agricultural lands the hydrologic condition is a combination of factors including percent ground cover, canopy of vegetation, amount of year–round cover, percent of residue cover on the ground, grazing usage, and degree of roughness. For arid and semi–arid lands the percent ground cover determines the hydrologic condition.

Hydrologic Soil Group – categorizes the surface and subsurface soils in terms of their ability to absorb water. Sandy soils tend to fall into group "A," whereas clay soils and rock outcrops are usually in the "D" group. "A" soils are relatively permeable whereas "D" soils are not. SCS Soil Surveys include aerial photograph maps of soil series, and for each series a hydrologic soil group has been assigned. SCS Soil Surveys are available by county for the majority of New Mexico. Most of the soil surveys were performed through aerial photo interpretation of large areas and detailed field inspections at selected locations. In watershed areas where excavation or extensive reworking of the surface soils has occurred, the designer should use field inspections to confirm the hydrologic soil group of the present surface soils.

Antecedent Moisture Condition (AMC) – describes the amount of moisture in the soil at the time rainfall begins. Antecedent moisture is categorized into three conditions: dry (I), average (II) and wet (III). **Tables 3–1 through 3–4** list curve number values for various land use categories and average AMC. The assumption of AMC = II is valid for design watershed conditions on NMSHTD projects. For arid lands, an AMC of II may appear conservative, but represents conditions which could reasonably occur in conjunction with the design rainfall event. Occasionally a different AMC may be considered on a specific project. When required, the curve number for an average AMC may be adjusted as shown in **Table 3–5**.

Table 3-1 — Runoff Curve Numbers for Arid and Semiarid Rangelands[1]
Source: USDA SCS, TR-55, 1986

Cover Description		Curve Numbers for Hydrologic Soil Group –			
Cover Type	Hydrologic Condition[2]	A[3]	B	C	D
Herbaceous—mixture of grass, weeds, and low growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak–aspen—mountain brush mixture of oak brush,	Poor				
aspen, mountain mahogany, bitter brush, maple,	Fair		66	74	79
and other brush.	Good		48	57	63
			30	41	48
Piñon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1] Average runoff condition.

[2] Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

[3] Curve numbers for group A have been developed only for desert shrub.

3.3.1.4 *TIME OF CONCENTRATION*

Time of Concentration is defined as the time required for runoff to travel from the hydraulically most distant part of the watershed to the point of interest. Time of concentration is one of the most important drainage basin characteristics needed to calculate the peak rate of runoff. An accurate estimate of a watershed's time of concentration is crucial to every type of hydrologic modeling.

The method used to calculate time of concentration must be consistent with the method of hydrologic analysis selected for design. Designers working on NMSHTD projects must use the time of concentration methods specified in this section for each hydrologic method. Mixing of methods is not allowed on NMSHTD projects. **Table 3–6** defines the correct time of concentration method to be used for each hydrologic method.

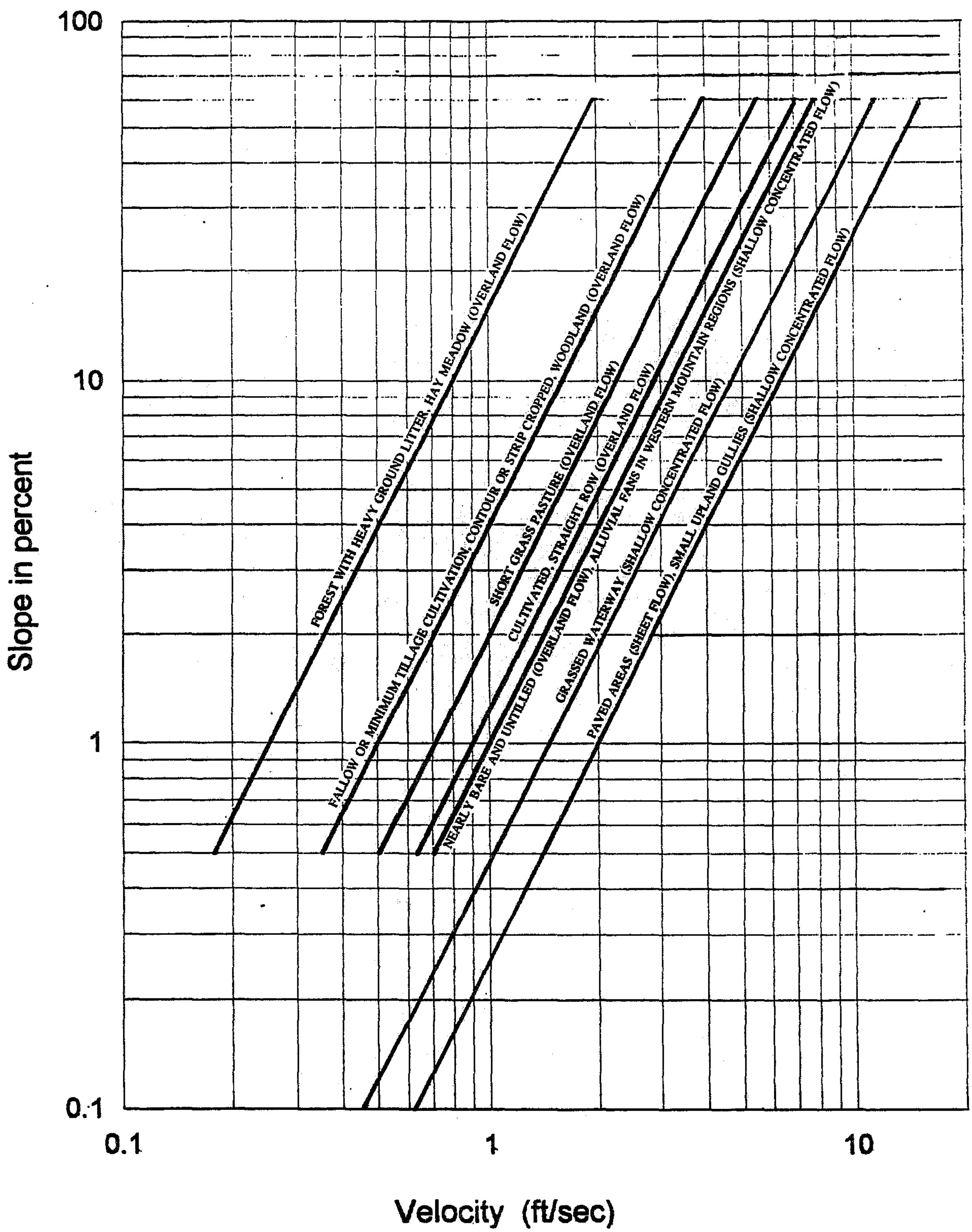
Within each watershed the designer must locate the primary watercourse. This is the watercourse that extends from the bottom of the watershed or drainage structure to the most hydraulically remote point in the watershed. Most designers begin at the bottom of the watershed and work their way upstream until the longest watercourse has been found. At the top of the watershed a defined watercourse may not exist. In these areas overland flow will be the dominant flow type. As the runoff proceeds downstream, overland flows will naturally begin to coalesce, gradually concentrating together. Shallow concentrated flow often has enough force to shape small gullies in erosive soils. Gullies eventually gather together until a defined stream channel is formed. The water course is now large enough to be identified on a quadrangle topographic map.

Sections along the primary watercourse should be identified which are hydraulically similar. Time of concentration is estimated for each section of the watercourse. Time of concentration in any given watershed is simply the sum of flow travel times within hydraulically similar reaches along the longest watercourse. Time of concentration is determined from measured reach lengths and estimated average reach velocities. The basic equation for time of concentration is:

$$T_c = \left(\frac{L_1}{V_1} + \frac{L_2}{V_2} + \frac{L_3}{V_3} + \ldots \frac{L_n}{V_n} \right) \frac{1}{60} \tag{3–17}$$

where

T_c = Time of concentration, minutes
V_1 = Average flow velocity in the uppermost reach of the watercourse, ft./sec.
L_1 = Length of the uppermost reach of the watercourse, ft.
$V_2, V_3, \ldots$ = Average flow velocities in subsequent reaches progressing downstream, ft./sec.
$L_2, L_3, \ldots$ = Lengths of subsequent reaches progressing downstream, ft.



Note: For watercourses with slopes less than 0.5 percent, use the overland flow velocity given for 0.5 percent, except for shallow concentrated flow where a flatter slope may be considered.

Figure 3–10
Flow Velocities for Overland and Shallow Concentrated Flows

Modified from SCS, NEH–4, 1972

3.3.1.4.2 *TIME OF CONCENTRATION BY THE KIRPICH FORMULA*

This method is used to calculate time of concentration in gullied watersheds when using the Rational Method or the Simplified Peak Flow Method. The Kirpich Formula should be used when gullying is evident in more than 10% of the primary watercourse. Gullying can be assumed if a blue line appears on the watercourse shown on the USGS quadrangle topographic map. The Kirpich Formula is given as:

$$T_c = 0.0078 \ L^{0.77} \ S^{-0.385} \tag{3–18}$$

where

T_c = time of concentration, in minutes
L = length from drainage to outlet along the primary drainage path, in feet
S = average slope of the primary drainage path, in ft./ft.

The Kirpich Formula should generally be used for the entire drainage basin. The exception to this rule occurs when the Simplified Peak Flow Method is being used on NMSHTD projects and the watercourse has a mixture of gullied and un–gullied sections. In these situations, mixing of time of concentration methods is allowed. The Upland Method is used for the ungullied portion of the primary watercourse, and the Kirpich Formula is used for the gullied portion of the watercourse. The two times of concentration are added together to obtain the total time of concentration of the watershed. Typically the Kirpich Formula is only used for that portion of the watercourse shown in blue on the quadrangle topo map. **Mixing of time of concentration methods is only allowed with the Simplified Peak Flow Method for NMSHTD projects.**

3.3.1.4.3 *THE STREAM HYDRAULIC METHOD*

The stream hydraulic method is used when calculating peak flows by the Unit Hydrograph Method in a watercourse where a defined stream channel is evident (blue line, solid or broken, on a quadrangle topo map). The designer must measure or estimate the hydraulic properties of the stream channel, and must divide the total watercourse into channel reaches which are hydraulically similar. Field reconnaissance measurements of the stream channel are best, however sometimes direct measurements are not possible. The designer must determine the slope, channel cross section and an appropriate hydraulic roughness coefficient for each channel reach. Average slope is often determined from the topographic mapping of the watershed. Channel cross section should be measured in the field whenever possible. Roughness coefficients of the waterway should be based on actual observations of the watercourse or of nearby watercourses which are believed to be similar and which are more accessible.

Time of Concentration by the stream hydraulic method is simply the travel time in the stream channel. Channel flow velocities can be estimated from normal depth calculations for the watercourse. In addition to the average flow velocity, designers should compute the Froude Number of the flow. If the Froude number of the flow exceeds a value of 1.3, then the designer should verify that supercritical flow conditions can actually be sustained. For most earth lined channels the velocity calculation should be recomputed using a larger effective

3.3.3 *Simplified Peak Flow Method*

The Simplified Peak Flow method estimates the peak rate of runoff and runoff volume from small to medium size watersheds. This method was developed by the Soil Conservation Service and revised by that agency for use in New Mexico ("Peak Rates of Discharge for Small Watersheds," Chapter 2, SCS, 1985). Infiltration and other losses are estimated using the SCS Curve Number (CN) methodology. Input parameters are consistent with those used in the SCS Unit Hydrograph method. The Simplified Peak Flow method is limited for NMSHTD use to single basins less than 5 square miles in area, and should not be used when T_c exceeds 8.0 hours. This method may be used on NMSHTD projects for those conditions identified in ***Section 3.2*** of this manual. This method should not be used for watersheds with perennial stream flow.

The original Chapter 2 method (SCS, 1973) included unit peak discharge curves for different rainfall distributions, varying from 45% to 85% of the rainfall occurring in the peak hour. After analysis of stream gage data, the 1985 update included only one peak discharge curve, representing a variable rainfall distribution depending on the Time of Concentration of the watershed. Therefore, a separate estimate of rainfall distribution is not required to use this method. The analysis of gage data also showed that the method overestimated peak flows at elevations above 7500 ft. Drainage structures above this elevation should be evaluated by the unit hydrograph or USGS regression equation methods.

3.3.3.1 *Application*

<u>Step 1</u> – Gather Input Data

- ♦ Establish the appropriate Design Frequency Flood(s) for analysis
- ♦ Estimate the drainage area, A, in acres (***Section 3.3.1.1***)
- ♦ Compute the Time of Concentration, T_c, in hours (***Section 3.3.1.4***)
- ♦ Determine the appropriate runoff Curve Number, CN, for the drainage basin (***Section 3.3.1.3***)
- ♦ Obtain the 24–hour rainfall depth, P_{24}, for the appropriate design frequency, from ***Appendix E***

Step 2 Determine the unit peak discharge, q_u, for the watershed. The unit peak discharge can be read from **Figure 3–18**, given the time of concentration, or calculated directly by the following equation:

$$q_u = 0.543\ T_c^{-0.812}\ 10^{-\frac{\left[\left|\log(T_c) + 0.3\right| - \log(T_c) - 0.3\right]^{1.5}}{10}} \tag{3–22}$$

where

q_u = unit peak discharge from the watershed, in cfs/ac–in
T_c = time of concentration, in hours

Note: for $T_c > 0.5$ hours, the last term of the equation, $10^{-\frac{\left[\left|\log(T_c) + 0.3\right| - \log(T_c) - 0.3\right]^{1.5}}{10}}$, is equal to 1.0

Step 3

Calculate the direct runoff from the watershed. The direct runoff is expressed as an average depth of water over the entire watershed, in inches. The direct runoff may be read from **Figure 3–17** using the 24–hour rainfall depth P_{24} in inches, and the runoff curve number, CN. The runoff depth may also be calculated from the following equation:

$$Q_d = \frac{\left[P_{24} - (200/CN) + 2\right]^2}{P_{24} + (800/CN) - 8} \tag{3–23}$$

where

Q_d = average runoff depth for the entire watershed, in inches

Step 4

Compute the peak discharge from the watershed by the following equation:

$$Q_p = A \bullet Q_d \bullet q_u \tag{3–24}$$

where

Q_p = peak discharge, in cfs
A = drainage area, in acres

Step 5

Compute the runoff volume, if required. The runoff volume is obtained by the equation:

$$Q_v = \frac{Q_d \bullet A}{12} \tag{3–25}$$

where

Q_v = runoff volume from the watershed, in ac–ft

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 3: DRAINAGE CALCULATIONS

ATTACHMENT III.3.B

U.S. DEPT. OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NATIONAL WEATHER SERVICE OFFICE OF HYDROLOGIC DEVELOPMENT HYDROMETEOROLOGICAL DESIGN STUDIES CENTER, JUNE 2006, NOAA ATLAS 14, VOLUME 1, VERSION 5

POINT PRECIPITATION FREQUENCY ESTIMATES FOR LATITUDE: 32.4438°, LONGITUDE: -103.0864°, PDS-BASED POINT PRECIPITATION FREQUENCY ESTIMATES WITH 90% CONFIDENCE INTERVALS (IN INCHES)

NOAA Atlas 14, Volume 1, Version 5
Location name: Eunice, New Mexico, US*
Latitude: 32.4438°, Longitude: -103.0864°
Elevation: 3451 ft*
* source: Google Maps

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.327 (0.292-0.367)	0.423 (0.377-0.474)	0.563 (0.500-0.630)	0.671 (0.594-0.749)	0.817 (0.720-0.912)	0.931 (0.815-1.04)	1.05 (0.915-1.17)	1.17 (1.01-1.30)	1.34 (1.15-1.49)	1.47 (1.25-1.64)
10-min	0.498 (0.444-0.559)	0.644 (0.574-0.721)	0.857 (0.761-0.960)	1.02 (0.905-1.14)	1.24 (1.10-1.39)	1.42 (1.24-1.58)	1.60 (1.39-1.78)	1.78 (1.55-1.99)	2.04 (1.75-2.27)	2.24 (1.91-2.50)
15-min	0.617 (0.550-0.693)	0.798 (0.711-0.894)	1.06 (0.944-1.19)	1.27 (1.12-1.42)	1.54 (1.36-1.72)	1.76 (1.54-1.96)	1.98 (1.73-2.21)	2.21 (1.92-2.46)	2.53 (2.17-2.82)	2.78 (2.36-3.10)
30-min	0.831 (0.741-0.933)	1.07 (0.957-1.21)	1.43 (1.27-1.60)	1.71 (1.51-1.91)	2.08 (1.83-2.32)	2.37 (2.07-2.63)	2.67 (2.33-2.97)	2.98 (2.58-3.32)	3.40 (2.92-3.79)	3.74 (3.18-4.17)
60-min	1.03 (0.917-1.16)	1.33 (1.19-1.49)	1.77 (1.57-1.98)	2.11 (1.87-2.36)	2.57 (2.27-2.87)	2.93 (2.56-3.26)	3.30 (2.88-3.67)	3.69 (3.19-4.10)	4.21 (3.62-4.69)	4.63 (3.94-5.17)
2-hr	1.22 (1.08-1.38)	1.57 (1.40-1.78)	2.13 (1.88-2.40)	2.56 (2.26-2.88)	3.16 (2.77-3.55)	3.64 (3.18-4.08)	4.15 (3.60-4.64)	4.69 (4.04-5.24)	5.44 (4.63-6.08)	6.05 (5.09-6.77)
3-hr	1.31 (1.17-1.48)	1.69 (1.51-1.91)	2.27 (2.01-2.55)	2.73 (2.42-3.06)	3.38 (2.97-3.78)	3.89 (3.41-4.35)	4.45 (3.87-4.97)	5.03 (4.34-5.62)	5.85 (4.98-6.54)	6.52 (5.50-7.31)
6-hr	1.53 (1.36-1.72)	1.96 (1.75-2.21)	2.60 (2.32-2.92)	3.13 (2.78-3.50)	3.87 (3.41-4.32)	4.46 (3.91-4.98)	5.10 (4.44-5.68)	5.78 (4.99-6.44)	6.74 (5.75-7.51)	7.53 (6.36-8.40)
12-hr	1.70 (1.51-1.91)	2.17 (1.93-2.45)	2.87 (2.55-3.23)	3.44 (3.05-3.86)	4.24 (3.73-4.76)	4.89 (4.28-5.48)	5.60 (4.86-6.25)	6.33 (5.44-7.07)	7.39 (6.27-8.26)	8.24 (6.92-9.23)
24-hr	1.94 (1.75-2.16)	2.49 (2.24-2.77)	3.31 (2.97-3.68)	3.98 (3.56-4.42)	4.93 (4.39-5.47)	5.71 (5.05-6.33)	6.54 (5.74-7.25)	7.43 (6.46-8.24)	8.70 (7.46-9.69)	9.74 (8.25-10.9)
2-day	2.10 (1.89-2.35)	2.70 (2.43-3.02)	3.62 (3.25-4.04)	4.37 (3.90-4.87)	5.46 (4.84-6.08)	6.36 (5.59-7.07)	7.33 (6.39-8.16)	8.38 (7.22-9.35)	9.90 (8.40-11.1)	11.2 (9.34-12.6)
3-day	2.22 (1.99-2.48)	2.85 (2.56-3.19)	3.84 (3.44-4.29)	4.65 (4.15-5.20)	5.84 (5.17-6.52)	6.83 (6.00-7.62)	7.92 (6.88-8.84)	9.09 (7.81-10.2)	10.8 (9.12-12.2)	12.2 (10.2-13.9)
4-day	2.33 (2.09-2.61)	3.00 (2.69-3.36)	4.06 (3.63-4.55)	4.94 (4.40-5.52)	6.23 (5.50-6.96)	7.31 (6.40-8.17)	8.50 (7.37-9.52)	9.80 (8.39-11.0)	11.7 (9.84-13.2)	13.3 (11.0-15.1)
7-day	2.62 (2.35-2.93)	3.37 (3.03-3.78)	4.57 (4.09-5.11)	5.56 (4.96-6.21)	7.00 (6.19-7.82)	8.21 (7.20-9.17)	9.55 (8.29-10.7)	11.0 (9.44-12.3)	13.1 (11.0-14.8)	14.9 (12.3-17.0)
10-day	2.88 (2.60-3.21)	3.72 (3.35-4.14)	5.03 (4.52-5.60)	6.12 (5.47-6.81)	7.71 (6.83-8.56)	9.03 (7.94-10.0)	10.5 (9.12-11.7)	12.1 (10.4-13.5)	14.4 (12.1-16.2)	16.4 (13.6-18.6)
20-day	3.63 (3.29-4.00)	4.65 (4.22-5.14)	6.16 (5.57-6.79)	7.36 (6.64-8.11)	9.04 (8.11-9.97)	10.4 (9.27-11.5)	11.8 (10.5-13.1)	13.4 (11.7-14.8)	15.5 (13.4-17.3)	17.3 (14.7-19.5)
30-day	4.20 (3.81-4.62)	5.36 (4.87-5.91)	7.02 (6.37-7.73)	8.33 (7.55-9.17)	10.1 (9.14-11.2)	11.6 (10.4-12.8)	13.1 (11.6-14.5)	14.7 (12.9-16.3)	16.9 (14.7-18.9)	18.7 (16.0-21.0)
45-day	4.95 (4.49-5.45)	6.34 (5.75-6.97)	8.31 (7.54-9.14)	9.86 (8.92-10.8)	12.0 (10.8-13.2)	13.7 (12.2-15.0)	15.4 (13.7-17.0)	17.2 (15.2-19.1)	19.7 (17.1-22.0)	21.7 (18.6-24.4)
60-day	5.69 (5.18-6.23)	7.26 (6.62-7.96)	9.43 (8.58-10.3)	11.1 (10.1-12.1)	13.3 (12.0-14.6)	15.0 (13.5-16.4)	16.7 (15.0-18.4)	18.5 (16.4-20.4)	20.9 (18.3-23.2)	22.7 (19.7-25.4)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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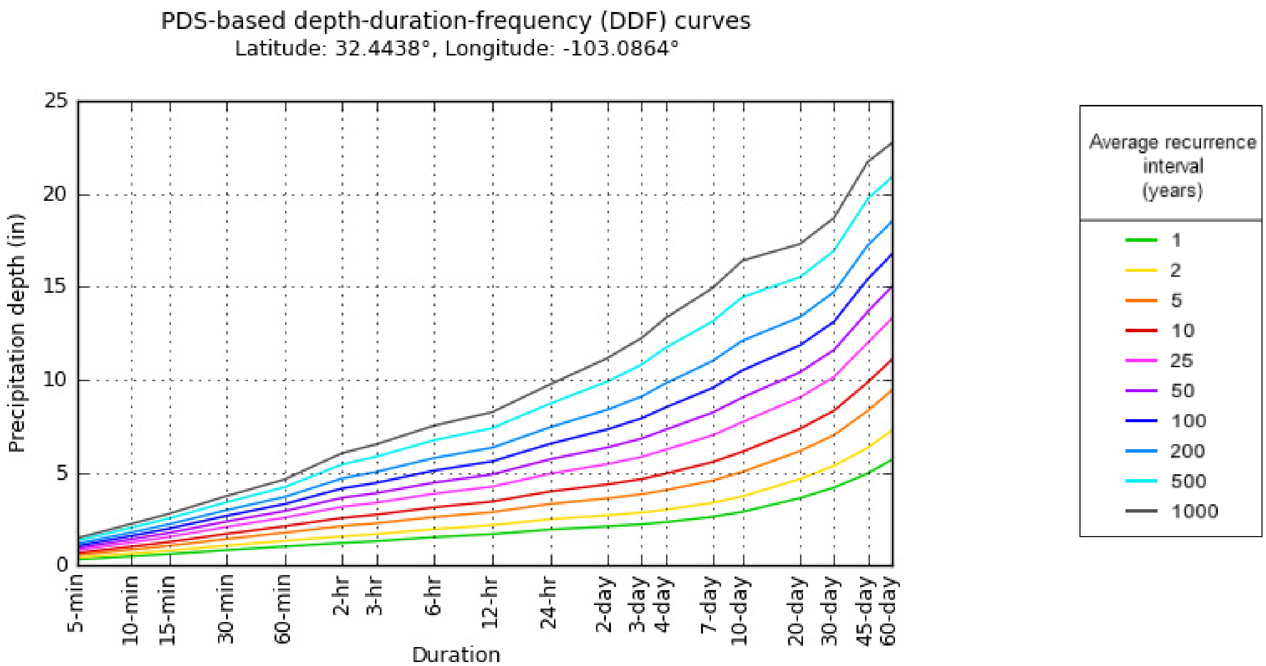
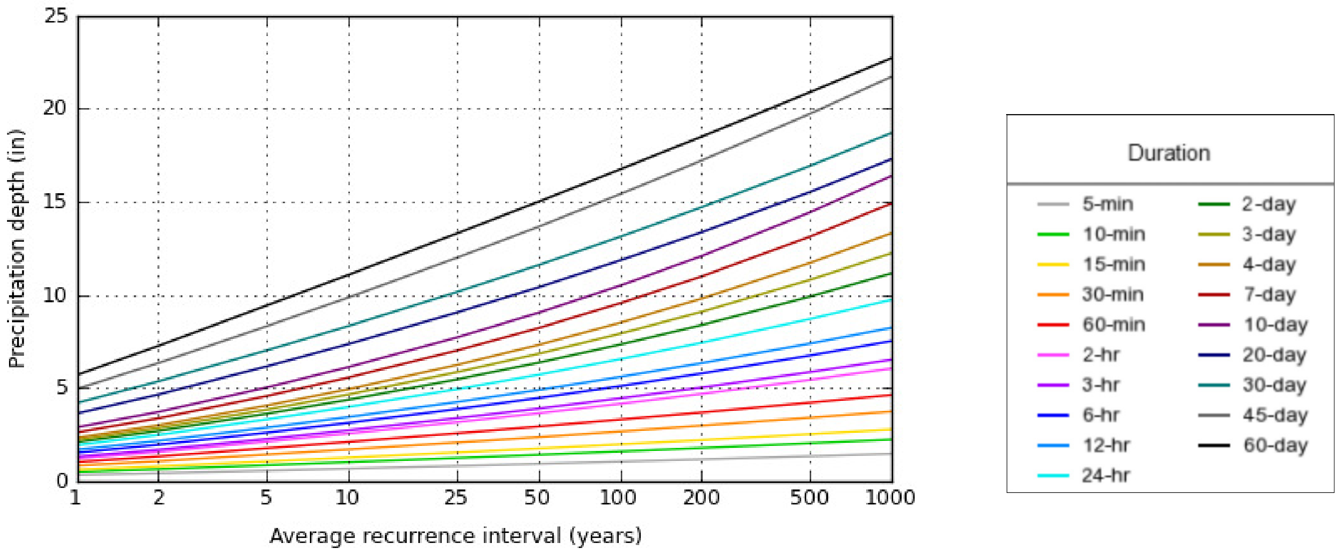
PF graphical





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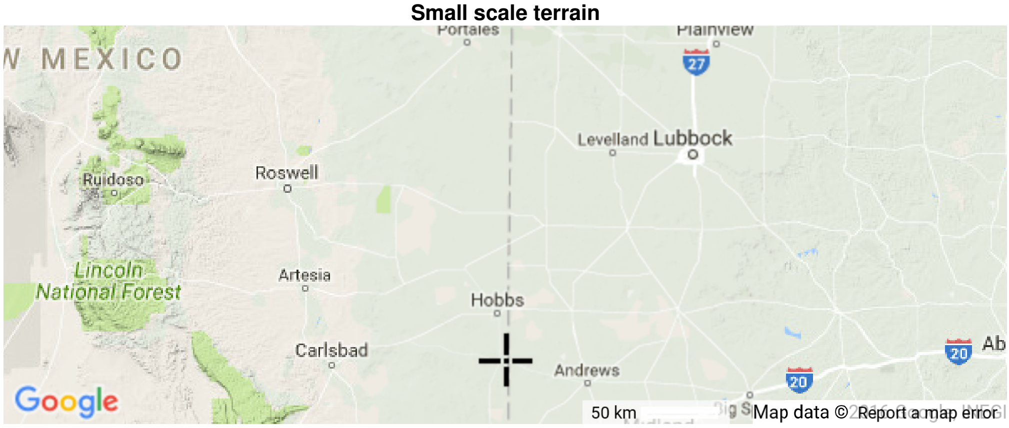
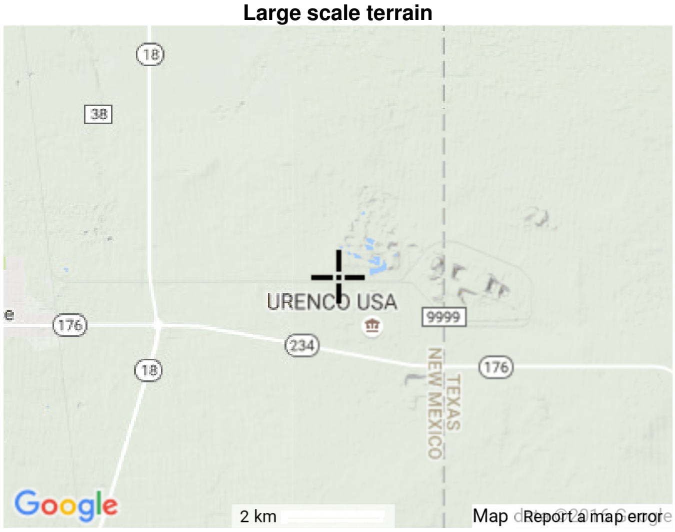
Maps & aerials

Small scale terrain



Large scale terrain



Large scale map

Large scale aerial

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US Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
National Water Center
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 3: DRAINAGE CALCULATIONS

ATTACHMENT III.3.C

AUTODESK,® INC, 2016, *STORM AND SANITARY ANALYSIS*

***EAST (INTERMEDIATE) PHASE* MODEL OUTPUT**

Project Description

File Name .... NewSundanceDrainage-Intermediate.SPF
Description ....
P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\Drainage Calculations\Submittal to JWJ-WestDrainage.dwg
P:\acad 2003\530.05.01\PERMIT FIGURES\2016-Draft 2 (Draft 1 OCD Comments)\Drainage\FINAL GRADING PLAN-mk3-Pasted.dwg
P:\acad 2003\530.05.01\PERMIT FIGURES\2016-Draft 2 (Draft 1 OCD Comments)\Drainage\FINAL GRADING PLAN-mk3-Pasted.dwg

Project Options

Flow Units .... CFS
Elevation Type .... Elevation
Hydrology Method .... SCS TR-20
Time of Concentration (TOC) Method .... SCS TR-55
Link Routing Method .... Hydrodynamic
Enable Overflow Ponding at Nodes .... YES
Skip Steady State Analysis Time Periods .... NO

Analysis Options

Start Analysis On	Jul 22, 2016	00:00:00
End Analysis On	Jul 23, 2016	00:00:00
Start Reporting On	Jul 22, 2016	00:00:00
Antecedent Dry Days	0	days
Runoff (Dry Weather) Time Step	0 01:00:00	days hh:mm:ss
Runoff (Wet Weather) Time Step	0 00:05:00	days hh:mm:ss
Reporting Time Step	0 00:05:00	days hh:mm:ss
Routing Time Step	30	seconds

Number of Elements

	Qty
Rain Gages	1
Subbasins...	14
Nodes...	10
Junctions	2
Outfalls	2
Flow Diversions	0
Inlets	0
Storage Nodes	6
Links...	6
Channels	1
Pipes	1
Pumps	0
Orifices	0
Weirs	4
Outlets	0
Pollutants	0
Land Uses	0

Rainfall Details

SN	Rain Gage ID	Data Source	Data Source ID	Rainfall Type	Rain Units	State	County	Return Period (years)	Rainfall Depth (inches)	Rainfall Distribution
1	LeaCty_NM-25Y	Time Series	TS-01	Cumulative	inches	New Mexico	Lea	25	4.93	NM Type IIA 60

Subbasin Summary

SN	Subbasin ID	Area (ac)	Weighted Curve Number	Total Rainfall (in)	Total Runoff (in)	Total Runoff Volume (ac-ft)	Peak Runoff (cfs)	Time of Concentration (days hh:mm:ss)
1	{Intermediat Grade Drainage Catchments}.Subbasin DB1	2.76	77.00	4.93	2.57	0.59	17.23	0 00:05:00
2	{Intermediat Grade Drainage Catchments}.Subbasin DB2	2.82	77.00	4.93	2.57	0.60	17.63	0 00:05:00
3	{Intermediat Grade Drainage Catchments}.Subbasin H	3.06	77.00	4.93	2.56	0.65	8.91	0 00:31:42
4	{Intermediat Grade Drainage Catchments}.Subbasin J	3.08	77.00	4.93	2.56	0.66	7.06	0 00:43:16
5	{Intermediat Grade Drainage Catchments}.Subbasin K	6.65	77.00	4.93	2.56	1.42	14.91	0 00:44:45
6	{Intermediat Grade Drainage Catchments}.Subbasin L	30.89	77.00	4.93	2.57	6.60	15.20	0 04:16:21
7	{Intermediat Grade Drainage Catchments}.Subbasin M	12.20	77.00	4.93	2.57	2.61	58.43	0 00:13:47
8	{Intermediat Grade Drainage Catchments}.Subbasin N	14.07	77.00	4.93	2.57	3.01	74.77	0 00:10:31
9	{Intermediat Grade Drainage Catchments}.Subbasin O	8.50	77.00	4.93	2.57	1.82	49.95	0 00:07:16
10	{Site 1}.SSI-NorthCentralCatchment-100%Retention	40.72	78.30	4.93	2.68	9.09	201.15	0 00:14:15
11	{Site 1}.SSI-NorthEastCatchment-100%Retention	100.19	76.20	4.93	2.50	20.83	420.48	0 00:17:01
12	{Site 1}.SSI-NorthWestCatchment-DrainsWest	41.63	72.00	4.93	2.14	7.44	106.79	0 00:28:09
13	{Site 1}.SSI-SouthCatchment-DrainsWest	177.14	72.00	4.93	2.14	31.65	181.30	0 01:26:22
14	NorthRun-On	106.25	77.00	4.93	2.57	22.71	226.50	0 00:47:28

Node Summary

SN	Element ID	Element Type	Invert Elevation (ft)	Ground/Rim (Max) Elevation (ft)	Initial Water Elevation (ft)	Surcharge Elevation (ft)	Ponded Area (ft²)	Peak Inflow (cfs)	Max HGL Elevation Attained (ft)	Max Surcharge Depth Attained (ft)	Min Freeboard Attained (ft)	Time of Peak Flooding Occurrence (days hh:mm)	Total Flooded Volume (ac-in)
1	Outflow Junction	Junction	19.00	20.00	19.00	20.00	0.00	0.00	19.00	0.00	50.00	0 00:00	0.00
2	RunOnChannel-FromSSI	Junction	38.00	41.00	38.00	41.00	0.00	73.22	39.85	0.00	20.15	0 00:00	0.00
3	Overflow	Outfall	18.00					0.00	18.00				
4	SSI_Bypass_LowVelo	Outfall	8.00					72.45	9.84				
5	DB-1	Storage Node	10.00	30.00	15.00		75000.00	248.89	29.63				0.00
6	DB-2	Storage Node	10.00	39.00	15.00		29000.00	116.80	37.52				0.00
7	Intermed-TransZone	Storage Node	-11.00	29.50	-11.00		750.00	162.48	3.20				0.00
8	SSI-FinalCover-EastPond	Storage Node	0.00	21.00	0.00		0.00	414.64	20.32				0.00
9	SSI-FinalCover-WestPond	Storage Node	0.00	18.00	0.00		0.00	200.52	14.73				0.00
10	SSI-SouthChannel	Storage Node	41.00	46.00	41.00		0.00	181.07	44.57				0.00

Total Time Flooded (min)
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00

Link Summary

SN	Element ID	Element Type	From (Inlet) Node	To (Outlet) Node	Length (ft)	Inlet Invert Elevation (ft)	Outlet Invert Elevation (ft)	Average Slope (%)	Diameter or Height (in)	Manning's Roughness	Peak Flow (cfs)	Design Flow Capacity (cfs)	Peak Flow/ Design Flow Ratio	Peak Flow Velocity (ft/sec)	Peak Flow Depth (ft)	Peak Flow Depth/ Total Depth Ratio
1	OverflowRouting	Pipe	Outflow Junction	Overflow	174.03	19.00	18.00	0.5700	0.000	0.0320	0.00	0.00	0.00	0.00	0.00	0.00
2	SSI-DrainagePassthroughChannel	Channel	RunOnChannel-FromSSI	SSI_Bypass_LowVelo	4400.00	38.00	8.00	0.6800	36.000	0.0320	72.45	212.81	0.34	4.12	1.84	0.61
3	DB-1 Drain	Weir	DB-1	Outflow Junction		10.00	19.00				0.00					
4	DB2-Drain	Weir	DB-2	Outflow Junction		10.00	19.00				0.00					
5	SSI-OutfallWeir	Weir	SSI-SouthChannel	RunOnChannel-FromSSI		41.00	38.00				73.22					
6	TransitionDrain	Weir	Intermed-TransZone	Outflow Junction		-11.00	19.00				0.00					

Total Time Reported Surcharged Condition (min)
0.00
0.00

Subbasin Hydrology

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin DB1

Input Data

Area (ac) 2.76
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	2.76	B	77.00
Composite Area & Weighted CN	2.76		77.00

Time of Concentration

TOC Method : SCS TR-55

Sheet Flow Equation :

Tc = (0.007 * ((n * Lf)^0.8)) / ((P^0.5) * (Sf^0.4))

Where :

Tc = Time of Concentration (hr)
n = Manning's roughness
Lf = Flow Length (ft)
P = 2 yr, 24 hr Rainfall (inches)
Sf = Slope (ft/ft)

Shallow Concentrated Flow Equation :

V = 16.1345 * (Sf^0.5) (unpaved surface)
V = 20.3282 * (Sf^0.5) (paved surface)
V = 15.0 * (Sf^0.5) (grassed waterway surface)
V = 10.0 * (Sf^0.5) (nearly bare & untilled surface)
V = 9.0 * (Sf^0.5) (cultivated straight rows surface)
V = 7.0 * (Sf^0.5) (short grass pasture surface)
V = 5.0 * (Sf^0.5) (woodland surface)
V = 2.5 * (Sf^0.5) (forest w/heavy litter surface)
Tc = (Lf / V) / (3600 sec/hr)

Where:

Tc = Time of Concentration (hr)
Lf = Flow Length (ft)
V = Velocity (ft/sec)
Sf = Slope (ft/ft)

Channel Flow Equation :

V = (1.49 * (R^(2/3)) * (Sf^0.5)) / n
R = Aq / Wp
Tc = (Lf / V) / (3600 sec/hr)

Where :

Tc = Time of Concentration (hr)
Lf = Flow Length (ft)
R = Hydraulic Radius (ft)
Aq = Flow Area (ft²)
Wp = Wetted Perimeter (ft)
V = Velocity (ft/sec)
Sf = Slope (ft/ft)
n = Manning's roughness

User-Defined TOC override (minutes): 5

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 17.23
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:05:00

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin DB2

Input Data

Area (ac) 2.82
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	2.82	B	77.00
Composite Area & Weighted CN	2.82		77.00

Time of Concentration

User-Defined TOC override (minutes): 5

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 17.63
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:05:00

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin H

Input Data

Area (ac) 3.06
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	3.06	B	77.00
Composite Area & Weighted CN	3.06		77.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	25	0.00	0.00
Slope (%) :	25	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.17	0.00	0.00
Computed Flow Time (min) :	2.44	0.00	0.00

Channel Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	1871.66	0.00	0.00
Channel Slope (%) :	.59	0.00	0.00
Cross Section Area (ft²) :	8	0.00	0.00
Wetted Perimeter (ft) :	8.9	0.00	0.00
Velocity (ft/sec) :	1.07	0.00	0.00
Computed Flow Time (min) :	29.26	0.00	0.00

Total TOC (min) 31.70

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.56
Peak Runoff (cfs) 8.91
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:31:42

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin J

Input Data

Area (ac) 3.08
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	3.08	B	77.00
Composite Area & Weighted CN	3.08		77.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	25	0.00	0.00
Slope (%) :	25	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.17	0.00	0.00
Computed Flow Time (min) :	2.44	0.00	0.00

Channel Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	2611.92	0.00	0.00
Channel Slope (%) :	.59	0.00	0.00
Cross Section Area (ft^2) :	8	0.00	0.00
Wetted Perimeter (ft) :	8.9	0.00	0.00
Velocity (ft/sec) :	1.07	0.00	0.00
Computed Flow Time (min) :	40.84	0.00	0.00

Total TOC (min) 43.28

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.56
Peak Runoff (cfs) 7.06
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:43:17

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin K

Input Data

Area (ac) 6.65
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	6.65	B	77.00
Composite Area & Weighted CN	6.65		77.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.32	.32	0.00
Flow Length (ft) :	100	54.69	0.00
Slope (%) :	25	25	0.00
2 yr, 24 hr Rainfall (in) :	2.50	2.50	0.00
Velocity (ft/sec) :	0.23	0.20	0.00
Computed Flow Time (min) :	7.40	4.57	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	26	0	0.00
Slope (%) :	25	0	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	8.07	0.00	0.00
Computed Flow Time (min) :	0.05	0.00	0.00

Channel Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.1	.1	0.00
Flow Length (ft) :	699.31	2503.65	0.00
Channel Slope (%) :	.56	.56	0.00
Cross Section Area (ft²) :	8	8	0.00
Wetted Perimeter (ft) :	8.9	8.9	0.00
Velocity (ft/sec) :	1.04	1.04	0.00
Computed Flow Time (min) :	11.22	40.18	0.00

Total TOC (min) 44.75

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.56
Peak Runoff (cfs) 14.91
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:44:45

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin L

Input Data

Area (ac) 30.89
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	30.89	B	77.00
Composite Area & Weighted CN	30.89		77.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	25	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.23	0.00	0.00
Computed Flow Time (min) :	7.40	0.00	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	28	0.00	0.00
Slope (%) :	25	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	8.07	0.00	0.00
Computed Flow Time (min) :	0.06	0.00	0.00

Channel Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	3798.98	0.00	0.00
Channel Slope (%) :	.56	0.00	0.00
Cross Section Area (ft²) :	1.7	0.00	0.00
Wetted Perimeter (ft) :	15.6	0.00	0.00
Velocity (ft/sec) :	0.25	0.00	0.00
Computed Flow Time (min) :	248.90	0.00	0.00

Total TOC (min) 256.35

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 15.20
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 04:16:21

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin M

Input Data

Area (ac) 12.20
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	12.20	B	77.00
Composite Area & Weighted CN	12.20		77.00

Time of Concentration

User-Defined TOC override (minutes): 13.79

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 58.43
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:13:47

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin N

Input Data

Area (ac) 14.07
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	14.07	B	77.00
Composite Area & Weighted CN	14.07		77.00

Time of Concentration

User-Defined TOC override (minutes): 10.53

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 74.77
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:10:32

Subbasin : {Intermediat Grade Drainage Catchments}.Subbasin O

Input Data

Area (ac) 8.50
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	8.50	B	77.00
Composite Area & Weighted CN	8.50		77.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	33	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.25	0.00	0.00
Computed Flow Time (min) :	6.62	0.00	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	213	0.00	0.00
Slope (%) :	33	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	9.27	0.00	0.00
Computed Flow Time (min) :	0.38	0.00	0.00

Channel Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	76.69	0.00	0.00
Channel Slope (%) :	29	0.00	0.00
Cross Section Area (ft²) :	6	0.00	0.00
Wetted Perimeter (ft) :	12.65	0.00	0.00
Velocity (ft/sec) :	4.88	0.00	0.00
Computed Flow Time (min) :	0.26	0.00	0.00

Total TOC (min) 7.27

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 49.95
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:07:16

Subbasin : {Site 1}.SSI-NorthCentralCatchment-100%Retention

Input Data

Area (ac) 40.72
Weighted Curve Number 78.30
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	28.50	B	72.00
Herbaceous range, Poor	12.22	D	93.00
Composite Area & Weighted CN	40.72		78.30

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.13	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	2	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.17	0.00	0.00
Computed Flow Time (min) :	9.89	0.00	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	999.79	0.00	0.00
Slope (%) :	5.6	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	3.82	0.00	0.00
Computed Flow Time (min) :	4.36	0.00	0.00

Total TOC (min) 14.25

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.68
Peak Runoff (cfs) 201.15
Weighted Curve Number 78.30
Time of Concentration (days hh:mm:ss) 0 00:14:15

Subbasin : {Site 1}.SSI-NorthEastCatchment-100%Retention

Input Data

Area (ac) 100.19
Weighted Curve Number 76.20
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	80.15	B	72.00
Herbaceous range, Poor	20.04	D	93.00
Composite Area & Weighted CN	100.19		76.20

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.13	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	8	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.29	0.00	0.00
Computed Flow Time (min) :	5.68	0.00	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	1899.63	0.00	0.00
Slope (%) :	3	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.79	0.00	0.00
Computed Flow Time (min) :	11.35	0.00	0.00

Total TOC (min) 17.03

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.50
Peak Runoff (cfs) 420.48
Weighted Curve Number 76.20
Time of Concentration (days hh:mm:ss) 0 00:17:02

Subbasin : {Site 1}.SSI-NorthWestCatchment-DrainsWest

Input Data

Area (ac) 41.63
Weighted Curve Number 72.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	57.22	B	72.00
Composite Area & Weighted CN	57.22		72.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.13	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	1.1	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.13	0.00	0.00
Computed Flow Time (min) :	12.56	0.00	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	1580.87	0.00	0.00
Slope (%) :	1.1	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	1.69	0.00	0.00
Computed Flow Time (min) :	15.59	0.00	0.00

Total TOC (min) 28.15

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.14
Peak Runoff (cfs) 106.79
Weighted Curve Number 72.00
Time of Concentration (days hh:mm:ss) 0 00:28:09

Subbasin : {Site 1}.SSI-SouthCatchment-DrainsWest

Input Data

Area (ac) 177.14
Weighted Curve Number 72.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	177.14	B	72.00
Composite Area & Weighted CN	177.14		72.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.13	.13	0.00
Flow Length (ft) :	100	100	0.00
Slope (%) :	5	10	0.00
2 yr, 24 hr Rainfall (in) :	2.50	2.50	0.00
Velocity (ft/sec) :	0.24	0.32	0.00
Computed Flow Time (min) :	6.85	5.19	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	355.52	942.76	0.00
Slope (%) :	25	2	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	8.07	2.28	0.00
Computed Flow Time (min) :	0.73	6.89	0.00

Channel Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.03	.03	0.00
Flow Length (ft) :	6566.85	3658.55	0.00
Channel Slope (%) :	.4	.17	0.00
Cross Section Area (ft^2) :	1.5	1.5	0.00
Wetted Perimeter (ft) :	5.1	5.1	0.00
Velocity (ft/sec) :	1.39	0.91	0.00
Computed Flow Time (min) :	78.78	67.33	0.00

Total TOC (min) 86.37

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.14
Peak Runoff (cfs) 181.30
Weighted Curve Number 72.00
Time of Concentration (days hh:mm:ss) 0 01:26:22

Subbasin : NorthRun-On

Input Data

Area (ac) 106.25
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	106.25	B	77.00
Composite Area & Weighted CN	106.25		77.00

Time of Concentration

Sheet Flow Computations	Flowpath A	Flowpath B	Flowpath C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	1.7	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.08	0.00	0.00
Computed Flow Time (min) :	21.69	0.00	0.00

Shallow Concentrated Flow Computations	Flowpath A	Flowpath B	Flowpath C
Flow Length (ft) :	3250	0.00	0.00
Slope (%) :	1.7	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.10	0.00	0.00
Computed Flow Time (min) :	25.79	0.00	0.00

Total TOC (min) 47.48

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 226.50
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:47:29

Junction Input

SN	Element ID	Invert Elevation (ft)	Ground/Rim (Max) Elevation (ft)	Ground/Rim (Max) Offset (ft)	Initial Water Elevation (ft)	Initial Water Depth (ft)	Surcharge Elevation (ft)	Surcharge Depth (ft)	Ponded Area (ft²)	Minimum Pipe Cover (in)
1	Outflow Junction	19.00	20.00	1.00	19.00	0.00	20.00	0.00	0.00	0.00
2	RunOnChannel-FromSSI	38.00	41.00	3.00	38.00	0.00	41.00	0.00	0.00	0.00

Junction Results

SN	Element ID	Peak Inflow (cfs)	Peak Lateral Inflow (cfs)	Max HGL Elevation Attained (ft)	Max HGL Depth Attained (ft)	Max Surcharge Depth Attained (ft)	Min Freeboard Attained (ft)	Average HGL Elevation Attained (ft)	Average HGL Depth Attained (ft)	Time of Max HGL Occurrence (days hh:mm)	Time of Peak Flooding Occurrence (days hh:mm)	Total Flooded Volume (ac-in)	Total Time Flooded (min)
1	Outflow Junction	0.00	0.00	19.00	0.00	0.00	50.00	19.00	0.00	0 00:00	0 00:00	0.00	0.00
2	RunOnChannel-FromSSI	73.22	0.00	39.85	1.85	0.00	20.15	38.56	0.56	0 07:57	0 00:00	0.00	0.00

Channel Input

SN	Element ID	Length (ft)	Inlet Invert Elevation (ft)	Inlet Invert Offset (ft)	Outlet Invert Elevation (ft)	Outlet Invert Offset (ft)	Total Drop (ft)	Average Slope (%)	Shape	Height (ft)	Width (ft)	Manning's Roughness	Entrance Losses	Exit/Bend Losses	Additional Losses
1	SSI-DrainagePassthroughChannel	4400.00	38.00	0.00	8.00	0.00	30.00	0.6800	Trapezoidal	3.000	22.000	0.0320	0.5000	0.5000	0.0000

Initial Flow (cfs)	Flap Gate
0.00	No

Channel Results

SN	Element ID	Peak Flow (cfs)	Time of Peak Flow Occurrence (days hh:mm)	Design Flow Capacity (cfs)	Peak Flow/ Design Flow Ratio	Peak Flow Velocity (ft/sec)	Travel Time (min)	Peak Flow Depth (ft)	Peak Flow Depth/ Total Depth Ratio	Total Time Surcharged (min)	Froude Number	Reported Condition
1	SSI-DrainagePassthroughChannel	72.45	0 07:57	212.81	0.34	4.12	17.80	1.84	0.61	0.00		

Storage Nodes

Storage Node : DB-1

Input Data

Invert Elevation (ft) 10.00
Max (Rim) Elevation (ft) 30.00
Max (Rim) Offset (ft) 20.00
Initial Water Elevation (ft) 15.00
Initial Water Depth (ft) 5.00
Ponded Area (ft²) 75000.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	DB-1 Drain	Trapezoidal	Yes	30.00	20.00	40.00	20.00	3.33

Output Summary Results

Peak Inflow (cfs) 248.89
Peak Lateral Inflow (cfs) 248.89
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 29.63
Max HGL Depth Attained (ft) 19.63
Average HGL Elevation Attained (ft) 24.17
Average HGL Depth Attained (ft) 14.17
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : DB-2

Input Data

Invert Elevation (ft) 10.00
Max (Rim) Elevation (ft) 39.00
Max (Rim) Offset (ft) 29.00
Initial Water Elevation (ft) 15.00
Initial Water Depth (ft) 5.00
Ponded Area (ft²) 29000.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	DB2-Drain	Trapezoidal	Yes	39.00	29.00	40.00	9.00	3.33

Output Summary Results

Peak Inflow (cfs) 116.80
Peak Lateral Inflow (cfs) 116.80
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 37.52
Max HGL Depth Attained (ft) 27.52
Average HGL Elevation Attained (ft) 28.22
Average HGL Depth Attained (ft) 18.22
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : Intermed-TransZone

Input Data

Invert Elevation (ft) .... -11.00
Max (Rim) Elevation (ft) 29.50
Max (Rim) Offset (ft) 40.50
Initial Water Elevation (ft) .... -11.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 750.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	TransitionDrain	Trapezoidal	Yes	29.00	40.00	40.00	10.00	3.33

Output Summary Results

Peak Inflow (cfs) 162.48
Peak Lateral Inflow (cfs) 162.48
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 3.20
Max HGL Depth Attained (ft) 14.2
Average HGL Elevation Attained (ft) .... -1.16
Average HGL Depth Attained (ft) 9.84
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : SSI-FinalCover-EastPond

Input Data

Invert Elevation (ft) 0.00
Max (Rim) Elevation (ft) 21.00
Max (Rim) Offset (ft) 21.00
Initial Water Elevation (ft) 0.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 0.00
Evaporation Loss 0.00

Output Summary Results

Peak Inflow (cfs) 414.64
Peak Lateral Inflow (cfs) 414.64
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 20.32
Max HGL Depth Attained (ft) 20.32
Average HGL Elevation Attained (ft) 13.97
Average HGL Depth Attained (ft) 13.97
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : SSI-FinalCover-WestPond

Input Data

Invert Elevation (ft) 0.00
Max (Rim) Elevation (ft) 18.00
Max (Rim) Offset (ft) 18.00
Initial Water Elevation (ft) 0.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 0.00
Evaporation Loss 0.00

Output Summary Results

Peak Inflow (cfs) 200.52
Peak Lateral Inflow (cfs) 200.52
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 14.73
Max HGL Depth Attained (ft) 14.73
Average HGL Elevation Attained (ft) 10.16
Average HGL Depth Attained (ft) 10.16
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : SSI-SouthChannel

Input Data

Invert Elevation (ft) 41.00
Max (Rim) Elevation (ft) 46.00
Max (Rim) Offset (ft) 5.00
Initial Water Elevation (ft) 41.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 0.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	SSI-OutfallWeir	Trapezoidal	No	43.00	2.00	10.00	20.00	3.33

Output Summary Results

Peak Inflow (cfs) 181.07
Peak Lateral Inflow (cfs) 181.07
Peak Outflow (cfs) 73.22
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 44.57
Max HGL Depth Attained (ft) 3.57
Average HGL Elevation Attained (ft) 42.84
Average HGL Depth Attained (ft) 1.84
Time of Max HGL Occurrence (days hh:mm) 0 07:49
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 3: DRAINAGE CALCULATIONS

ATTACHMENT III.3.D

AUTODESK,® INC, 2016, *STORM AND SANITARY ANALYSIS*

***FINAL PHASE* MODEL OUTPUT**

Project Description

File Name	NewSundanceDrainage-Final.SPF
Description	P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\Drainage Calculations\Submittal to JWJ-SiteDrainage.dwg P:\acad 2003\530.05.01\PERMIT FIGURES\2016-Draft 2 (Draft 1 OCD Comments)\Drainage\FINAL GRADING PLAN-mk3-Pasted.dwg P:\acad 2003\530.05.01\PERMIT FIGURES\2016-Draft 2 (Draft 1 OCD Comments)\Drainage\FINAL GRADING PLAN-mk3-Pasted.dwg

Project Options

Flow Units	CFS
Elevation Type	Elevation
Hydrology Method	SCS TR-20
Time of Concentration (TOC) Method	SCS TR-55
Link Routing Method	Hydrodynamic
Enable Overflow Ponding at Nodes	YES
Skip Steady State Analysis Time Periods	NO

Analysis Options

Start Analysis On	Jul 22, 2016	00:00:00
End Analysis On	Jul 23, 2016	00:00:00
Start Reporting On	Jul 22, 2016	00:00:00
Antecedent Dry Days	0	days
Runoff (Dry Weather) Time Step	0 01:00:00	days hh:mm:ss
Runoff (Wet Weather) Time Step	0 00:05:00	days hh:mm:ss
Reporting Time Step	0 00:05:00	days hh:mm:ss
Routing Time Step	30	seconds

Number of Elements

	Qty
Rain Gages	1
Subbasins	16
Nodes	10
Junctions	2
Outfalls	1
Flow Diversions	0
Inlets	0
Storage Nodes	7
Links	7
Channels	2
Pipes	0
Pumps	0
Orifices	0
Weirs	5
Outlets	0
Pollutants	0
Land Uses	0

Rainfall Details

SN	Rain Gage ID	Data Source	Data Source ID	Rainfall Type	Rain Units	State	County	Return Period (years)	Rainfall Depth (inches)	Rainfall Distribution
1	LeaCty_NM-25Y	Time Series	TS-01	Cumulative	inches	New Mexico	Lea	25	4.93	NM Type IIA 60

Subbasin Summary

SN	Subbasin ID	Area (ac)	Weighted Curve Number	Total Rainfall (in)	Total Runoff (in)	Total Runoff Volume (ac-ft)	Peak Runoff (cfs)	Time of Concentration (days hh:mm:ss)
1	{Drainage Subcatchments}.Subbasin A	25.67	77.00	4.93	2.56	5.49	8.86	0 06:25:58
2	{Drainage Subcatchments}.Subbasin B	27.73	77.00	4.93	2.57	5.93	11.22	0 05:19:14
3	{Drainage Subcatchments}.Subbasin C	24.20	77.00	4.93	2.57	5.17	10.75	0 04:47:46
4	{Drainage Subcatchments}.Subbasin D	35.74	77.00	4.93	2.57	7.64	12.86	0 06:07:20
5	{Drainage Subcatchments}.Subbasin DB	10.20	77.00	4.93	2.57	2.18	63.72	0 00:05:00
6	{Drainage Subcatchments}.Subbasin E	31.67	77.00	4.93	2.56	6.77	8.63	0 08:21:49
7	{Drainage Subcatchments}.Subbasin F	4.83	77.00	4.93	2.56	1.03	12.62	0 00:36:43
8	{Drainage Subcatchments}.Subbasin G	7.91	77.00	4.93	2.56	1.69	16.78	0 00:47:43
9	{Site 1}.SSI-NorthCentralCatchment-100%Retention	40.72	78.30	4.93	2.68	9.09	201.15	0 00:14:15
10	{Site 1}.SSI-NorthEastCatchment-100%Retention	100.19	76.20	4.93	2.50	20.83	420.48	0 00:17:01
11	{Site 1}.SSI-NorthWestCatchment-DrainsWest	41.63	72.00	4.93	2.14	7.44	106.79	0 00:28:09
12	{Site 1}.SSI-SouthCatchment-DrainsWest	169.17	72.00	4.93	2.14	30.23	97.69	0 02:45:46
13	NorthRun-On	111.94	72.00	4.93	2.14	20.00	199.92	0 00:45:00
14	ProcessingArea_'etc'	14.07	77.00	4.93	2.57	3.01	29.18	0 00:49:14
15	StabilizationArea	5.83	77.00	4.93	2.57	1.25	24.18	0 00:18:27
16	Treatment_Ponds	24.42	100.00	4.93	4.93	10.03	231.34	0 00:05:00

Node Summary

SN	Element ID	Element Type	Invert Elevation (ft)	Ground/Rim (Max) Elevation (ft)	Initial Water Elevation (ft)	Surcharge Elevation (ft)	Ponded Area (ft²)	Peak Inflow (cfs)	Max HGL Elevation Attained (ft)	Max Surcharge Depth Attained (ft)	Min Freeboard Attained (ft)	Time of Peak Flooding Occurrence (days hh:mm)	Total Flooded Volume (ac-in)
1	OutfallCollector	Junction	19.00	20.00	19.00	20.00	0.00	0.00	19.00	0.00	18.00	0 00:00	0.00
2	RunOnChannel-FromSSI	Junction	38.00	41.00	38.00	41.00	0.00	51.17	39.56	0.00	12.44	0 00:00	0.00
3	Overflow	Outfall	18.00					0.00	18.00				
4	BasinDB	Storage Node	8.00	20.00	8.00		296588.00	319.58	18.78				0.00
5	EvaporationPondBasin	Storage Node	9.00	22.00	9.00		77200.00	231.01	14.62				0.00
6	ProcessingAreaBasin	Storage Node	4.00	20.00	4.00		15133.00	29.08	12.59				0.00
7	SSI-FinalCover-EastPond	Storage Node	0.00	21.00	0.00		0.00	414.64	20.32				0.00
8	SSI-FinalCover-WestPond	Storage Node	0.00	18.00	0.00		0.00	200.52	14.73				0.00
9	SSI-SouthChannel	Storage Node	41.00	46.00	41.00		0.00	97.68	44.33				0.00
10	StabilizationAreaBasin	Storage Node	5.00	23.00	5.00		230741.00	23.52	5.23				0.00

Total Time Flooded (min)
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00

Link Summary

SN	Element ID	Element Type	From (Inlet) Node	To (Outlet) Node	Length (ft)	Inlet Invert Elevation (ft)	Outlet Invert Elevation (ft)	Average Slope (%)	Diameter or Height (in)	Manning's Roughness	Peak Flow (cfs)	Design Flow Capacity (cfs)	Peak Flow/ Design Flow Ratio	Peak Flow Velocity (ft/sec)	Peak Flow Depth (ft)	Peak Flow Depth/ Total Depth Ratio	Total Time Surcharged (min)
1	Link-03	Channel	RunOnChannel-FromSSI	BasinDB	4400.00	38.00	8.00	0.6800	36.000	0.0320	50.80	212.81	0.24	2.06	2.28	0.76	0.00
2	OutflowConnector	Channel	OutfallCollector	Overflow	134.06	19.00	18.00	0.7500	6.000	0.0320	0.00	2.57	0.00	0.00	0.00	0.00	0.00
3	BasinDB-Overflow	Weir	BasinDB	OutfallCollector		8.00	19.00				0.00						
4	EvapBasinOverflow	Weir	EvaporationPondBasin	ProcessingAreaBasin		9.00	4.00				0.00						
5	Link-01	Weir	SSI-SouthChannel	RunOnChannel-FromSSI		41.00	38.00				51.17						
6	ProcAreaBasin-Overflow	Weir	ProcessingAreaBasin	OutfallCollector		4.00	19.00				0.00						
7	StabAreaBasin-Overflow	Weir	StabilizationAreaBasin	ProcessingAreaBasin		5.00	4.00				0.00						

Reported
Condition

Subbasin Hydrology

Subbasin : {Drainage Subcatchments}.Subbasin A

Input Data

Area (ac) 25.67
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	25.67	B	77.00
Composite Area & Weighted CN	25.67		77.00

Time of Concentration

TOC Method : SCS TR-55

Sheet Flow Equation :

Tc = (0.007 * ((n * Lf)^0.8)) / ((P^0.5) * (Sf^0.4))

Where :

Tc = Time of Concentration (hr)
n = Manning's roughness
Lf = Flow Length (ft)
P = 2 yr, 24 hr Rainfall (inches)
Sf = Slope (ft/ft)

Shallow Concentrated Flow Equation :

V = 16.1345 * (Sf^0.5) (unpaved surface)
V = 20.3282 * (Sf^0.5) (paved surface)
V = 15.0 * (Sf^0.5) (grassed waterway surface)
V = 10.0 * (Sf^0.5) (nearly bare & untilled surface)
V = 9.0 * (Sf^0.5) (cultivated straight rows surface)
V = 7.0 * (Sf^0.5) (short grass pasture surface)
V = 5.0 * (Sf^0.5) (woodland surface)
V = 2.5 * (Sf^0.5) (forest w/heavy litter surface)
Tc = (Lf / V) / (3600 sec/hr)

Where:

Tc = Time of Concentration (hr)
Lf = Flow Length (ft)
V = Velocity (ft/sec)
Sf = Slope (ft/ft)

Channel Flow Equation :

V = (1.49 * (R^(2/3)) * (Sf^0.5)) / n
R = Aq / Wp
Tc = (Lf / V) / (3600 sec/hr)

Where :

Tc = Time of Concentration (hr)
Lf = Flow Length (ft)
R = Hydraulic Radius (ft)
Aq = Flow Area (ft^2)
Wp = Wetted Perimeter (ft)
V = Velocity (ft/sec)
Sf = Slope (ft/ft)
n = Manning's roughness

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	2	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.08	0.00	0.00
Computed Flow Time (min) :	20.32	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	410	0.00	0.00
Slope (%) :	2	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.28	0.00	0.00
Computed Flow Time (min) :	3.00	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	8293	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft^2) :	1.2	0.00	0.00
Wetted Perimeter (ft) :	15.6	0.00	0.00
Velocity (ft/sec) :	0.38	0.00	0.00
Computed Flow Time (min) :	362.65	0.00	0.00

Total TOC (min) 385.97

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.56
Peak Runoff (cfs) 8.86
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 06:25:58

Subbasin : {Drainage Subcatchments}.Subbasin B

Input Data

Area (ac) 27.73
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	27.73	B	77.00
Composite Area & Weighted CN	27.73		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	2	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.08	0.00	0.00
Computed Flow Time (min) :	20.32	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	213	0.00	0.00
Slope (%) :	2	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.28	0.00	0.00
Computed Flow Time (min) :	1.56	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	6800	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft²) :	1.2	0.00	0.00
Wetted Perimeter (ft) :	15.6	0.00	0.00
Velocity (ft/sec) :	0.38	0.00	0.00
Computed Flow Time (min) :	297.36	0.00	0.00

Total TOC (min) 319.24

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 11.22
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 05:19:14

Subbasin : {Drainage Subcatchments}.Subbasin C

Input Data

Area (ac) 24.20
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	24.20	B	77.00
Composite Area & Weighted CN	24.20		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	2	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.08	0.00	0.00
Computed Flow Time (min) :	20.32	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	210	0.00	0.00
Slope (%) :	2	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.28	0.00	0.00
Computed Flow Time (min) :	1.54	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	6081	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft^2) :	1.2	0.00	0.00
Wetted Perimeter (ft) :	15.6	0.00	0.00
Velocity (ft/sec) :	0.38	0.00	0.00
Computed Flow Time (min) :	265.92	0.00	0.00

Total TOC (min) 287.78

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 10.75
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 04:47:47

Subbasin : {Drainage Subcatchments}.Subbasin D

Input Data

Area (ac) 35.74
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	35.74	B	77.00
Composite Area & Weighted CN	35.74		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	2	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.08	0.00	0.00
Computed Flow Time (min) :	20.32	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	182	0.00	0.00
Slope (%) :	2	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.28	0.00	0.00
Computed Flow Time (min) :	1.33	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	7905	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft²) :	1.2	0.00	0.00
Wetted Perimeter (ft) :	15.6	0.00	0.00
Velocity (ft/sec) :	0.38	0.00	0.00
Computed Flow Time (min) :	345.68	0.00	0.00

Total TOC (min) 367.34

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 12.86
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 06:07:20

Subbasin : {Drainage Subcatchments}.Subbasin DB

Input Data

Area (ac) 10.20
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	10.20	B	77.00
Composite Area & Weighted CN	10.20		77.00

Time of Concentration

User-Defined TOC override (minutes): 5

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 63.72
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:05:00

Subbasin : {Drainage Subcatchments}.Subbasin E

Input Data

Area (ac) 31.67
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	31.67	B	77.00
Composite Area & Weighted CN	31.67		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	2	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.08	0.00	0.00
Computed Flow Time (min) :	20.32	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	345	0.00	0.00
Slope (%) :	2	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.28	0.00	0.00
Computed Flow Time (min) :	2.52	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	10953	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft²) :	1.2	0.00	0.00
Wetted Perimeter (ft) :	15.6	0.00	0.00
Velocity (ft/sec) :	0.38	0.00	0.00
Computed Flow Time (min) :	478.97	0.00	0.00

Total TOC (min) 501.82

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.56
Peak Runoff (cfs) 8.63
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 08:21:49

Subbasin : {Drainage Subcatchments}.Subbasin F

Input Data

Area (ac) 4.83
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	4.83	B	77.00
Composite Area & Weighted CN	4.83		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	15	0.00	0.00
Slope (%) :	25	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.15	0.00	0.00
Computed Flow Time (min) :	1.62	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	4134	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft^2) :	8	0.00	0.00
Wetted Perimeter (ft) :	8.9	0.00	0.00
Velocity (ft/sec) :	1.96	0.00	0.00
Computed Flow Time (min) :	35.11	0.00	0.00

Total TOC (min) 36.73

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.56
Peak Runoff (cfs) 12.62
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:36:44

Subbasin : {Drainage Subcatchments}.Subbasin G

Input Data

Area (ac) 7.91
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	7.91	B	77.00
Composite Area & Weighted CN	7.91		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	15	0.00	0.00
Slope (%) :	25	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.15	0.00	0.00
Computed Flow Time (min) :	1.62	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	5428	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft²) :	8	0.00	0.00
Wetted Perimeter (ft) :	8.9	0.00	0.00
Velocity (ft/sec) :	1.96	0.00	0.00
Computed Flow Time (min) :	46.10	0.00	0.00

Total TOC (min) 47.72

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.56
Peak Runoff (cfs) 16.78
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:47:43

Subbasin : {Site 1}.SSI-NorthCentralCatchment-100%Retention

Input Data

Area (ac) 40.72
Weighted Curve Number 78.30
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	28.50	B	72.00
Herbaceous range, Poor	12.22	D	93.00
Composite Area & Weighted CN	40.72		78.30

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.13	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	2	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.17	0.00	0.00
Computed Flow Time (min) :	9.89	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	999.79	0.00	0.00
Slope (%) :	5.6	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	3.82	0.00	0.00
Computed Flow Time (min) :	4.36	0.00	0.00

Total TOC (min) 14.25

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.68
Peak Runoff (cfs) 201.15
Weighted Curve Number 78.30
Time of Concentration (days hh:mm:ss) 0 00:14:15

Subbasin : {Site 1}.SSI-NorthEastCatchment-100%Retention

Input Data

Area (ac) 100.19
Weighted Curve Number 76.20
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	80.15	B	72.00
Herbaceous range, Poor	20.04	D	93.00
Composite Area & Weighted CN	100.19		76.20

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.13	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	8	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.29	0.00	0.00
Computed Flow Time (min) :	5.68	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	1899.63	0.00	0.00
Slope (%) :	3	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	2.79	0.00	0.00
Computed Flow Time (min) :	11.35	0.00	0.00

Total TOC (min) 17.03

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.50
Peak Runoff (cfs) 420.48
Weighted Curve Number 76.20
Time of Concentration (days hh:mm:ss) 0 00:17:02

Subbasin : {Site 1}.SSI-NorthWestCatchment-DrainsWest

Input Data

Area (ac) 41.63
Weighted Curve Number 72.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	57.22	B	72.00
Composite Area & Weighted CN	57.22		72.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.13	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	1.1	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.13	0.00	0.00
Computed Flow Time (min) :	12.56	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	1580.87	0.00	0.00
Slope (%) :	1.1	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	1.69	0.00	0.00
Computed Flow Time (min) :	15.59	0.00	0.00

Total TOC (min) 28.15

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.14
Peak Runoff (cfs) 106.79
Weighted Curve Number 72.00
Time of Concentration (days hh:mm:ss) 0 00:28:09

Subbasin : {Site 1}.SSI-SouthCatchment-DrainsWest

Input Data

Area (ac) 169.17
Weighted Curve Number 72.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Fair	177.14	B	72.00
Composite Area & Weighted CN	177.14		72.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.13	.13	0.00
Flow Length (ft) :	100	100	0.00
Slope (%) :	5	10	0.00
2 yr, 24 hr Rainfall (in) :	2.50	2.50	0.00
Velocity (ft/sec) :	0.24	0.32	0.00
Computed Flow Time (min) :	6.85	5.19	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	355.52	942.76	0.00
Slope (%) :	25	2	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	8.07	2.28	0.00
Computed Flow Time (min) :	0.73	6.89	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.03	.03	0.00
Flow Length (ft) :	6566.85	3658.55	0.00
Channel Slope (%) :	.4	.17	0.00
Cross Section Area (ft²) :	1.5	1.5	0.00
Wetted Perimeter (ft) :	5.1	5.1	0.00
Velocity (ft/sec) :	1.39	0.91	0.00
Computed Flow Time (min) :	78.78	67.33	0.00

Total TOC (min) 165.78

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.14
Peak Runoff (cfs) 97.69
Weighted Curve Number 72.00
Time of Concentration (days hh:mm:ss) 0 02:45:47

Subbasin : NorthRun-On

Input Data

Area (ac) 111.94
Weighted Curve Number 72.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
-	111.94	-	72.00
Composite Area & Weighted CN	111.94		72.00

Time of Concentration

User-Defined TOC override (minutes): 45

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.14
Peak Runoff (cfs) 199.92
Weighted Curve Number 72.00
Time of Concentration (days hh:mm:ss) 0 00:45:00

Subbasin : ProcessingArea_'etc'

Input Data

Area (ac) 14.07
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	14.07	B	77.00
Composite Area & Weighted CN	14.07		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	1.5	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.07	0.00	0.00
Computed Flow Time (min) :	22.80	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	522	0.00	0.00
Slope (%) :	1.5	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	1.98	0.00	0.00
Computed Flow Time (min) :	4.39	0.00	0.00

Channel Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.1	0.00	0.00
Flow Length (ft) :	2615.36	0.00	0.00
Channel Slope (%) :	2	0.00	0.00
Cross Section Area (ft²) :	8	0.00	0.00
Wetted Perimeter (ft) :	8.8	0.00	0.00
Velocity (ft/sec) :	1.98	0.00	0.00
Computed Flow Time (min) :	22.04	0.00	0.00

Total TOC (min) 49.24

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 29.18
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:49:14

Subbasin : StabilizationArea

Input Data

Area (ac) 5.83
Weighted Curve Number 77.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
Desert shrub range, Poor	5.83	B	77.00
Composite Area & Weighted CN	5.83		77.00

Time of Concentration

Sheet Flow Computations	Subarea A	Subarea B	Subarea C
Manning's Roughness :	.32	0.00	0.00
Flow Length (ft) :	100	0.00	0.00
Slope (%) :	3.5	0.00	0.00
2 yr, 24 hr Rainfall (in) :	2.50	0.00	0.00
Velocity (ft/sec) :	0.10	0.00	0.00
Computed Flow Time (min) :	16.25	0.00	0.00

Shallow Concentrated Flow Computations	Subarea A	Subarea B	Subarea C
Flow Length (ft) :	400	0.00	0.00
Slope (%) :	3.5	0.00	0.00
Surface Type :	Unpaved	Unpaved	Unpaved
Velocity (ft/sec) :	3.02	0.00	0.00
Computed Flow Time (min) :	2.21	0.00	0.00

Total TOC (min) 18.45

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 2.57
Peak Runoff (cfs) 24.18
Weighted Curve Number 77.00
Time of Concentration (days hh:mm:ss) 0 00:18:27

Subbasin : Treatment_Ponds

Input Data

Area (ac) 24.42
Weighted Curve Number 100.00
Rain Gage ID .... LeaCty_NM-25Y

Composite Curve Number

Soil/Surface Description	Area (acres)	Soil Group	Curve Number
HDPE_Liner	24.42	B	100.00
Composite Area & Weighted CN	24.42		100.00

Time of Concentration

User-Defined TOC override (minutes): 5

Subbasin Runoff Results

Total Rainfall (in) 4.93
Total Runoff (in) 4.93
Peak Runoff (cfs) 231.34
Weighted Curve Number 100.00
Time of Concentration (days hh:mm:ss) 0 00:05:00

Junction Input

SN	Element ID	Invert Elevation (ft)	Ground/Rim (Max) Elevation (ft)	Ground/Rim (Max) Offset (ft)	Initial Water Elevation (ft)	Initial Water Depth (ft)	Surcharge Elevation (ft)	Surcharge Depth (ft)	Ponded Area (ft²)	Minimum Pipe Cover (in)
1	OutfallCollector	19.00	20.00	1.00	19.00	0.00	20.00	0.00	0.00	0.00
2	RunOnChannel-FromSSI	38.00	41.00	3.00	38.00	0.00	41.00	0.00	0.00	0.00

Junction Results

SN	Element ID	Peak Inflow (cfs)	Peak Lateral Inflow (cfs)	Max HGL Elevation Attained (ft)	Max HGL Depth Attained (ft)	Max Surcharge Depth Attained (ft)	Min Freeboard Attained (ft)	Average HGL Elevation Attained (ft)	Average HGL Depth Attained (ft)	Time of Max HGL Occurrence (days hh:mm)	Time of Peak Flooding Occurrence (days hh:mm)	Total Flooded Volume (ac-in)	Total Time Flooded (min)
1	OutfallCollector	0.00	0.00	19.00	0.00	0.00	18.00	19.00	0.00	0 00:00	0 00:00	0.00	0.00
2	RunOnChannel-FromSSI	51.17	0.00	39.56	1.56	0.00	12.44	38.54	0.54	0 09:18	0 00:00	0.00	0.00

Channel Input

SN	Element ID	Length (ft)	Inlet Invert Elevation (ft)	Inlet Invert Offset (ft)	Outlet Invert Elevation (ft)	Outlet Invert Offset (ft)	Total Drop (ft)	Average Slope (%)	Shape	Height (ft)	Width (ft)	Manning's Roughness	Entrance Losses	Exit/Bend Losses	Additional Losses	Initial Flow (cfs)	Flap Gate
1	Link-03	4400.00	38.00	0.00	8.00	0.00	30.00	0.6800	Trapezoidal	3.000	22.000	0.0320	0.5000	0.5000	0.0000	0.00	No
2	OutflowConnector	134.06	19.00	0.00	18.00	0.00	1.00	0.7500	Trapezoidal	0.500	3.000	0.0320	0.5000	0.5000	0.0000	0.00	No

Channel Results

SN	Element ID	Peak Flow (cfs)	Time of Peak Flow Occurrence (days hh:mm)	Design Flow Capacity (cfs)	Peak Flow/ Design Flow Ratio	Peak Flow Velocity (ft/sec)	Travel Time (min)	Peak Flow Depth (ft)	Peak Flow Depth/ Total Depth Ratio	Total Time Surcharged (min)	Froude Number	Reported Condition
1	Link-03	50.80	0 09:18	212.81	0.24	2.06	35.60	2.28	0.76	0.00		
2	OutflowConnector	0.00	0 00:00	2.57	0.00	0.00		0.00	0.00	0.00		

Storage Nodes

Storage Node : BasinDB

Input Data

Invert Elevation (ft) 8.00
Max (Rim) Elevation (ft) 20.00
Max (Rim) Offset (ft) 12.00
Initial Water Elevation (ft) 8.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 296588.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	BasinDB-Overflow	Trapezoidal	No	20.00	12.00	500.00	2.00	3.33

Output Summary Results

Peak Inflow (cfs) 319.58
Peak Lateral Inflow (cfs) 319.58
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 18.78
Max HGL Depth Attained (ft) 10.78
Average HGL Elevation Attained (ft) 13.76
Average HGL Depth Attained (ft) 5.76
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : EvaporationPondBasin

Input Data

Invert Elevation (ft) 9.00
Max (Rim) Elevation (ft) 22.00
Max (Rim) Offset (ft) 13.00
Initial Water Elevation (ft) 9.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 77200.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	EvapBasinOverflow	Trapezoidal	No	22.00	13.00	500.00	2.00	3.33

Output Summary Results

Peak Inflow (cfs) 231.01
Peak Lateral Inflow (cfs) 231.01
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 14.62
Max HGL Depth Attained (ft) 5.62
Average HGL Elevation Attained (ft) 12.93
Average HGL Depth Attained (ft) 3.93
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : ProcessingAreaBasin

Input Data

Invert Elevation (ft) 4.00
Max (Rim) Elevation (ft) 20.00
Max (Rim) Offset (ft) 16.00
Initial Water Elevation (ft) 4.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 15133.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	ProcAreaBasin-Overflow	Trapezoidal	No	20.00	16.00	50.00	2.00	3.33

Output Summary Results

Peak Inflow (cfs) 29.08
Peak Lateral Inflow (cfs) 29.08
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 12.59
Max HGL Depth Attained (ft) 8.59
Average HGL Elevation Attained (ft) 9.37
Average HGL Depth Attained (ft) 5.37
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : SSI-FinalCover-EastPond

Input Data

Invert Elevation (ft) 0.00
Max (Rim) Elevation (ft) 21.00
Max (Rim) Offset (ft) 21.00
Initial Water Elevation (ft) 0.00
Initial Water Depth (ft) 0.00
Ponded Area (ft^2) 0.00
Evaporation Loss 0.00

Output Summary Results

Peak Inflow (cfs) 414.64
Peak Lateral Inflow (cfs) 414.64
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 20.32
Max HGL Depth Attained (ft) 20.32
Average HGL Elevation Attained (ft) 13.97
Average HGL Depth Attained (ft) 13.97
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft^3) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : SSI-FinalCover-WestPond

Input Data

Invert Elevation (ft) 0.00
Max (Rim) Elevation (ft) 18.00
Max (Rim) Offset (ft) 18.00
Initial Water Elevation (ft) 0.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 0.00
Evaporation Loss 0.00

Output Summary Results

Peak Inflow (cfs) 200.52
Peak Lateral Inflow (cfs) 200.52
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 14.73
Max HGL Depth Attained (ft) 14.73
Average HGL Elevation Attained (ft) 10.16
Average HGL Depth Attained (ft) 10.16
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : SSI-SouthChannel

Input Data

Invert Elevation (ft) 41.00
Max (Rim) Elevation (ft) 46.00
Max (Rim) Offset (ft) 5.00
Initial Water Elevation (ft) 41.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 0.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	Link-01	Rectangular	No	43.00	2.00	10.00	12.00	3.33

Output Summary Results

Peak Inflow (cfs) 97.68
Peak Lateral Inflow (cfs) 97.68
Peak Outflow (cfs) 51.17
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 44.33
Max HGL Depth Attained (ft) 3.33
Average HGL Elevation Attained (ft) 42.79
Average HGL Depth Attained (ft) 1.79
Time of Max HGL Occurrence (days hh:mm) 0 09:08
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

Storage Node : StabilizationAreaBasin

Input Data

Invert Elevation (ft) 5.00
Max (Rim) Elevation (ft) 23.00
Max (Rim) Offset (ft) 18.00
Initial Water Elevation (ft) 5.00
Initial Water Depth (ft) 0.00
Ponded Area (ft²) 230741.00
Evaporation Loss 0.00

Outflow Weirs

SN	Element ID	Weir Type	Flap Gate	Crest Elevation (ft)	Crest Offset (ft)	Length (ft)	Weir Total Height (ft)	Discharge Coefficient
1	StabAreaBasin-Overflow	Trapezoidal	No	23.00	18.00	50.00	2.00	3.33

Output Summary Results

Peak Inflow (cfs) 23.52
Peak Lateral Inflow (cfs) 23.52
Peak Outflow (cfs) 0.00
Peak Exfiltration Flow Rate (cfm) 0.00
Max HGL Elevation Attained (ft) 5.23
Max HGL Depth Attained (ft) 0.23
Average HGL Elevation Attained (ft) 5.15
Average HGL Depth Attained (ft) 0.15
Time of Max HGL Occurrence (days hh:mm) 1 00:00
Total Exfiltration Volume (1000-ft³) 0.000
Total Flooded Volume (ac-in) 0
Total Time Flooded (min) 0
Total Retention Time (sec) 0.00

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 4: HELP MODEL

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APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 4: HELP MODEL

1.0 INTRODUCTION

Sundance West Surface Waste Management Facility (Sundance West) is a proposed Surface Waste Management Facility for oil field waste processing and disposal services. The proposed Sundance West Facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD). The Facility has been designed in compliance with 19.15.36 NMAC, and will be constructed and operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned by, and will be constructed and operated by, Sundance West, Inc.

1.1 Description

The Sundance West site is comprised of a 320-acre ± tract of land located approximately 3 miles east of Eunice, 18 miles south of Hobbs, and approximately 1.5 miles west of the Texas/New Mexico state line in the South ½ of Section 30, Township 21 South, Range 38 East Lea County, New Mexico (NM). Site access will be provided via NM 18 and Wallach Lane. The Sundance West Facility will include two main components; a liquid oil field waste Processing Area (80 acres ±), and an oil field waste Landfill (120 acres ±). Oil field wastes are anticipated to be delivered to the Sundance West Facility from oil and gas exploration and production operations in southeastern NM and west Texas. The Site Development Plan provided in the **Permit Plans, Sheet 3**, identifies the locations of the Processing Area and Landfill facilities.

2.0 DESIGN CRITERIA

An alternate design for the Sundance West landfill liner system that includes the use of geosynthetics and geocomposites is proposed. In addition, an alternate design is proposed for its final cover system using on-site soils. The alternative liner and final cover are designed to meet the requirements of the New Mexico Oil Conservation Division (OCD) 19.15.36.14C NMAC. If an alternate liner design and alternate final cover design using geosynthetics or geocomposites is proposed,

19.15.36.14 C(9) NMAC requires:

> *"Alternatively, the operator may propose a performance-based landfill design system using geosynthetics or geocomposites, including geogrids, geonets, geosynthetics clay liners, composite liner systems, etc., when supported by EPA's "hydrologic evaluation of landfill performance" (HELP) model or other division-approved model. The operator shall design the landfill to prevent the "bathtub effect". The bathtub effect occurs when a more permeable cover is placed over a less permeable bottom liner or natural subsoil."*

and further, 19.15.36.14F NMAC specifies that:

> *"The leachate collection and removal system protective layer and soil component of the leak detection system shall consist of soil materials that shall be free of organic matter, shall have a portion of material passing the no. 200 sieve no greater than five percent by weight and shall have a uniformity coefficient (Cu) less than 6, where Cu is defined as D60/D10. Geosynthetic materials or geocomposites including geonets and geotextiles, if used as components of the leachate collection and removal or leak detection system, shall have a hydraulic conductivity, transmissivity and chemical and physical qualities that oil field waste placement, equipment operation or leachate generation will not adversely affect. These geosynthetics or geocomposites, if used in conjunction with the soil protective cover for liners, shall have a hydraulic conductivity designed to ensure that the liner's hydraulic head never exceeds one foot."*

3.0 PURPOSE

Throughout the past year and a half, OCD and its consultants have provided guidance and clarification to our understanding of 19.15.36 NMAC. The result of which has had an impact on the application of several design technical models and the associated effect on other design elements. One such impacted model is the United State Environmental Protection Agency (USEPA) Hydrologic Evaluation of Landfill Performance (HELP) Model which evaluates the performance of alternative liner designs, demonstrating the alternative design will perform as stipulated, i.e., *The operator shall design the landfill to prevent the "bathtub effect", (see citation above).* Updated application and associated input parameters resulted in the following revised sections to this document.

This document presents the results of modeling conducted using HELP Model to evaluate the performance of the alternate final cover system so as to not create a "bathtub effect" in the landfill, in which the percolation through the alternate final cover exceeds that of the alternate liner system. Also presented is a formal request for OCD approval to utilize the alternate liner design and allow the use of alternate soil gradation specifications for soils used in construction of the protective soil layer (PSL).

4.0 HELP MODEL METHODOLOGY

The methodology used to demonstrate that the performance of the alternate liner system design will prevent the bathtub effect relies on the USEPA's HELP Modeling program as referenced in 19.15.36.14C(9) NMAC. The demonstrations described below were performed using the HELP Model, Version 3.07a.

5.0 OVERVIEW OF DEMONSTRATION MODELING

Gordon Environmental, Inc. (GEI) has prepared performance demonstrations for an alternate landfill liner design and an alternate landfill final cover design. In the proposed alternate liner design, on-site soils in conjunction with a geocomposite are used for the leachate collection layer; a geonet is used as the leak detection layer; and a geocomposite clay liner (GCL) along with 6-inches of compacted Chinle formation soils are used to replace the prescribed clay barrier layer. In the proposed alternate final cover design, an evapotranspiration (ET) cover system is proposed.

Because the Sundance West Facility is planning to use alternate designs for its liner system and final cover system, the HELP model simulation analyses were organized to support three demonstrations:

- First, demonstrate the performance of the planned alternate liner system to establish a basis of comparative analysis for the planned alternative final cover system.
- Second, demonstrate that percolation through the alternate final cover top surface does not create a "bathtub effect" within the landfill.
- Third, demonstrate that percolation through the alternate final cover sideslopes do not create a "bathtub effect" within the landfill.

6.0 HELP MODEL DEMONSTRATION ANALYSES

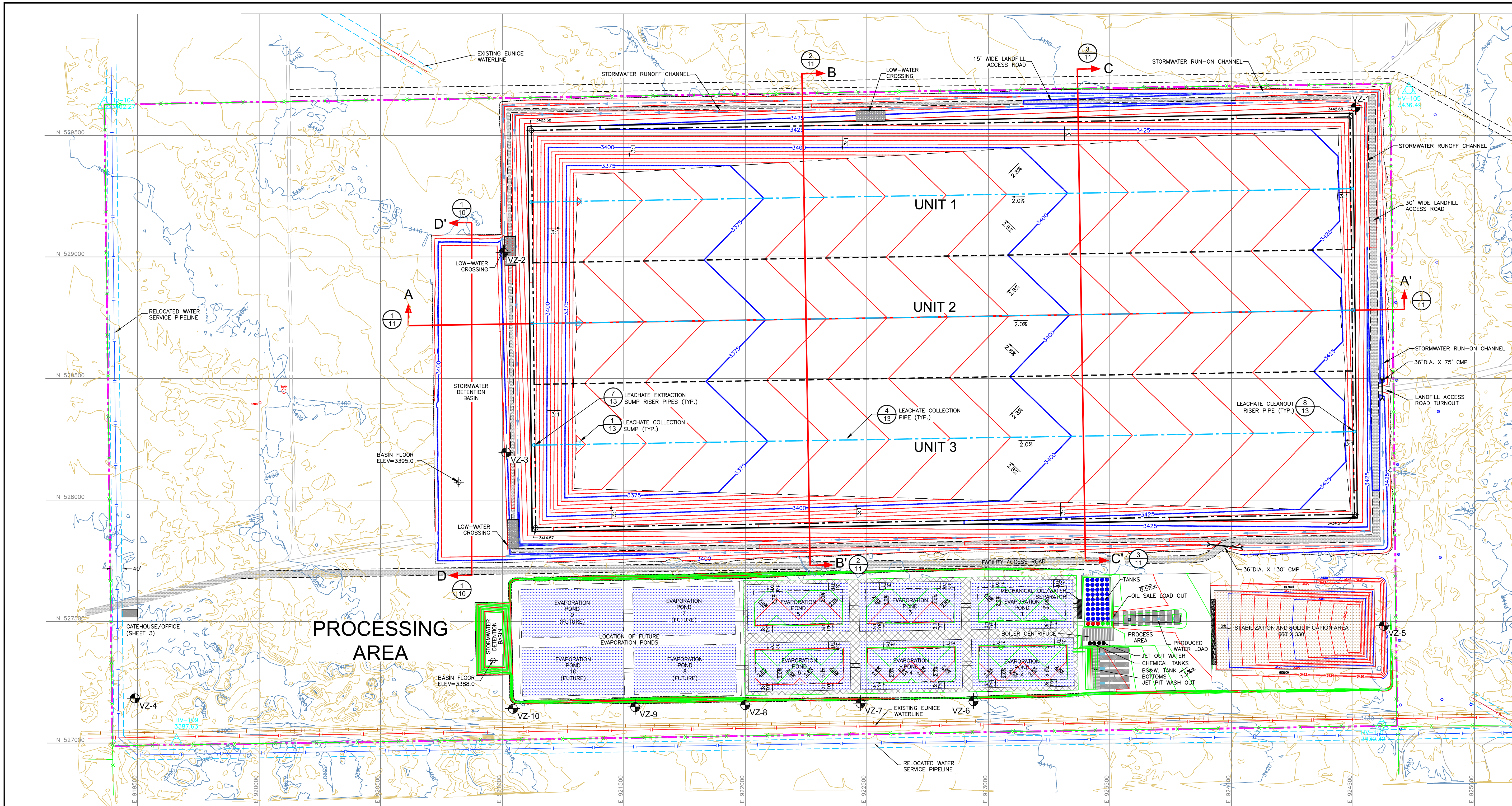
In each of the following three demonstrations, the input parameters for the HELP model have been selected utilizing guidance from the “Users Guide for Version 3” as provided by the USEPA (**Attachment III.4.C**).

6.1 Cell Design Parameters

Slope steepness and lateral drainage distance were selected from the design parameters for the cells in the landfill. The liner system in Unit 3 has the flattest floor slope and the longest lateral drainage distance (see **Figure III.4.1**). The top portion of the final cover system has a relatively uniform average slope of 5%; the longest lateral drainage distance occurs from the highest elevation of the landfill to a drainage diversion bench (see **Figure III.4.2**). Sideslopes will be constructed with drainage diversion benches. However, in keeping with a conservative approach, the benches were not utilized within the HELP modeling program inputs. Throughout these analyses, the following design parameters have been used:

- Liner system:
    - lateral drainage distance = 550 ft
    - slope = 2.8%
- Final cover system:
    - Top:
        - lateral drainage distance = 450 ft
        - slope = 5.0%
    - Sideslopes:
        - lateral drainage distance = 550 ft
        - slope = 25%

The outputs from the HELP model runs, which include a listing of the input parameters, are provided as attachments to this document in both hard copy (**Attachment III.4.A**) and electronic format (**Attachment III.4.D**).



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- TOP OF LANDFILL BERM
- TOE OF SLOPE
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- CUT AND FILL DAYLIGHT LINE
- DRAINAGE CHANNEL FLOW LINE
- LEACHATE COLLECTION PIPE AND RISERS
- FENCE
- EXISTING UNPAVED ROAD
- EXISTING PAVED ROAD
- NEW UNPAVED ROAD
- PAVED LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- NEW CULVERT
- DETAIL NUMBER / SHEET NUMBER
- CROSS SECTION LOCATION
- VZ-4 VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- 3395.0 SPOT ELEVATION
- HV-105 3436.49 SURVEY CONTROL POINT
- N 527500 E 922000 SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NORTH

0 200' 400'

I, KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

UPDATED: AUGUST, 2016

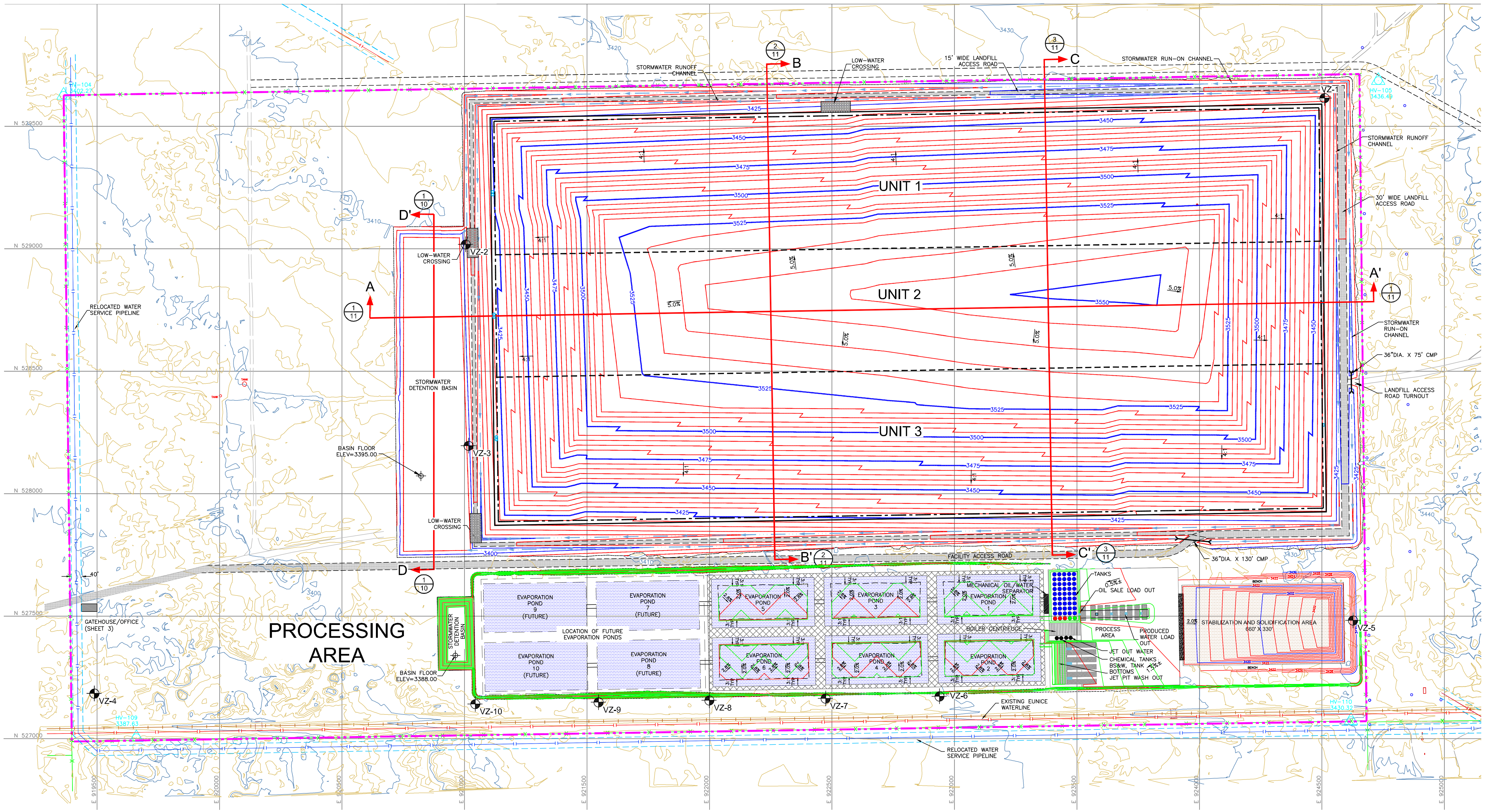
LANDFILL BASE GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991
geI@gordonenvironmental.com

DATE: 08/02/2016	CAD: 04 BASE GRADES.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	FIGURE III.4.1
APPROVED BY: IKG		

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\04 BASE GRADES.dwg
Date/Time:Aug. 03, 2016-13:47:07



NOTES

1) AERIAL SURVEY BY THOMAS R. MANN & ASSOCIATES AERIAL MAPPING SERVICES, 5115 COPPER NE, ALBUQUERQUE, NM 87108
DATE OF SURVEY: 10-01-08

2) NO CATTLE GUARDS IN PROJECT AREA

NOT FOR CONSTRUCTION
Drawing:P:\acad 2003\530.06.01\PERMIT PLANS (RAI 1)\05 FINAL GRADES.dwg
Date/Time:Aug. 03, 2016-13:44:57

LEGEND

- FACILITY BOUNDARY
- LIMIT OF WASTE
- UNIT BOUNDARY
- TOP OF LANDFILL BERM
- 10' CONTOUR (EXISTING)
- 2' CONTOUR (EXISTING)
- 25' CONTOUR (DESIGN)
- 5' CONTOUR (DESIGN)
- 1' CONTOUR (DESIGN)
- CUT AND FILL DAYLIGHT LINE
- DRAINAGE CHANNEL FLOW LINE
- FENCE
- LEACHATE COLLECTION RISER PIPES
- EXISTING UNPAVED ROAD
- EXISTING PAVED ROAD
- NEW UNPAVED ROAD
- PAVED LANDFILL ACCESS ROAD
- RAILROAD TRACKS
- RELOCATED WATER SERVICE PIPELINE
- EXISTING EUNICE WATERLINE
- PIPELINE EASEMENT
- NEW CULVERT
- DETAIL NUMBER / SHEET NUMBER (1 / 11)
- CROSS SECTION LOCATION (A A')
- VZ-4 VADOSE ZONE MONITORING WELL
- POWER POLE
- OIL STORAGE TANK
- EXISTING BOX CULVERT
- 3414.57 SPOT ELEVATION
- HV-105 3436.49 SURVEY CONTROL POINT
- N 527500 E 922000 SITE GRID
- PRODUCED WATER TANK
- CRUDE OIL RECOVERY TANK
- OIL SALES TANK

NORTH

0 200' 400'

I. KEITH GORDON, P.E.
N.M. PROFESSIONAL ENGINEER NO. 10984

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UPDATED: AUGUST 2016

LANDFILL FINAL GRADING PLAN

SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY
LEA COUNTY, NEW MEXICO

Gordon Environmental, Inc.
Consulting Engineers
213 S. Camino del Pueblo
Bernalillo, New Mexico, USA
Phone: 505-867-6990
Fax: 505-867-6991

DATE: 08/02/2016	CAD: 05 FINAL GRADES.dwg	PROJECT #: 530.06.01
DRAWN BY: DMI	REVIEWED BY: CWF	FIGURE III.4.2
APPROVED BY: IKG	gei@gordonenvironmental.com	

6.2 Alternate Liner Demonstration

The HELP model simulation analysis has been performed to support the EPA's HELP model as per 19.15.36.14C(9) NMAC.

6.2.1 Liner System Design

The design for the alternate liner system includes the following layers from the top down:

- 24-inches protective soil layer (on-site soils) (k = 5.2 x 10^{-4} cm/sec)
- 10 oz/yd^2 non-woven geotextile / 200-mil geonet (geocomposite) (k = 10 cm/sec)[(1)]
- FML (60-mil smooth HDPE)
- 200-mil geonet (k = 10 cm/sec)
- FML (60-mil smooth HDPE)
- GCL (k = 3.0 x 10^{-9} cm/sec)
- 6-inches of compacted Chinle formation soil layer (k = 1 x 10^{-4} cm/sec)

Note 1: Geocomposite not included in HELP Model as a default characteristic, a geonet is used in its place.

6.2.2 HELP Model Input Parameters

6.2.2.1 Soils

19.15.36.14F NMAC requires that the protective drainage layer be constructed using granular soils that contain no more than 5% fines by weight (i.e., material passing a No. 200 sieve) and that have a uniformity coefficient less than 6.0. As part of its design for the alternate liner system, Sundance proposes to use on-site soils in the protective soil layer that contain no more than 30% fines by weight and a uniformity coefficient less than 10.

Geotechnical analyses of on-site soils indicate that the soils available at the Sundance West site consist primarily of sand with varying amounts of fines (SM, silty sand and SC, clayey sand) and that they meet the proposed criteria for the protective soil layer. **Attachment III.4.B** provides a summary of geotechnical test results. The on-site soil that Sundance proposes to use when it places the PSL is within the range of soil type used in this modeling based on sieve analyses and hydraulic conductivity (**Attachment III.4.B**). The Unified Soils Classification for GB-2 soils is SM, i.e., consisting of silty sands and sand-silt mixtures with non-plastic fines or fines with low plasticity. The specified geotextile beneath the PSL has an apparent opening size (AOS) of 100 U. S. standard sieve. Soil retention opening size determined by "Task Force 25 Method" for soil particles < 50% passing the No 200 sieve is

AOS of the fabric > No. 50 sieve. Therefore, the AOS of the geotextile must be greater than a No. 50 sieve to perform as a drainage layer. The specified geotextile with an AOS of No. 100 exceeds the criteria. Based on the anticipated waste stream constituents, biological plugging of the PSL and/or geotextile were not considered. The type of soil used to represent the protective soil layer in the simulation is listed below:

Soil Description	**HELP Model Soil Type**	**USCS Soil Type**
silty sand	7	SM

The primary parameters that differentiate soils from one another are the saturated hydraulic conductivity, K_{sat}, and the moisture-retention characteristics that are related to the field capacity and the wilting point. As the HELP model soil type number increases, the saturated hydraulic conductivity decreases and the soils tend to retain more water. Default values from the HELP model were assigned to the porosity, field capacity and wilting point for each soil type.

6.2.2.2 Environmental

All of the simulation analyses for HELP modeling demonstrations were performed using identical environmental loading conditions. Precipitation and temperature data were derived from the Western Regional Climatic Center's database. The nearest location with sufficient data is Hobbs, New Mexico. Solar radiation data was synthetically generated by the HELP model based on coefficients for Midland, Texas. Midland, Texas was used as its latitude was the closest to the site's latitude as recommended by the User's Guide for Version 3 (**Attachment III.4.C**). Evapotranspiration data (e.g., average wind speed and seasonal relative humidity) was obtained from Hobbs, New Mexico. The evaporative zone depth was set to 24 inches and the maximum leaf area index was set to 0.0, i.e., bare ground. The surface layer, PSL, was modeled as having no vegetation.

6.2.2.3 Initial Conditions

The following alternate liner component default values for HELP Model Soil Texture Classes and Material Characteristics were used in the simulations:

- Protective Soil Layer
  - Soil Texture Class – 7
  - Total Porosity (vol/vol) - 0.473
  - Field Capacity (vol/vol) - 0.222
  - Wilting Point (vol/vol) – 0.104
  - Saturated Hydraulic Conductivity (cm/sec) – 5.2×10^{-4}
- Geocomposite Drainage layer
  - 200-mil Geonet
  - Material Characteristic – 20
  - Saturated Hydraulic Conductivity (cm/sec) – $1.0 \times 10^{+1}$
- Primary Liner
  - 60-mil smooth HDPE
  - Material Characteristic – 35
  - Saturated Hydraulic Conductivity (cm/sec) – 2.0×10^{-13}
- Leak Detection System
  - 200-mil Geonet
  - Material Characteristic – 20
  - Saturated Hydraulic Conductivity (cm/sec) – $1.0 \times 10^{+1}$
- Secondary Liner
  - 60-mil smooth HDPE
  - Material Characteristic – 35
  - Saturated Hydraulic Conductivity (cm/sec) – 2.0×10^{-13}
- GCL(Geosynthetic Clay Liner)
  - Material Characteristic – 17
  - Total Porosity (vol/vol) - 0.750
  - Field Capacity (vol/vol) - 0.747
  - Wilting Point (vol/vol) - 0.400
  - Saturated Hydraulic Conductivity (cm/sec) – 3.0×10^{-9}

- Base Soil Layer
  - Soil Texture Class – 16
  - Total Porosity (vol/vol) - 0.427
  - Field Capacity (vol/vol) - 0.418
  - Wilting Point (vol/vol) – 0.367
  - Saturated Hydraulic Conductivity (cm/sec) – 1.0×10^{-7}

6.2.3 Alternate Liner Simulation Analysis

In the alternate liner simulation analyses, the landfill has been assumed to be in an open condition with no waste present. All precipitation is retained within the landfill; there is no runoff. The FML was represented by using the default parameters for Material Characteristic type 35 from the HELP model. The input parameters used to represent the alternative liner system are provided in **Table III.4.1**.

6.2.4 Alternate Liner Demonstration Results

According to 19.15.36.14C(9), an alternate liner system is considered acceptable when supported by EPA's HELP model. Performance has been demonstrated to be sufficient in protection of the environment. The performance measure is the average annual rate of percolation through the bottom of the liner system and the head upon the liner. This is evaluated by the percolation rates calculated using the HELP model. The average annual percolation rate is summarized in **Table III.4.2**.

TABLE III.4.1
Sundance West
Alternative Liner System

Simulation	Protective Drainage Layer			Geocomposite Drainage Layer[1]			Primary FML			Leak Detection Layer			Secondary FML			Geocomposite Clay Liner			Base Layer		
	HELP Model Soil Type	Layer Thickness (in)	K_{sat} (cm/s)	HELP Model Soil Type	Layer Thickness (in)	K_{sat} (cm/s)	HELP Model Soil Type	FML	K_{sat} (cm/s)	HELP Model Soil Type	Layer Thickness (in)	K_{sat} (cm/s)	HELP Model Soil Type	Layer Thickness (in)	K_{sat} (cm/s)	HELP Model Soil Type	Layer Thickness (in)	K_{sat} (cm/s)	HELP Model Soil Type	Barrier Layer	K_{sat} (cm/s)
Alternative Liner System	7	24	5.2×10^{-4}	20	200-mil Geonet	10	35	60-mil HDPE	2.0×10^{-13}	20	200-mil Geonet	10	35	200-mil Geonet	2.0×10^{-13}	17	0.23	2.0×10^{-13}	16	6-in	1.0×10^{-7}

Note 1: Geocomposite not included in the HELP Modeling default characteristics, a Geonet was used in its place.

TABLE III.4.2
Sundance West
Performance Results for Alternate Liner System

Liner System	Soil Type for Protective Soil Layer	Average Annual Percolation Rate Through Bottom Liner (in/yr)	Average Annual Head on Primary HDPE Liner Layer 3 (in)
Alternate	7	0.00000	0.000

For the soil types analyzed, the average annual percolation rates calculated for the alternate liner system design is zero. In addition, the hydraulic head on the FML remains less than 12 inches. This simulation demonstrates that, for soils available on-site for use as the protective soil layer, the alternate liner system design provides performance that is supported by HELP modeling in accordance 19.15.36.14C(9).

6.3 Alternate Final Cover Demonstration

Two HELP model simulation analysis have been performed to support the alternative final cover demonstrations. In these demonstrations, the performance of the alternative final cover system is compared to the performance of the alternate liner system as to not to create a “bathtub effect” where percolation though the alternate final cover exceeds that of the alternate liner system.

6.3.1 Alternate Final Cover System Design

The alternate final cover system includes the following layers from the top down:

- 24-in. erosion/vegetative layer k = 1.9 x 10^{-4} cm/sec
- 6-in. barrier layer k = 1.9 x 10^{-4} cm/sec

6.3.2 HELP Model Input Parameters

6.3.2.1 Soils

The type of soil that was used to represent the barrier layer and erosion/vegetative layer in the simulation for the alternate final cover demonstration is listed below:

Soil Description	HELP Model Soil Type	USCS Soil Type
silty sand	9	SM

Default values from the HELP model were assigned to the porosity, field capacity and wilting point and an assumed hydraulic conductivity was used for each soil type as listed in **Section 6.3.2.3** Initial Conditions.

The erosion/vegetative layer was assigned a HELP model soil type number that is the same as the barrier layer, and is most representative of conditions in the field for final cover construction activities. The HELP model automatically accounts for the effects of root penetration and decay whenever vegetation is assumed to be present on the surface layer.

6.3.2.2 Environmental

All of the simulation analyses for HELP modeling demonstrations were performed using identical environmental loading conditions. Precipitation and temperature data were derived from the Western Regional Climatic Center's database. The nearest location with sufficient data is Hobbs, New Mexico. Solar radiation data was synthetically generated by the HELP model based on coefficients for Midland, Texas. Midland, Texas was used as its latitude was the closest to the site's latitude as recommended by the User's Guide for Version 3 (**Attachment III.4.C**). Evapotranspiration data (e.g., average wind speed and seasonal relative humidity) was obtained from Hobbs, New Mexico. The evaporative zone depth was set to 24 inches and the maximum leaf area index was set to 1.2. Vegetation on the cover was modeled as "poor grass".

6.3.2.3 Initial Conditions

The following alternate final cover component default values for HELP Model Soil Texture Classes were used in the simulations:

- Erosion/Vegetative Soil Layer
  - Soil Texture Class – 9
  - Total Porosity (vol/vol) - 0.501
  - Field Capacity (vol/vol) - 0.284
  - Wilting Point (vol/vol) – 0.135
  - Saturated Hydraulic Conductivity (cm/sec) – 1.9 x 10^{-4}
- Barrier Soil Layer
  - Soil Texture Class – 9
  - Total Porosity (vol/vol) - 0.501
  - Field Capacity (vol/vol) - 0.284
  - Wilting Point (vol/vol) – 0.135
  - Saturated Hydraulic Conductivity (cm/sec) – 1.9 x 10^{-4}

6.3.4 Alternate Cover Demonstration Results

According to 19.15.36.14C(9), an alternative cover is considered acceptable if its performance has been demonstrated to prevent the “bathtub effect”. The measure is the average annual rate of percolation through the primary FML layer of the liner system and bottom layer of the cover system (Barrier Layer). Performance is evaluated by comparing the percolation rates calculated for the alternate cover system to that calculated for the alternate liner system. The average annual percolation rates calculated for the two systems are summarized in **Table III.4.3**.

TABLE III.4.3
Sundance West
Performance Results for Alternate Liner and Alternate Final Cover Systems

System	**HELP Model Material Type**		**Average Annual Percolation Rate**
	Primary FML Layer	**Barrier Layer**	
Alternate Final Cover	—	9	0.00000
Alternate Liner	9	—	0.00000

When the alternate cover system is modeled using HELP model soil type 9, the rate of percolation calculated for the alternate final cover system is equivalent to the percolation rate calculated for the alternate liner system. The performance of the alternate final cover system design using soil type 9 prevents the "bathtub effect" as noted in 19.15.36.14C(9) NMAC.

7.0 CONCLUSIONS AND REQUEST FOR APPROVAL

Sundance has prepared performance demonstrations for its alternate liner system design and for its alternate final cover system design. These analyses were based on 19.15.36.14C(9) NMAC when supported by the HELP model; and the analyses demonstrate the following:

- For the alternate liner simulation analysis, the average annual percolation rate calculated for the alternate liner system design is zero. This simulation demonstrates that the alternate liner system design provides superior performance. Therefore, the alternate liner system design meets the OCD demonstration requirements.
- In the alternate final cover simulation analyses, when the infiltration layer is modeled using HELP model soil type 9 and a hydraulic conductivity of 1.9 x 10^{-4} cm/sec, the average annual percolation rate calculated for the alternate final cover system is zero. Therefore, for this soil type, the performance of the alternate final cover system

design meets the OCD demonstration requirements.

- In the simulation analyses, the percolation rates for the liner and final cover, calculated for the fifth year of each simulation is zero.

The HELP modeling for the analyses presented in this document demonstrates that the performance of the alternate liner and cover system designs meets the requirements of 19.15.36.14C NMAC. For the purposes of this demonstration, both the alternate liner design and the alternate cover design have been shown to be effective using soils available on the Sundance site.

To allow Sundance flexibility in using on-site soils as well as offsite materials to construct the protective soil layer, the erosion/vegetative layer and the barrier layer, this document serves as a request to OCD for approval to use the alternate liner and cover system designs and to construct those systems using soils that contain 30% fines and has a uniformity coefficient (Cu) less than 10.

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 4: HELP MODEL

ATTACHMENT III.4.A

HELP MODEL OUTPUT FILES

Attachment A-1

Sundance West – Alternative Landfill Liner

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                 HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)               **
**                   DEVELOPED BY ENVIRONMENTAL LABORATORY                  **
**                     USAE WATERWAYS EXPERIMENT STATION                    **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\sun\ssiwest\RAINFC1.D4
TEMPERATURE DATA FILE:        C:\sun\ssiwest\TEMPFC1.D7
SOLAR RADIATION DATA FILE:    C:\sun\ssiwest\SOLARFC1.D13
EVAPOTRANSPIRATION DATA:      C:\sun\ssiwest\EVAPFC1.D11
SOIL AND DESIGN DATA FILE:    C:\sun\ssiwest\ALTERNTE.D10
OUTPUT DATA FILE:             C:\sun\ssiwest\ALTERNTE.OUT


TIME:   8: 5     DATE:   6/30/2016


******************************************************************************

     TITLE:  SSI West - Alternative Landfill Liner

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                   LAYER  1
                                   --------

                         TYPE 2 - LATERAL DRAINAGE LAYER
                           MATERIAL TEXTURE NUMBER   7
           THICKNESS                     =     24.00   INCHES
           POROSITY                      =      0.4730 VOL/VOL
           FIELD CAPACITY                =      0.2220 VOL/VOL
           WILTING POINT                 =      0.1040 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.1340 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.520000001000E-03 CM/SEC
```

LAYER 2

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 20

THICKNESS	=	0.20	INCHES
POROSITY	=	0.8500	VOL/VOL
FIELD CAPACITY	=	0.0100	VOL/VOL
WILTING POINT	=	0.0050	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0063	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	10.0000000000	CM/SEC
SLOPE	=	2.80	PERCENT
DRAINAGE LENGTH	=	500.0	FEET

LAYER 3

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 35

THICKNESS	=	0.06	INCHES
POROSITY	=	0.0000	VOL/VOL
FIELD CAPACITY	=	0.0000	VOL/VOL
WILTING POINT	=	0.0000	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0000	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.199999996000E-12	CM/SEC
FML PINHOLE DENSITY	=	1.00	HOLES/ACRE
FML INSTALLATION DEFECTS	=	4.00	HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD	

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 20

THICKNESS	=	0.20	INCHES
POROSITY	=	0.8500	VOL/VOL
FIELD CAPACITY	=	0.0100	VOL/VOL
WILTING POINT	=	0.0050	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0063	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	10.0000000000	CM/SEC
SLOPE	=	2.80	PERCENT
DRAINAGE LENGTH	=	500.0	FEET

LAYER 5

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 35

THICKNESS	=	0.06 INCHES
POROSITY	=	0.0000 VOL/VOL
FIELD CAPACITY	=	0.0000 VOL/VOL
WILTING POINT	=	0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY	=	1.00 HOLES/ACRE
FML INSTALLATION DEFECTS	=	4.00 HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 17

THICKNESS	=	0.23 INCHES
POROSITY	=	0.7500 VOL/VOL
FIELD CAPACITY	=	0.7470 VOL/VOL
WILTING POINT	=	0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.300000003000E-08 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 7 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 500. FEET.

SCS RUNOFF CURVE NUMBER	=	88.00	
FRACTION OF AREA ALLOWING RUNOFF	=	0.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	145.800	ACRES
EVAPORATIVE ZONE DEPTH	=	24.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.216	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	11.352	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.496	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	3.391	INCHES
TOTAL INITIAL WATER	=	3.391	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
Hobbs New Mexico

STATION LATITUDE	=	32.26 DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00
START OF GROWING SEASON (JULIAN DATE)	=	67
END OF GROWING SEASON (JULIAN DATE)	=	317
EVAPORATIVE ZONE DEPTH	=	24.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	9.20 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	40.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	27.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	46.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	48.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ROSWELL NEW MEXICO

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
0.24	0.28	0.27	0.37	0.77	0.91
1.38	2.17	1.72	0.99	0.33	0.27

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ROSWELL NEW MEXICO

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
42.20	46.90	53.40	62.20	70.60	78.30
80.30	79.10	72.70	62.80	51.00	43.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR MIDLAND TEXAS
AND STATION LATITUDE = 32.36 DEGREES

****

ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	8.70	4604510.500	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	8.610	4556981.000	98.97
DRAINAGE COLLECTED FROM LAYER 2	0.0107	5643.412	0.12
PERC./LEAKAGE THROUGH LAYER 3	0.012905	6830.168	0.15
AVG. HEAD ON TOP OF LAYER 3	0.0000		
DRAINAGE COLLECTED FROM LAYER 4	0.0122	6438.304	0.14
PERC./LEAKAGE THROUGH LAYER 6	0.000000	0.218	0.00
AVG. HEAD ON TOP OF LAYER 5	0.0000		
CHANGE IN WATER STORAGE	0.067	35445.711	0.77
SOIL WATER AT START OF YEAR	3.392	1795376.620	
SOIL WATER AT END OF YEAR	3.459	1830822.250	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	1.319	0.00

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	10.35	5477779.500	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	10.662	5642897.000	103.01
DRAINAGE COLLECTED FROM LAYER 2	0.0002	129.725	0.00
PERC./LEAKAGE THROUGH LAYER 3	0.000603	319.314	0.01
AVG. HEAD ON TOP OF LAYER 3	0.0000		
DRAINAGE COLLECTED FROM LAYER 4	0.0006	319.262	0.01
PERC./LEAKAGE THROUGH LAYER 6	0.000000	0.052	0.00
AVG. HEAD ON TOP OF LAYER 5	0.0000		
CHANGE IN WATER STORAGE	-0.313	-165569.422	-3.02
SOIL WATER AT START OF YEAR	3.459	1830822.250	
SOIL WATER AT END OF YEAR	3.146	1665252.870	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	3.078	0.00

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	10.33	5467193.500	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	10.477	5544846.000	101.42
DRAINAGE COLLECTED FROM LAYER 2	0.0004	185.249	0.00
PERC./LEAKAGE THROUGH LAYER 3	0.001083	573.396	0.01
AVG. HEAD ON TOP OF LAYER 3	0.0000		
DRAINAGE COLLECTED FROM LAYER 4	0.0011	573.301	0.01
PERC./LEAKAGE THROUGH LAYER 6	0.000000	0.095	0.00
AVG. HEAD ON TOP OF LAYER 5	0.0000		
CHANGE IN WATER STORAGE	-0.148	-78413.508	-1.43
SOIL WATER AT START OF YEAR	3.146	1665252.870	
SOIL WATER AT END OF YEAR	2.998	1586839.370	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	2.245	0.00

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	9.25	4895601.000	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	9.171	4853880.500	99.15
DRAINAGE COLLECTED FROM LAYER 2	0.0002	95.721	0.00
PERC./LEAKAGE THROUGH LAYER 3	0.000723	382.441	0.01
AVG. HEAD ON TOP OF LAYER 3	0.0000		
DRAINAGE COLLECTED FROM LAYER 4	0.0007	382.094	0.01
PERC./LEAKAGE THROUGH LAYER 6	0.000000	0.150	0.00
AVG. HEAD ON TOP OF LAYER 5	0.0000		
CHANGE IN WATER STORAGE	0.078	41238.945	0.84
SOIL WATER AT START OF YEAR	2.998	1586839.370	
SOIL WATER AT END OF YEAR	3.076	1628078.370	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	3.554	0.00

****

ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	9.68	5123179.000	100.00
RUNOFF	0.000	0.000	0.00
EVAPOTRANSPIRATION	9.306	4925009.500	96.13
DRAINAGE COLLECTED FROM LAYER 2	0.0001	33.952	0.00
PERC./LEAKAGE THROUGH LAYER 3	0.000342	181.237	0.00
AVG. HEAD ON TOP OF LAYER 3	0.0000		
DRAINAGE COLLECTED FROM LAYER 4	0.0003	181.338	0.00
PERC./LEAKAGE THROUGH LAYER 6	0.000000	0.095	0.00
AVG. HEAD ON TOP OF LAYER 5	0.0000		
CHANGE IN WATER STORAGE	0.374	197951.766	3.86
SOIL WATER AT START OF YEAR	3.076	1628078.370	
SOIL WATER AT END OF YEAR	3.450	1826030.120	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	2.283	0.00

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.18	0.17	0.29	0.26	0.78	0.63
	1.66	1.91	1.64	0.79	0.84	0.49
STD. DEVIATIONS	0.19	0.04	0.26	0.21	0.74	0.77
	0.78	1.32	1.04	0.91	1.02	0.34
RUNOFF						
TOTALS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
EVAPOTRANSPIRATION						
TOTALS	0.308	0.207	0.195	0.145	0.627	0.772
	1.280	1.985	1.749	1.015	0.738	0.623
STD. DEVIATIONS	0.071	0.071	0.114	0.048	0.639	0.769
	1.105	1.483	0.977	0.421	0.673	0.330
LATERAL DRAINAGE COLLECTED FROM LAYER 2						
TOTALS	0.0000	0.0000	0.0021	0.0000	0.0000	0.0000
	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0047	0.0000	0.0000	0.0000
	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000
PERCOLATION/LEAKAGE THROUGH LAYER 3						
TOTALS	0.0000	0.0000	0.0024	0.0000	0.0001	0.0000
	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001
STD. DEVIATIONS	0.0000	0.0000	0.0054	0.0000	0.0001	0.0000
	0.0003	0.0002	0.0002	0.0002	0.0001	0.0001
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.0000	0.0000	0.0023	0.0000	0.0001	0.0000
	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001
STD. DEVIATIONS	0.0000	0.0000	0.0051	0.0000	0.0001	0.0000
	0.0003	0.0002	0.0002	0.0002	0.0001	0.0001

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 3

AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

****

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	9.66	(0.710)	5113652.5	100.00
RUNOFF	0.000	(0.0000)	0.00	0.000
EVAPOTRANSPIRATION	9.645	(0.8855)	5104723.00	99.825
LATERAL DRAINAGE COLLECTED FROM LAYER 2	0.00230	(0.00468)	1217.612	0.02381
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.00313	(0.00547)	1657.311	0.03241
AVERAGE HEAD ON TOP OF LAYER 3	0.000	(0.000)		
LATERAL DRAINAGE COLLECTED FROM LAYER 4	0.00298	(0.00514)	1578.860	0.03088
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000	(0.00000)	0.122	0.00000
AVERAGE HEAD ON TOP OF LAYER 5	0.000	(0.000)		
CHANGE IN WATER STORAGE	0.012	(0.2596)	6130.70	0.120

****

****

PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	1.17	619227.187
RUNOFF	0.000	0.0000
DRAINAGE COLLECTED FROM LAYER 2	0.00213	1125.85132
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.002409	1275.09448
AVERAGE HEAD ON TOP OF LAYER 3	0.001	
MAXIMUM HEAD ON TOP OF LAYER 3	0.011	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	0.0 FEET	
DRAINAGE COLLECTED FROM LAYER 4	0.00177	937.45807
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00372
AVERAGE HEAD ON TOP OF LAYER 5	0.001	
MAXIMUM HEAD ON TOP OF LAYER 5	0.001	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	0.0 FEET	
SNOW WATER	0.61	320599.8750
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.1999	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1040	

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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****

FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	3.2724	0.1364
2	0.0020	0.0100
3	0.0000	0.0000
4	0.0020	0.0100
5	0.0000	0.0000
6	0.1725	0.7500
SNOW WATER	0.000	

****
****

Attachment A-2

Sundance West Landfill Final Cover – Top Cover

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                 HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)               **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************

PRECIPITATION DATA FILE:    C:\sun\ssiwest\RAINFC1.D4
TEMPERATURE DATA FILE:      C:\sun\ssiwest\TEMPFC1.D7
SOLAR RADIATION DATA FILE:  C:\sun\ssiwest\SOLARFC1.D13
EVAPOTRANSPIRATION DATA:    C:\sun\ssiwest\EVAPFC1.D11
SOIL AND DESIGN DATA FILE:  C:\sun\ssiwest\SSIWSTTP.D10
OUTPUT DATA FILE:           C:\sun\ssiwest\SSIWSTTP.OUT


TIME:  15:29     DATE:   6/21/2016


******************************************************************************

     TITLE:  SSI West Landfill Final Cover Top Cover

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                LAYER  1
                                --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   9
           THICKNESS                    =     24.00    INCHES
           POROSITY                     =      0.5010 VOL/VOL
           FIELD CAPACITY               =      0.2840 VOL/VOL
           WILTING POINT                =      0.1350 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.1362 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.190000006000E-03 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  2.01
                  FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
```

LAYER 2

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 9

THICKNESS	=	6.00	INCHES
POROSITY	=	0.5010	VOL/VOL
FIELD CAPACITY	=	0.2840	VOL/VOL
WILTING POINT	=	0.1350	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.5010	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.190000006000E-03	CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 9 WITH A POOR STAND OF GRASS, A SURFACE SLOPE OF 5.% AND A SLOPE LENGTH OF 450. FEET.

SCS RUNOFF CURVE NUMBER	=	87.30	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	46.650	ACRES
EVAPORATIVE ZONE DEPTH	=	24.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.268	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	12.024	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	3.240	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	6.274	INCHES
TOTAL INITIAL WATER	=	6.274	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
Hobbs New Mexico

STATION LATITUDE	=	32.26	DEGREES
MAXIMUM LEAF AREA INDEX	=	1.20	
START OF GROWING SEASON (JULIAN DATE)	=	67	
END OF GROWING SEASON (JULIAN DATE)	=	317	
EVAPORATIVE ZONE DEPTH	=	24.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	9.20	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	40.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	27.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	46.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	48.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ROSWELL NEW MEXICO

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
0.46	0.46	0.54	0.79	1.93	1.85
2.16	2.37	2.54	1.54	0.55	0.55

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR MIDLAND TEXAS

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
42.20	46.90	53.40	62.20	70.60	78.30
80.30	79.10	72.70	62.80	51.00	43.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR MIDLAND TEXAS
AND STATION LATITUDE = 32.40 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	12.67	2145531.500	100.00
RUNOFF	0.204	34506.406	1.61
EVAPOTRANSPIRATION	11.939	2021676.250	94.23
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	0.528	89349.148	4.16
SOIL WATER AT START OF YEAR	6.274	1062379.620	
SOIL WATER AT END OF YEAR	6.801	1151728.750	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.391	0.00

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	18.56	3142941.250	100.00
RUNOFF	0.326	55189.676	1.76
EVAPOTRANSPIRATION	17.831	3019549.500	96.07
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	0.403	68201.492	2.17
SOIL WATER AT START OF YEAR	6.801	1151728.750	
SOIL WATER AT END OF YEAR	7.204	1219930.250	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.505	0.00

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	17.16	2905866.000	100.00
RUNOFF	0.190	32217.404	1.11
EVAPOTRANSPIRATION	15.695	2657795.500	91.46
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	1.275	215852.734	7.43
SOIL WATER AT START OF YEAR	7.204	1219930.250	
SOIL WATER AT END OF YEAR	8.396	1421751.500	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.083	14031.474	0.48
ANNUAL WATER BUDGET BALANCE	0.0000	0.310	0.00

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	13.25	2243748.500	100.00
RUNOFF	0.439	74359.305	3.31
EVAPOTRANSPIRATION	14.048	2378847.000	106.02
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	-1.237	-209457.234	-9.34
SOIL WATER AT START OF YEAR	8.396	1421751.500	
SOIL WATER AT END OF YEAR	7.242	1226325.750	
SNOW WATER AT START OF YEAR	0.083	14031.474	0.63
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	-0.341	0.00

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	17.23	2917720.250	100.00
RUNOFF	0.447	75745.547	2.60
EVAPOTRANSPIRATION	17.118	2898689.250	99.35
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	-0.335	-56715.016	-1.94
SOIL WATER AT START OF YEAR	7.242	1226325.750	
SOIL WATER AT END OF YEAR	6.907	1169610.750	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.651	0.00

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.33	0.28	0.60	0.56	1.97	1.29
	2.59	2.09	2.42	1.23	1.40	1.01
STD. DEVIATIONS	0.37	0.07	0.51	0.45	1.86	1.57
	1.22	1.44	1.54	1.42	1.70	0.70
RUNOFF						
TOTALS	0.000	0.000	0.000	0.000	0.082	0.065
	0.061	0.010	0.036	0.060	0.006	0.000
STD. DEVIATIONS	0.001	0.000	0.000	0.000	0.156	0.117
	0.062	0.016	0.081	0.135	0.009	0.000
EVAPOTRANSPIRATION						
TOTALS	0.642	0.365	0.691	0.529	2.225	1.176
	2.295	2.493	1.796	1.223	1.065	0.825
STD. DEVIATIONS	0.540	0.094	0.567	0.407	1.834	1.738
	1.085	1.329	1.298	0.701	0.308	0.186
PERCOLATION/LEAKAGE THROUGH LAYER 2						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 2						
AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	15.77	(2.637)	2671161.5	100.00
RUNOFF	0.321	(0.1233)	54403.67	2.037
EVAPOTRANSPIRATION	15.326	(2.3839)	2595311.25	97.160
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.00000	(0.00000)	0.000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	(0.000)		
CHANGE IN WATER STORAGE	0.127	(0.9523)	21446.23	0.803

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	2.03	343759.187
RUNOFF	0.354	59927.1719
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.000000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	
SNOW WATER	1.33	225413.0470
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.2723	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1350	

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	3.9010	0.1625
2	3.0060	0.5010
SNOW WATER	0.000	

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Attachment A-3

Sundance West Landfill Final Cover – Side Slopes

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**                                                                           **
**                                                                           **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**                HELP MODEL VERSION 3.07   (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                    USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY               **
**                                                                           **
**                                                                           **
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PRECIPITATION DATA FILE:     C:\sun\ssiwest\RAINFC1.D4
TEMPERATURE DATA FILE:       C:\sun\ssiwest\TEMPFC1.D7
SOLAR RADIATION DATA FILE:   C:\sun\ssiwest\SOLARFC1.D13
EVAPOTRANSPIRATION DATA:     C:\sun\ssiwest\EVAPFC1.D11
SOIL AND DESIGN DATA FILE:   C:\sun\ssiwest\SSIWSTSS.D10
OUTPUT DATA FILE:            C:\sun\ssiwest\SSIWSTss.OUT


TIME:  16: 3     DATE:   6/21/2016

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     TITLE:  SSI West Landfill Final Cover Side Slopes

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                            MATERIAL TEXTURE NUMBER   9
           THICKNESS                    =      24.00   INCHES
           POROSITY                     =       0.5010 VOL/VOL
           FIELD CAPACITY               =       0.2840 VOL/VOL
           WILTING POINT                =       0.1350 VOL/VOL
           INITIAL SOIL WATER CONTENT   =       0.1362 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =   0.190000006000E-03 CM/SEC
         NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  2.01
                FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
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LAYER 2

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 9

THICKNESS	=	6.00 INCHES
POROSITY	=	0.5010 VOL/VOL
FIELD CAPACITY	=	0.2840 VOL/VOL
WILTING POINT	=	0.1350 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.5010 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.190000006000E-03 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 9 WITH A POOR STAND OF GRASS, A SURFACE SLOPE OF 25.% AND A SLOPE LENGTH OF 550. FEET.

SCS RUNOFF CURVE NUMBER	=	87.70	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	98.930	ACRES
EVAPORATIVE ZONE DEPTH	=	24.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.268	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	12.024	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	3.240	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	6.274	INCHES
TOTAL INITIAL WATER	=	6.274	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
Hobbs New Mexico

STATION LATITUDE	=	32.26 DEGREES
MAXIMUM LEAF AREA INDEX	=	1.20
START OF GROWING SEASON (JULIAN DATE)	=	67
END OF GROWING SEASON (JULIAN DATE)	=	317
EVAPORATIVE ZONE DEPTH	=	24.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	9.20 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	40.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	27.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	46.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	48.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ROSWELL NEW MEXICO

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
0.46	0.46	0.54	0.79	1.93	1.85
2.16	2.37	2.54	1.54	0.55	0.55

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR MIDLAND TEXAS

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
42.20	46.90	53.40	62.20	70.60	78.30
80.30	79.10	72.70	62.80	51.00	43.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR MIDLAND TEXAS
AND STATION LATITUDE = 32.40 DEGREES

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ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	12.67	4549998.000	100.00
RUNOFF	0.231	82989.812	1.82
EVAPOTRANSPIRATION	11.939	4287401.000	94.23
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	0.500	179606.766	3.95
SOIL WATER AT START OF YEAR	6.274	2252973.250	
SOIL WATER AT END OF YEAR	6.774	2432580.000	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.706	0.00

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ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	18.56	6665191.000	100.00
RUNOFF	0.364	130883.469	1.96
EVAPOTRANSPIRATION	17.767	6380248.000	95.72
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	0.429	154059.500	2.31
SOIL WATER AT START OF YEAR	6.774	2432580.000	
SOIL WATER AT END OF YEAR	7.203	2586639.500	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.086	0.00

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ANNUAL TOTALS FOR YEAR 3

	INCHES	CU. FEET	PERCENT
PRECIPITATION	17.16	6162429.000	100.00
RUNOFF	0.224	80322.484	1.30
EVAPOTRANSPIRATION	15.687	5633356.000	91.41
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	1.250	448750.031	7.28
SOIL WATER AT START OF YEAR	7.203	2586639.500	
SOIL WATER AT END OF YEAR	8.370	3005633.250	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.083	29756.348	0.48
ANNUAL WATER BUDGET BALANCE	0.0000	0.626	0.00

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ANNUAL TOTALS FOR YEAR 4

	INCHES	CU. FEET	PERCENT
PRECIPITATION	13.25	4758286.000	100.00
RUNOFF	0.478	171732.094	3.61
EVAPOTRANSPIRATION	14.000	5027498.000	105.66
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	-1.228	-440944.906	-9.27
SOIL WATER AT START OF YEAR	8.370	3005633.250	
SOIL WATER AT END OF YEAR	7.225	2594444.750	
SNOW WATER AT START OF YEAR	0.083	29756.348	0.63
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.894	0.00

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ANNUAL TOTALS FOR YEAR 5

	INCHES	CU. FEET	PERCENT
PRECIPITATION	17.23	6187568.000	100.00
RUNOFF	0.489	175508.312	2.84
EVAPOTRANSPIRATION	17.044	6120683.000	98.92
PERC./LEAKAGE THROUGH LAYER 2	0.000000	0.000	0.00
AVG. HEAD ON TOP OF LAYER 2	0.0000		
CHANGE IN WATER STORAGE	-0.302	-108625.461	-1.76
SOIL WATER AT START OF YEAR	7.225	2594444.750	
SOIL WATER AT END OF YEAR	6.922	2485819.250	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	2.740	0.00

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.33	0.28	0.60	0.56	1.97	1.29
	2.59	2.09	2.42	1.23	1.40	1.01
STD. DEVIATIONS	0.37	0.07	0.51	0.45	1.86	1.57
	1.22	1.44	1.54	1.42	1.70	0.70
RUNOFF						
TOTALS	0.001	0.000	0.000	0.000	0.089	0.072
	0.070	0.013	0.040	0.065	0.008	0.000
STD. DEVIATIONS	0.001	0.000	0.000	0.000	0.167	0.128
	0.069	0.018	0.089	0.146	0.012	0.001
EVAPOTRANSPIRATION						
TOTALS	0.639	0.364	0.691	0.524	2.207	1.176
	2.282	2.495	1.794	1.216	1.078	0.822
STD. DEVIATIONS	0.542	0.094	0.565	0.407	1.821	1.734
	1.087	1.318	1.296	0.685	0.315	0.183
PERCOLATION/LEAKAGE THROUGH LAYER 2						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 2						
AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	15.77	(2.637)	5664694.5	100.00
RUNOFF	0.357	(0.1282)	128287.23	2.265
EVAPOTRANSPIRATION	15.287	(2.3591)	5489837.00	96.913
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.00000	(0.00000)	0.000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	(0.000)		
CHANGE IN WATER STORAGE	0.130	(0.9368)	46569.18	0.822

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	2.03	729005.250
RUNOFF	0.377	135550.4060
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.000000	0.00000
AVERAGE HEAD ON TOP OF LAYER 2	0.000	
SNOW WATER	1.33	478030.2810

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.2714

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1350

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FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	3.9162	0.1632
2	3.0060	0.5010
SNOW WATER	0.000	

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APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 4: HELP MODEL

ATTACHMENT III.4.B

SUMMARY OF GEOTECHNICAL SOIL TEST DATA

APPLICATION FOR PERMIT
SUNDANCE WEST
SURFACE WASTE MANAGEMENT FACILITY

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 4: HELP MODEL

ATTACHMENT III.4.B

SUMMARY OF GEOTECHNICAL SOIL TEST DATA

amec

Client:	Gordon Environmental, Inc. 213 Camino del Pueblo Bernalillo, NM 87004-	**Report Date:**	October 23, 2009
Attention:	Larry Coons	**Project #:**	8-519-005168
Project Name:	Gordon Environmental Inc. 2008 Misc. Testing	**Work Order #:**	2
	ABQ, NM	**Sampled By:**	Client
Project Manager:	Herman Garcia	**Date Sampled:**	

Sieve Analaysis (ASTM C117-04/C136-06)
Plasticity Index (ASTM D4318-05)
Soil Classification (ASTM D2487-06)

SOILS / AGGREGATES

Sample Location	Soil Class.	L.L.	P.I.	#200	#100	#50	#40	#30	#16	#10	#8	#4	1/4"	3/8"	1/2"	3/4'	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	6"	12"	Lab Number
GB-1 @ 15 - 20'	SC-SM	24	5	33	55	90	96	98	98	99	99	99		100											9-1213-01
GB-1 @ 20'	SC	42	18	29	47	70	74	76	78	79	80	83		87	88	93	100								9-1213-02
GB-1 @ 40 - 45'	CL	30	14	56	67	79	82	86	92	95	96	99		100											9-1213-03
GB-1 @ 45'	CL	46	28	80	92	97	98	98	99	99	99	100													9-1213-04
GB-2 @ 5'	SM	20	2	24	54	92	97	98	99	99	99	99		100											9-1213-05
GB-2 @ 10 - 20'	SM	NV	NP	27	46	80	85	88	91	93	94	97		100											9-1213-06
GB-2 @ 15'	SM	29	5	23	47	88	95	97	98	99	99	99		100											9-1213-07
CH-1 @ 154'	CL	38	16	65	77	96	99	100																	9-1213-08
CH-2 @ 149'	CL	30	11	73	78	91	97	99	100																9-1213-09
CH-3 @ 79'	ML	44	13	75	83	95	98	99	100																9-1213-10
CH-4 @ 64'	SM	24	3	30	53	67	73	81	94	96	97	99		100											9-1213-11

Reviewed By: ______________

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Client: Gordon Environmental, Inc.
213 Camino del Pueblo
Bernalillo, NM 87004-

Report Date: November 04, 2009

Project #: 8-519-005168
Report #: 1003
Work Order #: 2
Sampled By: Client
Date Sampled:

Attn: Larry Coons

Project Name: Gordon Environmental Inc. 2008 Misc Testing

ABQ, NM

Project Manager: Herman Garcia

SOILS / AGGREGATES

MOISTURE CONTENT OF SOIL (ASTM D2216-05) AND IN-SITU DENSITY

Lab #	Color & Type of Material	Sample Source	Test Method	Oven Temp. (C)	Mass less than Min Req.	Material Type *	Moisture (%)	Dry Density (pcf)
9-1213-01		GB-1 @ 15 - 20'	A	110			10	
9-1213-02		GB-1 @ 20'	A	110			12	
9-1213-03		GB-1 @ 40 - 45'	A	110			9	
9-1213-04		GB-1 @ 45'	A	110			12	
9-1213-05		GB-2 @ 5'	A	110			5	
9-1213-06		GB-2 @ 10 - 20'	A	110			3	
9-1213-07		GB-2 @ 15'	A	110			8	
9-1213-08		CH-1 @ 154'	A	110			13	
9-1213-09		CH-2 @ 149'	A	110			8	
9-1213-10		CH-3 @ 79'	A	110			20	
9-1213-11		CH-4 @ 64'	A	110			5	

*Sample contains more than one type of material.

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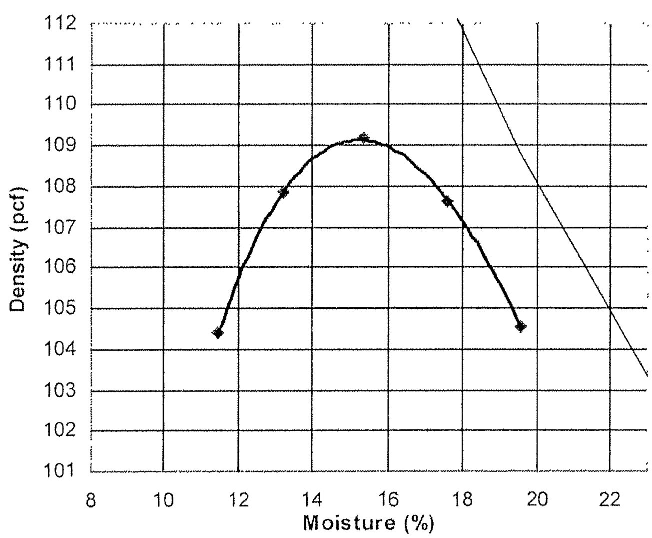
		Project #:	8-519-005168
		Work Order #:	2
Attn:	Larry Coons	**Lab #:**	9-1213-01
Project Name:	Gordon Environmental Inc. 2008 Misc. Testing ABQ, NM	**Sampled By:**	Client
		Date Sampled:	
		Visual Description of Material:	
Project Manager:	Herman Garcia	**Sample Source:**	GB-1 @ 15 - 20'

SOILS / AGGREGATES



Sieve Analysis (ASTM C117-04/C136-06)

200 Wash Procedure: A

Sieve Size	Passing
3/8in.	100%
#4	99%
#8	99%
#10	99%
#16	98%
#30	98%
#40	96%
#50	90%
#100	55%
#200	33%

Moisture Density Relationship: (ASTM D698-07) **Method:** A

Preparation Method: Dry **Rammer Type:** Mechanical

Specific Gravity: 2.651 **Assumed**

Maximum Density: 109.1

Optimum Moisture: 15.2

Plasticity Index (ASTM D4318-05)

Liquid Limit:	24
Plastic Limit:	19
Plasticity Index:	5

Preperation Method: Dry **Liquid Limit Method:** A

PI Air Dried.

Soil Classification (ASTM D2487-06) SC-SM

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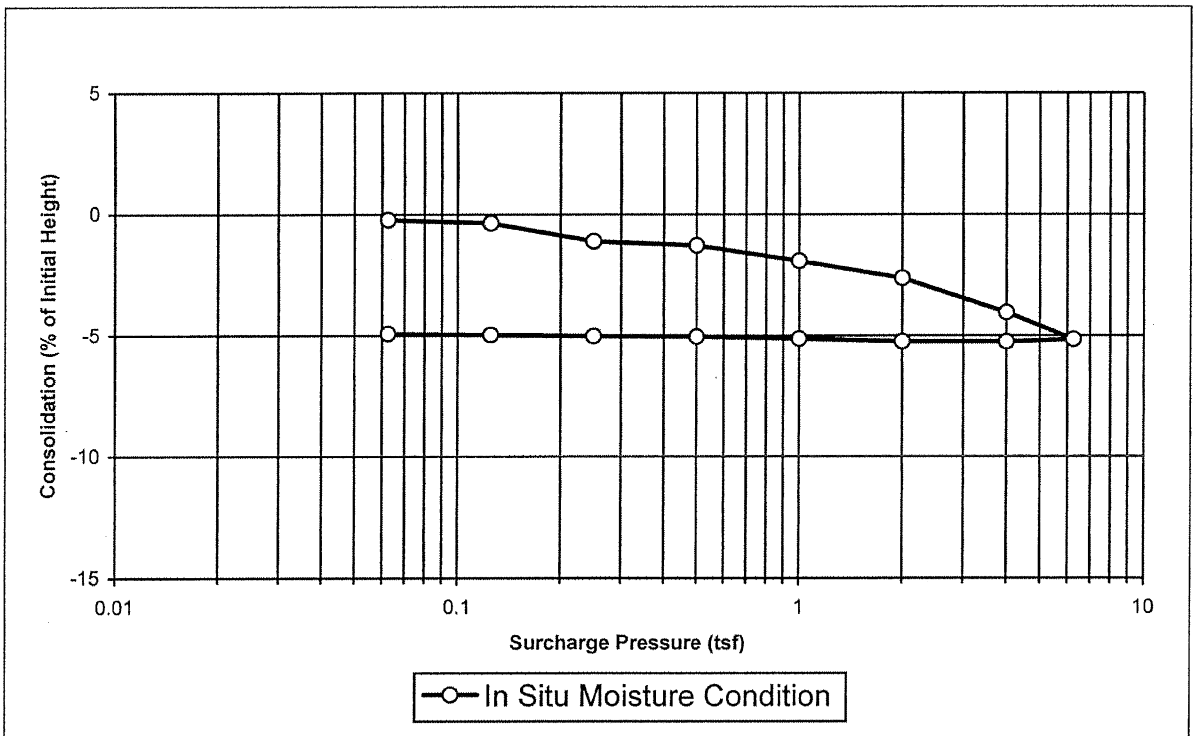
Client:	Gordon Environmental, Inc. 213 Camino Del Pueblo Bernalillo, NM 87004-	**Report Date:**	November 10, 2009
		Project #:	8-519-005168
		Work Order #:	2
Attn:	Larry Coons	**Lab #:**	9-1213-02
Project Name:	Gordon Environmental, Inc. 2008 Misc. Testing	**Sampled By:**	Client
		Date Sampled:	Unknown
	ABQ, NM	**Material:**	Silty Clayey Sand
		Sample Source:	GB-1 at 20 ft
Project Manager:	Herman Garcia	SOILS/AGGREGATES	

Measurement of Collapse Potential of Soils (ASTM D5333)

Sample Preparation: In Situ

Initial Volume (in^3):	4.60	**Final Volume (in^3):**	4.39
Initial Moisture (%):	17.7%	**Final Moisture (%)**	15.5%
Initial Dry Density (lb/ft^3):	80.3	**Initial Dry Density (lb/ft^3):**	83.9
Initial Degree of Saturation:	45%	**Final Degree of Saturation:**	42%
Initial Void Ratio:	1.0	**Final Void Ratio:**	0.9
Estimated Specific Gravity:	2.600	**Saturated At:**	Not Saturated



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PROJECT:	Gordon Environmental Inc. 2008 Misc Testing
CLIENT:	Smith Engineering Co.
MATERIAL:	Silty Clayey Sand
SAMPLE SOURCE:	GB-1 at 20 ft
PREPARATION:	In Situ

JOB NO: 8-519-005168
LAB NO: 9-1213-02
DATE SAMPLED: Unknown
SAMPLED BY: Client

REVIEWED BY:

Measurement of Hydraulic Conductivity (Applicable Portions of ASTM D5856-95)

Lab Number	Sample Source	Method	K_{sat} (cm/s)*	K_{sat} (ft/day)*	Initial Moisture Content ** (%)	Saturated Moisture Content ** (%)	Dry Bulk Density (lb/ft^3)	Calculated Porosity (%)
9-1213-02	GB-1 at 20 ft	Constant Head	9.36E-05	2.65E-01	17.6%	42.3%	80.2	50.6%

*Corrected to 20 °C
**Gravimetric Moisture (percent by mass)

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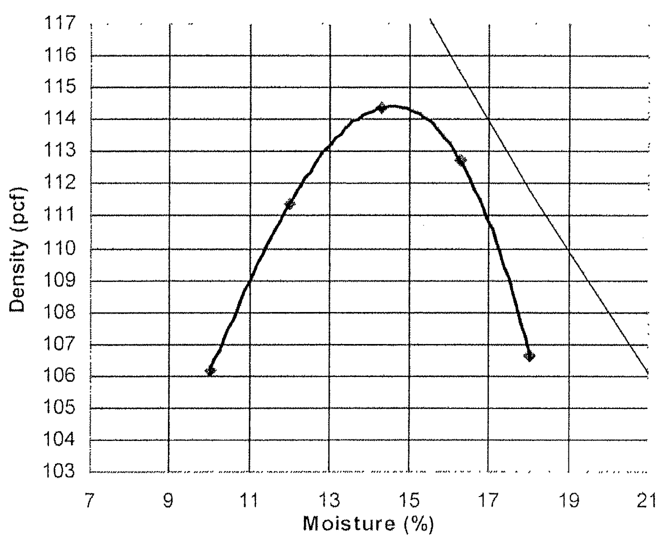
Client:	Gordon Environmental, Inc. 213 Camino del Pueblo Bernalillo, NM 87004-	**Report Date:**	October 26, 2009
		Project #:	8-519-005168
		Work Order #:	2
		Lab #:	9-1213-03
Attn:	Larry Coons	**Sampled By:**	Client
Project Name:	Gordon Environmental Inc. 2008 Misc. Testing	**Date Sampled:**	
	ABQ, NM	**Visual Description of Material:**	
		Sample Source:	GB-1 @ 40 - 45'
Project Manager:	Herman Garcia		

SOILS / AGGREGATES



Sieve Analysis (ASTM C117-04/C136-06)

200 Wash Procedure: A

Sieve Size	Passing
3/8in.	100%
#4	99%
#8	96%
#10	95%
#16	92%
#30	86%
#40	82%
#50	79%
#100	67%
#200	56%

Moisture Density Relationship: (ASTM D698-07) Method: B

Preparation Method: Dry Rammer Type: Mechanical

Specific Gravity: 2.651 Assumed

Maximum Density: 114.4

Optimum Moisture: 14.6

Plasticity Index (ASTM D4318-05)

Liquid Limit: 30

Plastic Limit: 16

Plasticity Index: 14

Preperation Method: Dry Liquid Limit Method: A

PI Air Dried.

Soil Classification (ASTM D2487-06) CL

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Client:	Gordon Environmental, Inc. 213 Camino del Pueblo Bernalillo, NM 87004	**Report Date:**	11/11/2009
		Project #:	8-519-005168
Attn:	Larry Coons	**Work Order #:**	2
		Lab #:	9-1213-04
Project Name:	Gordon Environmental Inc. 2008 Misc. Testing	**Sampled By:**	Client
		Date Sampled:	Unknown
		Visual Description of Material:	Sandy Clay
		Sample Source:	GB-1 at 45 ft

Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter (ASTM D5084-03)

SAMPLE PREPARATION: In Situ

METHOD OF COMPACTION: NA

PERMEANT LIQUID: Tap Water
TESTING METHOD: Method F: Constant Volume Falling Head (by Mercury) Rising Tailwater

FIELD MOISTURE:	NA	LAB MOISTURE:	NA
INITIAL DIAMETER (cm):	6.04	FINAL DIAMETER	6.17
INITIAL LENGTH (cm):	7.62	FINAL LENGTH	7.72
INITIAL MOISTURE CONTENT (%):	12.7	FINAL MOISTURE CONTENT (%):	20.7
CONSOLIDATED? (Y/N):	N		
CELL PRESSURE (psi):	NA	POST CONSOLIDATION DIAMETER (cm):	NA
BACKPRESSURE (psi):	NA	POST CONSOLIDATION LENGTH (cm):	NA

EFFECTIVE STRESS (psi):	4.0	SPECIFIC GRAVITY:	2.651
INITIAL DRY BULK DENSITY (lb/ft^3):	114.6	SPECIFIC GRAVITY ASSUMED? (Y/N):	Y
		PERCENT SATURATION:	100%
FINAL DRY BULK DENSITY (lb/ft^3):	108.5		
FINAL B PARAMETER READING:	1.00	FINAL BACKPRESSURE (psi):	70
AVERAGE K_{sat} * (cm/s):	**2.32E-06**	**AVERAGE K_{sat} * (ft/day):**	**6.58E-03**

MAXIMUM GRADIENT USED: 4.29
MINIMUM GRADIENT USED: 2.91

*Corrected to 20 °C
**N.B.: All final sample dimensions are subject to sample deformation caused by exsolution of air in pore water and handling during removal from cell.

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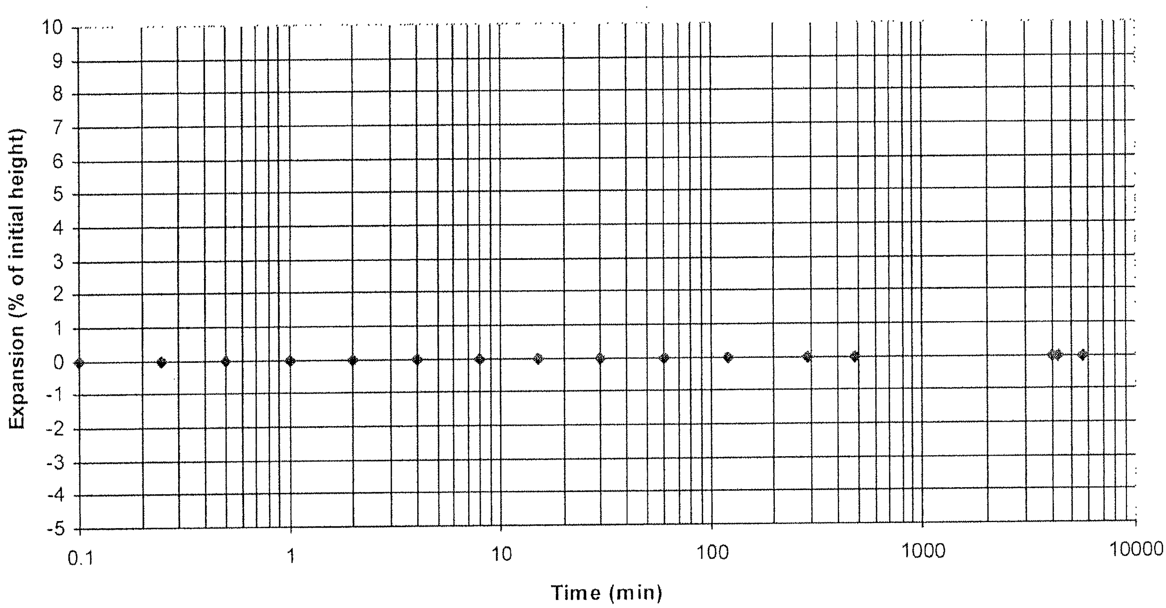
Client:	Gordon Environmental, Inc. 213 Camino del Pueblo Bernalillo, NM 87004-	**Report Date:**	November 05, 2009
		Project #:	8-519-005168
		Work Order #:	2
Attn:	Larry Coons	**Lab #:**	9-1213-04
Project Name:	Gordon Environmental Inc. 2008 Misc. Testing ABQ, NM	**Sampled By:**	Client
		Date Sampled:	
		Visual Description of Material:	
		Sample Source:	GB-1 @ 45'
Project Manager:	Herman Garcia		

SOILS / AGGREGATES

One-Dimensional Swell or Settlement Potential of Cohesive Soils (ASTM D4546-08)

Initial Volume (cu.in.):	4.58	Final Volume (cu.in.):	4.58
Initial Moisture (%):	9.6%	Final Moisture (%):	17.3%
Initial Dry Density (pcf):	104.7	Final Dry Density (pcf):	104.7
Final Degree Saturation:	79%	Initial Degree of Saturation:	44%
Initial Void Ratio:	0.6	Final Void Ratio:	0.6
Moisture pick-up (% Dry weight.):	7.7%	Moisture pick-up (% in volume):	12.9%
Estimated Specific Gravity:	2.651	Load:	1 tsf
Type of Water Used:	Distilled Water	Swell (% of Initial Height):	0.0%

Expansion - Log Time Curve



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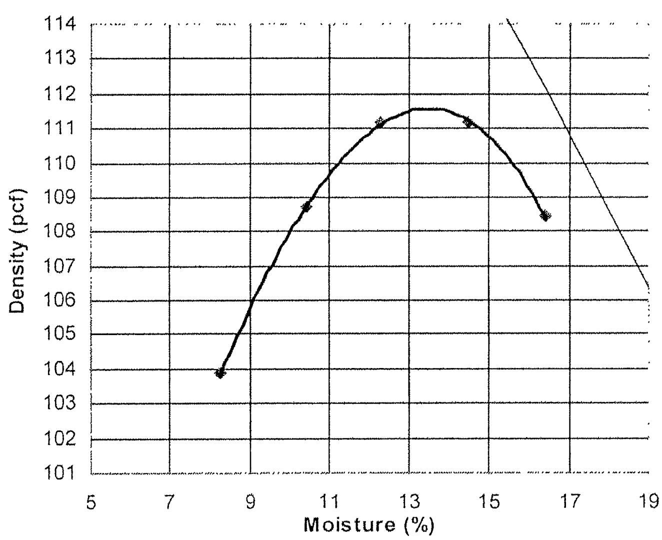
Client:	Gordon Environmental, Inc. 213 Camino del Pueblo Bernalillo, NM 87004-	**Report Date:**	October 26, 2009
		Project #:	8-519-005168
		Work Order #:	2
		Lab #:	9-1213-06
Attn:	Larry Coons	**Sampled By:**	Client
Project Name:	Gordon Environmental Inc. 2008 Misc. Testing	**Date Sampled:**	
	ABQ, NM	**Visual Description of Material:**	
		Sample Source:	GB-2 @ 10 - 20'
Project Manager:	Herman Garcia		

SOILS / AGGREGATES



Sieve Analysis (ASTM C117-04/C136-06)

200 Wash Procedure: A

Sieve Size	Passing
3/8in.	100%
#4	97%
#8	94%
#10	93%
#16	91%
#30	88%
#40	85%
#50	80%
#100	46%
#200	27%

Moisture Density Relationship: (ASTM D698-07) Method: B

Preparation Method: Dry **Rammer Type:** Mechanical

Specific Gravity: 2.551 **Assumed**

Maximum Density: 111.6

Optimum Moisture: 13.5

Plasticity Index (ASTM D4318-05)

Liquid Limit: NV

Plastic Limit: NV

Plasticity Index: NP

Preperation Method: Dry **Liquid Limit Method:** A

PI Air Dried.

Soil Classification (ASTM D2487-06) SM

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PROJECT: Gordon Environmental Inc. 2008 Misc Testing
CLIENT: Gordon Environmental, Inc.
MATERIAL: Silty Clayey Sand
SAMPLE SOURCE: GB-2 at 15 ft
PREPARATION: In Situ

JOB NO: 8-519-005168
LAB NO: 9-1213-07
DATE SAMPLED: Unknown
SAMPLED BY: Client

REVIEWED BY:

Measurement of Hydraulic Conductivity (Applicable Portions of ASTM D5856-95)

Lab Number	Sample Source	Method	K_{sat} (cm/s)*	K_{sat} (ft/day)*	Initial Moisture Content ** (%)	Saturated Moisture Content ** (%)	Dry Bulk Density (lb/ft^3)	Calculated Porosity (%)
9-1213-07	GB-2 at 15 ft	Constant Head	2.90E-04	8.22E-01	11.2%	24.5%	94.8	41.6%

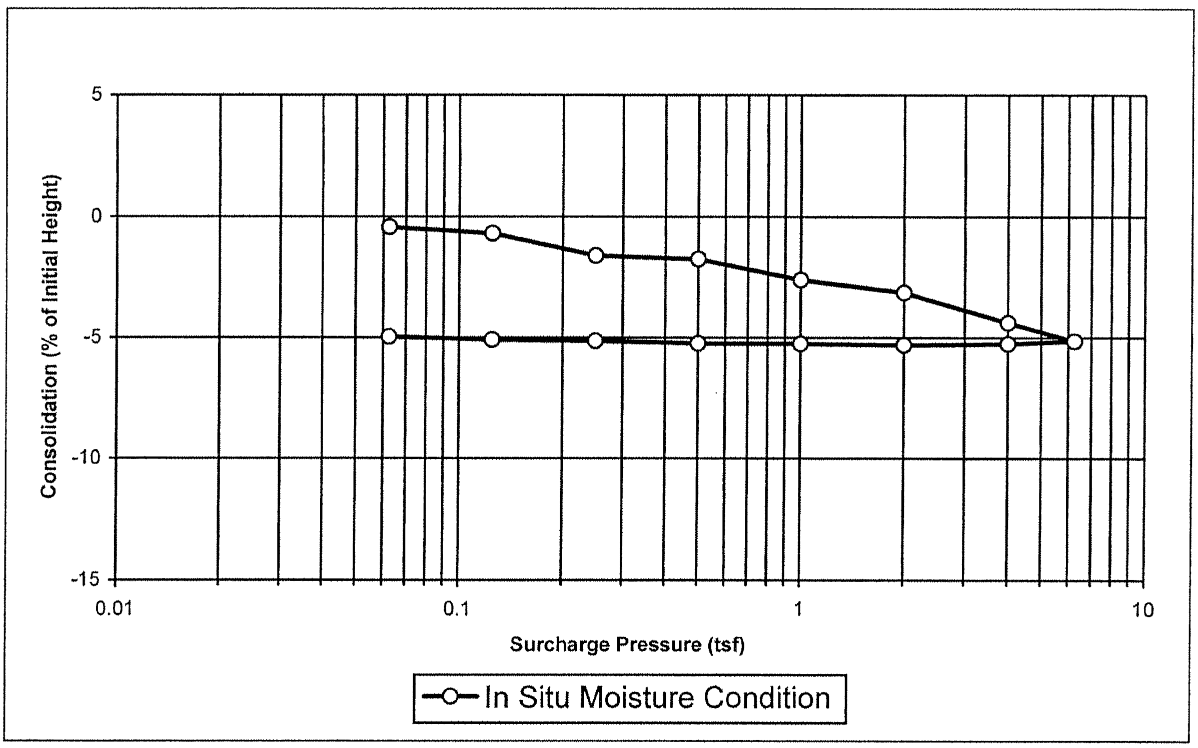
*Corrected to 20 °C
**Gravimetric Moisture (percent by mass)

Client:	Gordon Environmental, Inc. 213 Camino Del Pueblo Bernalillo, NM 87004-	**Report Date:**	November 10, 2009
		Project #:	8-519-005168
		Work Order #:	2
Attn:	Larry Coons	**Lab #:**	9-1213-07
Project Name:	Gordon Environmental, Inc. 2008 Misc. Testing	**Sampled By:**	Client
		Date Sampled:	Unknown
	ABQ, NM	**Material:**	Silty Clayey Sand
		Sample Source:	GB-2 at 15 ft
Project Manager:	Herman Garcia	**SOILS/AGGREGATES**	

Measurement of Collapse Potential of Soils (ASTM D5333)

Sample Preparation: In Situ

Initial Volume (in^3):	4.60	**Final Volume (in^3):**	4.40
Initial Moisture (%):	17.7%	**Final Moisture (%)**	15.5%
Initial Dry Density (lb/ft^3):	80.3	**Initial Dry Density (lb/ft^3):**	83.7
Initial Degree of Saturation:	45%	**Final Degree of Saturation:**	42%
Initial Void Ratio:	1.0	**Final Void Ratio:**	0.9
Estimated Specific Gravity:	2.600	**Saturated At:**	Not Saturated



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Calculated Porosities

Lab #	Test Sample	%
9-1213-02	K_{sat}	50.6
9-1213-02	Settlement	50.5
9-1213-04	K_{sat}	29.4
9-1213-04	Swell	39.9
9-1213-07	K_{sat}	41.6
9-1213-07	Settlement	29.9

Based on a specific gravity of 2.6 g/cm^3. Note that the Ksat and settlement for lab number 9-1213-04 were taken from different ring samples

APPLICATION FOR PERMIT
SUNDANCE WEST

VOLUME III: LANDFILL ENGINEERING CALCULATIONS
SECTION 4: HELP MODEL

ATTACHMENT III.4.C

HELP MODEL USERS GUIDE FOR VERSION 3

THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL

USER'S GUIDE FOR VERSION 3

by

Paul R. Schroeder, Cheryl M. Lloyd, and Paul A. Zappi
Environmental Laboratory
U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, Mississippi 39180-6199

and

Nadim M. Aziz
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Clemson University
Clemson, South Carolina 29634-0911

Interagency Agreement No. DW21931425

Project Officer

Robert E. Landreth
Waste Minimization, Destruction and Disposal Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Interagency Agreement No. DW21931425 to the U.S. Army Engineer Waterways Experiment Station. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Risk Reduction Engineering Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report presents guidance on the use of the Hydrologic Evaluation of Landfill Performance (HELP) computer program. The HELP program is a quasi-two-dimensional hydrologic model for conducting water balance analysis of landfills, cover systems, and other solid waste containment facilities. The model accepts weather, soil and design data, and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives. The model is a tool for both designers and permit writers.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The program was developed to conduct water balance analysis of landfills, cover systems, and solid waste disposal and containment facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection, and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to open, partially closed, and fully closed sites, is a tool for both designers and permit writers.

This report explains how to use Version 3 of the HELP model. Section 1 provides background and overview of the model, and lists software and hardware requirements. Section 2 describes basic landfill design and liquids management concepts. Section 3 presents definitions, options and limitations for input parameters as well as detailed guidance for selecting their input values. Section 4 provides detailed instructions on how to enter input, run the simulation and view or print output. Appendix A provides assistance for estimating material properties for moisture retention and saturated hydraulic conductivity.

The user interface or input facility is written in the Quick Basic environment of Microsoft Basic Professional Development System Version 7.1 and runs under DOS 2.1 or higher on IBM-PC and compatible computers. The HELP program uses an interactive and a user-friendly input facility designed to provide the user with as much assistance as possible in preparing data to run the model. The program provides weather and soil data file management, default data sources, interactive layer editing, on-line help, and data verification and accepts weather data from the most commonly used sources with several different formats.

HELP Version 3 represents a significant advancement over the input techniques of Version 2. Users of the HELP model should find HELP Version 3 easy to use and should be able to use it for many purposes, such as preparing and editing landfill profiles and weather data. Version 3 facilitates use of metric units, international applications, and designs with geosynthetic materials.

This report should be cited as follows:

> Schroeder, P. R., Aziz, N. M., Lloyd, C. M. and Zappi, P. A. (1994). "The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3," EPA/600/R-94/168a, September 1994, U.S. Environmental Protection Agency Office of Research and Development, Washington, DC.

This report was submitted in partial fulfillment of Interagency Agreement Number DW21931425 between the U.S. Environmental Protection Agency and the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. This report covers a period from November 1988 to June 1994 and work was completed as of June 1994.

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

ACKNOWLEDGMENTS

The support of the project by the Waste Minimization, Destruction and Disposal Research Division, Risk Reduction Engineering Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH and the Headquarters, U.S. Army Corps of Engineers, Washington, DC, through Interagency Agreement No. DW21931425 is appreciated. In particular, the authors wish to thank the U.S. EPA Project Officer, Mr. Robert Landreth, for his long standing support.

The draft version of this document was prepared at Clemson University by Dr. Nadim M. Aziz, the author of the HELP Version 3 user interface, under contract with the USEPA Risk Reduction Engineering Laboratory and the USAE Waterways Experiment Station. The final version of this document was prepared at the USAE Waterways Experiment Station by Dr. Paul R. Schroeder and Ms. Cheryl M. Lloyd. Appendix A was written by Mr. Paul A. Zappi. The figures used in the report were prepared by Messrs. Jimmy Farrell and Christopher Chao.

The report and user interface were reviewed by Messrs. Elba A. Dardeau, Jr., and Daniel E. Averett. This report has not been subjected to the EPA review and, therefore, the contents do not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

SECTION 1

INTRODUCTION

The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data, and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The program was developed to conduct water balance analysis of landfills, cover systems and solid waste disposal and containment facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to open, partially closed, and fully closed sites, is a tool for both designers and permit writers.

1.1 BACKGROUND

The HELP program, Versions 1, 2 and 3, was developed by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the U.S. Environmental Protection Agency (EPA), Risk Reduction Engineering Laboratory, Cincinnati, OH, in response to needs in the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, better known as Superfund) as identified by the EPA Office of Solid Waste, Washington, DC.

HELP Version 1 (Schroeder et al., 1984) represented a major advance beyond the Hydrologic Simulation on Solid Waste Disposal Sites (HSSWDS) program (Perrier and Gibson, 1980; Schroeder and Gibson, 1982), which was also developed at WES. The HSSWDS model simulated only the cover system, did not model lateral flow through drainage layers, and handled vertical drainage only in a rudimentary manner. The infiltration, percolation and evapotranspiration routines were almost identical to those used in the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, which was developed by Knisel (1980) for the U.S. Department of Agriculture (USDA). The runoff and infiltration routines relied heavily on the Hydrology Section of the National Engineering Handbook (USDA, Soil Conservation Service, 1985). Version 1 of the HELP model incorporated a lateral subsurface drainage model and improved unsaturated drainage and liner leakage models into the HSSWDS model. In addition, the HELP model provided simulation of the entire landfill including leachate collection and liner systems.

Version 2 (Schroeder et al., 1988) represented a great enhancement of the capabilities of the HELP model. The WGEN synthetic weather generator developed by the USDA Agricultural Research Service (ARS) (Richardson and Wright, 1984) was added to the model to yield daily values of precipitation, temperature and solar radiation. This replaced the use of normal mean monthly temperature and solar radiation values and improved the modeling of snow and evapotranspiration. Also, a vegetative growth model from the Simulator for Water Resources in Rural Basins (SWRRB) model developed by the ARS (Arnold et al., 1989) was merged into the HELP model to calculate daily leaf area indices. Modeling of unsaturated hydraulic conductivity and flow and lateral drainage computations were improved. Accuracy was increased with the use of double precision. Default soil data were improved, and the model permitted use of more layers and initialization of soil moisture content. Input and editing were simplified. Output was clarified, and standard deviations were reported.

In Version 3, the HELP model has been greatly enhanced beyond Version 2. The number of layers that can be modeled has been increased. The default soil/material texture list has been expanded to contain additional waste materials, geomembranes, geosynthetic drainage nets and compacted soils. The model also permits the use of a user-built library of soil textures. Computation of leachate recirculation between soil layers and groundwater drainage into the landfill have been added. Moreover, HELP Version 3 accounts for leakage through geomembranes due to manufacturing defects (pinholes) and installation defects (punctures, tears and seaming flaws) and by vapor diffusion through the liner. The estimation of runoff from the surface of the landfill has been improved to account for large landfill surface slopes and slope lengths. The snowmelt model has been replaced with an energy-based model; the Priestly-Taylor potential evapotranspiration model has been replaced with a Penman method, incorporating wind and humidity effects as well as long wave radiation losses (heat loss at night). A frozen soil model has been added to improve infiltration and runoff predictions in cold regions. The unsaturated vertical drainage model has also been improved to aid in storage computations. Input and editing have been further simplified with interactive, full-screen, menu-driven input techniques.

In addition, the HELP Version 3 model provides a variety of methods for specifying precipitation, temperature and solar radiation data. Now, data from the most commonly available government and commercial sources can be imported easily. Moreover, data used in HELP Version 2 can still be used with minimum user effort. Specifying weather data manually and editing previously entered weather data can be easily done by using built-in spreadsheet facilities.

The use of data files in Version 3 is much simpler and more convenient than HELP Version 2 because data are saved permanently in user defined file names at a user-specified location. Similarly, the user has more flexibility to define units for every type of data needed to run the HELP model. Finally, Version 3 of the HELP model provides on-line help at every step of the data preparation process.

Although applicable to most landfill applications, the HELP model was developed specifically to perform hazardous and municipal waste disposal landfill evaluations as required by RCRA. Hazardous waste disposal landfills generally should have a liner to prevent migration of waste from the landfill, a final cover to minimize the production of leachate following closure, careful controls of runon and runoff, and limits on the buildup of leachate head over the liner to no more than 1 ft. The HELP model is useful for predicting the amounts of runoff, drainage, and leachate expected for reasonable designs as well as the buildup of leachate above the liner. However, the model should not be expected to produce credible results from input unrepresentative of landfills.

1.2 OVERVIEW

The principal purpose of this User's Guide is to provide the basic information needed to use the computer program. Thus, while some attention must be given to definitions, descriptions of variables and interpretation of results, only a minimal amount of such information is provided. Detailed documentation providing in-depth coverage of the theory and assumptions on which the model is based and the internal logic of the program is also available (Schroeder et al., 1994). Potential HELP users are strongly encouraged to study the documentation and this User's Guide before attempting to use the program to evaluate a landfill design. Additional documentation concerning the sensitivity of program inputs, application of the model and verification of model predictions are under development.

1.3 SYSTEM AND OPERATING DOCUMENTATION

1.3.1 Computer Equipment

The model entitled "The Hydrologic Evaluation of Landfill Performance" (HELP) was written to run on IBM-compatible personal computers (PC) under the DOS environment.

1.3.2 Required Hardware

The following IBM-compatible CPU (8088, 80286, 80386 or 80486) hardware is required:

1. Monitor, preferably color EGA or better

2. Floppy disk drive (5.25-inch double-sided, double- or high-density; or 3.5-inch

double-sided, double- or high-density)

3. Hard disk drive or a second floppy disk drive

4. 400k bytes or more of available RAM memory

5. 8087, 80287, 80387 or 80486 math co-processor

6. Printer, if a hard copy is desired

1.3.3 Software Requirements

The user must use Microsoft or compatible Disk Operating Systems (MS-DOS) Version 2.10 or a higher version. The user interface executable module was compiled and linked with Microsoft Basic Professional Development System 7.1. Other executable components were compiled with the Ryan-McFarland FORTRAN Version 2.42. The Microsoft Basic Professional Development System and Ryan-McFarland FORTRAN compiler are not needed to run the HELP Model.

SECTION 2

BASIC LANDFILL DESIGN CONCEPTS

2.1 BACKGROUND

Over the past 20 to 30 years, the sanitary landfill has come to be widely recognized as an economic and effective means for disposal of municipal and industrial solid wastes. Today, modern methods of landfill construction and management are sufficiently developed to ensure that even large volumes of such materials can be handled and disposed of in such a way as to protect public health and minimize adverse effects on the environment.

Recently, public attention has been focused on a special class of materials commonly referred to as hazardous wastes. The chemical and physical diversity, environmental persistence, and acute and chronic detrimental effects on human, plant and animal health of many of these substances are such that great care must be exercised in their disposal. Hazardous wastes are produced in such large quantities and are so diverse that universally acceptable disposal methods have yet to be devised. However, for the present, disposal or storage in secure landfills is usually a prudent approach. The current state of the art is an extension of sanitary landfill technology using very conservative design criteria. Some important basic principles and concepts of landfill design are summarized below. Specific emphasis is given to disposal of hazardous materials, but the discussion is also applicable to ordinary sanitary landfills.

2.2 LEACHATE PRODUCTION

Storage of any waste material in a landfill poses several potential problems. One problem is the possible contamination of soil, groundwater and surface water that may occur as leachate produced by water or liquid wastes moving into, through and out of the landfill migrates into adjacent areas. This problem is especially important when hazardous wastes are involved because many of these substances are quite resistant to biological or chemical degradation and, thus, are expected to persist in their original form for many years, perhaps even for centuries. Given this possibility hazardous waste landfills should be designed to prevent any waste or leachate from ever moving into adjacent areas. This objective is beyond the capability of current technology but does represent a goal in the design and operation of today's landfills. The HELP model has been developed specifically as a tool to be used by designers and regulatory reviewers for selecting practical designs that minimize potential contamination problems.

In the context of a landfill, leachate is described as liquid that has percolated through the layers of waste material. Thus, leachate may be composed of liquids that originate from a number of sources, including precipitation, groundwater, consolidation, initial moisture storage, and reactions associated with decomposition of waste materials. The chemical quality of leachate varies as a function of a number of factors, including the quantity produced, the original nature of the buried waste materials, and the various chemical and biochemical reactions that may occur as the waste materials decompose. In the absence of evidence to the contrary, most regulatory agencies prefer to assume that any leachate produced will contaminate either ground or surface waters; in the light of the potential water quality impact of leachate contamination, this assumption appears reasonable.

The quantity of leachate produced is affected to some extent by decomposition reactions and initial moisture content; however, it is largely governed by the amount of external water entering the landfill. Thus, a key first step in controlling leachate migration is to limit production by preventing, to the extent feasible, the entry of external water into the waste layers. A second step is to collect any leachate that is produced for subsequent treatment and disposal. Techniques are currently available to limit the amount of leachate that migrates into adjoining areas to a virtually immeasurable volume, as long as the integrity of the landfill structure and leachate control system is maintained.

2.3 DESIGN FOR LEACHATE CONTROL

A schematic profile view of a somewhat typical hazardous waste landfill is shown in Figure 1. The bottom layer of soil may be naturally existing material or it may be hauled in, placed and compacted to specifications following excavation to a suitable subgrade. In either case, the base of the landfill should act as a liner with some minimum thickness and a very low hydraulic conductivity (or permeability). Treatments may be used on the barrier soil to reduce its permeability to an acceptable level. As an added factor of safety, an impermeable synthetic membrane may be placed on the top of the barrier soil layer to form a composite liner.

Immediately above the bottom composite liner is a leakage detection drainage layer to collect leakage from the primary liner, in this case, a geomembrane. Above the primary liner are a geosynthetic drainage net and a sand layer that serve as drainage layers for leachate collection. The drain layers composed of sand are typically at least 1-ft thick and have suitably spaced perforated or open joint drain pipe embedded below the surface of the liner. The leachate collection drainage layer serves to collect any leachate that may percolate through the waste layers. In this case where the liner is solely a geomembrane, a drainage net may be used to rapidly drain leachate from the liner, avoiding a significant buildup of head and limiting leakage. The liners are sloped to prevent ponding by encouraging leachate to flow toward the drains. The net effect is that very little leachate should percolate through the primary liner and virtually no migration of leachate through the bottom composite liner to the natural formations below. Taken as a whole, the drainage layers, geomembrane liners, and barrier soil liners may be referred to as the leachate collection and removal system (drain/liner system) and more specifically a double liner system.

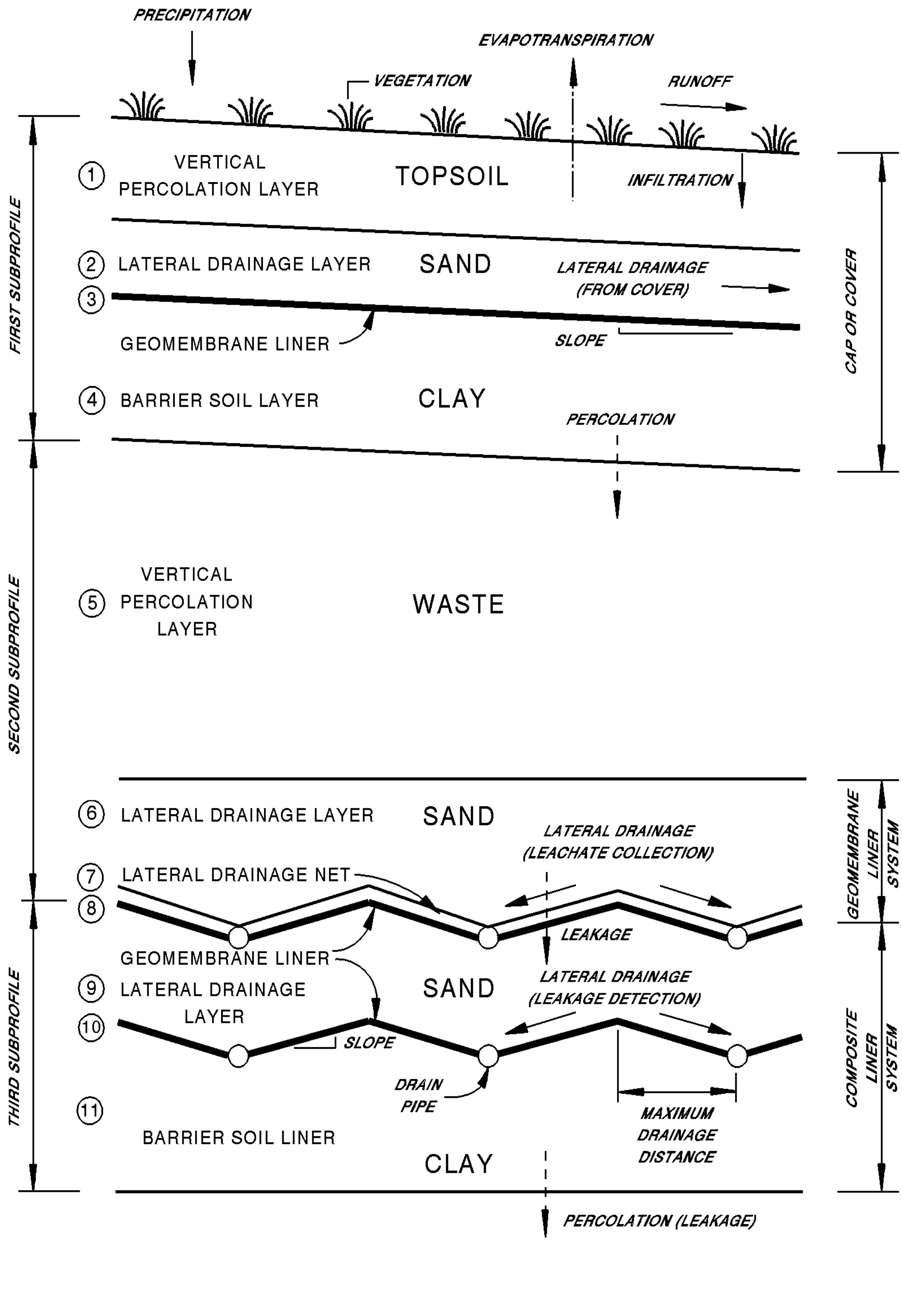

Figure 1. Schematic of Landfill Profile Illustrating Typical Landfill Features

After the landfill is closed, the leachate collection and removal system serves basically in a back-up capacity. However, while the landfill is open and waste is being added, these components constitute the principal defense against contamination of adjacent areas. Thus, care must be given to their design and construction.

Day-to-day operation of a modern sanitary landfill calls for wastes to be placed in relatively thin lifts, compacted, and covered with soil each day. Thus, wastes should not remain exposed for more than a few hours. Although the daily soil cover serves effectively to hide the wastes and limit the access of nuisance insects and potential disease vectors, it is of limited value for preventing the formation of leachate. Thus, even though a similar procedure can be used for hazardous wastes, the drainage/liner system must function well throughout and after the active life of the landfill.

When the capacity of the landfill is reached, the waste cells may be covered with a cap or final cover, typically composed of four distinct layers as shown in Figure 1. At the base of the cap is a drainage layer and a liner system layer similar to that used at the base of the landfill. Again, a geomembrane liner would normally be used in conjunction with the barrier soil liner for hazardous waste landfill but has been used less frequently in municipal waste landfills. The top of the barrier soil layer is graded so that water percolating into the drainage layer will tend to move horizontally toward some removal system (drain) located at the edge of the landfill or subunit thereof.

A layer of soil suitable for vegetative growth is placed at the top of final cover system to complete the landfill. A 2-ft-thick layer of soil having a loamy, silty nature serves this purpose well. The upper surface is graded so that runon is restricted and infiltration is controlled to provide moisture for vegetation while limiting percolation through the topsoil. Runoff is promoted but controlled to prevent excessive erosion of the cap. The vegetation used should be selected for ease of establishment in a given area, promotion of evapotranspiration and year-round protection from erosion. The root system should not penetrate, disrupt or desiccate the upper liner system (Layers # 3 and # 4). Grasses are usually best for this purpose; however, local experts should be consulted to aid in selection of appropriate species.

The combination of site selection, surface grading, transpiration from vegetation, soil evaporation, drainage through the sand, and the low hydraulic conductivity of the barrier soil liner serves effectively to minimize leachate production from external water. Added effectiveness is gained by the use of geomembrane liners in the cap in conjunction with the barrier soil liner. The cap should be no more permeable than the leachate collection and removal system so that the landfill will not gradually fill and overflow into adjacent areas following abandonment of the landfill. This phenomenon is sometimes referred to as the "bathtub" effect.

SECTION 3

PROGRAM DEFINITIONS, OPTIONS AND LIMITATIONS

3.1 INTRODUCTION

The HELP program was developed to provide landfill designers and regulators with a tool for rapid, economical screening of alternative designs. The program may be used to estimate the magnitudes of various components of the water budget, including the volume of leachate produced and the thickness of water-saturated soil (head) above liners. The results may be used to compare the leachate production potential of alternative designs, to select and size appropriate drainage and collection systems, and to size leachate treatment facilities.

The program uses weather (climatic), soil and design data to generate daily estimates of water movement across, into, through and out of landfills. To accomplish this objective and compute a water balance, daily precipitation is partitioned into surface storage (snow), snowmelt, interception, runoff, infiltration, surface evaporation, evapotranspiration from soil, subsurface moisture storage, liner leakage (percolation), and subsurface lateral drainage to collection, removal and recirculation systems.

This section discusses data requirements, nomenclature, important assumptions and limitations, and other fundamental information needed to run the program. The program documentation report (Schroeder et al., 1994) contains detailed explanations of the solution techniques employed and the computer programs.

The HELP program requires three general types of input data: weather data, soil data and design data. A summary of input options and data requirements is presented in this section. Section 4 provides step-by-step input instructions.

3.2 WEATHER DATA REQUIREMENTS

The weather data required in the HELP model are classified into four groups: evapotranspiration, precipitation, temperature, and solar radiation data. The HELP user may enter weather data using several options depending on the type of weather data being considered. The requirements for each weather data type are listed below. The units used are also listed next to each data type and/or variable. Customary units are based on the US Customary units, and Metric implies SI units.

3.2.1 Evapotranspiration Data

The evapotranspiration data can be entered in one of two ways:

1. ***Default Evapotranspiration Option with Location Specific Guidance*** *(Customary and Metric Units)*. This option uses the data provided by the HELP model for selected U.S. cities. The cities are listed in Table 1. The data needed for this option are:

   - **Location**

   - **Evaporative zone depth** (Guidance is available for the selected location based on a thick layer of loamy soil with a grassy form of vegetation. Clayey soils would generally have larger evaporative zone depths since it exerts greater capillary suction; analogously, sandy soils would have smaller evaporative depths. Shrubs and trees with tap roots would have larger evaporative zone depths than the values given in the guidance.) The user must specify an evaporative zone depth and can use the guidance along with specific design information to select a value. The program does not permit the evaporative depth to exceed the depth to the top of the topmost liner. Similarly, the evaporative zone depth would not be expected to extend very far into a sand drainage layer. The evaporative zone depth must be greater than zero. The evaporative zone depth is the maximum depth from which water may be removed by evapotranspiration. The value specified influences the storage of water near the surface and therefore directly affects the computations for evapotranspiration and runoff. Where surface vegetation is present, the evaporative depth should at least equal the expected average depth of root penetration. The influence of plant roots usually extends somewhat below the depth of root penetration because of capillary suction to the roots. The depth specified should be characteristic of the maximum depth to which the moisture changes near the surface due to drying over the course of a year, typically occurring during peak evaporative demand or when peak quantity of vegetation is present. Setting the evaporative depth equal to the expected average root depth would tend to yield a low estimate of evapotranspiration and a high estimate of drainage through the evaporative zone. An evaporative depth should be specified for bare ground to account for direct evaporation from the soil; this depth would be a function of the soil type and vapor and heat flux at the surface. The depth of capillary draw to the surface without vegetation or to the root zone may be only several inches in gravels; in sands the depth may be about 4 to 8 inches, in silts about 8 to 18 inches, and in clays about 12 to 60 inches.

   - **Maximum leaf area index** (Guidance is available for the selected location). The user must enter a maximum value of leaf area index for the vegetative cover. Leaf area index (LAI) is defined as the dimensionless ratio of the leaf area of actively transpiring vegetation to the nominal surface area of the land on which the vegetation is growing. The program provides the user with a maximum LAI value typical of the location selected if the value entered by the user cannot be supported without irrigation because of low rainfall or a short growing season. This statement should be considered only as a warning. The maximum LAI for bare ground is zero. For a poor stand of grass the LAI could approach 1.0; for a fair stand of grass, 2.0; for a good stand of grass, 3.5; and for an excellent

TABLE 1. CITIES FOR EVAPOTRANSPIRATION DATA AND SYNTHETIC TEMPERATURE AND SOLAR RADIATION DATA

- ALABAMA
  - Birmingham
  - Mobile
  - Montgomery
- ALASKA
  - Annette
  - Bethel
  - Fairbanks
- ARIZONA
  - Flagstaff
  - Phoenix
  - Tucson
  - Yuma
- ARKANSAS
  - Fort Smith
  - Little Rock
- CALIFORNIA
  - Bakersfield
  - Blue Canyon
  - Eureka
  - Fresno
  - Los Angeles
  - Mt. Shasta
  - Sacramento
  - San Diego
  - San Francisco
  - Santa Maria
- COLORADO
  - Colorado Springs
  - Denver
  - Grand Junction
  - Pueblo
- CONNECTICUT
  - Bridgeport
  - Hartford
  - New Haven
  - Windsor Locks
- DELAWARE
  - Wilmington
- DISTRICT OF COLUMBIA
  - Washington
- FLORIDA
  - Jacksonville
  - Miami
  - Orlando
  - Tallahassee
  - Tampa
  - West Palm Beach
- GEORGIA
  - Atlanta
  - Augusta
  - Macon
  - Savannah
  - Watkinsville
- HAWAII
  - Honolulu
- IDAHO
  - Boise
  - Pocatello
- ILLINOIS
  - Chicago
  - East St. Louis
- INDIANA
  - Evansville
  - Fort Wayne
  - Indianapolis
- IOWA
  - Des Moines
  - Dubuque
- KANSAS
  - Dodge City
  - Topeka
  - Wichita
- KENTUCKY
  - Covington
  - Lexington
  - Louisville
- LOUISIANA
  - Baton Rouge
  - Lake Charles
  - New Orleans
  - Shreveport
- MAINE
  - Augusta
  - Bangor
  - Caribou
  - Portland
- MARYLAND
  - Baltimore
- MASSACHUSETTS
  - Boston
  - Nantucket
  - Plainfield
  - Worchester
- MICHIGAN
  - Detroit
  - East Lansing
  - Grand Rapids
  - Sault Sainte Marie
- MINNESOTA
  - Duluth
  - Minneapolis
  - St. Cloud
- MISSISSIPPI
  - Jackson
  - Meridian
- MISSOURI
  - Columbia
  - Kansas City
  - St. Louis
- MONTANA
  - Billings
  - Glasgow
  - Great Falls
  - Havre
  - Helena
  - Kalispell
  - Miles City
- NEBRASKA
  - Grand Island
  - North Platte
  - Omaha
  - Scottsbluff
- NEVADA
  - Elko
  - Ely
  - Las Vegas
  - Reno
  - Winnemucca
- NEW HAMPSHIRE
  - Concord
  - Mt. Washington
  - Nashua
- NEW JERSEY
  - Edison
  - Newark
  - Seabrook
- NEW MEXICO
  - Albuquerque
  - Roswell
- NEW YORK
  - Albany
  - Buffalo
  - Central Park
  - Ithaca
  - New York
  - Syracuse
- NORTH CAROLINA
  - Asheville
  - Charlotte
  - Greensboro
  - Raleigh
- NORTH DAKOTA
  - Bismarck
  - Williston
- OHIO
  - Cincinnati
  - Cleveland
  - Columbus
  - Put-in-Bay
  - Toledo
- OKLAHOMA
  - Olkahoma City
  - Tulsa
- OREGON
  - Astoria
  - Burns
  - Meacham
  - Medford
  - Pendleton
  - Portland
  - Salem
  - Sexton Summit
- PENNSYLVANIA
  - Philadelphia
  - Pittsburgh
- RHODE ISLAND
  - Providence
- SOUTH CAROLINA
  - Charleston
  - Columbia
- SOUTH DAKOTA
  - Huron
  - Rapid City
- TENNESSEE
  - Chattanooga
  - Knoxville
  - Memphis
  - Nashville

(Continued)

TABLE 1 (continued). CITIES FOR EVAPOTRANSPIRATION DATA AND SYNTHETIC TEMPERATURE AND SOLAR RADIATION DATA

TEXAS	UTAH	WASHINGTON	WISCONSIN
Abilene	Cedar City	Olympia	Green Bay
Amarillo	Milford	Pullman	Lacrosse
Austin	Salt Lake City	Seattle	Madison
Brownsville	VERMONT	Spokane	Milwaukee
Corpus Christi	Burlington	Stampede Pass	WYOMING
Dallas	Montpelier	Walla Walla	Cheyenne
El Paso	Rutland	Yakima	Lander
Galveston	VIRGINIA	WEST VIRGINIA	PUERTO RICO
Houston	Lynchburg	Charleston	San Juan
Midland	Norfolk		
San Antonio	Richmond		
Temple			
Waco			

(Concluded)

stand of grass, 5.0. The LAI for dense stands of trees and shrubbery would also approach 5. The program is largely insensitive to values above 5. If the vegetative species limit plant transpiration (such as succulent plants), the maximum LAI value should be reduced to a value equivalent of the LAI for a stand of grass that would yield a similar quantity of plant transpiration. Most landfills would tend to have at best a fair stand of grass and often only a poor stand of grass because landfills are not designed as ideal support systems for vegetative growth. Surface soils are commonly shallow and provide little moisture storage for dry periods. Many covers may have drains to remove infiltrated water quickly, reducing moisture storage. Some covers have liners near the surface restricting root penetration and causing frequent saturation of the surface soil which limits oxygen availability to the roots. Some landfills produce large quantities of gas which, if uncontrolled, reduces the oxygen availability in the rooting zone and therefore limits plant growth.

The program produces values for the Julian dates starting and ending the growing season, the annual average wind speed, and the quarterly average relative humidity for the location. The values for the growing season should be checked carefully to agree with the germination and harvesting (end of seasonal growth) dates for your type of vegetation. For example, grasses in southern California would germinate in the fall when the rains occur and die off in late spring when the soil moisture is depleted. This contrasts with a typical growing season, which would start in the spring and end in the fall.

2. Manual Option *(Customary and Metric Units).* The data needed for this option are:

- **Location**

- **Evaporative zone depth**. The user must specify an evaporative zone depth and can use the guidance given under the default option along with specific design information to select a value. The program does not permit the evaporative depth to exceed the depth to the top of the topmost barrier soil layer. Similarly, the evaporative zone depth would not be expected to extend very far into a sand drainage layer. The evaporative zone depth must be greater than zero. The evaporative zone depth is the maximum depth from which water may be removed by evapotranspiration. The value specified influences the storage of water near the surface and, therefore, directly affects the computations for evapotranspiration and runoff. Where surface vegetation is present, the evaporative depth should at least equal the expected average depth of root penetration. The influence of plant roots usually extends somewhat below the depth of root penetration because of capillary suction to the roots. The depth specified should be characteristic of the maximum depth to which the moisture changes near the surface due to drying over the course of a year, typically occurring during peak evaporative demand or when peak quantity of vegetation is present. Setting the evaporative depth equal to the expected average root depth would tend to yield a low estimate of evapotranspiration and a high estimate of drainage through the evaporative zone. An evaporative depth should be specified for bare ground to account for direct evaporation from the soil; this depth would be a function of the soil type and vapor and heat flux at the surface. The depth of capillary draw to the surface without vegetation or to the root zone may be only several inches in gravels; in sands the depth may be about 4 to 8 inches, in silts about 8 to 18 inches, and in clays about 12 to 60 inches. Rooting depth is dependent on many factors -- species, moisture availability, maturation, soil type and plant density. In humid areas where moisture is readily available near the surface, grasses may have rooting depth of 6 to 24 inches. In drier areas, the rooting depth is very sensitive to plant species and to the depth to which moisture is stored and may range from 6 to 48 inches. The evaporative zone depth would be somewhat greater than the rooting depth. The local Agricultural Extension Service office can provide information on characteristic rooting depths for vegetation in specific areas.

- **Maximum leaf area index**. The user must enter a maximum value of leaf area index (LAI) for the vegetative cover. LAI is defined as the dimensionless ratio of the leaf area of actively transpiring vegetation to the nominal surface area of the land on which the vegetation is growing. The program provides the user with a maximum LAI value typical of the location selected if the value entered by the user cannot be supported without irrigation because of low rainfall or a short growing season. This statement should be considered only as a warning. The maximum LAI for bare ground is zero. For a poor stand of grass the LAI could approach 1.0; for a fair stand of grass, 2.0; for a good stand of grass, 3.5; and for an excellent stand of grass, 5.0. The LAI for dense stands of trees and shrubbery would also approach 5. The program is largely insensitive to values above 5. If the vegetative species limit plant transpiration (such as succulent plants), the maximum LAI value should be reduced to a value equivalent of the LAI for a stand of grass that would yield a similar quantity of plant transpiration. Most landfills would tend to have, at best, a fair stand of grass and often only a poor stand of grass because landfills are not designed as ideal support systems for vegetative growth. Surface soils are commonly shallow and provide little moisture storage for dry periods. Many covers may have drains to remove infiltrated water quickly, reducing moisture storage. Some covers have liners near the surface restricting root penetration and causing frequent saturation of the surface soil which limits oxygen availability to the roots. Some landfills produce large quantities of gas which, if uncontrolled, reduces the oxygen availability in the rooting zone and therefore limits plant growth.

- **Dates starting and ending the growing season**. The start of the growing season is based on mean daily temperature and plant species. Typically, the start of the growing season for grasses is the Julian date (day of the year) when the normal mean daily temperature rises above 50 to 55 degrees Fahrenheit. The growing season ends when the normal mean daily temperatures falls below 50 to 55 degrees Fahrenheit. In cooler climates the start and end would be at lower temperatures and in warmer climates at higher temperatures. Data on normal mean daily temperature is available from "Climates of the States" (Ruffner, 1985) and the "Climatic Atlas of the United States" (NOAA, 1974). In locations where the growing season extends year-round, the start of the growing season should be reported as day 0 and the end as day 367. The values for the growing season should be checked carefully to agree with the germination and harvesting (end of seasonal growth) dates for your type of vegetation. For example, grasses in southern California would germinate in the fall when the rains occur and die in late spring when the soil moisture is depleted. This contrasts with a typical growing season which would start in the spring and end in the fall.

- **Normal average annual wind speed**. This data is available from NOAA annual climatological data summary, "Climates of the States" (Ruffner, 1985) and the "Climatic Atlas of the United States" (NOAA, 1974).

- **Normal average quarterly relative humidity**. This data is available from NOAA annual climatological data summary, "Climates of the States" (Ruffner, 1985) and the "Climatic Atlas of the United States" (NOAA, 1974).

3.2.2 Precipitation Data

1. ***Default Precipitation Option*** *(Customary Units)*. The user may select 5 years of historical precipitation data for any of the 102 U.S. cities listed in Table 2. The input needed for this option is:

TABLE 2. CITIES FOR DEFAULT HISTORICAL PRECIPITATION DATA

- ALASKA
  - Annette
  - Bethel
  - Fairbanks
- ARIZONA
  - Flagstaff
  - Phoenix
  - Tucson
- ARKANSAS
  - Little Rock
- CALIFORNIA
  - Fresno
  - Los Angeles
  - Sacramento
  - San Diego
  - Santa Maria
- COLORADO
  - Denver
  - Grand Junction
- CONNECTICUT
  - Bridgeport
  - Hartford
  - New Haven
- FLORIDA
  - Jacksonville
  - Miami
  - Orlando
  - Tallahassee
  - Tampa
  - West Palm Beach
- GEORGIA
  - Atlanta
  - Watkinsville
- HAWAII
  - Honolulu
- IDAHO
  - Boise
  - Pocatello
- ILLINOIS
  - Chicago
  - East St. Louis
- INDIANA
  - Indianapolis
- IOWA
  - Des Moines
- KANSAS
  - Dodge City
  - Topeka
- KENTUCKY
  - Lexington
- LOUISIANA
  - Lake Charles
  - New Orleans
  - Shreveport
- MAINE
  - Augusta
  - Bangor
  - Caribou
  - Portland
- MASSACHUSETTS
  - Boston
  - Plainfield
  - Worcester
- MICHIGAN
  - East Lansing
  - Sault Sainte Marie
- MINNESOTA
  - St. Cloud
- MISSOURI
  - Columbia
- MONTANA
  - Glasgow
  - Great Falls
- NEBRASKA
  - Grand Island
  - North Omaha
- NEVADA
  - Ely
  - Las Vegas
- NEW HAMPSHIRE
  - Concord
  - Nashua
- NEW JERSEY
  - Edison
  - Seabrook
- NEW MEXICO
  - Albuquerque
- NEW YORK
  - Albany
  - Central Park
  - Ithaca
  - New York
  - Syracuse
- NORTH CAROLINA
  - Greensboro
- NORTH DAKOTA
  - Bismarck
- OHIO
  - Cincinnati
  - Cleveland
  - Columbus
  - Put-in-Bay
- OKLAHOMA
  - Oklahoma City
  - Tulsa
- OREGON
  - Astoria
  - Medford
  - Portland
- PENNSYLVANIA
  - Philadelphia
  - Pittsburgh
- RHODE ISLAND
  - Providence
- SOUTH CAROLINA
  - Charleston
- SOUTH DAKOTA
  - Rapid City
- TENNESSEE
  - Knoxville
  - Nashville
- TEXAS
  - Brownsville
  - Dallas
  - El Paso
  - Midland
  - San Antonio
- UTAH
  - Cedar City
  - Salt Lake City
- VERMONT
  - Burlington
  - Montpelier
  - Rutland
- VIRGINIA
  - Lynchburg
  - Norfolk
- WASHINGTON
  - Pullman
  - Seattle
  - Yakima
- WISCONSIN
  - Madison
- WYOMING
  - Cheyenne
  - Lander
- PUERTO RICO
  - San Juan

- Location

  NOTE: The user should be aware of the limitations of using the default historical precipitation data. None of the 102 locations for which data are available may be representative of the study site because rainfall is spatially very variable. In addition, the 5 years for which default data are available (1974-1978 in most cases) may not be typical, but were unusually wet or dry. The user should examine the rainfall and determine how representative it is of normal, wet and dry years at the study site. In addition, simulations should be run for more than five years to determine long-term performance of the landfill using, if necessary, another precipitation input option to examine the design under the range of possible weather conditions.

2. ***Synthetic Precipitation Option*** *(Customary or Metric Units)*. The program will generate from 1 to 100 years of daily precipitation data stochastically for the selected location using a synthetic weather generator. The precipitation data will have approximately the same statistical characteristics as the historic data at the selected location. If desired, the user can enter normal mean monthly precipitation values for the specific location to improve the statistical characteristics of the resulting daily values. The user is advised to enter normal mean monthly precipitation values if the project site is located more than a few miles from the city selected from Table 3 or if the land use or topography varies between the site and city. The daily values will vary from month to month and from year to year and will not equal the normal values entered. The same data is produced every time the option is used for a given location. The data required by the synthetic weather generator are:

   - Location (select from a list of 139 U.S. cities in Table 3)

   - Number of years of data to be generated

   - Normal mean monthly precipitation (Optional, default values are available.)

3. ***Create/Edit Precipitation Option*** *(Customary or Metric Units)*. Under the Create option, the user may enter from 1 to 100 years of daily precipitation data manually. The years, which need not be consecutive, can be entered in any order. The user may add or delete years of data or rearrange the order of the years of data. This same option can be used to edit the daily values of any year of data; commonly, this is used to add severe storm events, such as the 25-year, 24-hour precipitation event. The data required are:

   - Location

   - One or more years of daily precipitation data

TABLE 3. CITIES FOR SYNTHETIC PRECIPITATION DATA

- ALABAMA
  - Birmingham
  - Mobile
  - Montgomery
- ARIZONA
  - Flagstaff
  - Phoenix
  - Yuma
- ARKANSAS
  - Fort Smith
  - Little Rock
- CALIFORNIA
  - Bakersfield
  - Blue Canyon
  - Eureka
  - Fresno
  - Mt. Shasta
  - San Diego
  - San Francisco
- COLORADO
  - Colorado Springs
  - Denver
  - Grand Junction
  - Pueblo
- CONNECTICUT
  - Windsor Locks
- DELAWARE
  - Wilmington
- DISTRICT OF COLUMBIA
  - Washington
- FLORIDA
  - Jacksonville
  - Miami
  - Tallahassee
  - Tampa
- GEORGIA
  - Atlanta
  - Augusta
  - Macon
  - Savannah
- IDAHO
  - Boise
  - Pocatello
- ILLINOIS
  - Chicago
- INDIANA
  - Evansville
  - Fort Wayne
  - Indianapolis
- IOWA
  - Des Moines
  - Dubuque
- KANSAS
  - Dodge City
  - Topeka
  - Wichita
- KENTUCKY
  - Covington
  - Lexington
  - Louisville
- LOUISIANA
  - Baton Rouge
  - New Orleans
  - Shreveport
- MAINE
  - Caribou
  - Portland
- MARYLAND
  - Baltimore
- MASSACHUSETTS
  - Boston
  - Nantucket
- MICHIGAN
  - Detroit
  - Grand Rapids
- MINNESOTA
  - Duluth
  - Minneapolis
- MISSISSIPPI
  - Jackson
  - Meridian
- MISSOURI
  - Columbia
  - Kansas City
  - St. Louis
- MONTANA
  - Billings
  - Great Falls
  - Havre
  - Helena
  - Kalispell
  - Miles City
- NEBRASKA
  - Grand Island
  - North Platte
  - Scottsbluff
- NEVADA
  - Elko
  - Las Vegas
  - Reno
  - Winnemucca
- NEW HAMPSHIRE
  - Concord
  - Mt. Washington
- NEW JERSEY
  - Newark
- NEW MEXICO
  - Albuquerque
  - Roswell
- NEW YORK
  - Albany
  - Buffalo
  - New York
  - Syracuse
- NORTH CAROLINA
  - Asheville
  - Charlotte
  - Greensboro
  - Raleigh
- NORTH DAKOTA
  - Bismarck
  - Williston
- OHIO
  - Cleveland
  - Columbus
  - Toledo
- OKLAHOMA
  - Oklahoma City
  - Tulsa
- OREGON
  - Burns
  - Meachem
  - Medford
  - Pendleton
  - Portland
  - Salem
  - Sexton Summit
- PENNSYLVANIA
  - Philadelphia
  - Pittsburgh
- RHODE ISLAND
  - Providence
- SOUTH CAROLINA
  - Charleston
  - Columbia
- SOUTH DAKOTA
  - Huron
  - Rapid City
- TENNESSEE
  - Chattanooga
  - Knoxville
  - Memphis
  - Nashville
- TEXAS
  - Abilene
  - Amarillo
  - Austin
  - Brownsville
  - Corpus Christi
  - Dallas
  - El Paso
  - Galveston
  - Houston
  - San Antonio
  - Temple
  - Waco
- UTAH
  - Milford
  - Salt Lake City
- VIRGINIA
  - Norfolk
  - Richmond
- WASHINGTON
  - Olympia
  - Spokane
  - Stampede Pass
  - Walla Walla
  - Yakima
- WEST VIRGINIA
  - Charleston
- WISCONSIN
  - Green Bay
  - Lacrosse
  - Madison
  - Milwaukee
- WYOMING
  - Cheyenne

4. ***NOAA Tape Precipitation Option*** *(Customary Units)*. The option will convert the NOAA Summary of Day daily precipitation data written to diskette in ASCII print as-on-tape format into the format used by Version 3 of the HELP model. The following data are required for this option:

   - Location

   - NOAA ASCII print file of Summary of Day daily precipitation data in as-on-tape format

     NOTE: Daily precipitation data and normal mean monthly precipitation values for most locations are readily available in publications or on diskette from NOAA. Information on climatological data sources can be obtained from the National Climatic Data Center (NCDC), NOAA, Federal Building, Asheville, NC 28801, (704) 259-0682.

5. ***Climatedata™ Precipitation Option*** *(Customary Units)*. The program will convert daily precipitation data from an ASCII print file prepared by the Climatedata™
   CD-ROM data base program into the format used by Version 3 of the HELP model. The Climatedata™ format is used by other CD-ROM, state and regional data bases and, therefore, those files can also be converted by this option. For example, the State of California and the Midwest Climatic Data Consortium used this same format. The following data are required for this option:

   - Location

   - Climatedata™ prepared file containing daily precipitation data

     NOTE: Hydrosphere Data Products, Inc. sells NOAA Summary of the Day precipitation data in a 4-disc CD-ROM data base called Climatedata™, one disc for each of four U.S. regions. Information on Climatedata™ is available from Hydrosphere, 1002 Walnut, Suite 200, Boulder, CO 80302, (800) 949-4937.

6. ***ASCII Precipitation Option*** *(Customary or Metric Units)*. The HELP model converts daily precipitation data in an ASCII file to the HELP format. Each year of ASCII precipitation data should be stored in a separate file. The first 365 or 366 values will be converted; excess data will be ignored. Inadequate data will yield an error. This option should also be used to convert data from spreadsheet format by first printing each year of precipitation to individual print files. The following data are required for this option:

   - Location

- Files containing ASCII data

- Years

7. ***HELP Version 2 Data Option*** *(Customary Units)*. Version 3 of the HELP model converts precipitation data prepared for use in Version 2 of the HELP model (Schroeder et al., 1988b) into the HELP Version 3 format. This option requires the following data:

   - Location

   - File containing HELP Version 2 data

8. ***Canadian Climatological Data Option*** *(Metric Units)*. The HELP model converts Canadian Climatological Data (Surface) in compressed or uncompressed diskette formats into the HELP Version 3 format. The following data are required by this option:

   - Location

   - Canadian Climatological Data file containing years of daily precipitation values

     NOTE: Canadian Climatological Data for most locations are readily available in publications of the Environment Canada, Atmospheric Environment Service, Canadian Climate Centre, Data Management Division, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4.

3.2.3 Temperature Data

1. ***Synthetic Temperature Option*** *(Customary or Metric Units)*. The program will generate from 1 to 100 years of temperature data stochastically for the selected location. The synthetic generation of daily temperature values is a weak function of precipitation and as such the user must first specify the precipitation. Generation of temperature data is limited to the number of years of precipitation data available. The synthetic temperature data will have approximately the same statistical characteristics as the historic data at the selected location. If desired, the user can enter normal mean monthly temperature values for the specific location to improve the statistical characteristics of the resulting daily values. The user is advised to enter normal mean monthly temperature values if the project site is located more than 100 miles from the city selected from Table 1 or if the difference in elevation between the site and the city is more than 500 feet. The data required by the synthetic weather generator are:

   - Location (select from a list of 183 U.S. cities in Table 1)

- Number of years of data to be generated

- Years of daily precipitation values

- Normal mean monthly temperature (Optional, default values are available.)

2. ***Create/Edit Temperature Option*** *(Customary or Metric Units)*. Under the create option, the user may enter up to 100 years of daily temperature data manually. The years, which need not be consecutive, can be entered in any order. The user may add or delete years of data or rearrange the order of the years of data. This same option can be used to edit the daily values of any year of data. The data required are:

   - Location

   - One or more years of daily temperature data

3. ***NOAA Tape Temperature Option*** *(Customary Units)*. This option will convert the NOAA Summary of Day daily temperature data written to diskette in ASCII print as-on-tape format into the format used by Version 3 of the HELP model. The program will accept either mean daily temperature or daily maximum and minimum temperature values. If maximum and minimum temperatures are used, the program averages the two to compute the daily mean temperature value. If mean temperature values are used, the same file is specified as the maximum and minimum temperature files. The following data are required for this option:

   - Location

   - NOAA ASCII print file of Summary of Day data file containing years of daily maximum temperature values or daily mean temperature values in as-on-tape format

   - NOAA ASCII print file of Summary of Day data file containing years of daily minimum temperature values or daily mean temperature values in as-on-tape format

     NOTE: Daily temperature (mean or maximum and minimum) data and normal mean monthly temperature values for most locations are readily available in publications or on diskette from NOAA. Information on climatological data sources can be obtained from the National Climatic Data Center, NOAA, Federal Building, Asheville, NC 28801, (704) 259-0682.

4. ***Climatedata™ Temperature Option*** *(Customary Units)*. The program will convert daily maximum and minimum temperature data from ASCII print files prepared by the Climatedata™ CD-ROM data base program into the daily mean

temperature data file format used by Version 3 of the HELP model. The Climatedata™ format is also used by other CD-ROM, state and regional data bases and therefore those files can also be converted by this option. For example, the State of California and the Midwest Climatic Data Consortium used this same format. The following data are required for this option:

- Location
- Climatedata™ prepared file containing daily maximum temperature data
- Climatedata™ prepared file containing daily minimum temperature data

  NOTE: Hydrosphere Data Products, Inc. sells NOAA Summary of the Day daily temperature data in a 4-disc CD-ROM data base called Climatedata™, one disc for each of four U.S. regions. Information on Climatedata™ is available from Hydrosphere, 1002 Walnut, Suite 200, Boulder, CO 80302, (800) 949-4937.

5. ***ASCII Temperature Option*** *(Customary or Metric Units)*. The HELP model converts daily mean temperature data in an ASCII file to the HELP format. Each year of ASCII temperature data should be stored in a separate file. The program will convert the first 365 or 366 values; excess data will be ignored. Inadequate data will yield an error. This option should also be used to convert data from spreadsheet format by first printing each year of temperature to individual print files. The following data are required for this option:

   - Location
   - Files containing ASCII data
   - Years

6. ***HELP Version 2 Data Option*** *(Customary Units)*. Version 3 of the HELP model converts temperature data prepared for use in Version 2 of the HELP model (Schroeder et al., 1988b) into the HELP Version 3 format. This option requires the following data:

   - Location
   - File containing HELP Version 2 data

7. ***Canadian Climatological Data Option*** *(Metric Units)*. The HELP model converts Canadian Climatological Data (Surface) in compressed or uncompressed diskette formats into the HELP Version 3 format. Conversion is available only for daily mean temperature values. The following data are required by this option:

- Location

- Canadian Climatological Data file containing years of daily mean temperature values

  NOTE: Canadian Climatological Data for most locations are readily available in publications of the Environment Canada, Atmospheric Environment Service, Canadian Climate Centre, Data Management Division, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4.

3.2.4 Solar Radiation Data

1. ***Synthetic Solar Radiation Option*** *(Customary or Metric Units)*. The program will generate from 1 to 100 years of daily solar radiation data stochastically for the selected location. The synthetic generation of daily solar radiation values is a strong function of precipitation and as such the user must first specify the precipitation. Generation of solar radiation data is limited to the number of years of precipitation data available. The synthetic solar radiation data will have approximately the same statistical characteristics as the historic data at the selected location. If desired, the user can enter the latitude for the specific location to improve the computation of potential solar radiation and the resulting daily values. The user is advised to enter the latitude if the project site is more than 50 miles north or south of the city selected from Table 1. The data required by the synthetic weather generator are:

   - Location (select from a list of 183 U.S. cities in Table 1)

   - Number of years of data to be generated

   - Years of daily precipitation values

   - Latitude (optional, default value is available.)

2. ***Create/Edit Solar Radiation Option*** *(Customary or Metric Units)*. Under the create option, the user may enter up to 100 years of daily solar radiation data manually. The years, which need not be consecutive, can be entered in any order. The user may add or delete years of data or rearrange the order of the years of data. This same option can be used to edit the daily values of any year of data. The input requirements are:

   - Location

   - One or more years of daily solar radiation data

3. ***NOAA Tape Solar Radiation Option*** *(Customary Units)*. This option will convert the NOAA Surface Airways Hourly solar radiation data written to diskette in ASCII print as-on-tape format into the format used by Version 3 of the HELP model. The following data are required for this option:

   - Location

   - NOAA ASCII print file of Surface Airways Hourly solar radiation data in as-on-tape format

     NOTE: Daily temperature (mean or maximum and minimum) data and normal mean monthly temperature values for most locations are readily available in publications or on diskette from the NOAA. Information on climatological data sources can be obtained from the National Climatic Data Center, NOAA, Federal Building, Asheville, NC 28801, (704) 259-0682.

4. ***Climatedata™ Solar Radiation Option*** *(Customary Units)*. The program will convert the Surface Airways ASCII print files of daily average solar radiation data into a daily solar radiation data file of the format used by HELP Version 3. It is anticipated that this option may also work with some other data sources as they become available. The following data are required for this option:

   - Location

   - Surface Airways prepared file containing years of daily solar radiation data

     NOTE: EarthInfo Inc. sells NOAA Surface Airways daily global solar radiation data in a 12-disc CD-ROM data base called Surface Airways as part of their NOAA data base, three discs for each of four U.S. regions. Information on Surface Airways is available from EarthInfo Inc., 5541 Central Avenue, Boulder, CO 80301-2846, (303) 938-1788. Hydrosphere Inc. is also developing a CD-ROM data base of NOAA Surface Airways data as part of their Climatedata™. Information on Climatedata™ is available from Hydrosphere, 1002 Walnut, Suite 200, Boulder, CO 80302, (800) 949-4937.

5. ***ASCII Solar Radiation Option*** *(Customary or Metric Units)*. The HELP model converts daily solar radiation data in an ASCII file to the HELP format. Each year of ASCII daily solar radiation data should be stored in a separate file. The program will convert the first 365 or 366 values; excess data will be ignored. Inadequate data will yield an error. This option should also be used to convert data from spreadsheet format by first printing each year of solar radiation to individual print files. The following data are required for this option:

   - Location

- Files containing ASCII data
- Years

6. ***HELP Version 2 Data Option*** *(Customary Units)*. Version 3 of the HELP model converts solar radiation data prepared for use in Version 2 of the HELP model (Schroeder et al., 1988b) into the HELP Version 3 format. This option requires the following data:

    - Location
    - File containing HELP Version 2 data

7. ***Canadian Climatological Data Option*** *(Metric Units)*. The HELP model converts Canadian Climatological Data (Surface) in compressed or uncompressed diskette formats into the HELP Version 3 format. Conversion is available only for hourly global solar radiation values. The input requirements are:

    - Location
    - Canadian Climatological Data file containing years of hourly global solar radiation values

      NOTE: Canadian Climatological Data for most locations are readily available in publications of the Environment Canada, Atmospheric Environment Service, Canadian Climate Centre, Data Management Division, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4.

3.3 SOIL AND DESIGN DATA REQUIREMENTS

The user may enter soil data by using the default soil/material textures option, the user-defined soil texture option, or a manual option. If the user selects a default soil texture, the program will display porosity, field capacity, wilting point, and hydraulic conductivity values of the soil that is stored as default. There are 42 default soil/material textures. If user-defined soil textures are selected, the program will display the porosity, field capacity, wilting point, and hydraulic conductivity of the selected soil from the user-defined soil texture data file. In the manual soil texture option, the user must specify values for the soil parameters. General data requirements for all options are listed below. Detailed explanations are given in Sections 3.4 through 3.9.

3.3.1 Landfill General Information

1. Project title

2. Landfill area *(Customary or Metric)*

3. Percentage of landfill area where runoff is possible

4. Method of initialization of moisture storage (user-specified or program initialized to near steady-state)

5. Initial snow water storage (optional, needed when moisture storage is user-specified)

3.3.2 Layer Data

1. Layer type (Four types of layers are permitted -- 1) vertical percolation, 2) lateral drainage, 3) barrier soil liner and 4) geomembrane liner.)

2. Layer thickness *(Customary or Metric)*

3. Soil texture

   - Select from 42 default soil/material textures to get the following data.
     Porosity, in vol/vol
     Field capacity, in vol/vol
     Wilting point, in vol/vol
     Saturated hydraulic conductivity (cm/sec)

   - Select from user-built soil texture library to get the following data.
     Porosity, in vol/vol
     Field capacity, in vol/vol
     Wilting point, in vol/vol
     Saturated hydraulic conductivity (cm/sec)

   - Enter the following data for manual soil texture descriptions.
     Porosity, in vol/vol
     Field capacity, in vol/vol
     Wilting point, in vol/vol
     Saturated hydraulic conductivity (cm/sec)

4. Initial volumetric soil water content (storage), in vol/vol (optional, needed when initial moisture storage is user-specified)

5. Rate of subsurface inflow to layer *(Customary or Metric)*

3.3.3 Lateral Drainage Layer Design Data

1. Maximum drainage length *(Customary or Metric)*

2. Drain slope, percent

3. Percentage of leachate collected from drainage layer that is recirculated

4. Layer to receive recirculated leachate from drainage layer

3.3.4 Geomembrane Liner Data

1. Pinhole density in geomembrane liner *(Customary or Metric)*

2. Geomembrane liner installation defects *(Customary or Metric)*

3. Geomembrane liner placement quality (six available options)

4. Geomembrane liner saturated hydraulic conductivity (vapor diffusivity), cm/sec

5. Geotextile transmissivity, cm^2/sec (optional, when placed with geomembrane)

3.3.5 Runoff Curve Number Information

Three methods are available to define a SCS AMC II runoff curve number.

1. User-specified curve number used without modification

2. User-specified curve number modified for surface slope and slope length

3. Curve number computed by HELP program based on surface slope, slope length, default soil texture, and quantity of vegetative cover

3.4 LANDFILL PROFILE AND LAYER DESCRIPTIONS

The HELP program may be used to model landfills with up to twenty layers of materials -- soils, geosynthetics, wastes or other materials. Figure 1 shows a typical landfill profile with eleven layers. The program recognizes four general types of layers.

1. Vertical percolation layers

2. Lateral drainage layers

3. Barrier soil liners

4. Geomembrane liners

It must be noted that correct classification of layers is very important because the program models the flow of water through the four types of layers in different ways.

Flow in a vertical percolation layer (e.g., Layers 1 and 5 in Figure 1) is by unsaturated vertical drainage downward due to gravity drainage; upward flux due to evapotranspiration is modeled as an extraction. The rate of gravity drainage (percolation) in a vertical percolation layer is a function of soil moisture and soil parameters. The saturated hydraulic conductivity specified for a vertical percolation layer should be in the vertical direction for anisotropic materials. The main role of a vertical percolation layer is to provide moisture storage. Waste layers and layers designed to support vegetation and provide evaporative storage are normally designated as vertical percolation layers.

Lateral drainage layers (e.g., Layers 2, 6, 7 and 9 in Figure 1) are layers directly above liners that are designed to promote drainage laterally to a collection and removal system. Vertical flow in a lateral drainage layer is modeled in the same manner as a vertical percolation layer, but saturated lateral drainage is allowed. The saturated hydraulic conductivity specified for a lateral drainage layer should be in the lateral direction (downslope) for anisotropic materials. A lateral drainage layer may be underlain by only another lateral drainage layer or a liner. The drainage slope specified for a lateral drainage should be the slope of the surface of the liner underlying the drainage layer in the direction of flow (the maximum gradient for a section of liner in a single plane) and may range from 0 to 50 percent. The drainage length specified for a lateral drainage layer is the length of the horizontal projection of a representative flow path from the crest to the collector rather than the distance along the slope. For slopes of less than 10 percent, the difference is negligible. The drainage length must be greater than zero but does not have a practical upper limit. Recirculation is permitted from lateral drainage layers directly above a liner where 0 to 100 percent of the drainage collected can be recirculated and redistributed in a user-specified vertical percolation or lateral drainage layer.

Barrier soil liners (e.g., Layers 4, and 11 in Figure 1) are intended to restrict vertical drainage (percolation/leakage). These layers should have saturated hydraulic conductivities substantially lower than those of the other types of layers. Liners are assumed to be saturated at all times but leak only when there is a positive head on the top surface of the liner. The percolation rate depends upon the depth of water-saturated soil (head) above the base of the liner, the thickness of the liner and the saturated hydraulic conductivity. The saturated hydraulic conductivity specified for a barrier soil liner should be its value for passing the expected permeant in the vertical direction for anisotropic materials. The program allows only downward saturated flow in barrier soil liners. Evapotranspiration and lateral drainage are not permitted from a liner. Thus, any water moving into a liner will eventually percolate through the liner. In Version 3 composite liners are modeled as two layers -- a geomembrane liner and a barrier soil liner as shown in Figure 1.

Geomembrane liners (e.g., Layers 3, 8 and 10 in Figure 1) are virtually impermeable synthetic membranes that reduce the area of vertical drainage/percolation/leakage to a very small fraction of the area located near manufacturing flaws and installation defects (punctures, tears and faulty seaming). A small quantity of vapor transport across the membrane also occurs and can be modeled by specifying the vapor diffusivity as the saturated hydraulic conductivity of the geomembrane. Geomembranes leak only when there is a positive head on the top surface of the liner. The leakage rate depends on the depth of saturated soil (head) above the liner, the saturated hydraulic conductivity of the drainage limiting soil layer adjacent to the membrane, the contact between the membrane and the adjacent drainage limiting soil layer, geomembrane properties and the size and number of holes in the geomembrane liner. Aging of geomembranes is not considered.

While the HELP program is quite flexible, there are some basic rules that must be followed regarding the arrangement of layers in the profile.

1. A vertical percolation layer may not be underlying a lateral drainage layer.

2. A barrier soil liner may not be underlying another barrier soil liner.

3. A geomembrane liner may not be placed directly between two barrier soil liners.

4. A geomembrane liner may not be underlying another geomembrane liner.

5. A barrier soil liner may not be placed directly between two geomembrane liners.

6. When a barrier soil liner or a geomembrane liner is not placed directly below the lowest drainage layer, all drainage layers below the lowest liner are treated as vertical percolation layers. Thus, no lateral drainage is computed for the bottom section of the landfill.

7. The top layer may not be a barrier soil liner.

8. The top layer may not be a geomembrane liner.

9. The profile can contain no more than a total of five barrier soil liners and geomembrane liners.

The HELP model does not permit two barrier soil liners to be adjacent to each other. If a design has two soil layers adjacent to each other that would be expected to act as a single liner and both soils will remain nearly saturated and contribute significantly to the head loss and restriction of vertical drainage, then the thickness of the two layers should be summed and an effective saturated hydraulic conductivity should be computed for the combined liner. The effective saturated hydraulic conductivity should be computed as follows:

$$K_e = \frac{T_e}{\sum_{i=1}^{n} \frac{T_i}{K_i}} = \frac{T_1 + T_2}{\frac{T_1}{K_1} + \frac{T_2}{K_2}} \tag{1}$$

where

- K_e = effective saturated hydraulic conductivity of combined liner
- T_e = effective thickness of combined liner
- T_i = thickness of liner soil i
- K_i = saturated hydraulic conductivity of liner soil i
- n = number of liner soils in the combined liner

For computational purposes, the soil profile is partitioned into subprofiles. Subprofiles are defined in relation to the location of the liners. The first (top) subprofile shown on Figure 1 extends from the landfill surface to the bottom of the highest liner system (bottom of the composite liner, Layer 4) upper barrier soil layer. The second subprofile extends from the top of the layer (Layer 5) below the bottom of the first liner system to the base of the second liner system (Layer 8). The third (bottom) subprofile extends from the top of the layer below the second liner system (the leakage detection drainage layer, Layer 9) to the base of the lowest liner (Layer 11). The program allows up to five liner systems and, therefore, five subprofiles plus an additional subprofile of vertical percolation layers below the bottom liner system. The program models the flow of water through one subprofile at a time from top to bottom, with the percolation or leakage from one subprofile serving as the inflow to the underlying subprofile.

3.5 SOIL CHARACTERISTICS

The user can assign soil characteristics to a layer using the default option, the user defined soil option, or the manual option. Table 4 shows the default characteristics for 42 soil/material types. The soil texture types are classified according to two standard systems, the U.S. Department of Agriculture textural classification system and the Unified Soil Classification System. The default characteristics of types 1 through 15 are typical of surficial and disturbed agricultural soils, which may be less consolidated and more aerated than soils typically placed in landfills (Breazeale and McGeorge, 1949; England, 1970; Lutton et al., 1979; Rawls et al., 1982). Clays and silts in landfills would generally be compacted except within the vegetative layer, which might be tilled to promote vegetative growth. Untilled vegetative layers may be more compacted than the loams listed in Table 4. Soil texture types 22 through 29 are compacted soils. Type 18 is representative of typical municipal solid waste that has been compacted; type 19 is the same waste but it accounts for 65 percent of the waste being in dead zones not contributing to drainage and storage. Soil types 16 and 17 denote very well compacted clay soils that might be used for barrier soil liners. The user assigns default soil characteristics to a layer by specifying the appropriate number for the material type. The

TABLE 4. DEFAULT SOIL, WASTE, AND GEOSYNTHETIC CHARACTERISTICS

Classification			Total Porosity	Field Capacity	Wilting Point	Saturated Hydraulic Conductivity
HELP	USDA	USCS	vol/vol	vol/vol	vol/vol	cm/sec
1	CoS	SP	0.417	0.045	0.018	$1.0x10^{-2}$
2	S	SW	0.437	0.062	0.024	$5.8x10^{-3}$
3	FS	SW	0.457	0.083	0.033	$3.1x10^{-3}$
4	LS	SM	0.437	0.105	0.047	$1.7x10^{-3}$
5	LFS	SM	0.457	0.131	0.058	$1.0x10^{-3}$
6	SL	SM	0.453	0.190	0.085	$7.2x10^{-4}$
7	FSL	SM	0.473	0.222	0.104	$5.2x10^{-4}$
8	L	ML	0.463	0.232	0.116	$3.7x10^{-4}$
9	SiL	ML	0.501	0.284	0.135	$1.9x10^{-4}$
10	SCL	SC	0.398	0.244	0.136	$1.2x10^{-4}$
11	CL	CL	0.464	0.310	0.187	$6.4x10^{-5}$
12	SiCL	CL	0.471	0.342	0.210	$4.2x10^{-5}$
13	SC	SC	0.430	0.321	0.221	$3.3x10^{-5}$
14	SiC	CH	0.479	0.371	0.251	$2.5x10^{-5}$
15	C	CH	0.475	0.378	0.265	$1.7x10^{-5}$
16	Barrier Soil		0.427	0.418	0.367	$1.0x10^{-7}$
17	Bentonite Mat (0.6 cm)		0.750	0.747	0.400	$3.0x10^{-9}$
18	Municipal Waste (900 lb/yd^3 or 312 kg/m^3)		0.671	0.292	0.077	$1.0x10^{-3}$
19	Municipal Waste (channeling and dead zones)		0.168	0.073	0.019	$1.0x10^{-3}$
20	Drainage Net (0.5 cm)		0.850	0.010	0.005	$1.0x10^{+1}$
21	Gravel		0.397	0.032	0.013	$3.0x10^{-1}$
22	L*	ML	0.419	0.307	0.180	$1.9x10^{-5}$
23	SiL*	ML	0.461	0.360	0.203	$9.0x10^{-6}$
24	SCL*	SC	0.365	0.305	0.202	$2.7x10^{-6}$
25	CL*	CL	0.437	0.373	0.266	$3.6x10^{-6}$
26	SiCL*	CL	0.445	0.393	0.277	$1.9x10^{-6}$
27	SC*	SC	0.400	0.366	0.288	$7.8x10^{-7}$
28	SiC*	CH	0.452	0.411	0.311	$1.2x10^{-6}$
29	C*	CH	0.451	0.419	0.332	$6.8x10^{-7}$
30	Coal-Burning Electric Plant Fly Ash*		0.541	0.187	0.047	$5.0x10^{-5}$
31	Coal-Burning Electric Plant Bottom Ash*		0.578	0.076	0.025	$4.1x10^{-3}$
32	Municipal Incinerator Fly Ash*		0.450	0.116	0.049	$1.0x10^{-2}$
33	Fine Copper Slag*		0.375	0.055	0.020	$4.1x10^{-2}$
34	Drainage Net (0.6 cm)		0.850	0.010	0.005	$3.3x10^{+1}$

* Moderately Compacted (Continued)

TABLE 4 (continued). DEFAULT SOIL, WASTE, AND GEOSYNTHETIC CHARACTERISTICS

Classification		Total Porosity	Field Capacity	Wilting Point	Saturated Hydraulic Conductivity
HELP	Geomembrane Material	vol/vol	vol/vol	vol/vol	cm/sec
35	High Density Polyethylene (HDPE)				$2.0x10^{-13}$
36	Low Density Polyethylene (LDPE)				$4.0x10^{-13}$
37	Polyvinyl Chloride (PVC)				$2.0x10^{-11}$
38	Butyl Rubber				$1.0x10^{-12}$
39	Chlorinated Polyethylene (CPE)				$4.0x10^{-12}$
40	Hypalon or Chlorosulfonated Polyethylene (CSPE)				$3.0x10^{-12}$
41	Ethylene-Propylene Diene Monomer (EPDM)				$2.0x10^{-12}$
42	Neoprene				$3.0x10^{-12}$

(concluded)

user-defined soil option accepts non-default soil characteristics for layers assigned soil type numbers greater than 42. This is especially convenient for specifying characteristics of waste layers. User-specified soil characteristics can be assigned any soil type number greater than 42.

When a default soil type is used to describe the top soil layer, the program adjusts the saturated hydraulic conductivities of the soils in the top half of the evaporative zone for the effects of root channels. The saturated hydraulic conductivity value is multiplied by an empirical factor that is computed as a function of the user-specified maximum leaf area index. Example values of this factor are 1.0 for a maximum LAI of 0 (bare ground), 1.8 for a maximum LAI of 1 (poor stand of grass), 3.0 for a maximum LAI of 2 (fair stand of grass), 4.2 for a maximum LAI of 3.3 (good stand of grass) and 5.0 for a maximum LAI of 5 (excellent stand of grass).

The manual option requires values for porosity, field capacity, wilting point, and saturated hydraulic conductivity. These and related soil properties are defined below.

Soil Water Storage (Volumetric Content): the ratio of the volume of water in a soil to the total volume occupied by the soil, water and voids.

Total Porosity: the soil water storage/volumetric content at saturation (fraction of total volume).

Field Capacity: the soil water storage/volumetric content after a prolonged period of gravity drainage from saturation corresponding to the soil water storage when a soil exerts a soil suction of 1/3 bar.

Wilting Point: the lowest soil water storage/volumetric content that can be achieved by plant transpiration or air-drying, that is the moisture content where a plant will be permanently wilted corresponding to the soil water storage when a soil exerts a soil suction of 15 bars.

Saturated Hydraulic Conductivity: the rate at which water drains through a saturated soil under a unit pressure gradient.

Porosity, field capacity and wilting point are all dimensionless numbers between 0 and 1. Porosity must be greater than field capacity, which in turn must be greater than the wilting point. The wilting point must be greater than zero. The values for porosity, field capacity and wilting point are not used for liners, except for initializing the soil water storage of liners to the porosity value.

The soil moisture retention properties of a layer should be adjusted downward if some volume of the layer does not participate in the drainage and storage of infiltrated water. This condition commonly exists in shallow layers of municipal solid waste because municipal solid waste is very heterogeneous and poorly compacted. The plastics in the waste also channels the drainage, limits the spreading of infiltration, and restricts the wetting of the waste and, therefore, the storage. Default soil texture number 19 provides adjusted retention values for a municipal solid waste with significant channeling; it assumes that only 25 percent of the volume is actively involved in drainage and storage of infiltration. As the values were computed by multiplying the values for municipal solid waste (default texture number 18) by 0.25; the initial soil water content would also be multiply by 0.25.

The HELP user has the option of specifying the initial volumetric water storage (content) of all layers except liners. Liners are assumed to remain saturated at all times. If the user chooses not to specify initial water contents, the program estimates values near steady-state and then runs one year of initialization to refine the estimates before starting the simulation. The soil water contents at the end of this year of initialization are taken as the initial values for the simulation period. The program then runs the complete simulation, starting again from the beginning of the first year of data. The results for the initialization period are not reported. To improve initialization to steady-state moisture storage, the user should replace thick vertical percolation and lateral drainage layers, that are below the evaporative zone and above the saturated zone above liners, with thin layers. Then, run the simulation for a number of years until steady-state is approximated. The final dimensionless water storage values after nearing steady-state should then be specified as the initial water contents in your actual simulation using the true dimensions of the layers.

The initial moisture content of municipal solid waste is a function of the composition of the waste; reported values for fresh wastes range from about 0.08 to 0.20 vol/vol. The average value is about 0.12 vol/vol for compacted municipal solid waste. If using default waste texture 19, where 75% of the volume is inactive, the initial moisture content should be that of only the active portion, 25% of the values reported above.

The soil water storage or content used in the HELP model is on a per volume basis (θ), volume of water (V_w) per total (bulk--soil, water and air) soil volume ($V_t = V_s + V_w + V_a$), which is characteristic of practice in agronomy and soil physics. Engineers more commonly express moisture content on a per mass basis (w), mass of water (M_w) per mass of soil (M_s). The two can be related to each other by knowing the dry bulk density (ρ_{db}), dry bulk specific gravity (Γ_{db}) of the soil (ratio of dry bulk density to water density (ρ_w)), wet bulk density (ρ_{wb}), wet bulk specific gravity (Γ_{wb}) of the soil (ratio of wet bulk density to water density.

$$\theta = w \frac{\rho_{db}}{\rho_w} = w \, \Gamma_{db} \qquad \textbf{(2)}$$

$$\theta = \frac{w}{1 + w} \frac{\rho_{wb}}{\rho_w} = \frac{w}{1 + w} \Gamma_{wb} \qquad \textbf{(3)}$$

3.6 GEOMEMBRANE CHARACTERISTICS

The user can assign geomembrane liner characteristics (vapor diffusivity/saturated hydraulic conductivity) to a layer using the default option, the user-defined soil option, or the manual option. Saturated hydraulic conductivity for geomembranes is defined in terms of its equivalence to the vapor diffusivity. The porosity, field capacity, wilting point and intial moisture content are not needed for geomembranes. Table 4 shows the default characteristics for 12 geomembrane liners. The user assigns default soil characteristics to a layer simply by specifying the appropriate geomembrane liner texture number. The user-defined option accepts user specified geomembrane liner characteristics for layers assigned textures greater than 42. Manual geomembrane liner characteristics can be assigned any texture greater than 42.

Regardless of the method of specifying the geomembrane "soil" characteristics, the program also requires values for geomembrane liner thickness, pinhole density, installation defect density, geomembrane placement quality, and the transmissivity of geotextiles separating geomembranes and drainage limiting soils. These parameters are defined below.

Pinhole Density: the number of defects (diameter of hole equal to or smaller than the geomembrane thickness; hole estimated as 1 mm in diameter) in a given area generally resulting from manufacturing flaws such as polymerization deficiencies.

Installation Defect Density: the number of defects (diameter of hole larger than the geomembrane thickness; hole estimated as 1 cm^2 in area) per acre resulting primarily from seaming faults and punctures during installation.

Geotextile Transmissivity: the product of the in-plane saturated hydraulic conductivity and thickness of the geotextile.

The density of pinholes and installation defects is a subject of speculation. Ideally, geomembranes would not have any defects. If any were known to exist during construction, the defects would be repaired. However, geomembranes are known to leak and therefore reasonably conservative estimates of the defect densities should be specified to determine the maximum probable leakage quantities.

The density of defects has been measured at a number of landfills and other facilities and reported in the literature. These findings provide guidance for estimating the defect densities. Typical geomembranes may have about 0.5 to 1 pinholes per acre (1 to 2 pinholes per hectare) from manufacturing defects. The density of installation defects is a function of the quality of installation, testing, materials, surface preparation, equipment, and QA/QC program. Representative installation defect densities as a function of the quality of installation are given below for landfills being built today with the state-of-the-art in materials, equipment and QA/QC. In the last column the frequency of achieving a particular installation quality is given. The estimates are based on limited data but are characteristic of the recommendations provided in the literature.

Installation Quality	Defect Density (number per acre)	Frequency (percent)
Excellent	Up to 1	10
Good	1 to 4	40
Fair	4 to 10	40
Poor	10 to 20*	10

* Higher defect densities have been reported for older landfills with poor installation operations and materials; however, these high densities are not characteristic of modern practice.

The user must also enter the placement quality of the geomembrane liner if pinholes or installation defects are reported. There are six different possible entries for the geomembrane liner placement quality. The program selects which equation will be used to compute the geomembrane based on the placement quality specified and the saturated hydraulic conductivity of the lower permeability soil (drainage limiting soil) adjacent to the geomembrane. The program has different equations for three ranges of saturated hydraulic conductivity: greater than or equal to 0.1 cm/sec; less than 0.1 and greater than or equal to 0.0001 cm/sec; and less than 0.0001 cm/sec.

1. *Perfect*: Assumes perfect contact between geomembrane and adjacent soil that limits drainage rate (no gap, "sprayed-on" seal between membrane and soil formed in place).

2. *Excellent*: Assumes exceptional contact between geomembrane and adjacent soil that limits drainage rate (typically achievable only in the lab or small field lysimeters).

3. *Good*: Assumes good field installation with well-prepared, smooth soil surface and geomembrane wrinkle control to insure good contact between geomembrane and adjacent soil that limits drainage rate.

4. *Poor*: Assumes poor field installation with a less well-prepared soil surface and/or geomembrane wrinkling providing poor contact between geomembrane and adjacent soil that limits drainage rate, resulting in a larger gap for spreading and greater leakage.

5. *Worst Case*: Assumes that contact between geomembrane and adjacent soil does not limit drainage rate, resulting in a leakage rate controlled only by the hole.

6. *Geotextile separating geomembrane liner and drainage limiting soil*: Assumes leakage spreading and rate is controlled by the in-plane transmissivity of the geotextile separating the geomembrane and the adjacent soil layer that would have otherwise limited the drainage. This quality would not normally be used with a geosynthetic clay liner (GCL) as the controlling soil layer. Upon wetting, the bentonite swells and extrudes into the geotextile, filling its voids and reducing its transmissivity below the point where it can contribute significantly to spreading of leakage. GCL's, when properly placed, tend to have intimate contact with the geomembrane (Harpur et al., 1993).

3.7 SITE CHARACTERISTICS

The user must also supply a value of the Soil Conservation Service (SCS) runoff curve number for Antecedent Moisture Condition II (AMC-II) or provide information so that a curve number can be computed. Unlike Version 2 of the HELP model, Version 3 accounts for surface slope effects on curve number and runoff. In Version 3 of the HELP model, there are three different options by which a curve number can be obtained.

1. A curve number defined by the user

2. A curve number defined by the user and modified according to the surface slope and slope length of the landfill

3. A curve number is computed by the HELP model based on landfill surface slope, slope length, soil texture of the top layer, and the vegetative cover. Some general guidance for selection of runoff curve numbers is provided in Figure 2 (USDA, Soil Conservation Service, 1985).

Two of the options account for surface slope. The correlation between surface slope conditions and curve number were developed for slopes ranging from 1 percent to as high as 50 percent and for slope lengths ranging from 50 feet to 2000 feet.

3.8 OVERVIEW OF MODELING PROCEDURE

The hydrologic processes modeled by the program can be divided into two categories: surface processes and subsurface processes. The surface processes modeled are snowmelt, interception of rainfall by vegetation, surface runoff, and surface evaporation. The subsurface processes modeled are evaporation from soil profile, plant transpiration, unsaturated vertical drainage, barrier soil liner percolation, geomembrane leakage and saturated lateral drainage.

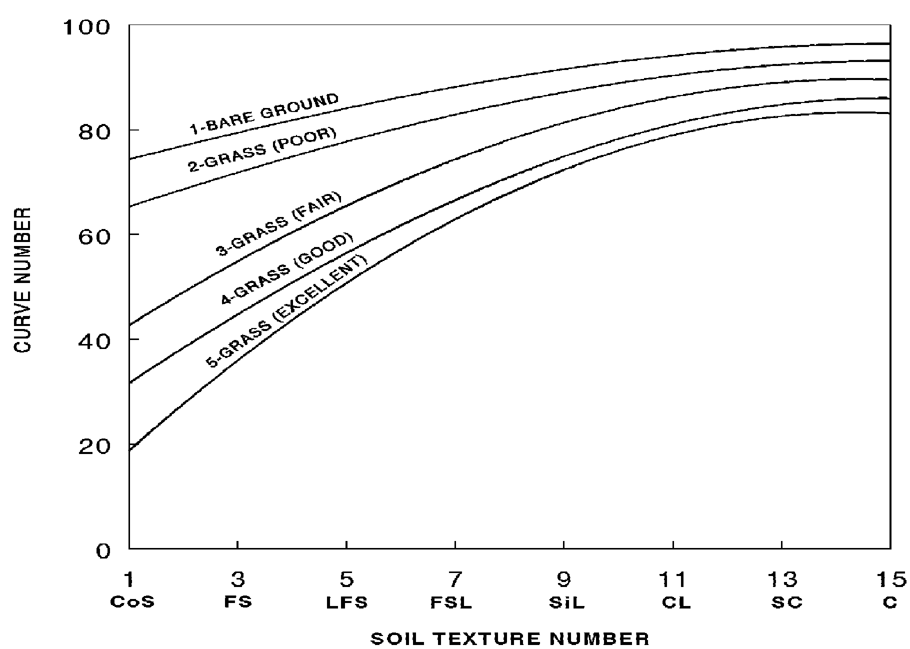

Figure 2. Relation between SCS Curve Number and Default Soil Texture Number for Various Levels of Vegetation

Daily infiltration into the landfill is determined indirectly from a surface water balance. Infiltration is assumed to equal the sum of rainfall, surface storage and snowmelt, minus the sum of runoff, additional storage in snowpack and evaporation of surface water. No liquid water is assumed to be held in surface storage from one day to the next except in the snowpack or when the top soil is saturated and runoff is not permitted. Each day, the free available water for infiltration, runoff, or evaporation from water on the surface is determined from the surface storage, discharge from the snowpack, and rainfall. Snowfall is added to the surface snow storage, which is depleted by either evaporation or melting. Snowmelt is added to the free available water and is treated as rainfall except that it is not intercepted by vegetation. The free available water is used to compute the runoff by the SCS rainfall-runoff relationship. The interception is the measure of water available to evaporate from the surface. Interception in excess of the potential evaporation is added to infiltration. Surface evaporation is then computed. Potential evaporation from the surface is first applied to the interception; any excess is applied to the snowmelt, then to the snowpack and finally to the groundmelt. Potential evaporation in excess of the evaporation from the surface is applied to the soil column and plant transpiration. The snowmelt and rainfall that does not run off or evaporate is assumed to infiltrate into the landfill along with any groundmelt that does not evaporate.

The first subsurface processes considered are soil evaporation and plant transpiration from the evaporative zone of the upper subprofile. A vegetative growth model accounts for the daily growth and decay of the surface vegetation. The other subsurface processes are modeled one subprofile at a time, from top to bottom, using a design-dependent time step ranging from 30 minutes to 6 hours. A storage-routing procedure is used to redistribute the soil water among the modeling segments that comprise the subprofile. This procedure accounts for infiltration or percolation into the subprofile and evapotranspiration from the evaporative zone. Then, if the subprofile contains a liner, the program computes the head on the liner. The head on the liner is then used to compute the leakage/percolation through the liner and, if lateral drainage is permitted above the top of the liner, the lateral drainage to the collection and removal system.

3.9 ASSUMPTIONS AND LIMITATIONS

3.9.1 Solution Methods

The modeling procedures documented in the previous section are necessarily based on many simplifying assumptions. Generally, these assumptions are reasonable and consistent with the objectives of the program when applied to standard landfill designs. However, some of these assumptions may not be reasonable for unusual designs. The major assumptions and limitations of the program are summarized below.

Runoff is computed using the SCS method based on daily amounts of rainfall and snowmelt. The program assumes that areas adjacent to the landfill do not drain onto the landfill. The time distribution of rainfall intensity is not considered. The program cannot be expected to give accurate estimates of runoff volumes for individual storm events on the basis of daily rainfall data. However, because the SCS rainfall-runoff relation is based on considerable daily field data, long-term estimates of runoff should be reasonable. The SCS method does not explicitly consider the length and slope of the surface over which overland flow occurs. This limitation has been removed by developing and implementing into the HELP input routine a procedure for computing curve numbers that take into consideration the effect of slope and slope length. The limitation, however, remains on the user specified curve number (the first method). This limitation is not a concern provided that the slope and slope length of the landfill do not differ dramatically from those of the test plots upon which the SCS method is based. Use of the SCS method probably underestimates runoff somewhat where the overland flow distance is very short or the slope is very steep or when the rainfall duration is very short and the intensity is very high.

The HELP model assumes Darcian flow by gravity influences through homogeneous soil and waste layers. It does not consider explicitly preferential flow through channels such as cracks, root holes, or animal burrows but allows for vertical drainage through the evaporative zone at moisture contents below field capacity. Similarly, the program allows vertical drainage from a layer at moisture contents below field capacity when the inflow would occupy a significant fraction of the available storage capacity below field capacity. The drainage rate out of a segment is assumed to equal the unsaturated hydraulic conductivity of the segment corresponding to its moisture content, provided that the underlying segment is not a liner and is not saturated. In addition to these special cases, the drainage rate out of a segment can be limited by the saturated hydraulic conductivity of the segment below it. When limited, the program computes an effective gradient for saturated flow through the lower segment. This permits vertical percolation or lateral drainage layers to be arranged without restrictions on their properties as long as they perform as their layer description implies and not as liners.

The model assumes that a. the soil moisture retention properties and unsaturated hydraulic conductivity can be calculated from the saturated hydraulic conductivity and limited soil moisture retention parameters (porosity, field capacity and wilting point) and b. the soil moisture retention properties fit a Brooks-Corey relation (Brooks et al., 1964) defined by the three soil moisture retention parameters. Upon obtaining the Brooks-Corey parameters, the model assumes that the unsaturated hydraulic conductivity relation with soil moisture is well described by the Campbell equation.

The model does not explicitly compute flow by differences in soil suction (soil suction gradient) and, as such, does not model the draw of water upward by capillary drying. This draw of water upward is modeled as an extraction rather than transport of water upward. Therefore, it is important that the evaporative zone depth be specified as the depth of capillary drying. Drainage downward by soil suction exerted by dry soils lower in the landfill profile is modeled as Darcian flow for any soil having a relative moisture content greater than the lower soils. The drainage rate is equal to the unsaturated hydraulic conductivity computed as a function of the soil moisture content. As such, the rate is assumed to be independent of the pressure gradient.

Leakage through barrier soil liners is modeled as saturated Darcian flow. Leakage is assumed to occur only as long as there is head on the surface of the liner. The model assumes that the head driving the percolation can be represented by the average head across the entire liner and can be estimated from the soil moisture storage. It is also assumed that the liner underlies the entire area of the landfill and, conservatively, that when leakage occurs, the entire area of the landfill leaks. The model does not consider aging or drying of the liner and, therefore, the saturated hydraulic conductivity of the liner does not vary as a function of time.

Geomembranes are assumed to leak primarily through holes. The leakage passes through the holes and spreads between the geomembrane and soil until the head is dissipated. The leakage then percolates through the soil at the rate dependent on the saturated hydraulic conductivity and the pressure gradient. Therefore, the net effect of a geomembrane is to reduce the area of percolation through the liner system. The program assumes the holes to be uniformly distributed and the head is distributed across the entire liner. The model does not consider aging of the liner and therefore the number and size of the holes do not vary as a function of time. In addition, it is conservatively assumed that the head on the holes can be represented by the average head across the entire liner and can be estimated from the soil moisture storage and that the liner underlies the entire area of the landfill.

The lateral drainage model is based on the assumption that the saturated depth profile is characteristic of the steady-state profile for the given average depth of saturation. As such, the model assumes that the lateral drainage rate for steady-state drainage at a given average depth of saturation is representative of unsteady lateral drainage rate for the same average saturated depth. In actuality the rate would be somewhat larger for periods when the depth is building and somewhat smaller for periods when the depth is falling. Steady drainage implies that saturated conditions exist above the entire surface of the liner, agreeing with the assumptions for leakage through liner systems.

The model assumes the vegetative growth and decay can be characterized by a vegetative growth model developed for crops and perennial grasses. In addition, it is assumed that the vegetation transpires water, shades the surface, intercepts rainfall and reduces runoff in similar quantities as grasses or as an adjusted equivalence of LAI.

3.9.2 Limits of Application

The model can handle water routing through or storage in up to twenty soil or waste layers; as many as five liner systems may be employed. The simulation period can range from 1 to 100 years. The model cannot simulate a capillary break or unsaturated lateral drainage.

The model has limits on the arrangement of layers in the landfill profile. Each layer must be described as being one of four types: vertical percolation layer, lateral drainage layer, barrier soil liner, or geomembrane liner. The model does not permit a vertical percolation layer to be placed directly below a lateral drainage layer. A barrier soil liner may not underlie another barrier soil liner. Geomembranes cannot envelop a barrier soil liner and barrier soil liners cannot envelop a geomembrane. The top layer may not be a liner. If a liner is not placed directly below the lowest lateral drainage layer, the lateral drainage layers in the lowest subprofile are treated by the model as vertical percolation layers. No other restrictions are placed on the order of the layers.

The lateral drainage equation was developed for the expected range of hazardous waste landfill design specifications. Permissible ranges for slope of the drainage layer are 0 to 50 percent. Due to dimensionless structure of the lateral drainage equation, there are no practical limits in the maximum drainage length.

Several interrelations must exist between the soil characteristics of a layer and of the soil subprofile. The porosity, field capacity and wilting point can theoretically range from 0 to 1 units of volume per volume; however, the porosity must be greater than the field capacity, and the field capacity must be greater than the wilting point.
Initial soil moisture storage must be greater than or equal to the wilting point and less than or equal to the porosity. The initial moisture content of liners must be equal to the porosity and the liners remain saturated. The field capacity and wilting point values are not used for barrier soil liners. Values for porosity, field capacity and wilting point are not needed for geomembranes.

Values for the leaf area index may range from 0 for bare ground to 5 for an excellent stand of grass. Detailed recommendations for leaf area indices and evaporative depths are given in the program.

The default values for the evaporation coefficient are based on experimental results. The basis for the calculation of these default values is described by Schroeder et al. (1994). The model imposes upper and lower limits of 5.1 and 3.3 so as not to exceed the range of experimental data.

Surface runoff from adjacent areas does not run onto the landfill, and the physical characteristics of the landfill specified by the user remain constant over the modeling period. No adjustments are made for the changes that occur in these characteristics as the landfill ages. Additionally, the program cannot model the filling process within a single simulation. Aging of materials and staging of the landfill operation must be modeled by successive simulations.

Default Soil Characteristics

The HELP model contains default values of soil characteristics based on soil texture class. The documentation for Version 3 describes the origin of these default values

(Schroeder et al., 1994). Recommended default values for LAI and evaporative depth based on thick loamy top soils are given in the program.

Manual Soil Characteristics

The HELP model computes values for the three Brooks-Corey parameters as described in the documentation for Version 3 (Schroeder et al., 1994) based on the values for porosity, field capacity and wilting point.

Soil Moisture Initialization

The soil moisture of the layers may be initialized by the user or the program. When initialized by the program, the process consists of three steps. The first step sets the soil moisture of all layers except barrier soil liners equal to field capacity and all barrier soil liners to porosity (saturation). In the second step, the program computes a soil moisture for each layer below the top barrier soil liner. These soil moisture contents are computed to yield an unsaturated hydraulic conductivity equal to 85 percent of the lowest effective saturated hydraulic conductivity of the all liner systems above the layer, including consideration for the presence of a synthetic geomembrane liner. If the unsaturated hydraulic conductivity is less than 1×10^{-6} cm/sec and if the computed soil moisture is greater than field capacity, the soil moisture is set to equal computed soil moisture instead of the field capacity. The third step in the initialization consists of running the model for one year of simulation using the first year of climate data and the initial soil moisture values selected in the second step. At the end of this year of initialization, the soil moisture values existing at that point are reported as the initial soil moisture values. The simulation is then restarted using the first year of climate data.

Synthetic Temperature and Solar Radiation Values

The synthetically generated temperature and solar radiation values are assumed to be representative of the climate at the site. Synthetic daily temperature is a function of normal mean monthly temperature and the occurrence of rainfall. Synthetic daily solar radiation is a function of latitude, occurrence of rainfall, average daily dry-day solar radiation and average daily wet-day solar radiation.

SECTION 4

PROGRAM INPUT

4.1 INTRODUCTION

This section describes the procedures and options available to input data, execute the model, and obtain results. The discussion includes general input information, some definitions and rules, the program structure, and detailed explanations of the options reached from the Main Menu. Guidance is given throughout the section for selecting the most appropriate values in certain situations, but the main purpose of this section is to describe the mechanics of using the user interface. Detailed guidance on the definitions of input parameters and selection of their values is presented in Section 3.

Version 3 of the HELP program is started by typing "HELP3" from the DOS prompt in the directory where the program resides. The program starts by displaying a title screen, a preface, a disclaimer and then the main menu. The user moves from the title screen to the main menu by striking any key such as the space bar. Upon reaching the main menu, the user can select any of seven options. The program automatically solicits input from the user based on the option selected. In general the HELP model requires the following data, some of which may be selected from the default values.

1. Units
2. Location
3. Weather data file names
4. Evapotranspiration information
5. Precipitation data
6. Temperature data
7. Solar radiation data
8. Soil and design data file name
9. General landfill and site information
10. Landfill profile and soil/waste/geomembrane data
11. SCS runoff curve number information

4.2 DEFINITIONS AND RULES

There are a few fundamental rules regarding the input facility that a user must keep in mind when using the model. These rules should be followed to move around the screens and to move within the same screen. Below are some definitions and rules.

1. ***Screens.*** A screen in the HELP user interface as used in this report is a single screen of information. These screens are divided into three categories:

- Input Screen: a screen on which the user can input data

- Selection Screen: a screen from which the user selects an entry from a list

- On-line Help Screen: a screen where assistance is provided. General assistance on the interface is displayed by pressing the ***F1*** key, technical assistance by pressing the ***F2*** key, and key operations by pressing the ***F3*** key.

This terminology is used throughout this section. Each module consists of two types of screens: "primary" and "secondary." Primary screens are main screens that form a loop for each option of HELP. Secondary screens are displayed from the primary screens as part of the input process. These screens can be input screens or selection screens.

2. ***Input Cells.*** When the program highlights a number of spaces (called an ”input cell” throughout this section), an input from the user is expected. At any input cell, the user has one of several options: enter the data requested, accept existing value, seek on-line help, or select one of the menu items listed at the bottom of the screen. Each cell is associated with a variable that is used directly or indirectly in the HELP model. Therefore, every effort must be made to assign a value to each cell when applicable. The user may input the value the first time around, or return to the cell at a later time during the program session. If an input cell is left blank, a value of zero will be assigned to the corresponding variable. If zero is not an appropriate answer to the question, it will produce erroneous results. The program will warn the user when a blank or zero is an inappropriate value.

   Trailing decimal points are not required on input because the program automatically knows whether to treat a value as an integer or a floating point variable. For example, if a user wishes to enter the number nine, either 9, 9. or 9.00 is acceptable, provided the input cell is wide enough.

3. ***Selection Cells.*** These are cells that are used to select from a list of options. Selection cells highlight one item at a time. An item/option must be highlighted before it can be selected. Selection is made by pressing the ***Enter*** key.

4. ***Moving Between Cells.*** The user can move from one input screen to another, by pressing the ***Page Down*** key for the next screen or ***Page Up*** key for the previous screen in the loop of primary or secondary screens. Input screens are arranged in a loop format such that if the ***Page Down*** key is pressed from the last input screen the control will return to the first screen, and vice versa. The ***up and down arrows*** are used to move up and down through the cells of a screen. If the ***up arrow*** is pressed from the first cell on the screen, control will transfer to the last cell on the same screen, and vice versa. The ***Tab and Shift-Tab*** keys can be used to move to the right and to the left, respectively, among input and selection cells that are located on the same line. In addition, the ***left and right arrows*** may be used to move between

selection cells that are located on the same line.

5. ***Moving Within an Input Cell.*** Each input cell is set to a given width depending on the type of information expected to be entered in that cell. The cursor will be initially located on the first character space of the cell. The ***left and right arrow*** keys may be used to move the cursor to different spaces within the cell. If a value is typed in the first space of the cell, the cell contents will be deleted. To delete a character, move the cursor to the character location and then press the ***Delete*** key, or move the cursor to the space that is to the right of the character and then press the ***Backspace*** key. A character can be inserted between characters in an input cell by moving the cursor to the desired position and then pressing the ***Insert*** key. The ***Insert*** key will shift all characters that are at and to the right of the cursor one position to the right.

6. ***Terminating.*** At any time during the session, the user may press the ***F9*** key to quit without saving changes, return to the main menu or exit the program. The ***Esc*** key and the ***Ctrl-Break*** keys will end some options and allow you to continue with other operations. The ***F10*** key is used to save the data or proceed. If necessary, the user can terminate input or execution by rebooting (***Ctrl-Alt-Del*** keys), resetting, or turning off the computer; however, the user is discouraged from terminating a run in these manners because some of the data may be lost.

7. ***On-Line Help.*** On-line help is available to the user from any cell location on the screen. By pressing ***F1***, information about the operations and purpose of the screen is displayed, and by pressing ***F2***, specific technical assistance for the highlighted cell is displayed. Note that the on-line help screens contain sections from this User's Guide and that the figures and tables mentioned on the screens are located in this document. The ***F3*** key displays various functions of keystrokes. Other specific information of the input screen is listed in menu line(s) at the bottom of screen.

8. ***System of Units.*** Throughout the HELP program the user is required to select a system of units. The HELP model allows the user to use either the customary system of units (a mixture of U.S. Customary and metric units traditionally used in landfill design and in Version 2 of the HELP model) or the Metric (SI) system of units. The user is not restricted to the same system for all data types; for example, the soil and design data can be in one system of units and the weather data can be in the other system. Moreover, it is not necessary for all types of weather data to have the same system of units (i.e., evapotranspiration data can be in the Metric system of units, while precipitation data is in customary units; the solar radiation data can be in customary units, while temperature data is in Metric units, and so on). Appropriate units are displayed in proper locations to keep the user aware of which units should be used for each data entry. Consistency in units is only required within each data type.

4.3 PROGRAM STRUCTURE

The flow or logic of the input facility of the HELP program may be viewed as a tree structure. The tree structure consists of nodes where new branches of the tree are started. The first node is called the trunk, root or parent node, and the terminal nodes of the tree are called leaves. All components (nodes) of the tree structure in the HELP model are screens that have different functions as defined previously, with the trunk node being the Main Menu. During an input session, the user should reach the leaf node if all the data for a given branch (module) are entered. Some of the nodes (screens) are common to more than one branch. The user must return to the node where the branch started in order to go to another branch. These movements can be accomplished with the special keys discussed above, such as ***Page Up, Page Down, F9, F10,*** etc.

4.4 MAIN MENU

At the beginning of each run, the Main Menu is displayed. A schematic of the main menu in Figure 3 shows the seven available modules (branches). Selection from the main menu is made by either moving the cursor to the desired module or by pressing the number of that option. Once a selection is made, program control transfers into an environment specific to that option and cannot transfer to another main menu option without exiting that environment to the main menu and then selecting another option. A brief description of each main menu option is presented below. More details are given in the following sections about specific data requirements for each option.

Option 1 on the main menu is ***"Enter/Edit Weather Data."*** This module permits the user to read evapotranspiration, precipitation, temperature, and solar radiation data files and then review, edit, and save the data or create new files. There are four primary screens in this module; they are a file selection screen, evapotranspiration data screen, a screen that controls the method used for specifying precipitation, temperature and solar radiation data, and a screen for saving weather data files. Several options are available for specifying precipitation, temperature and solar radiations data. These vary from using default data (for precipitation only) to synthetic and other user-defined data sources, such as NOAA Tape, Climatedata™, ASCII data, HELP Version 2 data, and Canadian Climatological data. Data may also be entered manually. Default and synthetic weather data generation is performed by selecting the city of interest from a list of cities and specifying (optional) additional data.

Option 2 on the main menu is ***"Enter/Edit Soil and Design Data."*** This module allows the user to read an already existing soil and design data file and then review, edit, and save the data or create a new data file. There are eight primary screens in the soil and design data module; they are a file selection screen, a landfill general information screen, three screens for entering design, soil and geomembrane liner data by layers, a screen for entering a runoff curve number, a data verification screen, and a screen for saving the soil and design data file. Input screens associated with this module provide

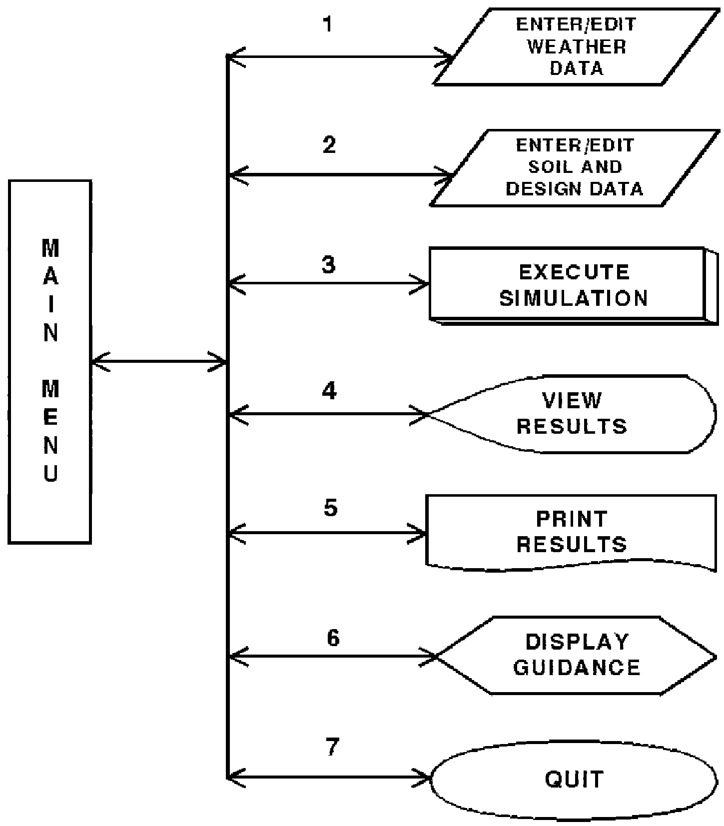

Figure 3. HELP3 Main Menu

cells for entering project title; system of units; initial soil conditions; landfill area; layer design information, such as layer type, thickness, soil texture, drainage characteristics; geomembrane liner information; and runoff curve number information including the ability to adjust the curve number a function of surface slope and length. At the end of this module, the user may request that the data be checked for possible violation of the design rules explained in Section 3. Under this module, the HELP model verifies the design data, soil and geomembrane liner properties and layer arrangement.

Option 3 on the main menu is ***"Execute Simulation."*** In this option the user defines the data files to be used in running the simulation component of the HELP model and selects the output frequency and simulation duration desired from execution. In this option the user can also view the list of files available and can make file selections from these lists.

Option 4 on the main menu is ***"View Results."*** This option allows the user to browse through the output file and examine the results of the run after executing the program. Option 5 is ***"Print Results,"*** and Option 6 is ***"Display Guidance"*** on general landfill design procedures and on the HELP model itself, containing much of the text of this user's guide. Finally, Option 7 is used to ***"Quit"*** running the model and return to DOS.

In the following sections, detailed explanations of the main menu options are presented, and methods of data entry to the program and various options are discussed.

4.5 WEATHER DATA

As mentioned above, this module is selected from the main menu by pressing 1, ***"Enter/Edit Weather Data."*** A schematic of this module is shown in Figure 4. In this module, the user can specify all of the weather data (evapotranspiration, precipitation, temperature and solar radiation) required to run the model. The four primary screens in this module are "Weather Data - File Editing", "Evapotranspiration Data", "Precipitation, Temperature, and Solar Radiation Data", and "Weather Data - File Saving". Several secondary screens may appear during the session depending upon the action taken by the user. On-line help screens are always available for display by pressing ***F1 or F2***. The individual primary screens and their secondary screens of this module are discussed below.

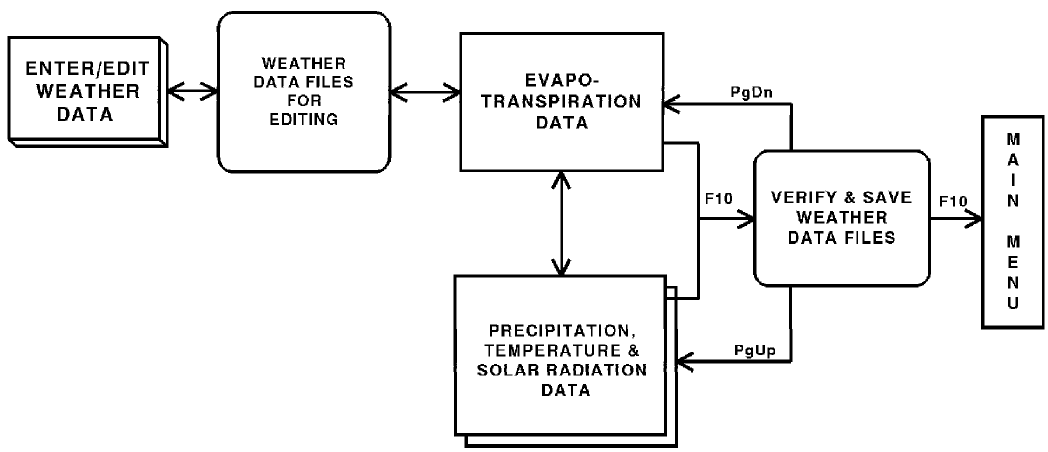

Figure 4. Schematic of Weather Data Module

4.5.1 Weather Data File Selection

The first screen in the weather data module is the "Weather Data - File Editing" screen. A schematic of this screen is shown in Figure 5. On this screen, the user may enter file names of existing files to select previously generated HELP Version 3 files for editing or leave the file names blank to create new data. One file name for each of the four types of weather data to be edited is needed. The DOS path may be specified if different from the active or default drive and subdirectory, such as C:\HELP3\DATA. The following gives file naming and extension information as displayed on the screen.

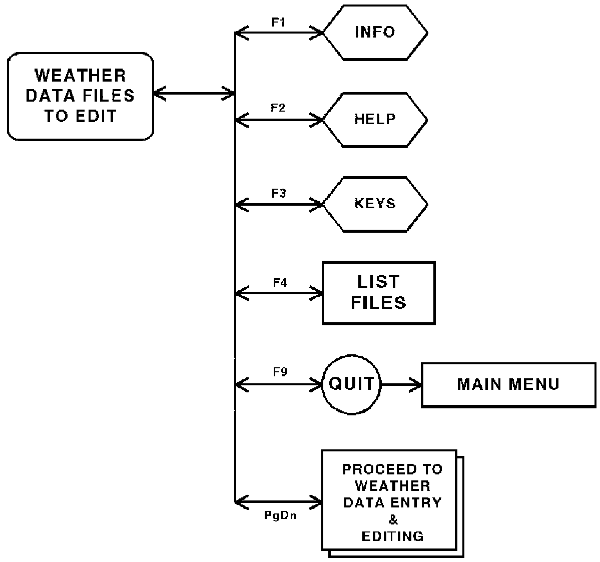

Figure 5. Schematic of "Weather Data - File Editing" Screen

Data Type	DOS Path (Drive and/or Subdirectory)	User Specified File Name
Precipitation		*.D4
Temperature		*.D7
Solar radiation		*.D13
Evapotranspiration		*.D11

* Any valid DOS name that the user desires (up to eight characters) is acceptable. The HELP program supplies the extension.

This convention must be always remembered when selecting file names for editing, saving, or converting data from other sources. However, when typing a file name on this screen, the user should not enter the extension because the program automatically assigns the proper extension to the file according to the weather types.

The current directory is displayed on the screen. The user may obtain a listing of all data files that reside on the current directory by pressing ***F4***. By pressing ***F4***, the program obtains a directory of all files that pertain to the weather data cell from which ***F4*** was pressed. For example, if ***F4*** was pressed from the temperature file cell, the program will display the list of files with an extension of D7 that reside on the currently specified directory. Up to 120 data files for any weather data type can be displayed on the screen. The name of the current directory where these files are located is also displayed. To obtain the data files pertaining to the weather information needed that reside in another directory, the user should type in the name of a valid drive and subdirectory in the Directory column and then press ***F4*** for the list of files in that subdirectory. To display a directory for another type of data, move the cursor to the row for that data type and repeat the process listed above.

To select a file from the list of displayed files, move the cursor to the desired file name and press ***Enter***. This action transfers control back to the previous screen, and the name of the file just selected will be displayed in the proper cell. The user can exit the "Data Files" screen without selecting a file by pressing the ***Esc*** key.

If the user wants to enter the file name in the file cell, the user must first enter the correct directory name. If an invalid directory is entered, the program will displayed the message, "Invalid Directory," and replace the entered directory name with the default directory name (where the program was started). The user then has another opportunity to enter the correct directory name. If the program cannot find the file name as entered, the message, "File Not Found," will be displayed. The previously entered file name is erased and the user has another opportunity to enter a correct file name. Pressing ***Page Down*** causes the program to read the valid data files selected and then proceeds to the first weather data entry screen.

4.5.2 Evapotranspiration (ET) Data

The evapotranspiration data requirements are listed in Section 3 and are entered to the program from the "Evapotranspiration Data" screen. This screen contains all information required by the HELP model to construct the evapotranspiration data file (*.D11). If the user specified an edit file name for the evapotranspiration data, the contents of the file will be displayed in the appropriate cells on this screen. The user can move the cursor to any cell to edit its contents. However, if no file was selected as an edit file, then data must be specified by the user. First, the user must select the system of units to be used for the evapotranspiration data, which may be entered in customary or metric units as explained in a previous section. A schematic of this screen is shown in Figure 6. The two methods for entering this data are the manual option and the default option.

Manual Option

This option requires the user to enter all evapotranspiration data manually. The user should first specify a location in the form of a city, state and latitude, followed by the evaporative zone depth, the maximum leaf area index, the Julian dates of the start (planting) and end (harvest) of the growing season, the annual average wind speed, and quarterly average relative humidities (in percentages) for the entered location.

Default Option

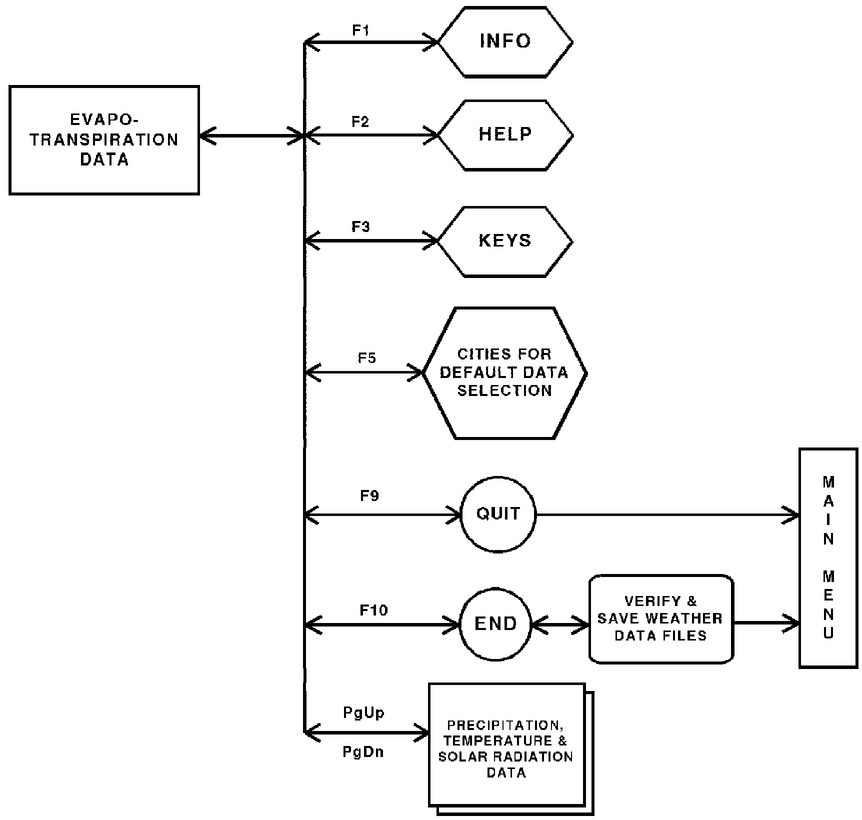

Figure 6. Schematic of "Evapotranspiration Data" Screen

This option takes advantage of an available list of cities for which default values are provided for most of the evapotranspiration data; guidance information is available for the rest of the data. This option is triggered from any input cell on the "Evapotranspiration Data" screen by pressing ***F5*** and selecting a location (state and city) from a displayed list of locations. This list of cities is the same as that in Table 3.

Once a city is selected, the program automatically displays values in the appropriate input cells for the city, state, latitude, growing season dates, wind speed, and the four quarterly humidity values for that location. The program, however, displays guidance information on the evaporative zone depth for that location depending on the vegetative cover. The user must enter a value of the evaporative zone depth that is appropriate for the landfill design, location, top soil, and vegetation. (See Section 3 for detailed guidance.)

The user must also enter a value for the maximum leaf area index for the site. If the value entered is greater than the default maximum allowable value based on the climate for the selected city, the program will display that value only as a guidance to the user. The user is not forced to change the entered value.

If the user decides to edit the name of the city or state, the program will erase the guidance information. Guidance is provided only for cities that are selected from the list obtained by pressing ***F5***.

The location of the landfill being evaluated is likely to be some distance from all of the listed cities. In this case, the user has the option to select a city that has an similar climate and edit the values to improve the data or to simply enter the information manually.

The bottom line of the "Evapotranspiration Data" screen provides additional help information. Once all data are entered, the user can move on to another screen by pressing ***Page Up*** or ***Page Down***, return to the main menu by pressing ***F9***, or proceed to save the evapotranspiration data by pressing ***F10***.

4.5.3 Precipitation, Temperature and Solar Radiation Data

The second screen in the weather data module is entitled "Precipitation, Temperature and Solar Radiation." From this screen, the user can select methods for creating the precipitation data file (*.D4), the temperature data file (*.D7), and the solar radiation data file (*.D13). A schematic of the main options available on this screen are shown in Figure 7. In Version 3 of the HELP model, all of the weather data need not be generated by the same method. For example, the user can enter the precipitation data using the synthetic weather generator, the temperature data using data from a NOAA data file, and solar radiation from an ASCII file. Seven options are available for entering temperature and solar radiation data. Under the precipitation data there are the same seven plus a default option. Figures 8, 9, and 10 show the possible options.

Default Precipitation

If the ***default precipitation option*** (*Customary Units Only*) is selected, the program will prompt the user with the list of states having default data. The HELP model provides default precipitation values for the list of cities in Table 1. To select a state, move the cursor to the desired state name and press ***Enter***. At this time the program prompts the user with the list of cities in the selected state for which default precipitation data is available. Similarly, the city can be selected by moving the cursor to the desired city and pressing ***Enter***. The user can return to the "Precipitation, Temperature and Solar Radiation" screen from either list by pressing ***Esc***. By doing so, neither a city nor a state is considered selected. However, once a city is selected, the program reads the five years of default precipitation data for the selected city. The usefulness of the default precipitation option is limited since it contains only five years of precipitation data. It is additionally limiting since these five years may be dry or wet years and may not be representative of the site in question.

The following options are available for entering "Precipitation, Temperature, and Solar Radiation" data.

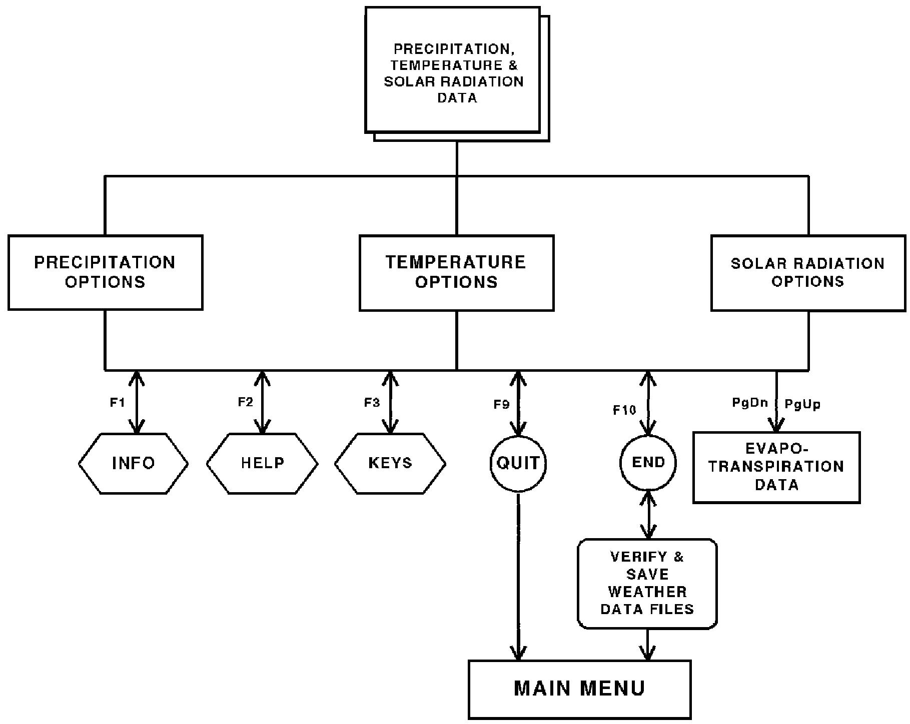

Figure 7. Schematic of "Precipitation, Temperature and Solar Radiation" Screen

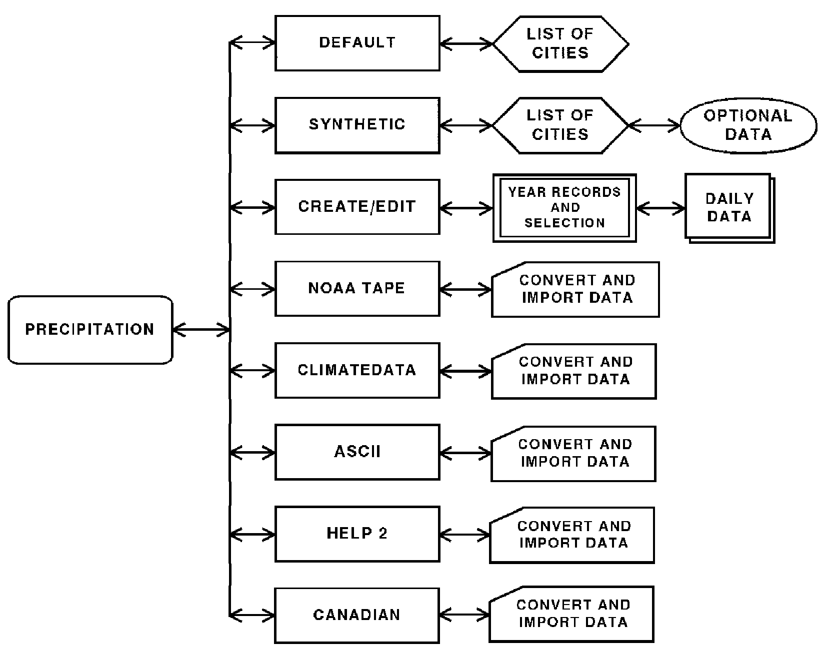

Figure 8. Precipitation Options

Synthetic

The second available method for entering precipitation data is to use the ***synthetic weather generator*** (*Customary or Metric Units*). (This is the first method on the screen for entering temperature and solar radiation data.) This option can be selected for temperature and solar radiation only if the user has previously entered precipitation data since the synthetic weather generator requires precipitation values for generating both temperature and solar radiation. By selecting the synthetic data option, the program prompts the user with a list of states for which it has synthetic weather data coefficients. Again the user can move the cursor to the appropriate state and press ***Enter*** to obtain the list of cities in that state for which synthetic data can be generated. From this list, the user can select the city where the project is located or a city with a climate similar to the project location. Selection is accomplished by moving the cursor to the selection cell highlighting the desired city and pressing ***Enter***. At any time, the user may abandon the input for the synthetic weather generator by pressing ***Esc***; the program will return to the "Precipitation, Temperature and Solar Radiation" screen without loss of previously entered data.

Once a city is selected, the program displays another screen called "Synthetic Precipitation Data", "Synthetic Temperature Data" or "Synthetic Solar Radiation Data." On this screen, the city and state are displayed, and the user is asked to provide additional

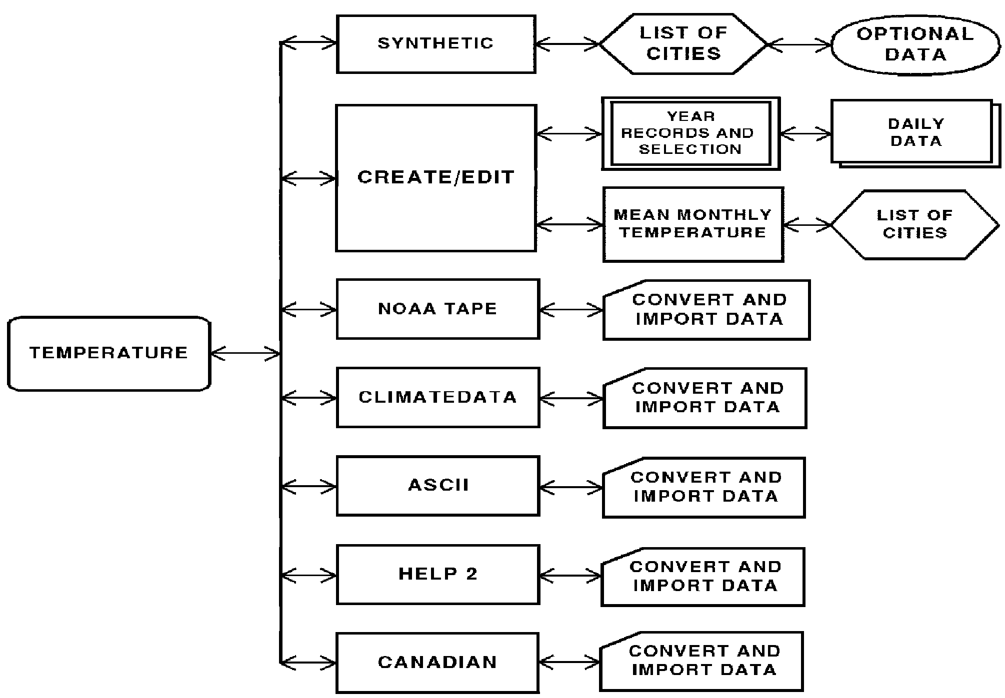

Figure 9. Temperature Options

information. The first value that must be entered is the number of years of synthetic data to be generated. The rest of the information on the screen is optional. For precipitation, the user can elect to use the default normal mean monthly precipitation values provided by the HELP program or to enter normal mean monthly precipitation values to be used in generating the synthetic precipitation for that location. For temperature, the user has the option to use the default normal mean monthly temperature values provided by the HELP program or to enter normal mean monthly temperature values to be used in generating the synthetic temperature for that location. Users are encouraged to enter their own normal mean monthly values especially if the landfill is not located at the selected city. The program uses the normal mean monthly data to adjust the data generated by the synthetic weather generator. If the user decides not to use the default values, the program will transfer control to the normal mean monthly data option under the "User" heading. At this time the user must input values for January through December. A blank cell for a given month will be recorded as zero, and the user must be careful not to leave a cell without an entry. A zero entry, however, is a valid entry. For solar radiation the optional value is the latitude for the location. The default latitude of the selected city will be displayed, but the user is encouraged to enter the latitude of the actual landfill location to obtain better solar radiation values.

Create/Edit

If the user selects the ***create/edit option*** (*Customary or Metric Units*) for manually

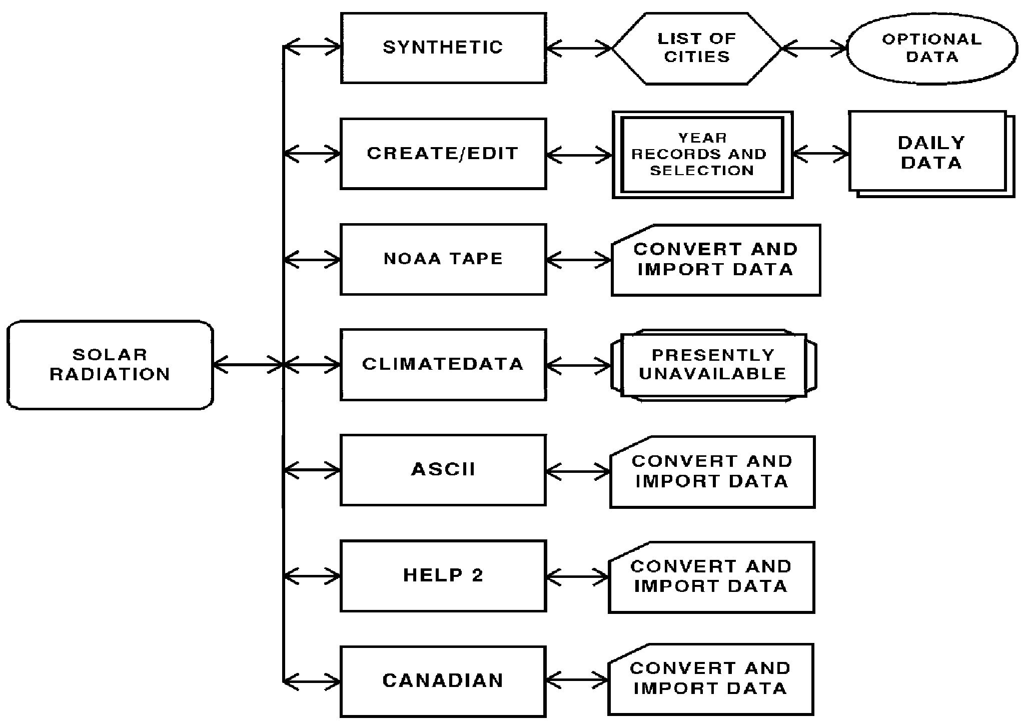

Figure 10. Solar Radiation Options

entering or editing precipitation, temperature and/or solar radiation data, the program prompts the user with a request to enter the city and state of the location and the units that will be used for entering the data manually. These requests appear on the same screen as "Precipitation, Temperature and Solar Radiation" screen and will be filled in with information when editing an existing data file. The user may press the ***Esc*** key to abandon the entry of this information and return to the selection of another weather data option. Once the location and units are specified, the program displays the yearly data screen.

Yearly Data Screen

This screen is like a spreadsheet that has four columns. Two of these columns are for the precipitation data, and one column each is for temperature and solar radiation. The first column is for the year for which the precipitation data is to be entered, and the second column is for total annual precipitation. The user cannot access the yearly total precipitation column since this total is computed by the program after the daily data for the year is entered. If the user reaches this screen from the precipitation option on the "Precipitation, Temperature, and Solar Radiation" screen, the user will only be able to move within the column under precipitation. Similarly, if the user reaches this screen from the temperature data option, then only movement in the temperature column is permitted, and analogously, for the solar radiation option.

To enter a new year of daily values, the user should move the cursor to a empty cell, type in the year and press ***Enter***. The program will display the daily data screen on which the daily values are entered. The user can return to the yearly data screen by pressing ***F10*** to retain the data (to a temporary file) or by pressing ***Esc*** to abandon the created data.

The user can enter up to 100 years of daily data. The yearly data screen can only display 20 rows at a time. The user, however, can move the cursor to the bottom of the screen and then cursor down to move to the next row until the hundredth row is displayed. Similarly, the user can move the cursor upward to display the rows in the spreadsheet that are not shown on the screen, if any. To move down 20 rows, press ***Page Down***, and to move up 20 rows, press ***Page Up***. To reach the last row, press ***End***, and to go to the first row press ***Home***.

To edit an existing year of daily values, the user must first create and/or read weather data. If the data were previously saved, the user should specify the existing data file "Weather Data - File Editing" screen immediately after selecting the "Enter/Edit Weather Data" option from the main menu. The HELP model reads the data from the edit file and stores it in a temporary file. Upon entering the ***create/edit*** option, the program displays the list of years for precipitation, the total annual precipitation for each year, and a list of years for the temperature and solar radiation data. To edit, move the cursor to the year that is to be edited and press ***Enter***. The program will display the daily data screen and the user may type over any values that need to be edited. The operation of the yearly data spreadsheet and the daily data spreadsheet is the same when editing existing data or when creating new data.

After entering or editing years of daily weather data, the user can return to the "Precipitation, Temperature and Solar Radiation" screen to exercise other weather data options. To retain the newly created or edited years of daily weather data, the user should press ***F10*** from the yearly data screen; the program will then replace the existing temporary data file containing all of the years of data for that type of weather data. To lose the newly entered or edited daily data, the user should press ***F9*** or ***Esc***; the program will retain the previously existing temporary data file containing the values of that type of weather data prior to entering the ***create/edit*** option.

Daily Data Screen

Upon selecting or specifying a year from the yearly data screen, the program displays the daily data screen, a spreadsheet for entering daily data. This spreadsheet consists of 10 columns and 37 rows. The spreadsheet contains information on the file name, the year, month, and day. This information is displayed at the top of the spreadsheet. The day and month are continuously updated as the user moves from one cell to another. The first day is considered January 1, and the last day is December 31. The spreadsheet is divided into two parts, the first part being rows 1 through 19, and the second part, rows 20 through 37. The user can move the cursor to the bottom of the screen and cursor down to move to the next row until the 37th row is displayed. Similarly, the user can move the cursor upward to display any rows in the spreadsheet that are not shown. To move from the upper to the lower portions of the spreadsheet and vice versa, press ***Page Down*** and ***Page Up***, respectively. To reach the last cell in the spreadsheet, press ***End***, and to return to the first cell, press ***Home***.

The user should input values one day at a time without leaving empty cells between months. For example, the first month (January) will extend to the first cell (or column) in the fourth row. The values for the first day in February should start in column 2 of row 4; no empty cells are left between months. An empty cell is considered by the program to indicate a value of zero for that day. A zero is a valid entry. The program keeps track of leap years and adjusts the month and day at the top of the spreadsheet accordingly. Since there are 37 lines with each line containing 10 days of data, there will be empty cells at the end of line 37 in the spreadsheet. These cells are ignored by the program.

If the user decides to quit entering data in the daily spreadsheet and return to the yearly spreadsheet, the user should press the ***Esc*** key. By doing so, whatever data were entered on the daily data sheet will be lost; the previously existing data will be retained. To exit the daily spreadsheet and retain the data entered on that sheet, the user should press ***F10***. Note that the ***F10*** key will retain the data in a temporary file only and not in any previously selected file. A separate temporary file is maintained for each year of daily data.

Once the user returns to the yearly weather sheet, more years can be entered or edited, and the daily values for these years can be input on the daily sheet in the same manner described above. After exiting the precipitation spreadsheet by pressing ***F10***, and upon returning to the yearly sheet, the annual total precipitation for that year is computed and displayed next to the year.

Editing Data on Yearly Data Screen

Besides selecting years for creating or editing daily data, the user has the options on the yearly data screen to select only a portion of a weather file for future use, to rearrange the years of data, to repeat the same year(s) of data for a longer simulation period or to insert years of data into an existing file. These options are performed using the functions to add (insert) a year above or below an existing year in the list of years, delete a year, move a year to a position above or below an existing year in the list of years, or copy a year to a position above or below an existing year in the list of years. The options are performed only on the type of data (precipitation, temperature or solar radiation) highlighted when the ***create/edit*** option was selected. This is done by using the following key combinations of functions:

Alt A adds/inserts a year (either new, being moved or being copied) above the highlighted year (where the cursor is positioned)

Alt B adds/inserts a year (either new, being moved or being copied) below the highlighted year (where the cursor is positioned)

Alt D deletes the highlighted year (where the cursor is positioned)

Alt M tags the highlighted year (where the cursor is positioned) to be moved to another location to be designated using the cursor and ***Alt A*** or ***Alt B***

Alt C tags the highlighted year (where the cursor is positioned) to be copied to another location to be designated using the cursor and ***Alt A*** or ***Alt B***

To add a new year directly above a certain year, for example above the year on line 29 (Line numbering is shown on the left edge of the screen.), the user should move the cursor to line 29, hold the ***Alt*** key down, and press ***A***. The result of this action is that a blank cell is inserted above line 29, and the program shifts the year on line 29 and all the years below it one line downward (i.e. year on line 29 moves to line 30, year on line 30 moves to line 31, etc.), and line 29 will be a blank line for the user to enter the value for the new year.

To add a year directly below a certain year, for example below the year on line 5, the user should move the cursor to line 5, hold the ***Alt*** key down, and press ***B***. The result of this action is that a blank cell is inserted below line 5, and the program shifts the year on line 6 and all the years below it one line downward (i.e. year on line 6 moves to line 7, year on line 7 moves to line 8, etc.), and line 6 will be a blank cell for the user to enter the value of the new year.

The ***Alt D*** combination causes the program to delete a year from the list of years. For example, to delete the year on line 15, the user should move the cursor to line 15, hold the ***Alt*** key down, and press ***D***. The program will delete information on line 15 and will shift the years on lines 16 to 100 upward one line (i.e., year on line 16 moves to line 15, year on line 17 moves to line 16, etc.), and cell on line 100 becomes an empty cell. The user is cautioned that the deleted year cannot be recovered without quitting and losing all changes (***F9*** or ***Esc***). The original temporary file is replaced only when the changes are finally retained by pressing ***F10*** from the yearly data screen.

The copy command allows the user to place a year that is identical to another year on another line. For example, to copy the year on line 70 to line 5, move the cursor to line 70 and press the ***Alt C*** combination, then move the cursor to line 5 and press the ***Alt A*** combination. At this point, the user must specify a value for the new year; the value must be different from the value of any other year in the data set for that type of weather data. This action will cause the new value for the year to appear on line 5 but the daily values will be the same as those found for the year copied and previously found in line 70. (The user may obtain the same result after the ***Alt C*** combination by moving to line 4 and pressing the combination ***Alt B***).

The move command allows the user to move one year from one location on the yearly data screen to another. For example, to move the year on line 32 above the year on line 56, move the cursor to line 32, press the ***Alt M*** combination, and move the cursor to line 56 and press the ***Alt A*** combination. This action will cause the year on line 32 to be deleted and be placed directly above the year on line 56. (The user may obtain the same result after the ***Alt M*** combination by moving to line 55 and pressing the combination ***Alt B***).

The ***Esc*** key can be used to quit the move and copy functions (after pressing ***Alt M*** or ***Alt C*** and before pressing ***Alt A*** or ***Alt B***. By editing the data as discussed above, the user is actually arranging the order of the precipitation data of the years. Actual rearranging of data in the data file, however, takes place only after the user presses ***F10***.

NOAA Tape Data

This option allows the user to enter data to the HELP model from a NOAA data set

(*Customary Units Only*). If this option is selected, the user must enter the city and state for the site and the NOAA file name. For the precipitation and temperature options, the NOAA data file should contain daily Summary of Day data written in as-on-tape format. Note that for temperature data two file names are requested, one for the maximum temperature and the other for the minimum temperature. If the user has only a mean temperature data file, the mean temperature data file name should be entered for both maximum and minimum temperature data file names. For the solar radiation option the NOAA data file should contain hourly Surface Airways data written in as-on-tape format. Example NOAA data files are included with the HELP program -- PC49215A.PRN for precipitation, MX49215A.PRN for maximum temperature and MN49215A.PRN for minimum temperature. When entering the NOAA file name, the user should include the DOS path (if the file location is different than the default directory), file name and extension. The user can abandon the entry of this data by pressing ***Esc***. Once valid information is entered, the program reads the data from the specified file and converts it to the HELP Version 3 format.

Climatedata™

This option allows the user to enter daily precipitation or temperature data to the HELP model from Climatedata™ (*Customary Units Only*). If this option is selected, the user must enter the city and state for the site and the Climatedata™ file name. Note that for temperature data, two file names are requested, one for the maximum temperature file and the other for the minimum temperature file. The Climatedata™ file should have been created by exporting or printing the CD-ROM data to an ASCII print file. This same format is used by data bases other than Climatedata™ and therefore these data bases can be converted using this same option. Example Climatedata™ files are included with the HELP program -- BIRM.PRC for precipitation, BIRM.MAX for maximum temperature and BIRM.MIN for minimum temperature. When entering the Climatedata™ file name, the user should include the DOS path (if the file location is different than the default directory), file name and extension. The user can abandon the entry of this data by pressing ***Esc***. Once valid information is entered, the program reads the data from the specified file and converts it to the HELP Version 3 format.

ASCII Data

This option allows the user to enter daily weather data to the HELP model from ASCII data files (*Customary or Metric Units*). The ASCII data set is composed of lines of data whose values are separated by a blank(s), a comma or other non-numeric symbol. If this option is selected, the user must enter the city and state for the site, the units of the data in the ASCII files. The user can abandon the entry of this data by pressing ***Esc***. Once valid information is entered, the program then asks for the file name and year of the ASCII data set, one year at a time. Each file should contain only one year of daily values for a particular type of data, either precipitation, mean temperature or solar radiation. Example ASCII data files are included with the HELP program -- RAIN.1 and RAIN.2 for precipitation, TEMP.1 and TEMP.2 for temperature and SOLAR.1 and

SOLAR.2 for solar radiation. When entering the ASCII data file name, the user should include the DOS path (if the file location is different than the default directory), file name and extension. In order to return from this option to the "Precipitation, Temperature, and Solar Radiation" screen, press ***Esc***.

HELP 2

This option allows the user to enter weather data to the HELP model Version 3 from a data file used in the HELP model Version 2 (*Customary Units Only*). If this option is selected, the user must enter the city and state for the site and the HELP Version 2 data file name. Example HELP 2 data files are included with the HELP program -- ALA4 for precipitation, ALA7 for temperature and ALA13 for solar radiation. When entering the HELP 2 data file name, the user should include the DOS path (if the file location is different than the default directory), file name and extension. The user can abandon the entry of this data by pressing ***Esc***. Once valid information is entered, the program reads the data from the specified file and converts it to the HELP Version 3 format.

Canadian

This option allows the user to enter weather data to the HELP model from a Canadian Climatological Data (Surface) file (*Metric Units Only*). If this option is selected, the user must enter the city and state for the site and the Canadian Climatological Data file name. The precipitation and mean temperature data files should contain daily values written in either compressed or uncompressed diskette format. The solar radiation data file should contain hourly global solar radiation values also written in either compressed or uncompressed diskette format. Example Canadian data files are included with the HELP program -- CAN4.DAT and CCAN4.DAT for precipitation, CAN7.DAT and CCAN7.DAT for temperature and CAN13.DAT and CCAN13.DAT for solar radiation. When entering the Canadian data file name, the user should include the DOS path (if the file location is different than the default directory), file name and extension. The user can abandon the entry of this data by pressing ***Esc***. Once valid information is entered, the program reads the data from the specified file and converts it to the HELP Version 3 format.

4.5.4 Saving Weather Data

During the creation of the weather data explained above, the data are saved in temporary files. To save the data to permanent files, the user must press ***F10*** from the primary screens. Once the ***F10*** key is pressed, the program verifies that all the data have been entered. If any of the data is incomplete, the program displays a list of the problem areas. The user can return to the primary screens to complete the data or continue to save the incomplete data. After displaying the deficiencies, the program displays the "Weather Data - File Saving" screen. Here the user may save all or only some of the four weather types, or completely abandon the save option. The user should tag each type of data to be saved by entering a "Y" in the "SAVE" column and those not to be saved by entering a "N" in the "SAVE" column. Default file names are displayed in appropriate locations on this screen; these are the same names as used in Version 2. At this time, the user may enter new file names for any or all of the four types of weather data. (See Section 4.5.1 for file naming convention used in HELP.) If the file already exists, the program will display "File Already Exists" after entering the name. After replacing all file names of interest, the user should press ***F10*** or ***Page Down*** to complete the saving to the requested file names. If files already exists for any of the file names as they would for the default names, the program will ask the user about overwriting each existing file. If the user answers "Y" for all of the files, the program will overwrite the files, complete the saving process and return to the main menu. If the user answers "N" for any file, the program will interrupt the saving, return to the "SAVE" column and change the tag to "N". The user can then change the tag back to "Y", rename the file, and restart the saving by pressing ***F10*** or ***Page Down***. The program provides other options listed on the "File Saving" screen to enable the user to return the weather data entry screens (***Page Up***) or to return to the main menu without saving the data (***F9***). The user must be cautioned that the ***F9*** option will cause all the data created (if any) to be lost. Figure 11 shows the available options.

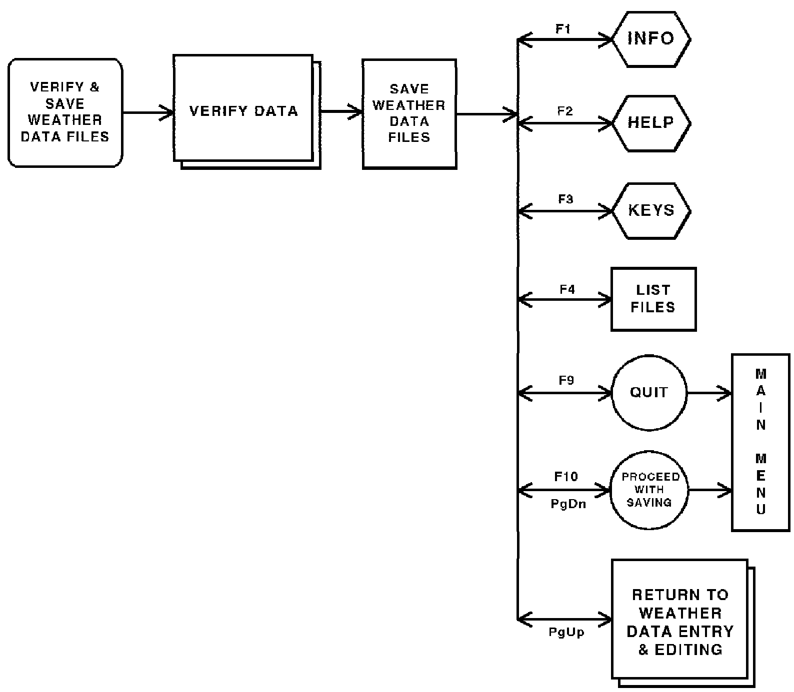

Figure 11. "Weather Data - File Saving" Screen Options

4.6 SOIL AND DESIGN DATA

This module is selected from the main menu by pressing 2, ***"Enter/Edit Soil and Design."*** While in this module, the user will be able to enter site information, a landfill profile, layer design data, characteristics of soils, geomembranes and other materials, and SCS runoff curve number information. The primary screens in this module are the "Soil and Design Data - File Editing" screen, "Landfill General Information" screen, three Landfill Profile Design and Layer Data screens, "Runoff Curve Number Information" screen, "Verification and Saving" screen and "Soil and Design Data - File Saving" screen. Several secondary screens may appear during the session depending on the action taken by the user. On-line help screens are always available for display by pressing ***F1*** or ***F2***. The individual primary screens and their secondary screens of this module are discussed below. Figure 12 shows a schematic of the soil and design data module.

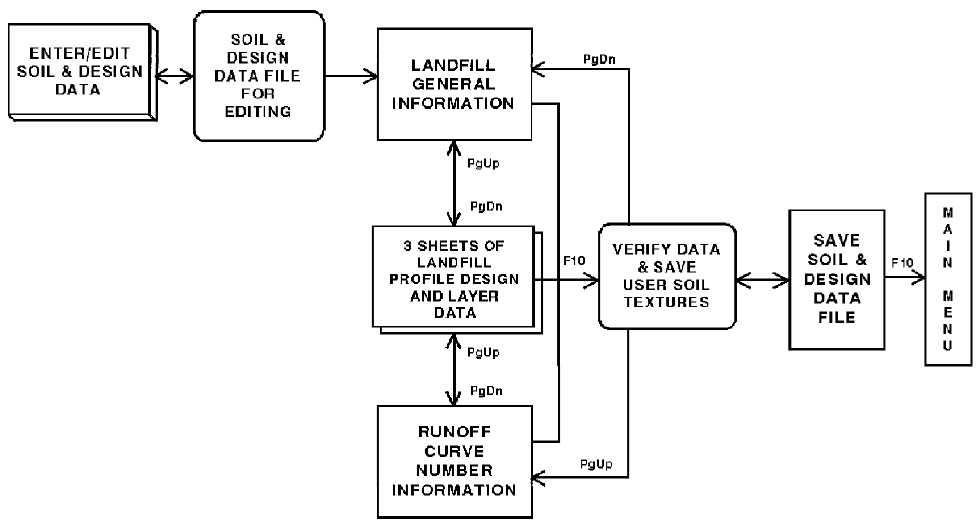

Figure 12. Schematic of Soil and Design Data Module

4.6.1 Soil and Design Data File Selection

The first screen in the soil and design module is the "Soil and Design Data - File Editing" screen. A schematic of this screen is shown in Figure 13. On this screen the user may enter the file name of an existing file to select a previously generated HELP Version 3 file for editing or leave the file name blank to create new data. When selecting a file to be edited, the user may specify the DOS path if different from the default drive and subdirectory, such as C:\HELP3\DATA. The default directory is initially displayed in the directory cell on the screen. If the user specifies a drive or a directory that does not exist, the program will display respectively "Invalid Drive" or "Invalid Directory" and replaces the content with the default directory. The soil and design data file may have any valid DOS name of up to 8 characters. If the user enters an illegal file name, the program displays "Bad File Name" and clears the file name. If the user specifies a file name that does not exist, the program displays "File Not Found" and clears the file name.

The program adds an extension of .D10 to the file name. As such, the user should not specify the extension in HELP Version 3 whenever entering a file name for editing or saving.

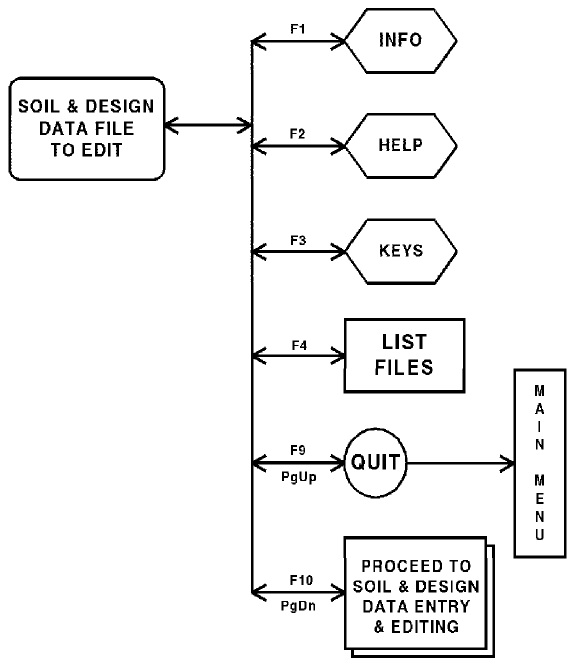

Figure 13. "Soil and Design Data - File Editing" Screen Options

As shown in Figure 13, the user may obtain a listing of all soil and design data files that reside on the directory currently specified in the directory cell by pressing ***F4***. Up to 120 data files can be displayed on the screen. The name of the current directory where these files are located is also displayed. To change to another directory, the user should enter the name of that directory in the column labeled DIRECTORY. To select a file from the list of displayed files, move the cursor to the file and select it by pressing ***Enter***. This transfers control back to the previous screen and the name of the file just selected will be displayed in the proper cell. The user can exit the list-of-files screen without selecting a file by pressing ***F4*** again or ***Esc***.

When ready to proceed to enter new data or edit existing data, the user should press ***Page Down*** or ***F10***. The program then reads the data file to be edited, if a file is specified, and proceeds to the "Landfill General Information" screen. If a new data set is to be created (file name left blank), the program initializes the soil and design data and then asks for the system of units to be used throughout the module (*Customary or Metric*). Proper units are displayed throughout the module for entries that require units.

4.6.2 Landfill General Information

The second input screen in the soil and design data module is the "Landfill General Information" screen. Figure 14 shows the screen and its branches as a schematic. By moving the cursor to the appropriate cell, the user can enter new information or edit the information that was read from the edit file. The first entry is the ***project title*** which is only used for identification of the simulation.

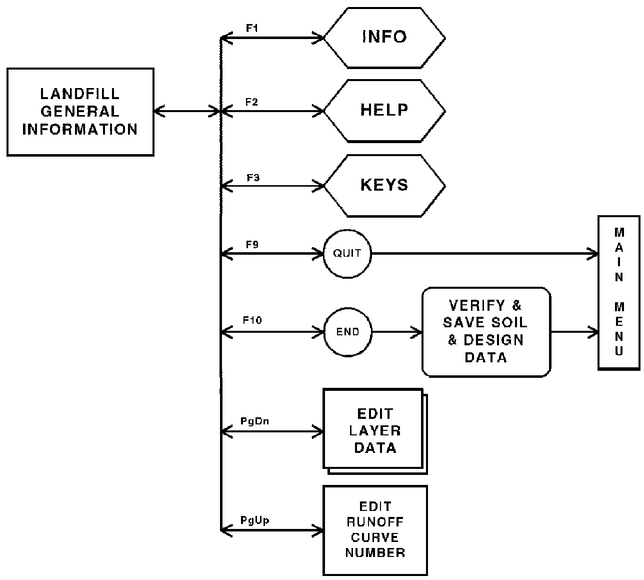

Figure 14. Schematic of "Landfill General Information" Screen

The second entry on this screen is the ***landfill area***. The units of the area are displayed next to the input cell according to the system of units selected. The user should enter the area in acres for Customary units or in hectares for Metric units. The third entry is for the ***percent of area where runoff is possible***. This variable specifies the portion of the area that is sloped in a manner that would permit drainage off the surface. The runoff estimates predicted by the model are equal to the computed runoff by the curve number method times this percent. The difference between the computed runoff and the actual runoff is added to the infiltration.

Next, the user must select the method of ***moisture content initialization***; that is whether or not the user wishes to specify the initial moisture storage. If the user answers "N" (no) to this question, the program assumes near steady-state values and then runs the first year of the simulation to improve the initialization to steady-state. The soil water contents at the end of this year of initialization are taken as the initial values for the simulation period. The program then runs the complete simulation, starting again at the beginning of the first year of weather data. The results for the initialization period are not reported. However, if the user answers "Y" (yes), the user is requested to enter the ***amount of water or snow water on the surface*** in the units selected. Later, the user should enter the initial moisture content of each layer as explained in the next section.

4.6.3 Landfill Layer Data

The next step in the soil and design data module is to input the design specifications of the landfill profile, one layer at a time. Layer data are entered in three screens. These screens have a spreadsheet layout where each row represents a layer. Figure 15 shows the three spreadsheets and their associated screens. The first row of cells on the screens is the uppermost layer in the landfill. Each column of cells on the screens represents a variable or a property of the layer or its material. Variable names are listed in the first two rows of the screen, and the third row contains the units of that variable, if any. Every highlighted cell is associated with a highlighted property (heading of a column) and a highlighted layer number (row label). The user should enter the value of the specified property for the corresponding layer. All entries must obey certain rules which are discussed below.

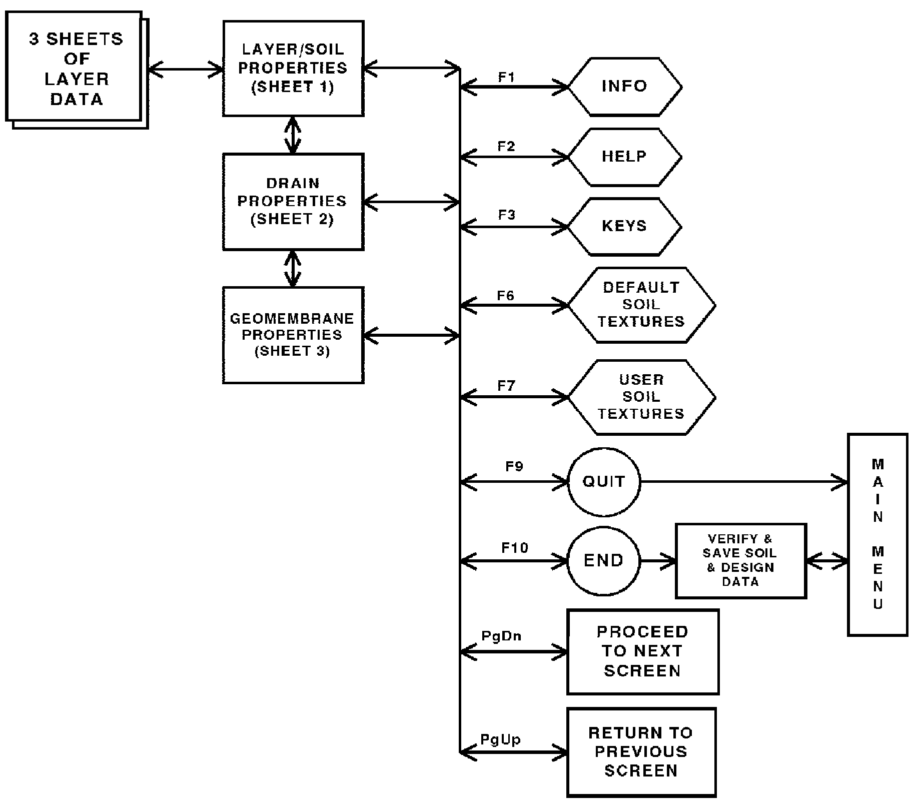

Figure 15. Schematic of Landfill Layer Data

Layer Type

The user should input ***layer type*** in the first column of the spreadsheet. The four layer types and their associated code numbers that the program recognizes are vertical percolation (1), lateral drainage (2), barrier soil liner (3), and geomembrane liner (4). These are defined as follows:

1. A layer of moderate to high permeability material that drains vertically primarily as unsaturated flow is classified as a ***vertical percolation layer*** as long as it is not underlain by a liner with a lateral drainage collection and removal system. The primary purpose of a vertical percolation layer is to provide moisture storage; as such, top soil layers and waste layers are often vertical percolation layers.

2. A layer of moderate to high permeability material that is underlain by a liner with a lateral drainage collection and removal system is classified as a ***lateral drainage layer***. The layer drains vertically primarily as unsaturated flow and laterally as a saturated flow.

3. A layer of low permeability soil designed to limit percolation/leakage is classified as a ***barrier soil liner***. The layer drains only vertically as a saturated flow.

4. A geomembrane (synthetic flexible membrane liner) designed to restrict vertical drainage and limit leakage is classified as a ***geomembrane liner***. Leakage is modeled as vapor diffusion and leakage through small manufacturing defects and installation flaws.

While the HELP program is quite flexible, there are some basic rules regarding the arrangement of layers in the profile that must be followed.

1. A vertical percolation layer may not be underlying a lateral drainage layer.

2. A barrier soil liner may not be underlying another barrier soil liner.

3. A geomembrane liner may not be placed directly between two barrier soil liners.

4. A geomembrane liner may not be underlying another geomembrane liner.

5. A barrier soil liner may not be placed directly between two geomembrane liners.

6. When a barrier soil liner or a geomembrane liner is not placed directly below the lowest drainage layer, all drainage layers below the lowest liner are treated as vertical percolation layers. Thus, no lateral drainage is computed for the bottom section of the landfill.

7. The top layer may not be a barrier soil liner.

8. The top layer may not be a geomembrane liner.

9. The profile can contain no more than a total of five barrier soil liners and geomembrane liners.

The program checks for rule violations only at the time the user saves the data. Therefore, to reduce the time involved in evaluating a landfill, the user is encouraged to design a proper layer sequence before saving the data.

In the second column, which has the heading "***Layer Thickness***," the user should enter the thickness of each layer in the landfill profile even for the geomembrane liner, in inches or cm. The values must be greater than zero; a blank cell is taken as a value of zero. Again, during data verification the program checks for layer thickness of zero and issues a violation statement when the user tries to save the data.

In the third column, the user should enter the ***soil texture number*** of the soil that forms the layer. The 4 possible options for the user to enter soil texture numbers are:

1. Select from a list of default textures for 42 soils, wastes, geomembranes, geosynthetics and other materials.

2. Select from a library of user-defined textures that were previously saved and numbered by the user (up to 100 such textures are allowed).

3. Enter a new soil texture number that can be used again in this design and that can later be saved in the library of user defined textures (material properties must also be entered manually for this texture).

4. Leave the texture number blank and enter the material properties manually.

Default Soil/Material Textures

Default soil/material textures have numbers from 1 to 42 and are listed in Table 4. The user can either type the soil texture number or press ***F6*** to select a texture from the list of default textures. If the user enters a default soil/material texture number manually, the program automatically assigns the default values for ***porosity, field capacity, wilting point, and hydraulic conductivity*** to the layer. On the other hand, the user may press ***F6*** to obtain the list of soil textures on a separate screen. On the soil texture screen, the user can move the cursor to the desired texture or press ***Page Down*** to display the rest of the default soil textures. After cursoring to the desired texture, press ***Enter*** to select it. At this time, program control returns to layer spreadsheet screen and displays the selected soil texture number, along with the porosity, field capacity, wilting point, and hydraulic conductivity in appropriate cells. Notice that the only information available for the default geomembrane liners is the hydraulic conductivity (liner vapor diffusivity). If the user changes any of the four soil properties obtained for a default soil/material texture, the program automatically resets the soil texture number to 0. The user can then assign the values a new soil texture number that is not used in either the list of default or previously saved user defined textures if the user wishes to save the material characteristics for future use.

As mentioned above, default soil/material textures are obtained by pressing ***F6*** and are available on all three screens. To move from one screen of default soil/material textures to another the user should press ***Page Up*** or ***Page Down***. To return to the layer spreadsheet without making a selection, press ***Esc***. A selection is made only by moving the cursor to the desired soil texture and pressing ***Enter***.

User-Defined Soil Texture

In Version 3 of the HELP model, the user has three options to specify material characteristics, in addition to selecting soil textures from the default list. One method is to enter all of the material characteristics manually without specifying a soil texture number. This method is used when the user does not wish to save these characteristics for use again in this simulation or future simulations. The second method, which allows the user to assign a new soil texture number to the manually entered values for the soil properties, is used when the same characteristics are to be used in future simulations and the characteristics are to be permanently saved in a library of user-defined textures. A library of up to 100 soil textures may be saved in a "user-defined soil texture" data file. The creation and addition of textures to this file are explained in Section 4.6.5 of this User’s Guide. The third method is to select a user-defined texture that was previously saved in the library. If this library of user-defined soil textures exists, the user can display the list of available textures for selection by pressing ***F7***. Selecting a user-defined soil texture for a given layer is identical to that of selecting a default soil/material textures; the user should move the cursor to the desired soil texture and press ***Enter***. At this point, program control returns to the layer spreadsheet and displays soil texture values, porosity, field capacity, wilting point, and hydraulic conductivity of the selected soil in the layer (row) where ***F7*** was pressed. Also, in the same manner as in default soil/material textures, the user can simply type the number of the user-defined soil texture in "Soil Texture No." column of the first screen of the layer spreadsheets, and the program will automatically obtain the soil characteristics for that soil texture and place them in the proper location on the layer spreadsheet.

Whenever ***F7*** is pressed, control transfers to the user-defined soil textures. To move among pages of soil textures press ***Page Up*** and ***Page Down***. To make a selection, press ***Enter***, and to return to the layer spreadsheet without making a selection, press ***Esc***.

The values entered for the moisture storage parameters in columns 4 through 7 of the first screen of layer spreadsheets are interrelated. In column 4 the ***porosity*** must be greater than zero but less than 1. In column 5 the ***field capacity*** must be between zero and 1 but must be smaller than the porosity. In column 6 the ***wilting point*** must be greater than zero but less than the field capacity. In column 7 the ***initial moisture content*** must be greater than or equal to the wilting point and less than or equal to the porosity. If the user had indicated on the "Landfill General Information" screen that the program should specify initial moisture content for the soil layers, the program will ignore all input in column 7. As such, the user does not need to enter data in this column. On the other hand, if the user had indicated that the user wishes to specify the initial moisture content, these values must be entered manually. An empty cell is interpreted as zero for initial moisture, violating the rules. If the layer is a liner, the program during execution automatically sets the initial water content equal to the porosity of the layer. The program will detect violations of these values and will report them to the user during verifications when the data is to be saved to a file.

The second screen of layer spreadsheets can be obtained by pressing ***Page Down***. On this sheet the user will notice that the layer type is already appearing. In the first column of cells the ***saturated hydraulic conductivity*** must be specified in the appropriate units (cm/sec). If the soil texture selected was a default soil/material texture or a user-defined soil texture, the saturated hydraulic conductivity will be displayed in this column. Remember that changing the saturated hydraulic conductivity causes the soil texture number on the previous screen to revert to zero in the same manner as changing any of the other material characteristics (porosity, field capacity or wilting point).

Drainage Layer Design

Information on lateral drainage layer design must be entered manually for each lateral drainage layer directly above the liner regardless of the method used to enter soil textures. The required information is the drainage length, drainage layer slope, recirculation percentage and recirculation destination. These parameters are found in the second through fifth column of cells on the second spreadsheet screen of layer data. These columns are used only for the lateral drainage layers directly above the liner; data placed in rows for other layers will be ignored during execution. The second column of cells on this second screen of layer data is for entering the ***maximum drainage length*** of lateral drainage layers, which is the length of the horizontal projection of the flow path down the slope of a liner to the water/leachate collection system. This length must be greater than zero. In third column of cells the user should enter the ***drain slope*** in percent. This slope is the maximum gradient of the surface of the liner at the base of the lateral drainage layer; this is the slope along the flow path.

In Version 3, the HELP program allows ***leachate/drainage recirculation*** to be simulated. The amount of leachate/lateral drainage to be recirculated from a given layer should be entered as a percent of the layer's drainage in the fourth column of cells. The layer to which this leachate drainage should be recirculated should be entered on the same row in the fifth column of cells. The value entered is the number of the layer receiving recirculation. Layer numbers are those numbers displayed on the left side of the screen. These numbers are 1 through 20 and refer to the order of the layers in the profile. The

HELP model does not allow leachate recirculation to a liner.

Version 3 of the HELP model also allows the user to specify ***subsurface inflow*** into the landfill from a groundwater source. The amount of subsurface inflow into each layer should be entered in the last column of the second spreadsheet of layer data and is considered to be a steady flow rate into the landfill at the layer where the inflow value is entered. If subsurface inflow is specified for the bottom layer, the program will assume no leakage through the bottom of the landfill. For most landfills, the inflows will be zero and this column can be left blank.

After entering the necessary values in the second spreadsheet screen of layer data, the user should press ***Page Down*** to go to the third and last screen of layer data. Pressing ***Page Up*** will return to the first spreadsheet of layer data, allowing the user to edit the previously entered values. Again, on the third spreadsheet screen, the layer type of all layers in the profile are displayed to aid in positioning data on the screen.

Geomembrane Liner Design

All of the entries on third screen of layer data pertain to geomembrane liner properties such as ***geomembrane liner pinhole density***, ***geomembrane liner installation defect density***, ***geomembrane liner placement quality***, and associated ***geotextile transmissivity*** (if present). Values must be entered for each geomembrane liner (layer type 4) in the profile. Guidance on estimating the pinhole and installation defect density as well as definitions for these parameters is provided in Section 3. The placement quality options are also described in Section 3 and are presented below. The geotextile transmissivity should be specified only when a placement quality of 6 is used.

In the third column of cells the user should input the geomembrane liner placement quality. The HELP program recognizes the following six types of placement quality.

1. Perfect contact
2. Excellent contact
3. Good field placement
4. Poor field placement
5. Bad contact -- worst case
6. Geotextile separating geomembrane liner and controlling soil layer

Typically, placement quality 6 would not be used with a geosynthetic clay liner (GCL) despite the presence of a geotextile since, upon wetting, the clay extrudes through the geotextile and provides intimate contact with the geomembrane.

After completing input for one layer, the user can go back to the first spreadsheet and enter information for other layers. ***Page Up*** and ***Page Down*** are used to move backward and forward between spreadsheets. The user may also input values on one spreadsheet completely filling it, and move on to the next spreadsheet filling in the information for the layers entered in the first spreadsheet and so on. No blank rows be left in the spreadsheet between layers; however, if the user does leave some blank lines, the program will not save these as layers.

Layer Editing

While entering or editing the properties of the layers in the landfill defined in the three spreadsheets of layer data, the user has the option to add a layer to the profile, delete a layer, move a layer to another location in the profile, or copy a layer to another location. When using these layer editing functions, the program operates simultaneously on all three screens of layer data. This is done by using the following key combinations:

Alt A adds/inserts a layer (either new, being moved or being copied) above the highlighted layer (where the cursor is positioned)

Alt B adds/inserts a layer (either new, being moved or being copied) below the highlighted layer (where the cursor is positioned)

Alt D deletes the highlighted layer (where the cursor is positioned)

Alt M tags the highlighted layer (where the cursor is positioned) to be moved to another location to be designated using the cursor and ***Alt A*** or ***Alt B***

Alt C tags the highlighted layer (where the cursor is positioned) to be copied to another location to be designated using the cursor and ***Alt A*** or ***Alt B***

To add a new layer directly above a certain layer, for example above the layer on line 6 (shown on the left edge of the screen), the user should move the cursor to line 6, hold the ***Alt*** key down, and press ***A***. The result of this action is that a blank line is inserted above the layer that was at line 6, and the program shifts the layer on line 6 and all the layers below it one line downward (i.e. layer on line 6 moves to line 7, layer on line 7 moves to line 8, etc.), and line 6 will be a blank line for the user to enter the values for the new layer.

To add a layer right below a certain layer, for example below the layer on line 5, the user should move the cursor to line 5, hold the ***Alt*** key down, and press ***B***. The result of this action is that a blank line is inserted below line 5, and the program shifts the layer on line 6 and all the layers below it one line downward (i.e. layer on line 6 moves to line 7, layer on line 7 moves to line 8, etc.), and line 6 will be a blank cell for the user to enter the value of the new layer.

The ***Alt D*** combination causes the program to delete a layer from the list of layers. For example, to delete the layer on line 3, the user should move the cursor to line 3, hold the ***Alt*** key down and press ***D***. The program will delete all information on line 3 and will shift the layers on lines 4 to 20 upward one line (i.e., layer on line 4 moves to line 3, layer on line 5 moves to line 4, etc.), and line 20 becomes a blank line. The user is cautioned that the deleted layer cannot be recovered without quitting and losing all changes (***F9*** or ***Esc***).

The copy command allows the user to place a layer that is identical to another layer on another line. For example, to copy the layer on line 7 to line 2, move the cursor to line 7 and press the ***Alt C*** combination, then move the cursor to line 2 and press the ***Alt A*** combination. This action will cause the program to insert a layer with values the same as those formerly found at line 7 above the layer formerly found at line 2. The layers formerly at and below line 2 will be moved downward one line. (The user may obtain the same result after the ***Alt C*** combination by moving to line 1 and pressing the combination ***Alt B***).

The move command allows the user to move a layer from one row on the screens of layer data to another row. For example, to move the layer on line 3 above the layer on line 6, move the cursor to line 3, press the ***Alt M*** combination, and move the cursor to line 6 and press the ***Alt A*** combination. This action will cause the layer on line 3 to be deleted and be placed directly above the layer on line 6. This will cause line 4 to move up one line to line 3, line 5 to move to line 4 and line 3 to move to line 5; the other lines will be unchanged. (The user may obtain the same result after the ***Alt M*** combination by moving to line 5 and pressing the combination ***Alt B***).

The ***Esc*** key can be used to quit the move and copy functions (after pressing ***Alt M*** or ***Alt C*** and before pressing ***Alt A*** or ***Alt B***). By editing the data as discussed above, the user may arrange the order of the layers and run the model to test several possible configurations.

If the user has 20 lines completely filled with layers and then decides to add or copy a layer, the layer that is already in line 20 will disappear and cannot be recovered. Therefore, care must be taken not to add layers that will cause the loss of the layers at the bottom of the spreadsheet.

When all the layers of the profile are entered, press ***Page Down*** from the third layer spreadsheet to proceed with the rest of the soil and design data entry. Pressing ***Page Up*** from the first layer spreadsheet passes control to the "Landfill General Information" screen.

4.6.4 Runoff Curve Number

The "Runoff Curve Number Information" screen may be reached from the third layer spreadsheet by pressing ***Page Down***, or from the "Landfill General Information" Screen by pressing ***Page Up***. A schematic of the options associated with the "Runoff Curve Number Information" screen is shown in Figure 16. This screen is composed of three options that can be used to specify the runoff curve number. The first option is to use an ***user-specified curve number*** that the HELP model will use without modification. The second option is to request the HELP model to ***modify a user-specified curve number*** according to the surface slope and surface slope length. In the third option the user requests a ***HELP model computed runoff curve number*** based on surface slope, slope length, soil texture of the top layer in the landfill profile, and vegetation. To select one of these three options, the user should move the cursor to the desired option and press ***Enter***. This action will cause the program to transfer control down to the box for the option selected. For each option, the user must input all required information. Although the user can move from one box to the other (use ***Tab*** and ***Shift Tab*** keys), care should be taken to insure that the desired method is the one that will be used by HELP. The HELP model uses that option in which data was last entered; this option is marked by a small arrow in front of the option.

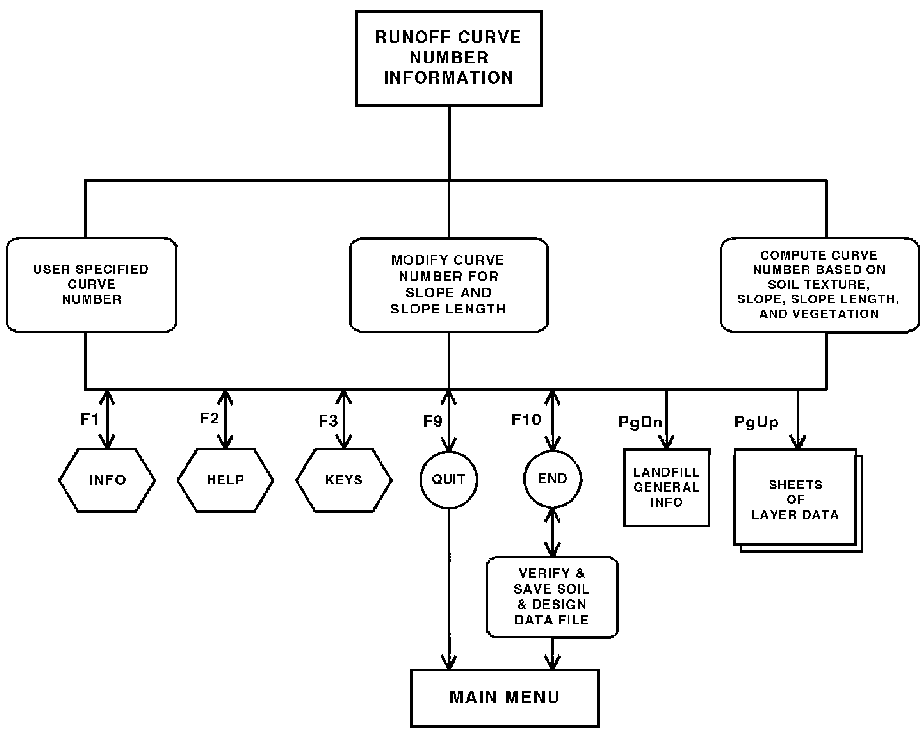

Figure 16. Schematic of "Runoff Curve Number Information" Screen Options

The user should refer to the HELP model documentation for Version 3 for the techniques used in the computation of the curve number based on slope and slope length. The value of the slope must be input in percent, and slope length must be input in the units indicated. If the top layer in the landfill is obtained from the default soil/material textures, the soil texture number for that layer will be displayed in the appropriate cell on the screen. The user can solicit help on the ***vegetation cover*** by pressing the ***F2*** key. The only valid entries for the vegetation are 1 through 5, according to the following:

1. Bare ground

2. Poor stand of grass

3. Fair stand of grass

4. Good stand of grass

5. Excellent stand of grass

If the user selects the option that requires the HELP model to compute the curve number, the program first calculates the SCS runoff curve number for landfills with mild surface slopes (2 to 5 percent) based on the vegetation type and the soil texture on the top layer if one of the default soil/material textures is selected (soil texture types 1 through 18, 20 and 22 through 29) in the same manner as Version 2 (Schroeder et al., 1988b). HELP Version 3 then adjusts the SCS runoff curve number based on the surface slope and the length of the slope.

4.6.5 Verifying and Saving Soil and Design Data

Pressing ***F10*** anywhere in the soil and design option transfers control to the "Verification and Saving" screen. This screen provides the user with several options: verify landfill general design data, verify soil layer/geomembrane properties, verify layer arrangement, review/save user-defined soil textures, and save soil and design data. The user can select any of these options by moving the cursor to the option and pressing ***Enter***. Figure 17 shows the verify and save soil and design data options.

The user can verify the data before attempting to save the data by exercising the first three options on the "Verification and Saving" screen. These options are available mainly for the convenience of the new user since experienced users will be familiar with data requirements and the data will always be verified before saving. To check the data entered on the general landfill and runoff information screens, the user should select the first option, "Verify Landfill General Information Design Data." If there are no violations or warnings, the program will write "OK" to the right of the option; otherwise the program will list the problems and then write "BAD" to the right of the option.

The user can check the layer descriptions (the values on a row of the third screens

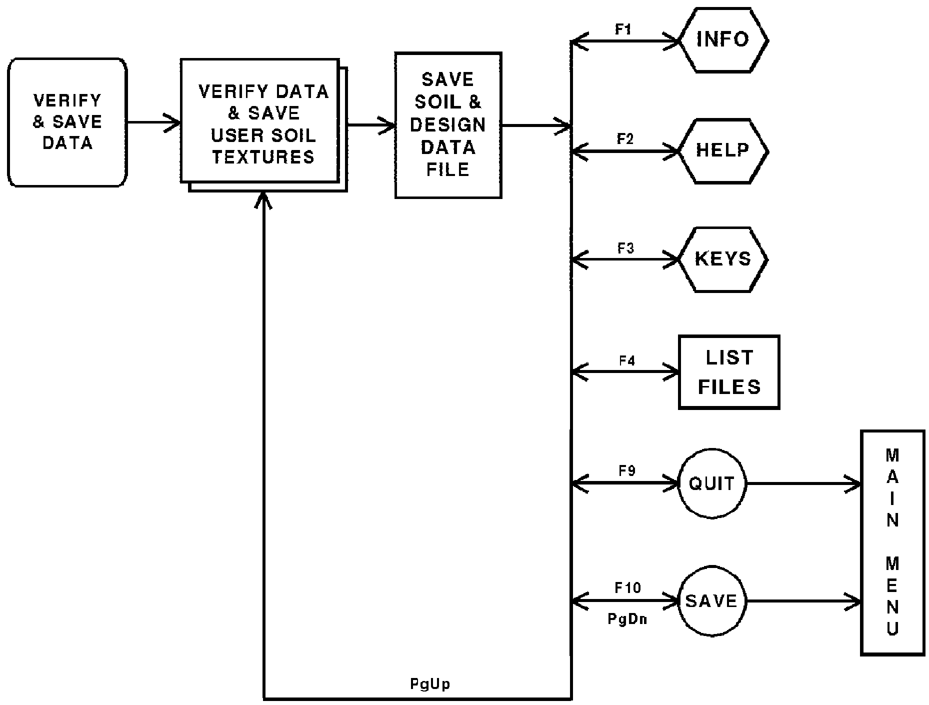

Figure 17. Verify and Save Soil and Design Data Options

of layer data) by selecting the "Verify Soil Layer/Geomembrane Properties" option. The program will examine each row for completeness for the type of layer described; for example, the program will insure that a placement quality was entered for all geomembrane liners (layer type 4). It will also check for the appropriateness of the values; for example, it will insure that the porosity is greater than the field capacity. If there are no violations or warnings, the program will write "OK" to the right of the option; otherwise the program will list the problems and then write "BAD" to the right of the option. Similarly, the user can check for violations in the ordering of the layers from top to bottom based on the layer types specified by selecting the "Verify Layer Arrangement" option. This option will check the nine rules for ordering of layers; for example, the program will insure that the top layer is not a liner. This option operates in the same manner as the verification options.

Another available option on this screen is to review the user defined soil textures that were used in the landfill profile for inclusion in or deletion from the library of user defined soil textures. Upon selecting this option, the program lists all of the non-zero user-defined soil textures used in the profile and allows the user to enter or edit a name to describe the material in the user soil library. Then after entering the names or labels, the user should tag all of the soil textures to be included in the library with a "Y" in the column of cells under the "SAVE" heading. Similarly, the user should tag all of the soil textures to be deleted from or not included in the library with a "N" in the column of cells under the "SAVE" heading. To complete the additions and deletions to the library, the user should press ***F10***; to cancel the additions and deletions and return to the

"Verification and Saving" screen, the user should press ***Esc*** or ***F9***.

If the user selects the "Save Soil and Design Data" option, the program automatically checks for possible violation of rules or errors in the soil and design data. This checking encompasses verification of presence, arrangement and values entered for the general landfill information, the landfill profile and layer data, and the runoff curve number information. The program scans through the three landfill profile spreadsheets of layer data one layer at a time and reports the errors as they are encountered. If any violations or inconsistencies are found, the program displays them on multiple screens. The user should press ***Enter*** or ***Page Down*** to proceed through the screens and reach the "File Saving" screen where the data can be saved in a file. If the user wishes to return to "Verification and Saving" screen, press ***Esc***.

Upon reaching the "File Saving" screen, the user can return to the verification and input screens to correct violations by editing the data. To return, press ***Page Up*** successively until the desired screen is reached. On the other hand, the user can still save the data now and make corrections at a later time if there were violations. However, it should not be expected that the HELP model will provide meaningful answers for such data.

Soil and design data are saved in a file specified on the "Soil and Design Data - File Saving" screen. The program displays the default file name, DATA10, for saving in the default directory. DATA10 is the same name for the soil and design data as used in Version 2 except that Version 3 adds an extension of .D10 to the specified soil and design data file name. To save the data, the user should enter "Y" in the "Save" column. Then, the user should specify the directory in which to save the file. If the directory cannot be found, the program responds "Invalid Directory" and replaces it with the default directory. After the directory, the user should enter the file name (no extension or period). If the file already exists, the program will display "File Already Exists." After entering the file name, the user should press ***F10*** or ***Page Down*** to complete the saving to the requested file name. If the file already exists as the default file would, the program will ask whether the user wishes to have the existing file overwritten. If the user answers "Y", the program will overwrite the file, complete the saving process and return to the main menu. If the user answers "N", the program will interrupt the saving, return to the "SAVE" column and change the tag to "N". The user can then change the tag back to "Y", rename the file, and restart the saving by pressing ***F10*** or ***Page Down***. The program provides other options listed on the "File Saving" screen to provide the means for the user to display a directory of existing soil and design data files (***F4***), to return to the data entry screens (***Page Up***) or to return to the main menu without saving the data (***F9***). The user must be cautioned that the ***F9*** option will cause all the data created (if any) to be lost. Figure 17 shows the available options.

4.7 EXECUTING THE SIMULATION

Option 3 on the main menu is "Execute Simulation". This option is composed of two primary screens: "Execution Files - File Management" screen and "Output Selection" screen and is shown schematically in Figure 18.

Execution Files

This screen is used to define the weather and soil and design data files that contain the data to be used in the HELP model simulation. Six files must be specified to run HELP model. The input data files required are a precipitation data file, a temperature data file, a solar radiation data file, an evapotranspiration data file, and a soil and design data file; and for output, the HELP model requires one file on which the results are to be written.

The user must enter the file names without extension since the HELP model recognizes the following extensions for the various types of files:

.D4 for precipitation data

.D7 for temperature data

.D11 for evapotranspiration data

.D13 for solar radiation data

.D10 for soil and design data

.OUT for the output

When the program initially displays the "Execution Files - File Management" screen, the program lists the default directory name in each cell in the directory column and the file names of each type of data that were used in the last simulation. The user should enter the directory, if different than the default directory, for each type of file. If an invalid directory is entered, the program displays the message "Invalid Directory" and replaces the directory with the default directory. If user enters a file name that could not be found on the specified directory, then the program displays the message "File Not Found" and erases the file name.

As shown in Figure 18, the user may obtain a list of all files that reside on the current directory by pressing ***F4***. When the user presses ***F4***, the program obtains a directory of all files that pertain to the type of file at the cell where ***F4*** was pressed. For example, if ***F4*** was pressed from the temperature file cell, the program will display the list of files with extension D7 that reside on the current directory displayed in temperature file row. Up to 120 data files for any file type can be displayed on a separate screen. The name of the current directory where these files are located is also displayed. The user can obtain the list of data files with the same extension that are available in another valid

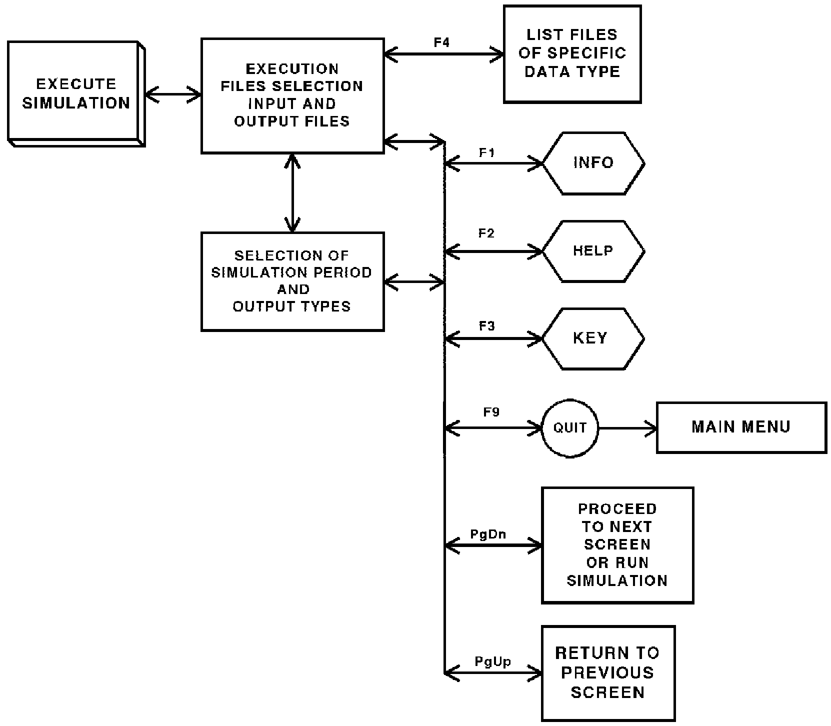

Figure 18. Schematic of "Execute Simulation" Option

directory by entering the name of that directory in the column labeled DIRECTORY and on the same row as the file type of interest.

To select a file from the list of displayed files, move the cursor to the file and select it by pressing ***Enter***. This transfers control back to the previous screen and the name of the file just selected will be displayed in the proper cell. The user can exit the list-of-files screen without selecting a file by pressing the ***Esc*** key.

Once file names have been selected, the user can proceed to the next screen of the execution module by pressing ***Page Down*** or ***F10***. If the output file already exists, the user is prompted with a warning indicating that this file already exists. The program then asks whether the file should be overwritten. If the user answers "N", the program moves the cursor to the output file name cell so that the user can enter a new file name. If the user answers "Y", the program proceeds to the "Output Selection" screen. Before displaying the next screen, the program reads the weather data files to determine the maximum allowable simulation period.

Output Selection

On this screen, the user selects the units of the HELP model output, the number of years to simulate, and the output frequency. The user may use a maximum of 100 years of simulation provided that weather data are available for that many years. If the weather data in the selected files have a different number of years, the HELP model allows the simulation period to be no larger than the minimum number of years available in any of the daily weather data files. If the simulation period selected is smaller than the maximum allowable period, the program will use the years of weather data starting at the top of the files.

The rest of the information available on this screen is for selecting the type of optional output desired (daily, monthly or annual). The user may select any, all or none of the available options. The program will always write the summary output to the output file as well as a description of the input data. In order to select additional or different output frequencies, move the cursor to the desired output frequency and type "Y". Once all execution files and output frequency data are selected, the user should press ***Page Down*** or ***F10*** to start the simulation. To move back to the "Execution Files" screen, press ***Page Up***.

4.8 VIEWING RESULTS

Option 4 on the main menu is to view the results of execution. This option is used to browse through the output file before printing. Figure 19 is a schematic of this option. The program displays the "View Results" screen. The user should enter the desired directory and file name. The file name can be selected from a list of files by pressing ***F4***. After selecting the file, press ***Page Down*** or ***F10*** to display the selected file. The viewing function uses the LIST program written by Vernon D. Buerg and instructions on its use are available on screen by typing ***?*** or ***F1***. To display other types of files, first enter the extension of the file of interest, then the directory and the file name. To return to the main menu, press ***Page Down*** or ***F10***.

4.9 PRINTING RESULTS

Option 5 on the main menu is used to print the output file. Figure 20 is a schematic of this option. The program displays the "Print Results" screen. The user should enter the desired directory and file name. The file name can be selected from a list of files by pressing ***F4***. After selecting the file, press ***Page Down*** or ***F10*** to print the selected file. The print function uses the DOS PRINT command and instructions on its use are available in a DOS manual. The output file is 80 characters wide for all output options except daily output, which can be up to 132 characters wide. When printing output with daily results, it may be necessary to select a compressed font on your printer before printing to avoid wrapping or loss of output.

To print other types of files, first enter the extension of the file of interest, then the directory and the file name. To return to the main menu, press ***Page Down*** or ***F10***. Alternatively, the output file or any data file, which are ASCII text files, could be imported into other software such as word processors and printed in the format desired.

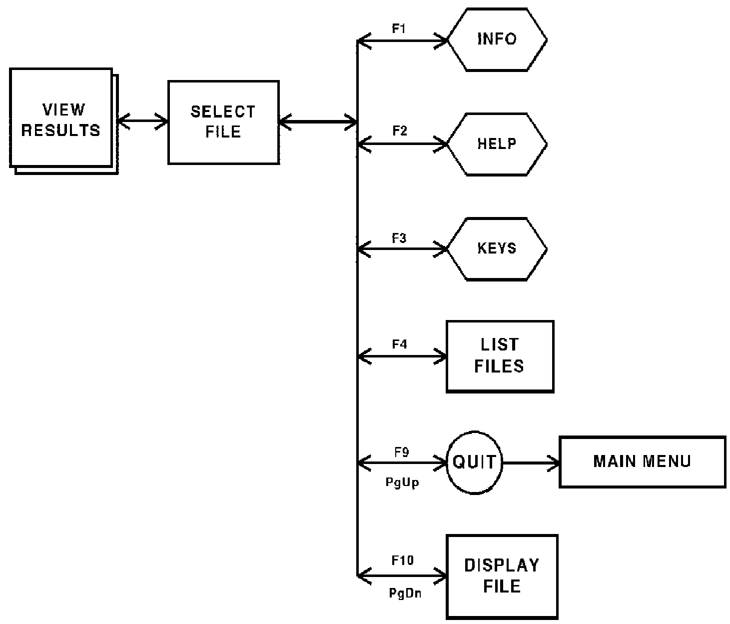

Figure 19. Schematic of "View Results" Option

Similarly, the output, in total or part, can be printed within the Viewing Option using the LIST program and blocking sections to be printed.

4.10 DISPLAYING GUIDANCE

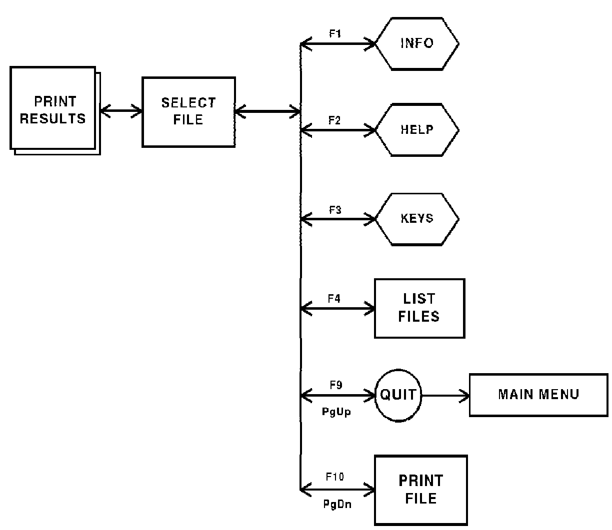

Figure 20. Schematic of "Print Results" Option

On-line help is provided throughout the program. However, option 6 on the main menu gives an overview of the HELP program, as well as, general criteria for landfill design and guidance on using the model. Most of this user guide is displayed in this option and the guidance refers to figures and tables in this guide. In addition, the on-line guidance uses the same section numbering as this guide.

4.11 QUITTING HELP

Option 7 on the main menu is to quit the HELP program and return to DOS.

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APPENDIX A

CALCULATING SOIL, WASTE AND MATERIAL PROPERTIES

A.1 BACKGROUND

The HELP program requires values for the total porosity, field capacity, wilting point, and saturated hydraulic conductivity of each layer of soil, waste, or other material in a landfill profile. These values can be selected from a list of default materials provided by the HELP program (Table 4) or specified by the user. User-specified values can be measured, estimated, or calculated using empirical or semi-empirical methods presented in this appendix. Selecting the HELP values from default materials or calculating them based on empirical or semi-empirical techniques are not intended to replace laboratory or field generated data. Default and calculated values are suitable for planning purposes, parametric studies, and design comparisons, but are not recommended for accurate water balance predictions. The default and calculated values are for water retention and flow; therefore, leachate is assumed to behave the same as water. The effects of macropores resulting from poor construction practices, burrowing animals, desiccation cracks, etc. are not taken into account in the calculation of the properties or in the default values, but the saturated hydraulic conductivity of the surface soil described by the default values is modified for grassy vegetation.

A.2 EMPIRICAL METHOD

The empirical method for calculating HELP program user-defined values employs empirical equations reported by Brakensiek et al. (1984) and Springer and Lane (1987) to determine soil water retention parameters (field capacity and wilting point) and an empirical equation developed by Kozeny-Carman to determine saturated hydraulic conductivity. The total porosity and percent sand, silt, and clay of each layer is the minimum data required to calculate user-defined values using this method.

A.2.1 Total Porosity

Total porosity is a measure of the volume of void (water and air) space in the bulk volume of porous media. At 100 percent saturation, total porosity is equivalent to the volumetric water content of the media (volume of water per total volume of media) or

$$Total\ Porosity = \frac{Water\ Volume}{Total\ Volume} \tag{A-1}$$

Total porosity can be calculated by developing a solid, liquid, and air phase relationship of each layer. This relationship can be calculated using the water content (on a weight basis) and density (wet or dry) of a sample. Introductory geotechnical engineering textbooks such as Holtz and Kovacs (1981) and Perloff and Baron (1976) provide detail guidance for determining phase relationships. Total porosity is also related to void ratio (ratio of void volume to solid volume) by the following equation:

$$\textit{Total Porosity} = \frac{\textit{Void Ratio}}{1 + \textit{Void Ratio}} \tag{A-2}$$

A.2.2 Soil-Water Retention

Field capacity is the volumetric water content of a soil or waste layer at a capillary pressure of 0.33 bars. Field capacity is also referred to as the volumetric water content of a soil remaining following a prolonged period of gravity drainage. Wilting point is the volumetric water content of a soil or waste layer at a capillary pressure of 15 bars. Wilting point is also referred to as the lowest volumetric water content that can be achieved by plant transpiration. The general relation among soil moisture retention parameters and soil texture class is shown below.

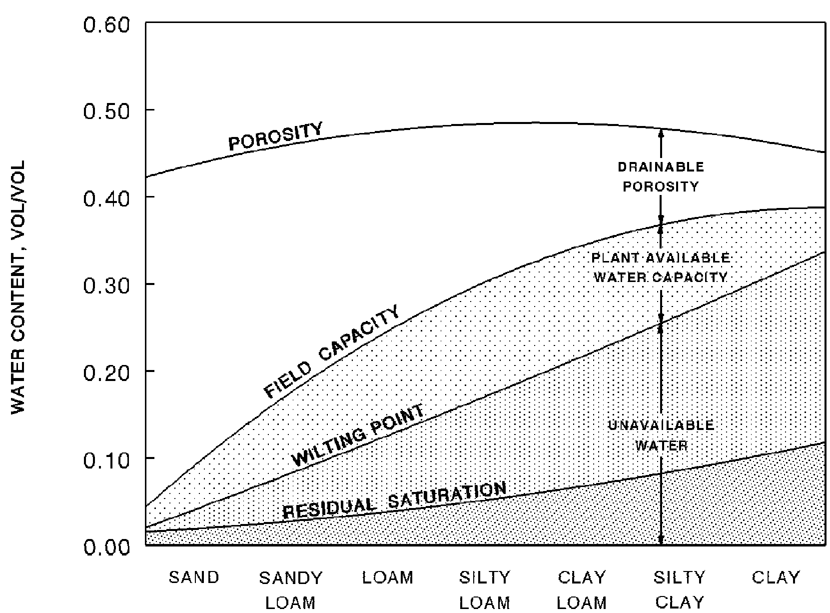

Figure A-21. General Relation Among Soil Moisture Retention Properties and Soil Texture Class

Brakensiek et al. (1984) and Springer and Lane (1987) reported the following empirical equations, which were developed using data from natural soils with a wide range of sand (5-70 percent) and clay (5-60 percent) content:

$$\textit{Field Capacity} = 0.1535 - (0.0018)(\%\ Sand) + (0.0039)(\%\ Clay) + (0.1943)(Total\ Porosity) \quad \text{(A-3)}$$

$$\textit{Wilting Point} = 0.0370 - (0.0004)(\%\ Sand) + (0.0044)(\%\ Clay) + (0.0482)(Total\ Porosity) \quad \text{(A-4)}$$

Sand and clay percentages should be determined using a grain size distribution chart and particle sizes defined by the U.S. Department of Agriculture textural soil classification system. According to this system, sand particles range in size from 0.05 mm to 2.0 mm, silt particles from 0.002 mm to 0.05 mm, and clay particles are less than 0.002 mm.

Numerous other equations relating field capacity and wilting point to soil textural properties have been developed. Most of these equation were developed using site-specific data. However, Gupta and Larson (1979) developed empirical equations for field capacity and wilting point using data from separate and mixed samples of dredged sediment and soil from 10 geographic locations in eastern and central United States. Rawls and Brakensiek (1982) and Rawls et al. (1982) also developed empirical equations by fitting the Brooks and Corey's (1964) soil water retention equation to soil water retention and matrix potential data from 500 natural soils in 18 states. Rawls' (1982) equations are not applicable to soils subjected to compactive efforts.

Williams et al. (1992) concluded that equations used to predict water contents based on texture and bulk density alone provided poorer estimates of water content, with large errors at some capillary pressures, in comparison with models that incorporate even one known value of water content. HELP users generally do not have adequate information to use models that require unsaturated water content information; therefore, Equations A-3 and A-4 are used to calculate the water retention of soil and waste layers.

A.2.3 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (sometimes referred to as the coefficient of permeability) is used as a constant in Darcy's law governing flow through porous media. Hydraulic conductivity is a function of media properties, such as the particle size, void ratio, composition, fabric and degree of saturation, and the kinematic viscosity of the fluid moving through the media. Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g. water). Permeability, unlike saturated hydraulic conductivity, is solely a function of media properties. Henri Darcy's experiments resulted in the following equation for hydraulic conductivity (Freeze and Cherry, 1979):

$$K = \left(\frac{g}{\nu}\right) C\ d^2 \tag{A-5}$$

where

- $\boldsymbol{K}$ = hydraulic conductivity, cm/sec
- $\boldsymbol{g}$ = acceleration due to gravity, 981 cm/sec^2
- υ = kinematic viscosity of water, 1.14 x 10^{-2} cm^2/sec at 15°C
- $\boldsymbol{C}$ = proportionality constant, replaced in Equation A-6 by a function of the porosity
- $\boldsymbol{d}$ = particle diameter, cm, approximated for nonuniform particles by Equation A-7

Darcy's proportionality constant is dependent on the shape and packing of the soil grains (Freeze and Cherry, 1979). Since porosity represents an integrated measure of the packing arrangement in a porous media, the following semi-empirical, uniform pore-size equation relating Darcy's proportionality constant and porosity was developed by Kozeny-Carman (Freeze and Cherry, 1979):

$$K_s = \left(\frac{g}{\nu}\right)\left[\frac{n^3}{(1-n)^2}\right]\left(\frac{d_g^2}{1.80\times 10^4}\right) \tag{A-6}$$

where

- $\boldsymbol{K_s}$ = saturated hydraulic conductivity, cm/sec
- $\boldsymbol{g}$ = acceleration due to gravity = 981 cm/sec^2
- υ = kinematic viscosity of water, 1.14 x 10^{-2} cm^2/sec at 15°C
- $\boldsymbol{n}$ = total porosity
- $\boldsymbol{d_g}$ = geometric mean soil particle diameter, mm, computed by Equation A-7

The original Kozeny equation was obtained from a theoretical derivation of Darcy's Law where the porous media was treated as a bundle of capillary tubes (Bear 1972). Carman introduced an empirical coefficient to Kozeny's equation to produce the semi-empirical Kozeny-Carman equation (Brutsaert 1967). The Kozeny-Carman's equation reported in Freeze and Cherry (1979) was altered to allow the mean particle size to be entered in millimeters.

Freeze and Cherry (1979) indicated that the particle diameter of a non-uniform soil can be described using a mean particle size diameter. Shirazi and Boersma (1984) indicated that geometric rather than arithmetic statistical properties are advocated for describing soil samples. The reason, in part, is that there is a wide range of particle sizes in a natural soil sample making the geometric scale much more suitable than the arithmetic scale. Therefore, the mean particle diameter in Kozeny-Carman's equation reported in Freeze and Cherry (1979) was identified as the geometric mean soil particle diameter.

Shirazi et al. (1988) and Shiozawa and Campbell (1991) indicated that bimodal models describe particle grain size curves more accurately than unimodal models. However, analysis performed by Shiozawa and Campbell (1991) on six Washington state soils exhibiting varying sand, silt, and clay fractions indicated that the unimodal model accurately predicted the geometric mean soil particle diameter in all soils tested. Therefore, Shiozawa and Campbell (1991) developed an equation for geometric mean soil particle diameter by using the unimodal model developed by Shirazi and Boersma (1984); using geometric mean particles sizes based on the USDA classification system, as recommended by Shirazi, et al. (1988); and assuming that the soil was composed entirely of clay, silt, and sand. Shiozawa and Campbell's (1991) equation was altered to relate percent silt and clay to the particle diameter; resulting in the following equation:

$$d_g = \exp\left[-1.151 - 0.07713\,(\%\ Clay) - 0.03454\,(\%\ Silt)\right] \qquad \text{(A-7)}$$

where

d_g = geometric mean soil particle diameter, mm

Percent silt and clay should be determined using a grain size distribution chart and grain sizes defined by the U.S. Department of Agriculture (USDA) textural soil classification system (see para A.2.2).

Kozeny-Carman's equation coupled with Shiozuwa and Campbell's equation for mean diameter was applied to soils data provided by Lane and Washburn (1946). These data included void ratio and grain size distribution curves for three soils composed of differing degrees of silt and sand. The saturated hydraulic conductivity predicted by Kozeny-Carman's equation was compared with laboratory data provided by Lane and Washburn (1946). This comparison indicated that Kozeny-Carman's saturated hydraulic conductivity equation coupled with Shiozuwa and Campbell's mean diameter equation can overpredict measured values by one to two orders of magnitude. Although conservative, these results reemphasize the fact that semi-empirical equations are not meant to replace laboratory or field measured data.

Numerous other empirical equations, with limited application, have been developed to estimate saturated hydraulic conductivity from the physical properties of soils. For example, Freeze and Cherry (1979), Holtz and Kovacs (1981), and Lambe and Whitman (1969) presented various forms of Allen Hazen's equation for determining the saturated hydraulic conductivity of silt, sand, and gravel soils. Rawls and Brakensiek (1985) also presented an equation for determining the saturated hydraulic conductivity of soils with varying degrees of sand (5-70 percent) and clay (5-60 percent).

A.3 SEMI-EMPIRICAL METHOD

The semi-empirical method for determining the HELP program user-defined values employs a theoretical equation developed by Brooks and Corey (1964) to determine soil-water retention parameters (field capacity and wilting point) and a semi-empirical equation developed by Brutsaert (1967) and Rawls et al. (1982) to calculate saturated hydraulic conductivity. The total porosity, residual volumetric water content, pore-size distribution index, and bubbling pressure of each layer are the minimum data required to calculate the user-defined values for this method. As previously mentioned, total porosity can be calculated using Equation A-1 or A-2.

A.3.1 Soil-Water Retention

The HELP program does not allow the user to define the Brooks-Corey parameters (residual volumetric water content, pore-size distribution index, and bubbling pressure) of the soil, waste, or barrier layers; therefore, if these data are available, the user must first calculate field capacity and wilting point using Brooks and Corey's (1964) water retention equation:

$$\frac{\theta - \theta_r}{\phi - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda} \qquad \text{(A-8)}$$

where

θ = volumetric water content (field capacity or wilting point), unitless

θ_r = residual saturation volumetric water content, unitless

ϕ = total porosity, unitless

λ = pore-size distribution index, unitless

ψ = capillary pressure, bars (at field capacity, 0.33, or wilting point, 15.0)

ψ_b = bubbling pressure, bars

The volumetric water content in Equation A-8 is, by definition, equivalent to field capacity at a capillary pressure of 0.33 bar and is equivalent to wilting point at a capillary pressure of 15 bars. The HELP program will use the calculated field capacity and wilting point values to recalculate the Brooks-Corey parameters; however, because the program estimates the residual saturation water content from the wilting point before using Equation A-8 to calculate the other Brooks-Corey parameters, the program values will differ slightly from the laboratory data.

A.3.2 Saturated Hydraulic Conductivity

Brutsaert (1967) derived a saturated hydraulic conductivity relation by substituting Brooks-Corey's water retention equation into the Childs and Collis-George (1950) series-parallel coefficient of permeability integral. Rawls et al. (1982 and 1983) presented the following form of Brutsaert's (1967) equation:

$$K_s = a \frac{(\phi - \theta_r)^2}{(\psi_b)^2} \frac{\lambda^2}{(\lambda + 1)(\lambda + 2)} \tag{A-9}$$

where

K_s = saturated hydraulic conductivity, cm/sec

a = constant representing the effects of various fluid constants and gravity, 21 cm^3/sec

ϕ = total porosity, unitless

θ_r = residual volumetric water content, unitless

ψ_b = bubbling pressure, cm

λ = pore-size distribution index, unitless

Childs and Collis-George's (1950) series-parallel coefficient of permeability model assumes that the porous media is equivalent to a number of parallel portions each with a different hydraulic conductivity and each with uniform pore size. The hydraulic conductivity of each portion is obtained from the assumption of a bundle of capillary tubes parallel to the direction of flow. The media is fractured at a normal plane with two resulting faces, which are then rejoined after some random displacement (Brutsaert, 1967).

Rawls et al. (1982) fit Equation A-9 (using geometric mean values for Brooks-Corey parameters) to saturated hydraulic conductivity values from their data base and obtained a good correlation between these and predicted values. Rawls et al. (1982) and Rawls et al. (1983) subsequently recommended using an "a" constant of 21 cm/sec. However, Rawls et al. (1982) fit Equation A-9 to data presented by other researchers and obtained saturated hydraulic conductivities that overpredicted the data by three to four times. Although conservative, these results re-emphasize the fact that empirical equations are not meant to replace laboratory or field measured data.

A.4 VEGETATED, SATURATED HYDRAULIC CONDUCTIVITY

If the saturated hydraulic conductivity of a soil or waste layer is not selected from the HELP default data base, the program will not adjust the saturated hydraulic conductivity to account for root penetration by surface vegetation. Therefore, the user must adjust the saturated hydraulic conductivity in the top half of the evaporative zone. The program adjusts the default values using the following equation developed by regressing changes in infiltration resulting from vegetation.

$$(K_s)_v = [1.0 + 0.5966\ (LAI) + 0.132659\ (LAI)^2 + 0.1123454\ (LAI)^3 - 0.04777627\ (LAI)^4 + 0.004325035\ (LAI)^5]\ (K_s) \qquad \text{(A-10)}$$

where

$(K_s)_v$ = vegetated saturated hydraulic conductivity in top half of evaporative zone, cm/sec

LAI = leaf area index, unitless

K_s = unvegetated saturated hydraulic conductivity in top half of evaporative zone, cm/sec

A.5 CONCLUSIONS

The HELP program user-defined values for total porosity, field capacity, wilting point, and saturated hydraulic conductivity can be conservatively calculated using empirical or semi-empirical methods presented in this appendix. Total porosity, percent sand, silt and clay, and particle diameter are the minimum data required to calculate user-defined values using the empirical method. Total porosity and Brooks-Corey parameters are the minimum data required for the semi-empirical method. Where available, comparisons with measured values re-emphasized the fact that neither of these methods is intended to replace laboratory or field generated data.

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