C.8 LCRS FLOW CAPACITY AND PUMP SIZING

LCRS Flow Capacity and Pump Sizing

Purpose:

1. Determine the potential flow rate into the leachate collection and removal sumps.

2. Size the flow elements (geonets, pipes, and gravel) and pumps to handle the projected flows.

3 Determine most effective method and pump requirements for run-off flows

Method:

1. Identify flow sources. The single largest source of liquid entering the sumps will be from infiltration when the cell has been completed but only the 2 foot thick select waste layer has been placed.

2. The design will assume the 25 year-24 hour storm event occurs just after placement of the select waste layer.

3. An infiltration factor will be selected.

4. The quantity of run-off will be calculated. Methods for handling run-off (which shall be considered hazardous waste) will be identified.

5. The quantity of infiltration, and the resultant flow to the sumps will be calculated. The sump flow elements will be sized to handle that flow. Pumps capable of evacuating that flow from the sumps will be identified.

Summary

1. 25 Year-24 Hour storm yields 2 inches of precipitation

2. Infiltration flow is controlled by unsaturated flow.

3. The maximum LCRS flow is 2 gallons per minute.

4. The geonet has insufficient capacity for the maximum infiltration flow and must be supplemented by 3 inch diameter slotted pipes (see layout in Figure 3).

5. In run-off systems must be able to store up to171,000 gallons of water, or be capable of pumping up to 100 gpm, if only a nominal impoundment is desired.

6. The maximum requirement for out of cell capacity is 300,000 gallons, assuming no measures to reduce contact between precipitation and waste are utilized.

Analysis:

Hydrology

1. The critical period for sizing the leachate collection system (i.e., when the greatest flow is likely to occur) is directly after placement of the 2 foot thick layer of select

LCRS Flow Capacity and Pump Sizing

waste over the bottom. The quantity of infiltration reaching the LCRS through the waste will be the greatest at this point, although all water touching the waste will be considered leachate. During the construction period precipitation will be impounded within the cell, removed and discharged to the existing channels.

2. Figure 1 shows the configuration of Cell 12. Each phase of the cell is indicated along with slope, bottom, and total catchment areas. Cell 12C includes the top deck area where Cell 12 adjoins Cell 11.

3. The 25 year-24 hour storm yields 2 inches of precipitation (Reference 1A). The working deck is assumed to be well compacted by heavy equipment running over its surface, yielding a relatively high run-off curve number. Since the characteristics of the waste soil are unknown at this time assume soil group B (Reference 1A) and an SCS RCN of 85 (Ref 2A). Further assume run-off from the slopes (with the sacrificial liner) is intercepted and directed to run-off collection tanks/ponds. Table 1, below, shows the distribution for precipitation falling on the floor only:

Table 1

Cell	Area (ac)	Precipitation (ac-ft)	Run-off (ac-ft)	Infiltration (ac-ft)
12A	2.36	0.39	0.16	0.24
12B	1.81	0.30	0.12	0.18
12C	1.46	0.24	0.10	0.15

LCRS Infiltration:

1. No allowance is made for evaporation, and all infiltration will be routed through the LCRS system. This provides a conservative total volume for the system design.

2. Sandy soils, assumed to comprise the 2 foot protective layer, have a wide range of porosities and moisture retention values. Typical values are taken from the HELP model literature (Reference 3A) as being conservative representations of this soil. The values are:

Soil Type	SC
Hydraulic Conductivity	1.2×10^{-4} cm/s
Porosity	0.398
Field Capacity	0.244
Wilting Point	0.136

3. For the largest infiltration case, Cell 12A, there is 0.24 ac-ft, or nearly 80,000 gallons, of infiltration. It is necessary to determine whether saturated or unsaturated flow conditions control drainage into the LCRS. It is assumed that the soil layer contains, at most, sufficient moisture to be at field capacity (i.e., no gravity drainage is initially occuring within the soil). A 2 foot thick layer of soil of unit area therefore has an available pore space of approximately:

$$2\,ft^3 \times 7.48\frac{gal}{ft^3} \times (0.398 - 0.244) = 2.3\,gal/ft^2$$

LCRS Flow Capacity and Pump Sizing

4. The rate at which the storm saturates the soil layer is given by:

$$0.24\text{ac}-\text{ft}\times\frac{1}{2.36\text{ac}}\times 7.48\frac{\text{gal}}{\text{ft}^3}\times\frac{1\text{day}}{1440\text{min}}\cong\frac{1\text{gal}}{1850\text{min}}$$

It would require nearly three days of steady rain at this rate to saturate the 2 foot soil layer assuming no simultaneous drainage occured. Conversely, only 34 percent of the available pore space is filled. Therefore unsaturated flow controls drainage from the 2 foot soil layer. Laminar flow through a porous media is estimated by:

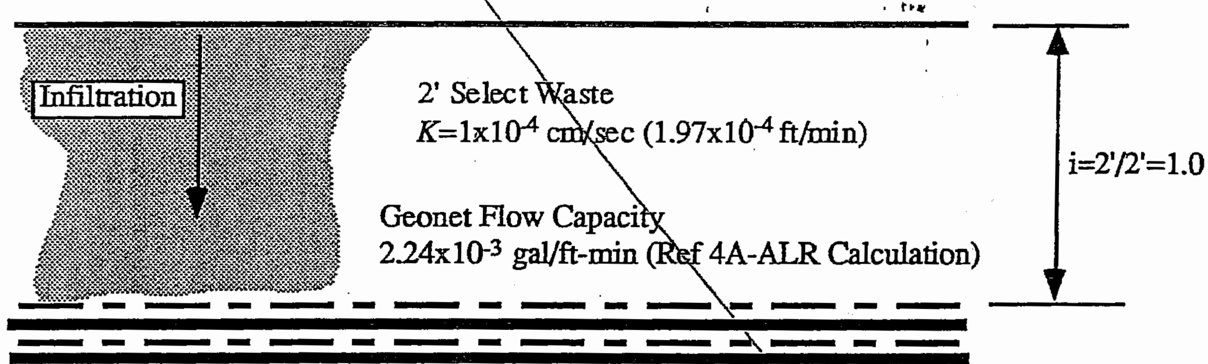
$$Q = Kia \qquad (1)$$

Where:

Where:	Q	Flow (ft^3/min)
	K	Hydraulic Conductivity (ft/min)
	i	gradient
	a	flow area (ft^2)

for the unsaturated case unsaturated hydraulic conductivity, K_u, replaces K.

5. The unit flow parameters are shown in Figure 2 below:



6 Unsaturated hydraulic conductivity is estimated by Campbell's equation (Reference 3B), definitions for the terms are found in the reference:

$$K_u = K_s\left(\frac{\Theta-\Theta_r}{\phi-\Theta_r}\right)^{3+(\frac{2}{\lambda})}$$

7. The residual water content, Θ_r, is the amount of water remaining in the soil pores under infinite capillary suction. Residual water content is calculated by Rawls (Reference 3C) as follows:

$$\Theta_r = 0.014 + .25WP; WP \geq 0.04$$

LCRS Flow Capacity and Pump Sizing

Where WP is wilting point, which for the designated soil is 0.136>0.04. Therefore the equation is applicable. The residual water content is then:

$$\Theta_r = 0.048$$

8. As discussed in the reference, residual water content and the pore-size distribution index, λ, are constants in the Brooks-Corey equation relating volumetric content to matrix potential (capillary pressure and adsorptive forces, Reference 3D):

$$\frac{\Theta - \Theta_r}{\phi - \Theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda}$$

9. This equation is solved assuming the volumetric water content is the field capacity, at 0.33 bars of capillary suction, ψ, and then the wilting point, at 15 bars capillary suction. Solving simutaneously yields both the pore size distribution index and bubbling pressure. Solving for the values assumed for the site soil yields the following:

Constants:

Θr	0.048			
φ	0.398			
Variables	Θ	ψ	**Θ–Θr/φ–Θr**	**(ψb/ψ)λ**
Field Capacity	0.244	0.33	0.56	0.56
Wilting Point	0.136	15	0.25	0.25
Solved Values				
ψb	0.021			
λ	0.210			

10. Since only 34 percent of the available pore space was filled by infiltration the volumetric water content is:

$$\Theta = FC + 0.34(\phi - FC)$$
$$\Theta = 0.244 + 0.34(0.398 - 0.244)$$
$$\Theta = 0.296$$

11. Based on this calculation the unsaturated hydraulic conductivity is calculated from the following using Campbell's equation:

$$K_u = 1\times10^{-4}\frac{\text{cm}}{\text{sec}}\left(\frac{0.296-0.048}{0.398-.048}\right)^{\left(3+\left(\frac{2}{0.210}\right)\right)}$$

$$K_u = 1.361\times10^{-6}\frac{\text{cm}}{\text{sec}} = 2.68\times10^{-6}\frac{\text{ft}}{\text{min}}$$

LCRS Flow Capacity and Pump Sizing

Previous Calc

12. Conservatively using a unit hydraulic gradient and assuming no evaporation, the rate at which the infiltration drains from the 2 foot layer into a unit area of the LCRS is:

$$q=\left(2.68\times10^{-6}\frac{\text{ft}}{\text{min}}\right)(1.0)=2.68\times10^{-6}\frac{\text{ft}^3}{\text{ft}^2-\text{min}}$$

$$q=2.68\times10^{-6}\frac{\text{ft}^3}{\text{ft}^2-\text{min}}\left(7.48\frac{\text{gal}}{\text{ft}^3}\right)=2.00\times10^{-5}\frac{\text{gal}}{\text{ft}^2-\text{min}}$$

Drainage over the entire 2.36 acre cell is then:

$$Q=\left(2.00\times10^{-5}\frac{\text{gal}}{\text{ft}^2-\text{min}}\right)(2.36\text{ac})\left(\frac{43{,}560\text{ft}^2}{\text{ac}}\right)$$

$$Q=\frac{2.06\text{gal}}{\text{min}}$$

13. To accomodate this flow into the LCRS the geonet must have a minimum perimeter of 2.06/2.24x10^{-3}=919 feet. Since providing this much flow capacity with geocomposite alone is infeasible a pipe system will be provided to improve drainage characteristics into the LCRS sumps.

14. A single 3 inch diameter corrugated polyethylene pipe (manning n=0.015) at a slope of 1 percent has a flow capacity of approximately 34 gallons per minute (Reference 5A). This is more than sufficient to accomodate the maximum LCRS flow into the sump. As shown in Figure 3, the pipes will be located in along the grade breaks of the bottom with lateral lines located every 100 feet along the grade break length. The basis for the layout is described below.

15. From the manufacturer's literature 3" diameter pipe comes with slots providing 1.44 in^2 (Reference 5B) of flow area per foot. The orifice equation (Reference 6A) is used to estimate flow into the pipe per foot of length. The orifice equation is as follows:

$$Q=CA\sqrt{2gH}$$

The coefficient C=0.6, g=32.2ft/s^2, and H is assumed to be 1 inch. The calculation is therefore:

$$Q=(0.6)(1.44\text{in}^2)\left(\frac{1\text{ft}^2}{144\text{in}^2}\right)\sqrt{2\left(\frac{32.2\text{ft}}{\text{sec}^2}\right)(1\text{in})\left(\frac{1\text{ft}}{12\text{in}}\right)}$$

$$Q=\frac{0.014\text{ft}^3}{\text{sec}}\left(\frac{7.48\text{gal}}{\text{ft}^3}\right)\left(\frac{60\text{sec}}{\text{min}}\right)=6.2\text{gpm}$$

LCRS Flow Capacity and Pump Sizing

Since this is substantially more than the maximum estimated flow rate, the spacing of laterals is controlled by the flow capacity of the geocomposite. As stated above the geocomposite can accomodate 2.24×10^{-3} gpm per foot of width. Since water percolates into the geocomposite at the rate of 2.00x10-5 gpm per square foot the lateral spacing is calculated as follows:

$$L = \left(2.24 \times 10^{-3} \frac{\text{gal}}{\text{min} - \text{ft}}\right)\left(\frac{\text{min} - \text{ft}^2}{2.00 \times 10^{-5}\,\text{gal}}\right)$$

$$L = 111\text{ft}$$

Use 100 foot spacing for lateral pipes.

16. The LCRS sump is configured as shown in Figure 4. Beginning at the 10 percent slope the sump is filled with clean 1" diameter (nom.) drain rock. To assure unimpeded drainage into the riser the 3" diameter lines will be continued until adjacent to the riser.

17 The LCRS pump must be capable of lifting the leachate vertically approximately 100 feet, the maximum depth of fill above the sump. Head losses in the discharge line are expected to be minimal, allow 5 feet of loss. Minor losses are anticipated to be no more than 20 percent of the subtotaled loss, or approximately 21 feet. Total estimated dynamic head (TDH) is therefore:

$$TDH = 100ft + 5ft + 21ft = 126ft$$

18. Using a factor of safety of 4 for the pump capacity yields 8 gallons per minute. A Protec recipricating pump, Model No. RP-2, with variable speed electric control is recommended (See Reference 7).

<u>Surface Run-Off:</u>

1. During the critical period when waste filling has just started the greatest quantity of run-off is generated by Cell 12A. Approximately 0.16 acre-feet (53,000 gallons) of precipitation runs off the cell bottom. Since the slopes are covered by a sacrificial liner, no infiltration occurs at those surfaces and run-off is equal to the direct precipitation. Since Cell 12A has the largest slope area it is the conservative case. If a gutter system is not used another 0.19 acre-feet (61,000 gallons) runs off the slopes. Handling of run-off is an operational consideration. However, two methods are likely 1) directing the run-off to a temporary lined pond; 2) transferring the liquid to a holding tank.

2. If run-off is directed to a temporary holding pond it must have a capacity of:

(53,000 gal+61,000 gal)(1.5)=171,000 gal

LCRS Flow Capacity and Pump Sizing

The value 1.5 is a factor of safety to assure adequate containment capacity. The volume of a regular type pond (frustrum of a pyramid) is found by the following formula (Reference 8A):

$$V = \frac{1}{3}h\left(A_{top} + A_{bot} + \sqrt{A_{top}A_{bot}}\right)$$

Assuming a depth of 5 feet, 80 foot sides, and 2:1 slopes yields a volume of

$$V = \frac{1}{3}(5)\left((80)^2 + (80-20)^2 + \sqrt{(80)^2(80-20)^2}\right)$$

$$V = 24{,}667\text{ft}^3\left(\frac{7.48\text{gal}}{\text{ft}^3}\right) = 185{,}000\text{gal} > 171{,}000\text{gal}$$

During the initial fill stages the bottom of the cell will slope towards the sump. The most likly location for a storage pond would be in the adjacent cell area. A pump system, as described below, would be necessary until the sufficient waste has been deposited to create the desired grade.

3. In the event alternative 2 is chosen a suitable pump must be specified. The peak flow into the sump, or other run-off collection area, can be estimated by the SCS unit hydrograph method (Reference 2B) where:

$$Q_p = \frac{484A}{T_R}$$

Total catchment area, A, is shown in Figure 1 to be 3.49 acres ($5.45\text{x}10^{-3}$ mi^2). A factor of 484 is used, which is likely conservative given the generally flat nature of the catchment slope. T_R is the rising time and is calculated by the following relationship (Reference 2C):

$$T_R = \frac{D}{2} + t_p$$

The duration of the storm event, D, is 24 hours. The lag time, t_p, is found by the following equation (Reference 2D):

$$t_p = \frac{l^{0.8}(S+1)^{0.7}}{1900y^{0.5}}$$

The catchment length, l, is found from Figure 1 to be approximately 450 feet (Cell 12A, east to west). The average catchment slope is 1 percent. The factor S is calculated from the SCS curve number, previously identified as 85. The relationship is
(Reference 2E):

LCRS Flow Capacity and Pump Sizing

$$S = \left(\frac{1000}{CN}\right) - 10 = \left(\frac{1000}{85}\right) - 10 = 1.76$$

This implies the lag time is:

$$t_p = \frac{(450)^{0.8}(1.76+1)^{0.7}}{1900(1)^{0.5}} = 0.14\text{hrs}$$

Given that result, the rising time is calculated to be:

$$T_R = \frac{24}{2} + 0.14 = 12.14\text{hrs}$$

and the peak flow is then:

$$Q_p = \frac{484(5.45\times10^{-3}\text{mi}^2)}{12.14} = 0.22\text{cfs}\left(\frac{449\text{gpm}}{\text{cfs}}\right) = 98\text{gpm}$$

4. To successfully transfer the accumulated water without undo ponding, and thus greater infiltration into the LCRS, a small impoundment (e.g., 10,000-20,000 gallons) and a high capacity pump (e.g. 100 gpm) are required. The pump must be capable of generating sufficient head to lift the water out of the cell and into the desired holding facility. It is assumed the landfill operations staff will size the impoundment and select the necessary pump if this alternative is selected.

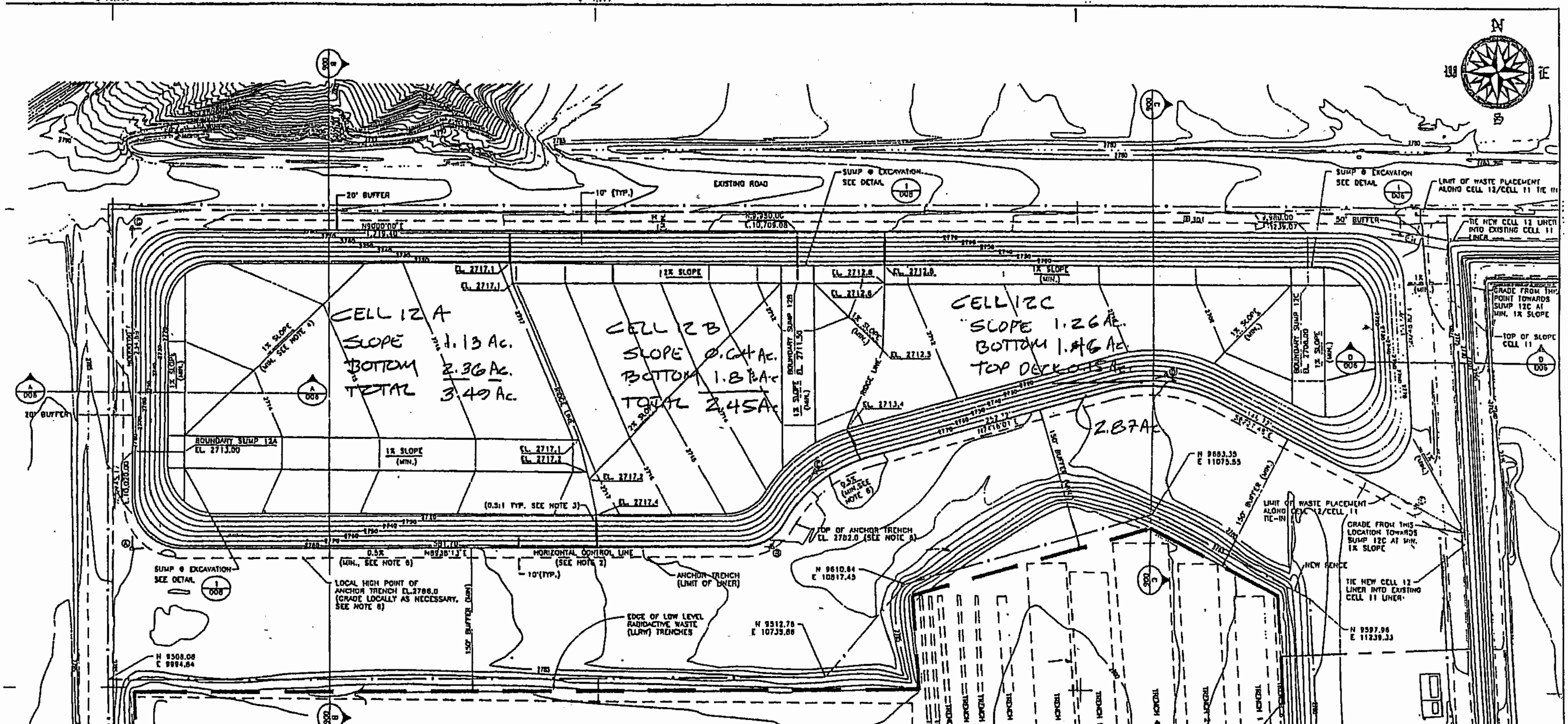
5. Construction of the starter berms, buttress fills and cover system will begin once waste filling is within 3 feet of the top of the excavation slope. The maximum waste area of (8.9 acres) within the horizontal control line (Figure 1) is potentially exposed to precipitation. As a conservative estimate it is assumed no exposure reduction measures are implemented, and the maximum run-off volume is contact water (i.e., has contacted waste).

6. The maximum volume of contact run-off is 198,282 gallons. The three foot freeboard around the facility is sufficient to contain this liquid on the surface of the fill. Should it be necessary to transfer the water out of the cell approximately 300,000 gallons of capacity is required (with a 50 percent factor of safety).

~85'

1 : 0.5 — 2 MIDHEIGHT PERIMETER (MHP)

85' × MHP = SLOPE AREA



NOTES:

1. PLAIN TEXT INDICATES CALLOUTS FROM SOURCE DOCUMENT, ITALIC TEXT INDICATES CALLOUTS FROM ENVIRONMENTAL SOLUTIONS, INC.
2. THE HORIZONTAL CONTROL LINE IS ESTABLISHED BY THE OFFSETS (BUFFERS) INCLUDED ON THE REFERENCE DRAWING (NV-148-TRE-003). THE H.C.L. IS THE LIMIT OF WASTE PLACEMENT ON THE NORTH, SOUTH AND WEST SIDES OF CELL 12.
3. ALL SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e. THE HORIZONTAL CONTROL LINE).
4. THE MAXIMUM BOTTOM SLOPE, TOWARDS THE SUMPS IS 1%, THEREFORE SLOPE BREAKS ARE USED TO CONTROL BOTTOM GRADING.
5. CONTRACTOR SHALL PROVIDE A DETAILED SURVEY CONTROL PLAN FOR APPROVAL, BASED ON THE HORIZONTAL CONTROL PRIOR TO COMMENCING WORK.
6. PROVIDE LOCAL GRADING AS NECESSARY TO ESTABLISH MINIMUM ANCHOR TRENCH FLOWLINES, WHICH ARE REQUIRED FOR THE COVER SYSTEM DRAIN PIPE (SEE SHEET 4).

LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- LIMITS OF COMPLETED TRENCH
- PERMIT LINE
- FENCE LINE
- UNIMPROVED ROAD
- 5' EXISTING CONTOUR INTERVAL, FEET (MSL)
- 1' EXISTING CONTOUR INTERVAL, FEET (MSL)
- SITE COORDINATE SYSTEM MARKER LOCATION IN NORTHING AND EASTING
- • 302 MONITOR WELL LOCATION AND NUMBER

50 25 0 50
SCALE FEET

DATE OF AERIAL TOPOGRAPHY: JUNE 1994

SURVEY CONTROL TABLE

CURVE	COORDINATES		RADIUS	LENGTH	TANGENT	DELTA
A	N 9,844.99	E 10,020.00	50.00'	78.88'	50.32'	90°21'42"
B	N 9,849.16	E 10,660.78	50.00'	52.05'	28.88'	59°38'42"
C	N 9,226.83	E 10,725.59	150.00'	115.91'	61.02'	44°16'25"
D	N 9,829.88	E 11,090.66	150.00'	113.28'	59.49'	43°16'11"
E	N 9,893.93	E 11,351.04	50.00'	105.02'	87.21'	120°20'44"
F	N 9,980.00	E 11,337.00	50.00'	76.09'	47.81'	87°11'28"
G	N 9,980.00	E 10,020.00	50.00'	78.54'	50.00'	90°00'00"

Rev	Drawn	Check	Appr	Date	Description
3	DKK			5/95	REVISION OF CELL 12 ABOVE GRADE
2	DKK	JCS	SDD	10/94	ADDED COORDINATES TO LLRW FENCELINE
1	DKK	JCS	SDD	7/94	SITE TOPO/LLRW CAP REVISED PER SURVEY 8/94

REVISIONS

American Ecology
5333 WESTHEIMER
Suite 1000
Houston, Texas 77056

Reference Drawings
NV-148-TRE-003

BOB JONES

HAZARDOUS WASTE MANAGEMENT FACILITY
U.S. ECOLOGY
BEATTY NEVADA

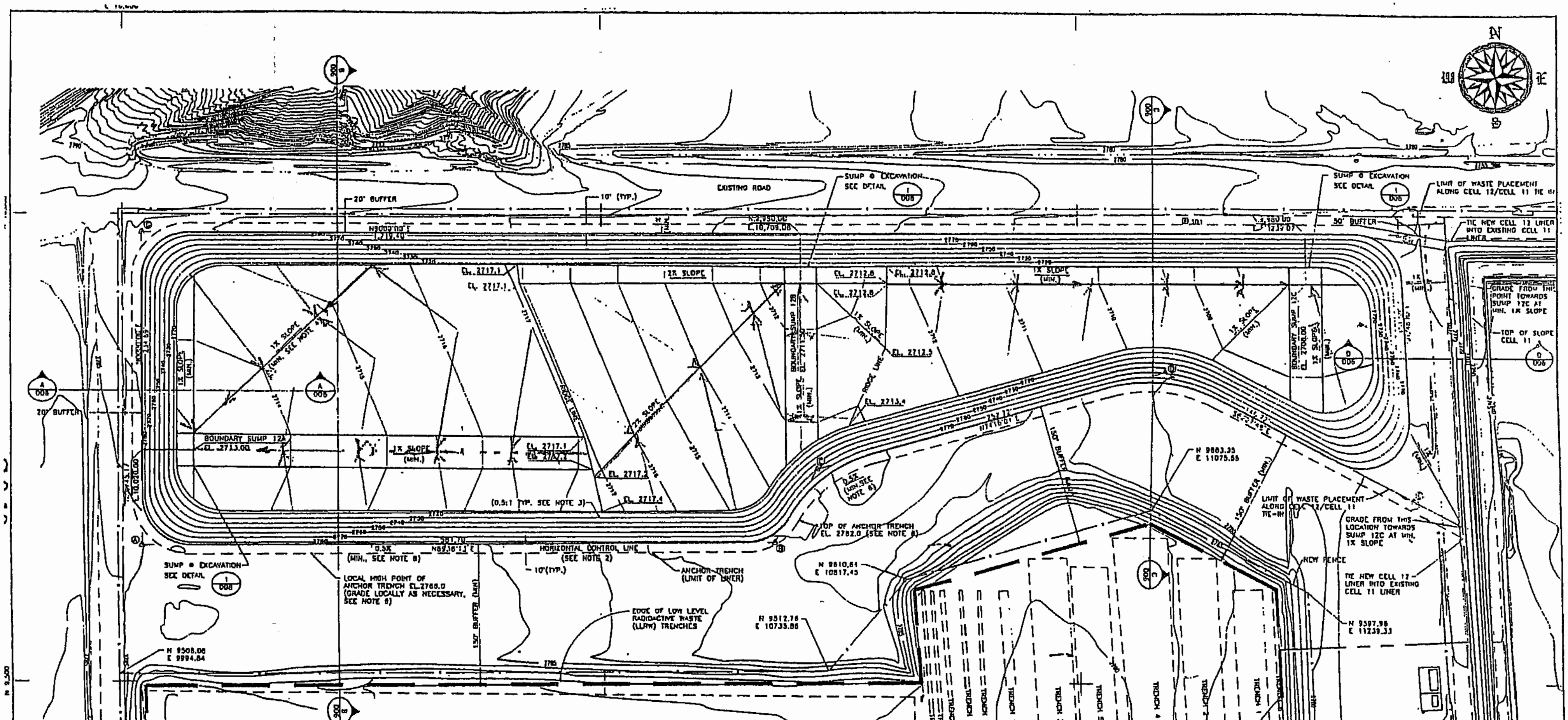
EXCAVATION PLAN AND LIMITS OF GRADING CELL 12

ENVIRONMENTAL SOLUTIONS, INC.

95284 | D-95284-BL003 | 3
AS NOTED

Figure

SHEET 10 of 11



NOTES:

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2. THE HORIZONTAL CONTROL LINE IS ESTABLISHED BY THE OFFSETS (BUFFERS) INCLUDED ON THE REFERENCE DRAWING (HV-148-TRE-003). THE H.C.L. IS THE LIMIT OF WASTE PLACEMENT ON THE NORTH, SOUTH AND WEST SIDES OF CELL 12.
3. ALL SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e. THE HORIZONTAL CONTROL LINE).
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SCALE FEET

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C	N 9,228.83	E 10,725.59	150.00'	115.91'	61.02'	44°16'25"
D	N 9,829.88	E 11,090.88	150.00'	113.28'	59.49'	43°16'11"
E	N 9,883.93	E 11,351.04	80.00'	105.02'	67.21'	120°20'44"
F	N 9,980.00	E 11,337.00	50.00'	76.09'	47.81'	87°11'28"
G	N 9,980.00	E 10,020.00	50.00'	78.54'	50.00'	90°00'00"

Rev	Drawn	Check	Appr	Date	Description
3	DKK			5/95	ADDITION OF CELL 12 ABOVE GRADE
2	DKK	JGS	SDD	10/94	ADDED COORDINATES TO LLRW FENCELINE
1	DKK	JGS	SDD	7/94	SITE TOPO/LLRW CAP REVISED PER SURVEY 6/91

REVISIONS

American Ecology
5333 WESTHEIMER
Suite 1000
Houston, Texas 77056

Reference Drawings
HV-148-TRE-003

DRAWN BY BOB JONES

HAZARDOUS WASTE MANAGEMENT FACILITY
U.S. ECOLOGY

EXCAVATION PLAN AND LIMITS OF GRADING
CELL 12

ENVIRONMENTAL SOLUTIONS, INC.

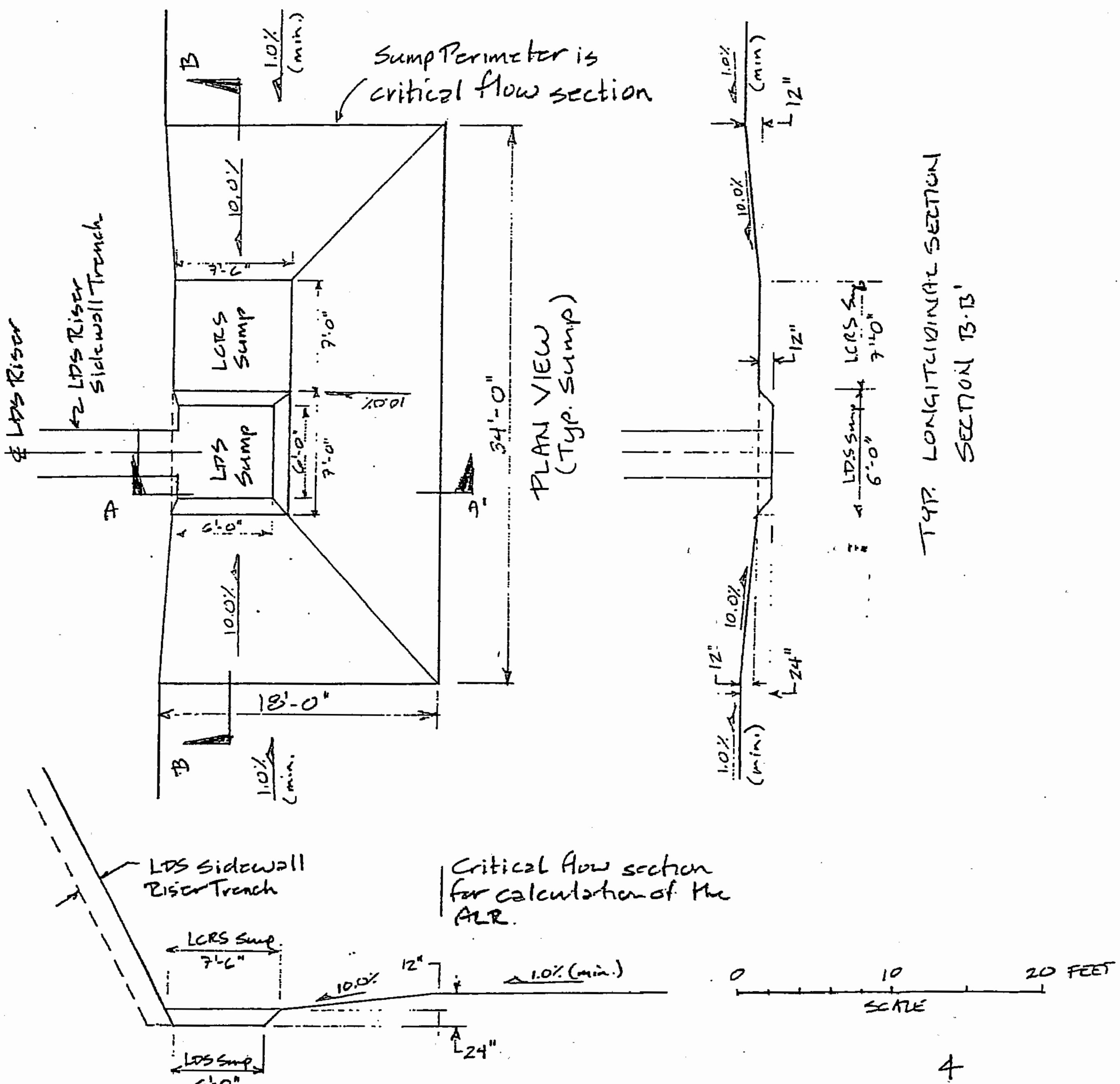
JOB NO. 95284
SCALE AS NOTED
D-95284-BL003
SHEET 3

FIGURE 3

ENVIRONMENTAL SOLUTIONS, INC.

By RVH Date 1/20/96 Subject BEATTY LANDFILL-CELL 12 Sheet No. 11 of 11

Chkd. By LMC Date 1/23/96 AMERICAN ECOLOGY CORP. Proj. No. 95-284



SECTION A-A'

FIGURE ~~2~~ 4

TYPICAL SUMP GEOMETRY

Notes:

1) Liner elements & riser pipes not shown for clarity.

REF 1

SECTION IV.D

LANDFILL REPORT

US ECOLOGY, INC.

BEATTY, NEVADA

REF 1

APPENDIX D

DRAINAGE DIVERSION DITCHES

DESIGN CALCULATIONS

BEATTY RUN-ON CONTROL SYSTEM DESIGN

Drainage Area Characteristics:

1. Drainage area = 1.7 sq. mi.
2. Max. flow length (ℓ) = 21,650 ft.
3. Avg. land slope (γ) = $^{160}/(3.87)\ (5280) = 0.0078 = 0.78\%$
4. Sandy soil, barren land. SCS classifies soils as predominantly hydrological group B with some group A. Therefore, use soil group B and SCS Pasture/Range class with poor hydrologic condition.
5. Use AMC II for worst case.
6. SCS runoff curve No. (RCN) = 79 to account for steps 4 and 5

Compute Time of Concentration (Tc):

$$\text{LAG (L)} = \frac{(\ell)^{.8}\ (S+1)^{.7}}{1900\ (\gamma)^{.5}}$$

$$S = \frac{1000}{RCN} - 10 = \frac{1000}{79} - 10 = 2.66$$

$$L = \frac{(21{,}650)^{.8}\ (3.66)^{.7}}{1900\ (0.78)^{.5}} = 4.35 \text{ hrs.}$$

$$Tc = {}^{L}/0.6 = \frac{4.35}{0.6} = 7.25 \text{ hrs.}$$

Compute Excess Rainfall (Q):

25-yr, 24-hr storm = 2.0 in.

(From NOAA, Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume VII - Nevada)

Q = 0.52 in. for RCN = 79

Compute Peak Flow for 25-yr, 24-hr Rainfall:

Ref: SCS ENGR-20 (Rev. 2)

PK = (D.A.) (Q) (CSM)

CSM = 83 for Tc = 6 hrs, T_t = 0 hrs.
CSM = 72 for Tc = 7.25 hrs by interpolation
CSM = 66 for Tc = 8 hrs, T_t = 0 hrs.

Peak flow = (1.7) (0.52) (72) = **63.65 CFS** ok cfs/sc ?

Hydrology and Floodplain Analysis

Philip B. Bedient • Wayne C. Huber

REF 2

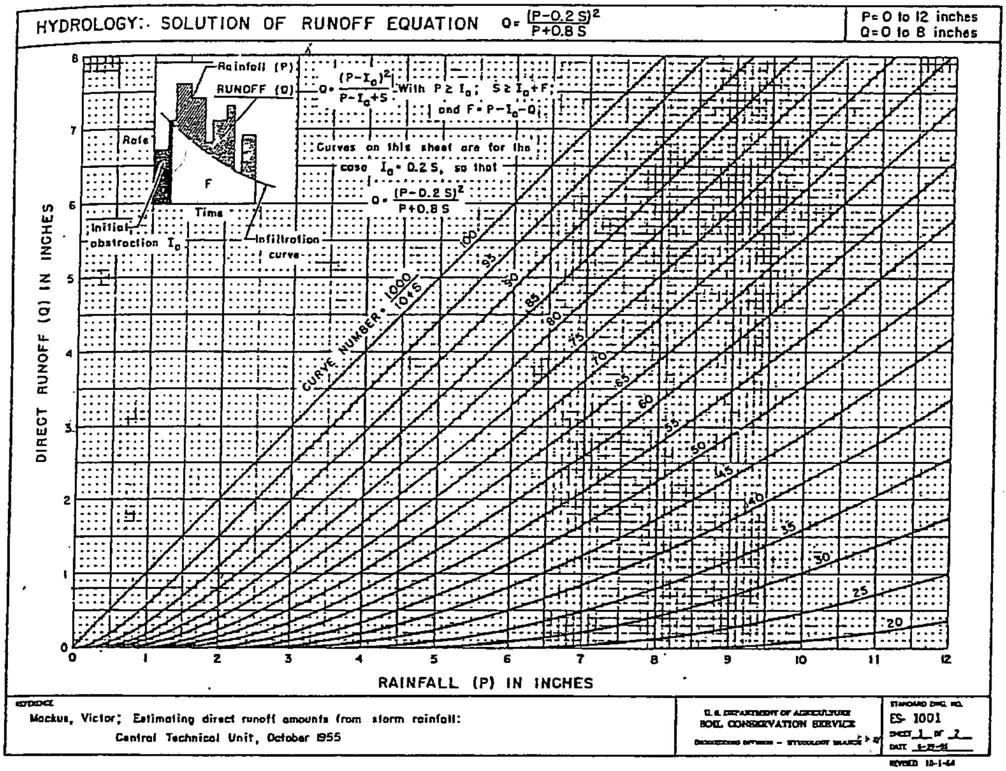


FIGURE 2.14

Graphical solution of rainfall-runoff equation.

EXAMPLE 2.8

SCS UNIT HYDROGRAPH

For the watershed of Example 2.7, develop a unit hydrograph using the SCS method. The watershed consists of meadows in good condition with soil group D. The average slope in the watershed is 100 ft/mi. Assume the same duration of rainfall as found in Example 2.7. Sketch the resulting hydrograph.

SOLUTION

Equation (2.18) gives the following relationship for t_p:

$$t_p = \frac{\ell^{0.8}\,(S+1)^{0.7}}{1900y^{1/2}}.$$

From Table 2.1, the SCS curve number is found to be 78. Therefore, Since this is a small watershed,

$$T_b \approx 4t_p = 4(8.6)\ \text{hr}$$

$$\boxed{T_b = 34.4\ \text{hr.}}$$

And the duration of rainfall

$$D = t_p/5.5$$
$$= 8.6/5.5\ \text{hr}$$

$$\boxed{D = 1.6\ \text{hr.}}$$

SCS Method

The method developed by the Soil Conservation Service (SCS, 1957) is based on a **dimensionless hydrograph,** developed from a large number of unit hydrographs ranging in size and geographic location. The hydrograph is represented as a simple triangle (Fig. 2.13), with rainfall duration D (hr), time of rise T_R (hr), time of fall B(hr), and peak flow Q_p (cfs). The volume of direct runoff is

$$\text{Vol} = \frac{Q_p T_R}{2} + \frac{Q_p B}{2}, \qquad \text{or}$$

$$Q_p = \frac{2\ \text{Vol}}{T_R + B} \tag{2.14}$$

From a review of a large number of hydrographs, it was found that

$$B = 1.67\ T_R. \tag{2.15}$$

Therefore, Eq. (2.14) becomes, for 1.0 in. of rainfall excess,

$$Q_p = \frac{0.75\ \text{Vol}}{T_R}$$
$$= \frac{(0.75)(640)A(1.008)}{T_R}$$
$$= \frac{484A}{T_R}, \tag{2.16}$$

REF 2-3

where

A = area of basin (sq mi),

T_R = time of rise (hr).

Capece et al. (1984) found that a factor as low as 10–50 holds for flat, high-water-table watersheds rather than the value 484 presented here. Thus, care must be used when applying this method.

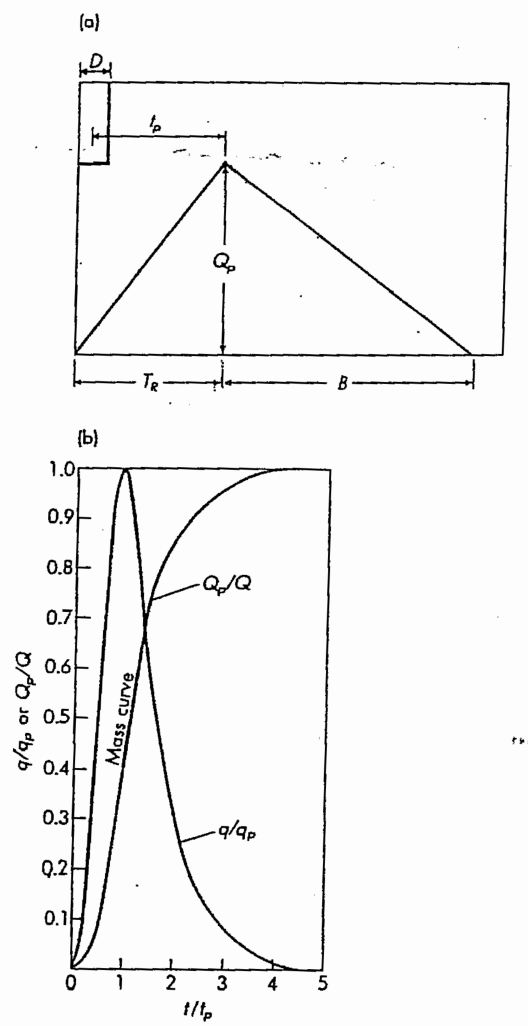


FIGURE 2.13

(a) SCS triangular unit hydrograph. (b) SCS dimensionless unit hydrograph (SCS, 1964).

From Fig. 2.13 it can be shown that

$$T_R = D/2 + t_p, \qquad \text{REF 2C} \quad (2.17)$$

where

D = rainfall duration (hr),

t_p = lag time from centroid of rainfall to Q_p (hr).

Lag time t_p is estimated from any one of several empirical equations used by the SCS, such as

$$t_p = \frac{\ell^{0.8}(S+1)^{0.7}}{1900y^{0.5}}, \qquad (2.18)$$

REF 20

where

t_p = lag time (hr),

ℓ = length to divide (ft),

y = average watershed slope (%),

$S = 1000/\mathrm{CN} - 10$,

CN = curve number for various soil/land use (see Table 2.1).

The SCS dimensionless unit hydrograph can be used to develop a curved hydrograph, using the same t_p and Q_p as the triangular hydrograph in Fig. 2.13.

Soil Conservation Service (1964) runoff estimates assume a relationship between accumulated total storm rainfall P, runoff Q, and infiltration plus initial abstraction $(F + I_a)$. It is assumed that

$$F/S = Q/P_e, \qquad (2.19)$$

where F is infiltration occurring after runoff begins, S is **potential abstraction**, Q is direct runoff in in., and P_e is effective storm runoff $(P - I_a)$. With $F = (P_e - Q)$ and $P_e = (P - I_a) = (P - 0.2S)$ based on data from small watersheds,

$$Q = \frac{(P-0.2S)^2}{P+0.8S}. \qquad (2.20)$$

The SCS method uses the **runoff curve number** CN, which is related to storage by

$$\mathrm{CN} = 1000/(S+10), \qquad (2.21)$$

REF 2E

where potential abstraction S (in.) becomes

$$S = (1000/\mathrm{CN}) - 10. \qquad (2.22)$$

Figure 2.14 presents the SCS solution in graphical form for a range of CNs and rainfall amounts. Runoff curve numbers for selected land uses are presented in Table 2.1. The hydrologic soil group varies from A for sandy, well-drained soils to D for clayey, poorly drained soils. The SCS report *Urban Hydrology for Small Watersheds* (1986) provides a simple graphical and tabular procedure for determining peak flows for urban areas. Example 2.8 illustrates the SCS UH method.

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/R-94/168b
September 1994

3
REF

EPA

The Hydrologic Evaluation of Landfill Performance (HELP) Model

Engineering Documentation for Version 3

REF IA
3

TABLE 1. DEFAULT LOW DENSITY SOIL CHARACTERISTICS

Soil Texture Class			Total Porosity vol/vol	Field Capacity vol/vol	Wilting Point vol/vol	Saturated Hydraulic Conductivity cm/sec
HELP	USDA	USCS				
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	0.251	$2.5x10^{-5}$
21	G	GP	0.397	0.032	0.013	$3.0x10^{-1}$

a = constant representing the effects of various fluid constants and gravity, 21 cm^3/sec

ϕ = total porosity, vol/vol

θ_r = residual volumetric water content, vol/vol

ψ_b = bubbling pressure, cm

λ = pore-size distribution index, dimensionless

A more detailed explanation of Equation 11 can be found in Appendix A of the HELP program Version 3 User's Guide and the cited references.

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g., water). The saturated hydraulic conductivity of each layer is specified in the input. Equations for estimating the hydraulic conductivity for soils and other materials are presented in Appendix A of the HELP Program Version 3 User's Guide.

Unsaturated Hydraulic Conductivity

Unsaturated hydraulic conductivity is used to describe flow through a layer when the void spaces are filled with both wetting and non-wetting fluid (e.g., water and air). The HELP program computes the unsaturated hydraulic conductivity of each soil and waste layer using the following equation, reported by Campbell (1974):

RCF 2B
3

$$K_u = K_s \left[\frac{\theta - \theta_r}{\phi - \theta_r} \right]^{3 + \left(\frac{2}{\lambda}\right)} \tag{5}$$

where

K_u = unsaturated hydraulic conductivity, cm/sec

K_s = saturated hydraulic conductivity, cm/sec

θ = actual volumetric water content, vol/vol

θ_r = residual volumetric water content, vol/vol

ϕ = total porosity, vol/vol

λ = pore-size distribution index, dimensionless

Residual volumetric water content is the amount of water remaining in a layer under infinite capillary suction. The HELP program uses the following regression equation, developed using mean soil texture values from Rawls et al. (1982), to calculate the residual volumetric water content:

RCF 2C
3

$$\theta_r = \begin{cases} 0.014 + 0.25\,WP & \textit{for } WP \geq 0.04 \\ 0.6\,WP & \textit{for } WP < 0.04 \end{cases} \tag{6}$$

where

WP = volumetric wilting point, vol/vol

The residual volumetric water content and pore-size distribution index are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces) (Brooks and Corey, 1964):

3

REF 2D

$$\frac{\theta - \theta_r}{\phi - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda} \tag{7}$$

where

ψ = capillary pressure, bars

ψ_b = bubbling pressure, bars

Bubbling pressure is a function of the maximum pore size forming a continuous network of flow channels within the medium (Brooks and Corey, 1964). Brakensiek et al. (1981) reported that Equation 7 provided a reasonably accurate representation of water retention and matrix potential relationships for tensions greater than 50 cm or 0.05 bars (unsaturated conditions).

The HELP program solves Equation 7 for two different capillary pressures simultaneously to determine the bubbling pressure and pore-size distribution index of volumetric moisture content for use in Equation 7. The total porosity is known from the input data. The capillary pressure-volumetric moisture content relationship is known at two points from the input of field capacity and wilting point. Therefore, the field capacity is inserted in Equation 7 as the volumetric moisture content and 0.33 bar is inserted as the capillary pressure to yield one equation. Similarly, the wilting point and 15 bar are inserted in Equation 7 to yield a second equation. Having two equations and two unknowns (bubbling pressure and pore-size distribution index), the two equations are solved simultaneously to yield the unknowns. This process is repeated for each layer to obtain the parameters for computing moisture retention and unsaturated drainage.

3.3.3 Saturated Hydraulic Conductivity for Vegetated Materials

The HELP program adjusts the saturated hydraulic conductivities of soils and waste layers in the top half of the evaporative zone whenever those soil characteristics were selected from the default list of soil textures. This adjustment, developed for the model from changes in runoff characteristics and minimum infiltration rates as function of vegetation, is made to account for channeling due to root penetration. These adjustments for vegetation are not made for user-specified soil characteristics; they are made only for default soil textures, which assumed that the soil layer is unvegetated and free of continuous root channels that provide preferential drainage paths. The HELP program calculates the vegetated saturated hydraulic conductivity as follows:

Environmental Solutions, Inc.

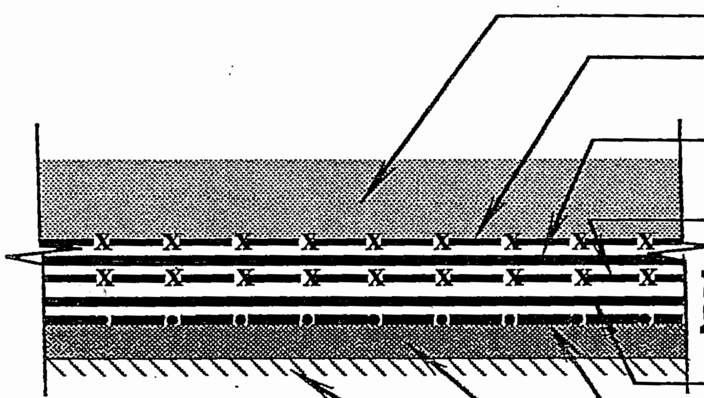
By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

Checked By: EC
Checked On: 3/8/96

LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

Figure 1



2. The sump locations are shown on Figure 2 (Attached). There are three sumps proposed for Cell 12. The typical geometry is shown in Figure 3 (Attached).

Flow Capacities

1. The following flow elements will be used in the LDS

   - Double sided geocomposite (Texnet TN3002/1125)
   - Geonet (Polynet PN3000)-used in the sump areas if additional flow capacity is required.
   - Gravel (clean, poorly graded, nominal 3/4" diameter)-used in the sump proper only.

2. The double sided geocomposite is used in the slope liner LDS as well as in the bottom liner as shown in Figure 1. A continuous strip of geocomposite will be used for each system. Therefore flow within the LDS will be controlled by the minimum bottom slope.

3. Flow within the geosynthetics is calculated using Darcy's Equation (which assumes laminar flow within the net) as follows (Reference 2A):

REF 4

Environmental Solutions, Inc.

By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

Checked By: EC
Checked On: 3/5/96

LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

$$q = \Theta_{eff} i \qquad (1)$$

Where:

q = flow per unit width

Θ_{eff} = effective transmissivity

i = hydraulic gradient

Flow within the gravel also uses Darcy's formula, however, transmissivity is replaced with hydraulic conductivity and the thickness of the flow area.

4. Effective transmissivity for the geosynthetics is calculated by applying several safety factors to the published transmissivity value. The following formula (Reference 2B) is used for that calculation, definitions are provided in the attached reference:

$$\Theta_{eff} = \frac{\Theta}{(FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC})} \qquad (2)$$

5. The following table shows the unit flow capacity for the geosynthetic elements and the gravel based on the applicable transmissivity, or hydraulic conductivities, hydraulic gradients, and safety factors:

Table 1

Flow Element	Q	FS_{CR}	FS_{IN}	FS_{CC}	FS_{BC}	Q_{eff}[1]	i	q	q
Units:	m2/s	NA	NA	NA	NA	m2/s	NA	m3/m-s	gal/ft-day
TN3002/1125	2.20E-04	1.4	1.5	1.5	1.5	4.66E-05	0.01	4.66E-07	3.24
PN3000	2.00E-03	1.4	1.5	1.5	1.5	4.23E-04	0.01	4.23E-06	29.45
TN3002/1125	2.20E-04	1.4	1.5	1.5	1.5	4.66E-05	0.1	4.66E-06	32.39
PN3000	2.00E-03	1.4	1.5	1.5	1.5	4.23E-04	0.1	4.23E-05	294.47

Transmissivity values are provided by the manufacturer (Reference 3A and 3B). Safety factors are taken from the literature and are attached (Reference 2C). Flow capacities are shown at hydraulic gradients of 1 percent and 10 percent for the nominal cell bottom slope and the minimum sump slope, respectively. Since the gravel is used only within the minimum sump boundaries around the riser pipes, flow capacities are calculated for the geosynthethics only.

Controlling Section

1. As shown in Figure 3 there are two potentially controlling sections: 1) the 7'x7' LDS perimeter; and 2) the perimeter at the grade break between the 1 and 10 percent slopes. In the controlling sections multiple layers of geocomposite or geonet alone may be used to provide sufficient flow capacity.

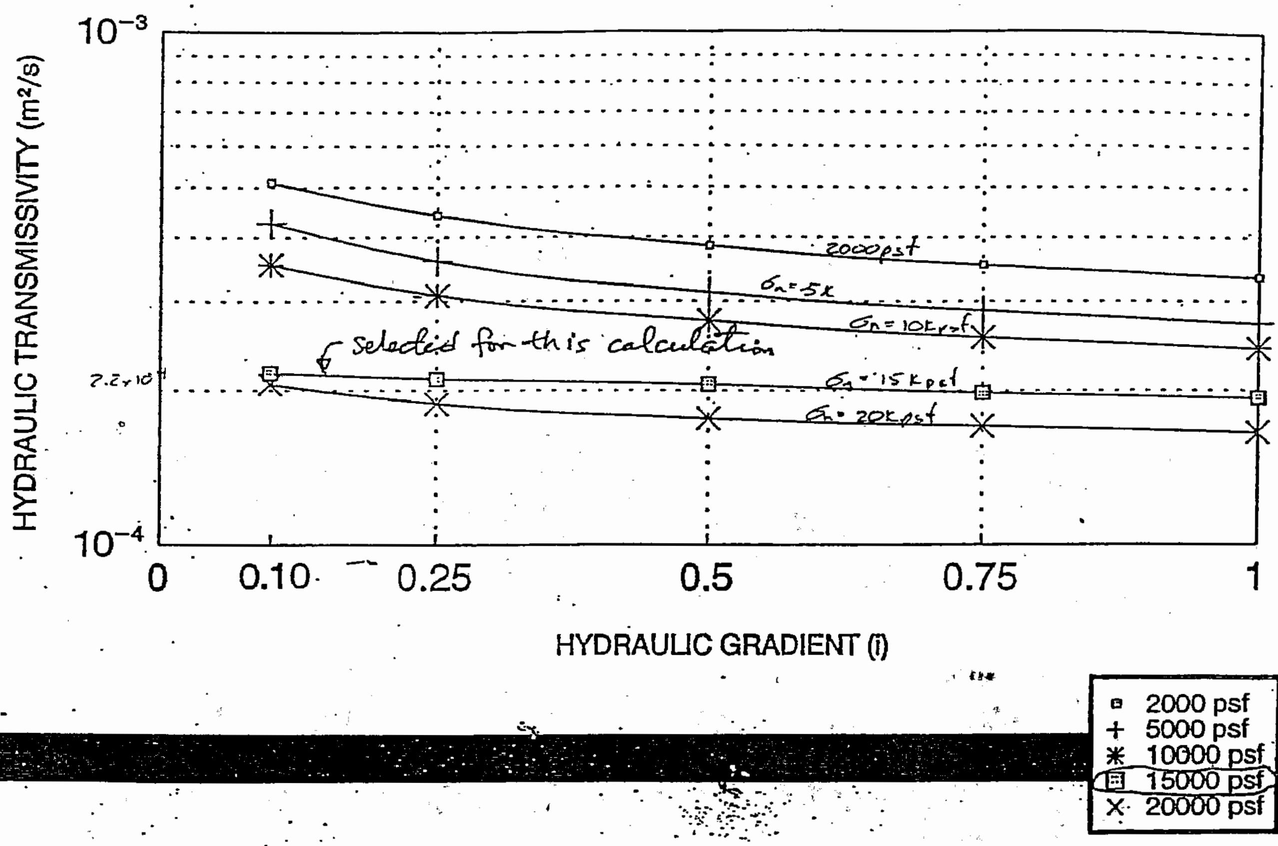
[1] The effective transmissivity of the geocomposite (using the factors of safety listed in Table 1) still exceeds the minimum transmissivity requirement ($3x10^{-5}$ m^2/s) of 40 CFR § 264.301(c)(3)(ii).

REF 2A
9

Attachment B

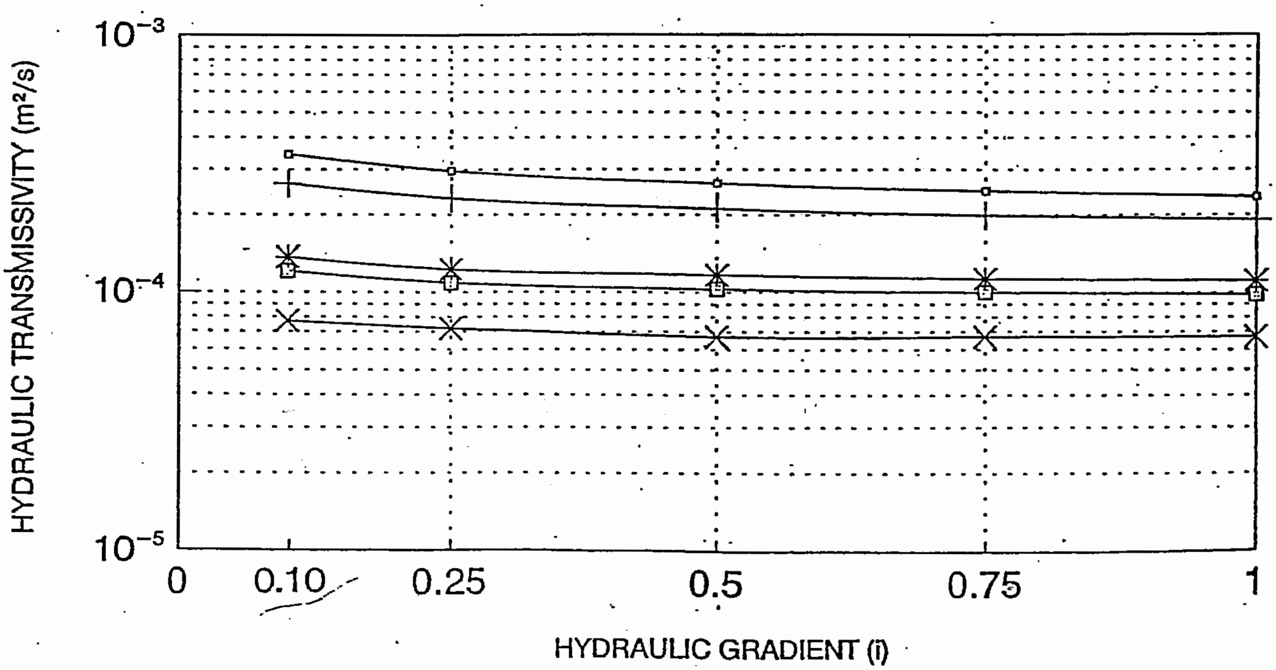
TEX-NET TN3002/1125

plate/FRICTION SEAL/TN3002/1125/FRICTION SEAL/plate



TEX-NET TN3002CN/1125

plate/FRICTION SEAL/TN3002CN/1125/FRICTION SEAL/plate



REP 4/7 5

ADS
SPECIFIER MANUAL

ADVANCED DRAINAGE SYSTEMS, INC.

ADVANCED DRAINAGE SYSTEMS, II

TABLE 7

CIRCULAR PIPE FLOW CAPACITY
Full Flow (cubic feet per second)

Mannings "n"= 0.015

Dia. (in.)	*Conv. Factor	% Slope (feet per 100 feet) 0.02	0.05	0.10	0.20	0.35	0.50	0.75	1.00	1.25	1.50	1.75	2.0	2.5	5.0	10.0	20.0
		(c.f.s.)															
3	0.766	0.011	0.017	0.024	0.034	0.045	0.054	0.066	0.077	0.086	0.09	0.10	0.11	0.12	0.17	0.24	0.34
4	1.649	0.023	0.037	0.052	0.074	0.098	0.117	0.143	0.165	0.184	0.20	0.22	0.23	0.26	0.37	0.52	0.74
5	2.991	0.042	0.067	0.095	0.134	0.177	0.211	0.259	0.299	0.334	0.37	0.40	0.42	0.47	0.67	0.95	1.34
6	4.863	0.069	0.109	0.154	0.217	0.288	0.344	0.421	0.486	0.544	0.60	0.64	0.69	0.77	1.09	1.54	2.17
8	10.473	0.148	0.234	0.331	0.468	0.620	0.741	0.907	1.047	1.171	1.28	1.39	1.48	1.66	2.34	3.31	4.68
10	18.99	0.27	0.42	0.60	0.85	1.12	1.34	1.64	1.90	2.12	2.33	2.51	2.69	3.00	4.25	6.00	8.49
12	30.88	0.44	0.69	0.98	1.38	1.83	2.18	2.67	3.09	3.45	3.78	4.08	4.37	4.88	6.90	9.76	13.81
15	55.98	0.79	1.25	1.77	2.50	3.31	3.96	4.85	5.60	6.26	6.86	7.41	7.92	8.85	12.52	17.70	25.04
18	91.04	1.29	2.04	2.88	4.07	5.39	6.44	7.88	9.10	10.18	11.15	12.04	12.87	14.39	20.36	28.79	40.71
21	137.32	1.94	3.07	4.34	6.14	8.12	9.71	11.89	13.73	15.35	16.82	18.17	19.42	21.71	30.71	43.43	61.41
24	196.06	2.77	4.38	6.20	8.77	11.60	13.86	16.98	19.61	21.92	24.01	25.94	27.73	31.00	43.84	62.00	87.68
27	268.41	3.80	6.00	8.49	12.00	15.88	18.98	23.24	26.84	30.01	32.87	35.51	37.96	42.44	60.0	84.9	120.0
30	355.48	5.03	7.95	11.24	15.90	21.03	25.14	30.79	35.55	39.74	43.54	47.03	50.27	56.21	79.5	112.4	159.0
36	578.05	8.17	12.93	18.28	25.85	34.20	40.87	50.06	57.81	64.63	70.80	76.47	81.75	91.40	129.3	182.8	258.5
42	872.0	12.33	19.50	27.57	38.99	51.6	61.7	75.5	87.2	97.5	106.8	115.3	123.3	137.9	195.0	275.7	389.9
48	1244.9	17.61	27.84	39.37	55.67	73.6	88.0	107.8	124.5	139.2	152.5	164.7	176.1	196.8	278.4	393.7	556.7

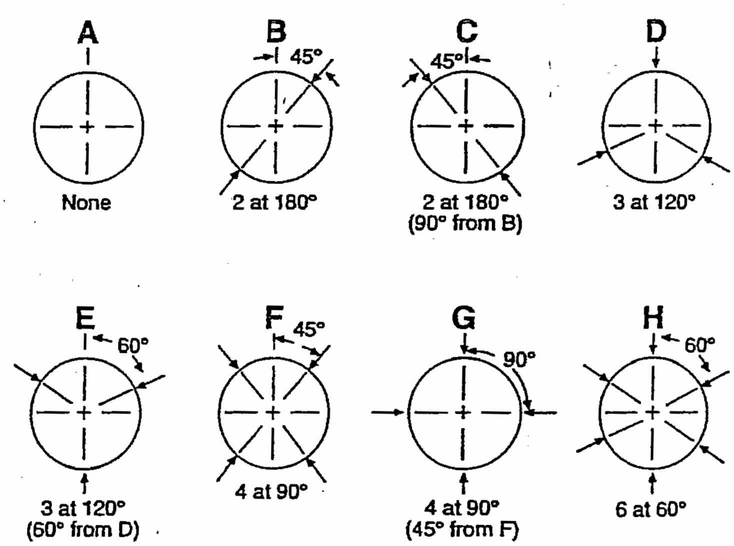
* Conveyance Factor = (1.486 x R2/3 x A) / n

REF 5B

ADVANCED DRAINAGE SYSTEMS, INC.
"FACT SHEET"
STANDARD PIPE PERFORATIONS
3-24" I.D. SINGLE WALL PIPE

Nominal I.D.	Perforation Type	Slot Length or Diameter (Max.)	Slot Width (Max.)	Nominal Water Inlet Area (Sq. In./Ft.)	Perforation Configuration
3	Slot	1.25	0.125	1.44	AF
4	Slot	1.25	0.125	2.01	AH
5	Slot	1.57	0.125	2.01	AH
6	Slot	1.88	0.125	2.01	AH
8	Slot	2.50	0.125	1.57	AD
10	Slot	2.50	0.125	1.26	AD
12	Slot	2.50	0.125	3.38	H
15	Slot	2.50	0.125	1.58	H
18	Circular	0.375	—	1.58	H
24	Circular	0.375	—	1.58	11" Centers

PERFORATION CONFIGURATIONS



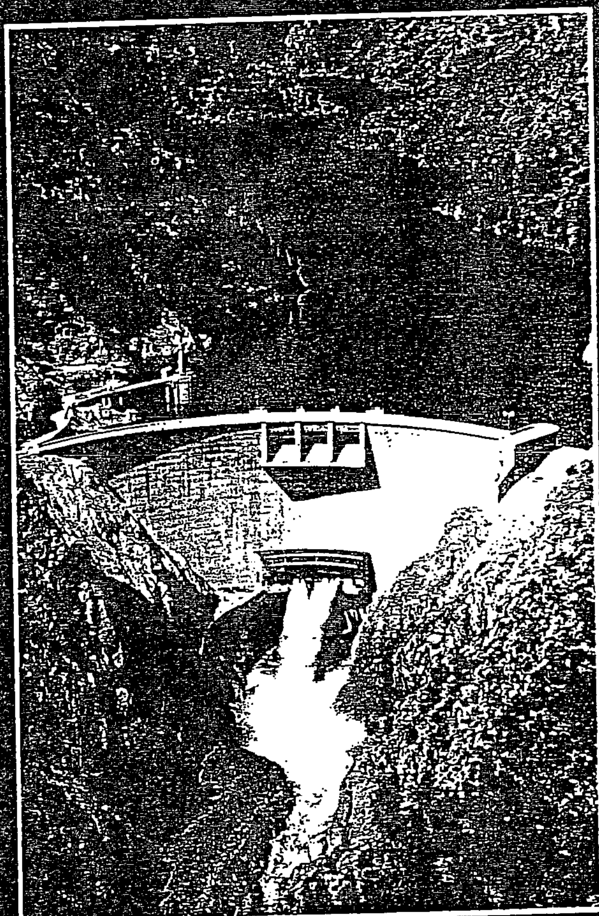
NOTE 1
ADS pipe is perforated for water entry with slots or circular perforations. The perforations are uniformly spaced along the length and circumference of the pipe.

NOTE 2
Unless otherwise specified, ADS pipe is manufactured to comply with the perforation requirements specified in the following industry standards: ASTM F405, ASTM F667, AASHTO M252, AASHTO M294, and SCS Code 606.

Issued: March 15, 1991

REF 8
4

DAVIS' HANDBOOK OF APPLIED HYDRAULICS



FOURTH EDITION

Vincent J. Zipparro
Hans Hasen

REF 8A

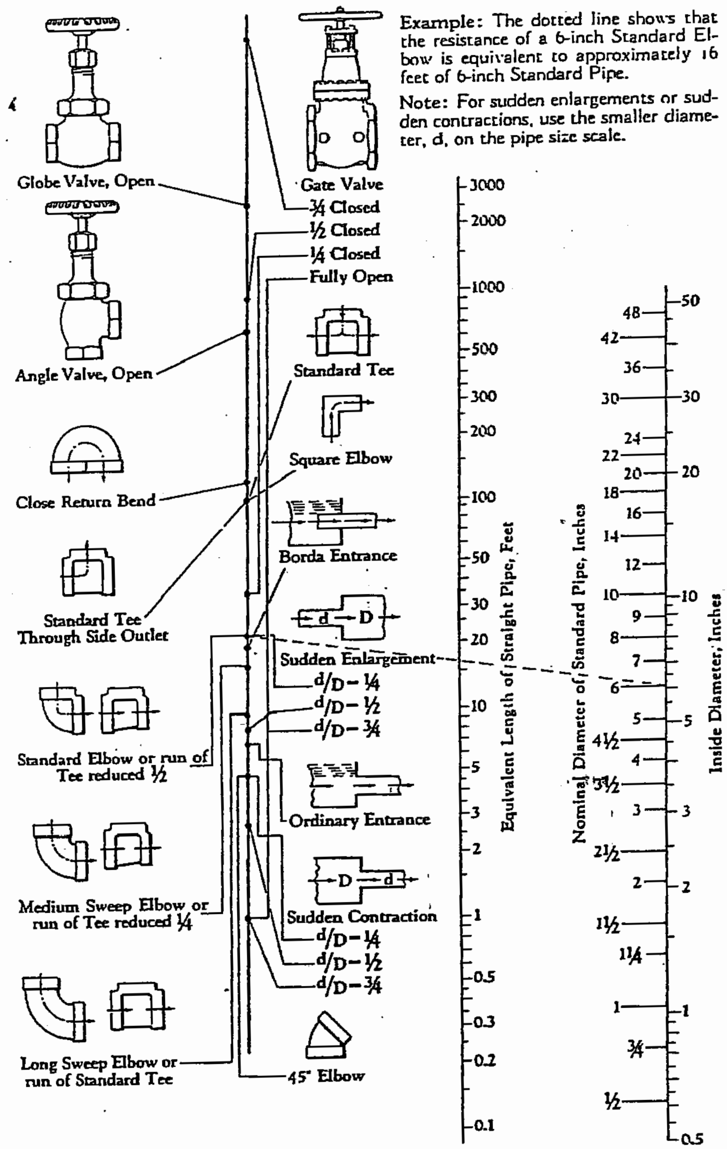


FIGURE 17 Resistance of valves and fittings to flow of fluid.

ORIFICES

25. High Head. When the head is relatively large, as compared with the size of the orifice, the following equation will apply:

$$Q = CA\sqrt{2gH} \tag{37}$$

REF 7

TO: Stan Christie
ESI 714-727-7399
FROM: Mark Patton
PAGES: 5

PROTEC®
RECIP® PUMP

GROUNDWATER & LEACHATE RECOVERY PUMPS

Stan Christie
714-727-7399
For your file
Mark Patton

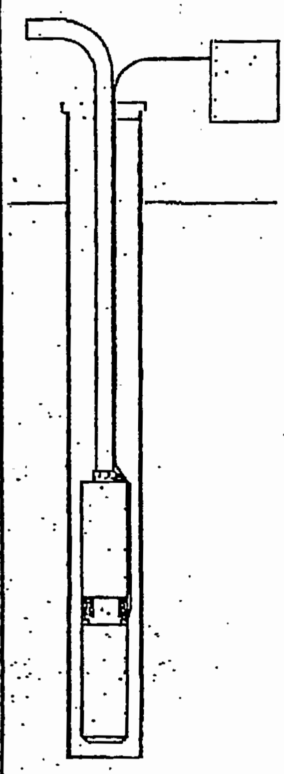
PROTEC

ENVIRONMENTAL EQUIPMENT

A COMPLETE LINE OF GROUNDWATER REMEDIATION LANDFILL LEACHATE & SAMPLING PUMPS

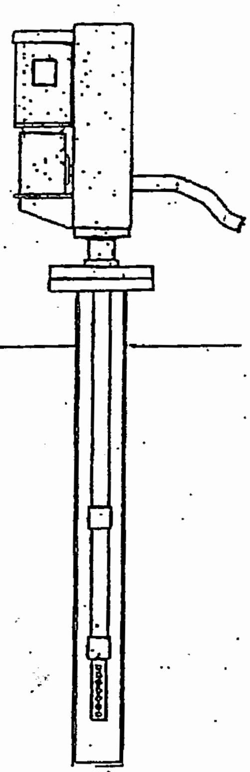
GUARDIAN

Variable Speed Electric Submersible Pump



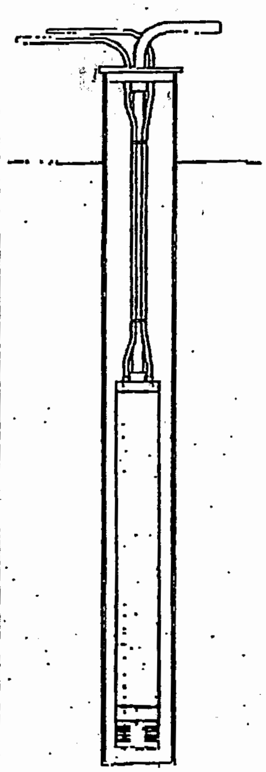
RECIP

Electric or Air Driven Piston Pump



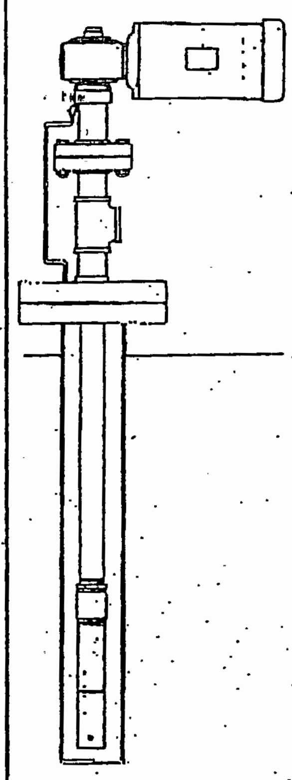
AUTOPILOT

Automatic "Controllerless" Air Pump



ROTARY

Electric Drive Progressing Cavity Pump

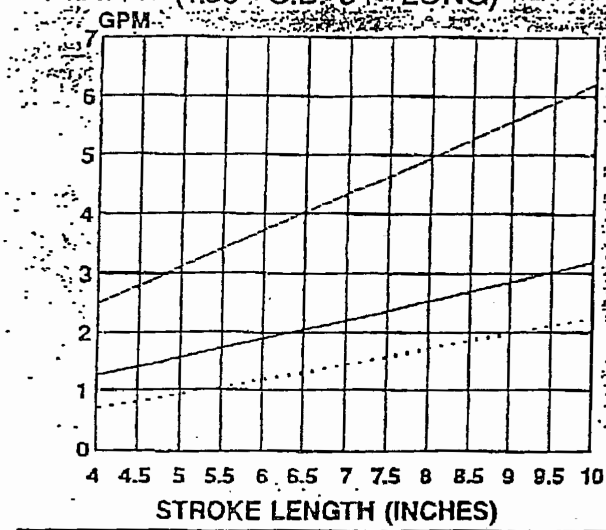


PROTEC

HOUSTON, TX
SALES: 918-493-6101
TULSA, OK

PROTEC RECIP PUMP CURVES

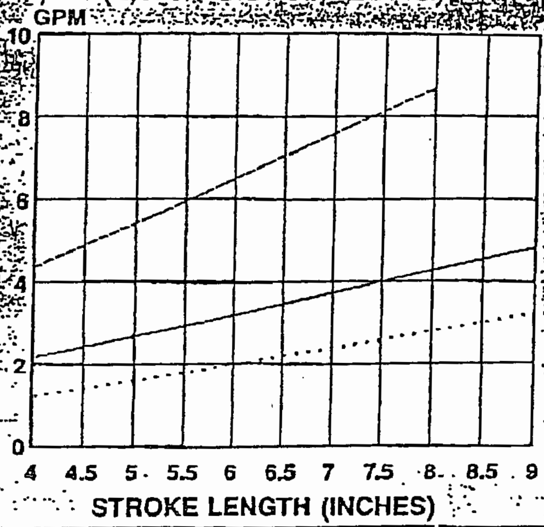
MODEL RP1
(1.90" O.D. 34" LONG)



···· 23 SPM —— 35 SPM —— 69 SPM

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 1 HP

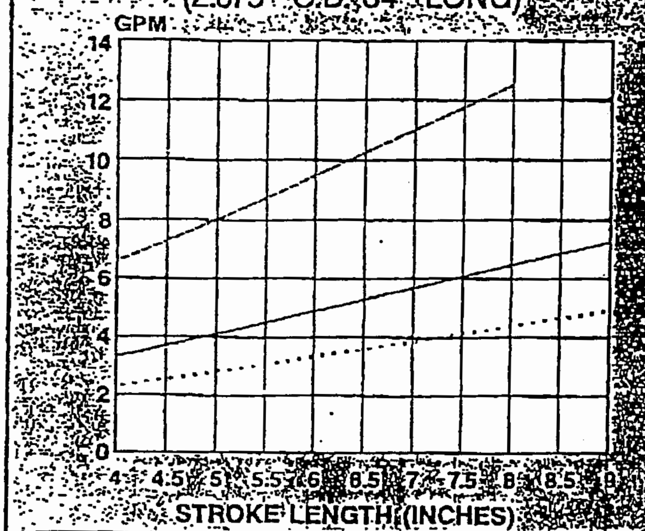
MODEL RP2
(2.375" O.D. 34" LONG)



···· 23 SPM —— 35 SPM —— 69 SPM

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 1.5 HP

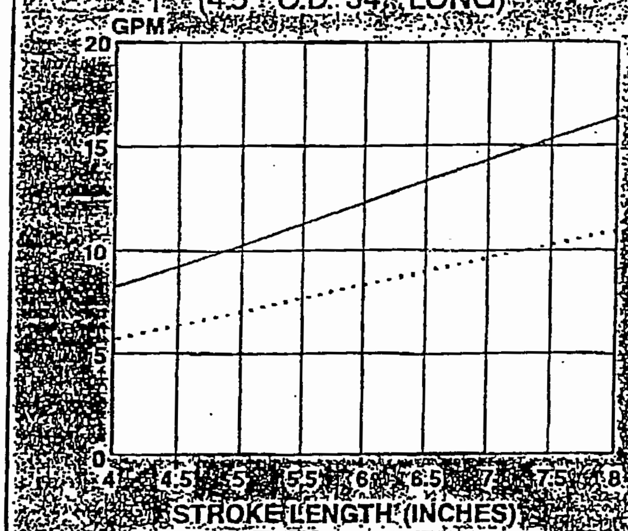
MODEL RP3
(2.875" O.D. 34" LONG)



···· 23 SPM —— 35 SPM —— 69 SPM

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 2 HP

MODEL RP5
(4.5" O.D. 34" LONG)

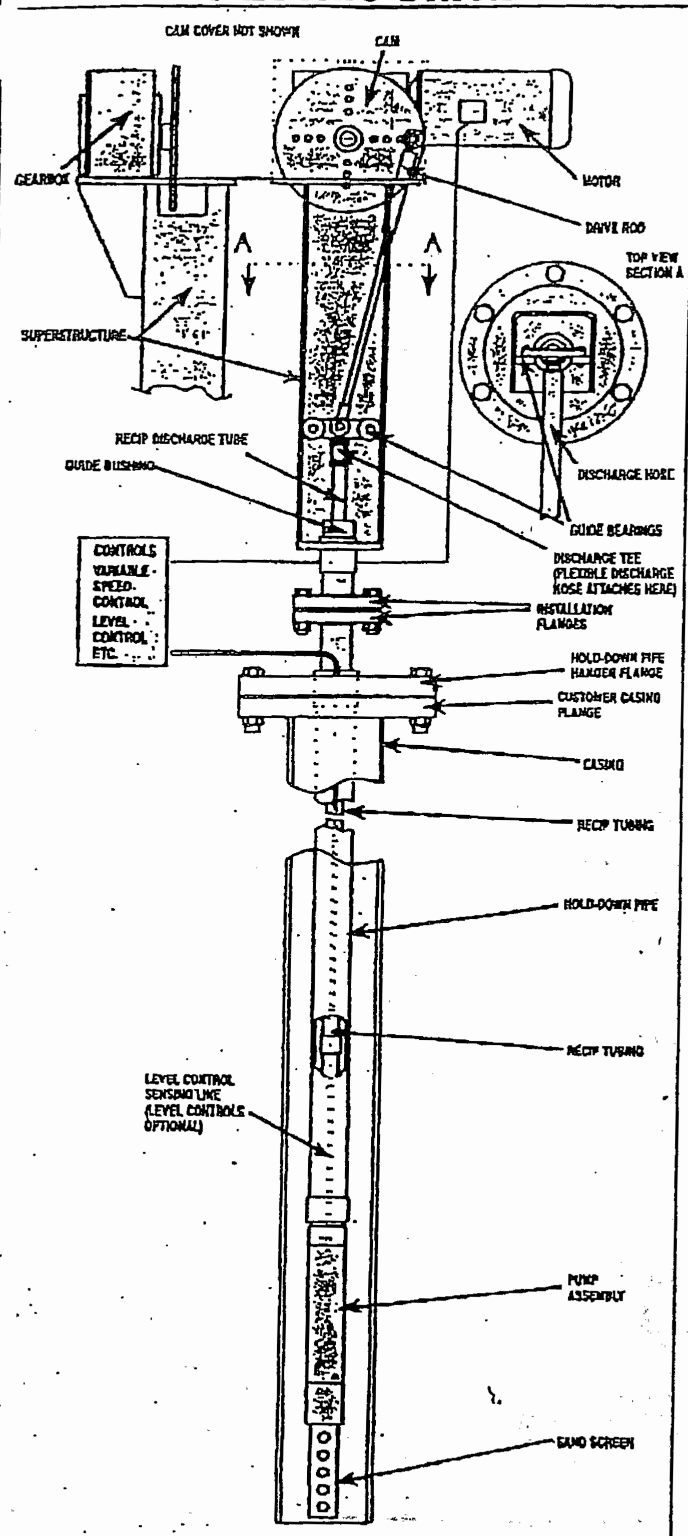


···· 23 SPM —— 35 SPM

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM
1750 RPM MTR = 35 SPM, APPROX. 3 HP

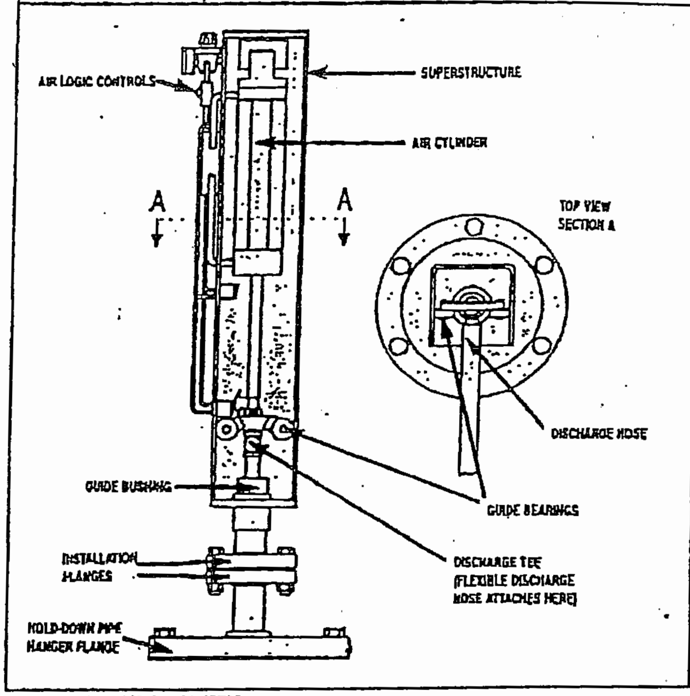
PROTEC
7136 S. Yale, Suite 200 • Tulsa, OK 74136 • 918-493-6101

ELECTRIC DRIVE



SURFACE DRIVE ASSY. APPROX. DIMENSIONS
ELECTRIC DRIVE: 55" H x 24" W x 12" D
AIR DRIVE: 51" H x 8" W x 8" D
LOW PROFILE DRIVES ALSO AVAILABLE
WHEN THERE ARE HEIGHT LIMITATIONS

AIR DRIVE



THE RECIP PUMP SYSTEM

The **RECIP PUMP** is a surface driven (air drive or electric drive) down-hole reciprocating pump. The down-hole pump assembly is anchored by a string of stationary pipe (Hold-Down Pipe). The pump piston is attached to the bottom of a string of reciprocating tubing (Recip Tubing) which is run inside the Hold-Down Pipe. The surface drive assembly alternately lifts and lowers the Recip Tubing which gives the down-hole pump its reciprocating motion. The surface drive assembly can be either Air Drive or Electric Drive. The Air Drive unit utilizes a dual acting air cylinder. The Electric Drive unit utilizes an electric motor (TEFC or X-Proof) coupled to a gearbox and cam assembly.

The **RECIP PUMP** is a positive displacement piston pump with pumping rate (GPM) directly proportional to strokes per minute (SPM) and stroke length (SL). On the Electric Drive unit SL is adjusted manually by changing the position of the drive rod connection to the cam and SPM depends on the motor RPM selected (1140, 1750 or 3450 RPM). An optional electronic VSD (Variable Speed Drive) is also available to give variable SPM capability to the Electric Drive unit. The Air Drive unit comes standard as a variable speed device since the pump speed (SPM) can be controlled by the pressure regulator on the drive unit. The Recip Pump is currently available in four sizes: RP1, RP2, RP3 and RP5. Pump rates range from fractional GPM to 16 GPM.

Down-hole pump materials of construction are stainless steel and Teflon for service in highly corrosive fluids. **RECIP PUMP** can run dry without causing damage to the pump. Pump operation is easily interfaced with down-hole level controls, tank level controls, safety shut-downs, timers, etc. to meet the operating requirements of any particular site.

APPLICATIONS

The **RECIP PUMP** is an efficient low-maintenance system for installation in extraction wells and trench sumps associated with groundwater recovery and leachate collection projects. **RECIP PUMP** is also useful as a dedicated sampling pump for groundwater monitoring.

Notice that the Model RP1 can pump up to 6 GPM from wells with 2" casing. This means that often existing monitoring wells can be utilized for continuous recovery when a project advances from the sampling stage to the remedial pump and treat stage. And when new recovery wells must be drilled it is less expensive to drill and equip 2" wells than larger diameter wells.

IN SUMMARY

High volumetric pump efficiency and low power requirements make the **RECIP PUMP** a highly efficient pumping system. Simple design, rugged construction and low operating speeds result in long operating life and low maintenance. Other features are: low noise, small size, quick installation and all moving parts fully enclosed.

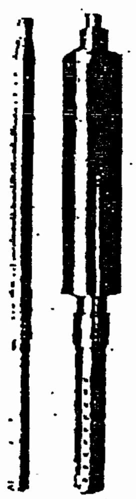
PUMP SELECTION TABLE

PUMP MODEL	RP1	RP2	RP3	RP5
PUMP OUTSIDE DIAMETER	1.90 IN.	2.375 IN.	2.875 IN.	4.50 IN.
STANDARD MOTOR HP[1]	1.0 HP	1.5 HP	2.0 HP	3.0 HP
PUMP SETTING DEPTH	1 - 200 FT.	1 - 200 FT.	1 - 200 FT.	1 - 200 FT.
GPM RANGE				
1. FIXED SPEED ELECTRIC ADJUSTABLE SL[2]				
DEPENDS ON MOTOR RPM:				
WITH 1140 RPM MOTOR[3]	0.8-2.1 GPM	1.4-3.2 GPM	2.2-4.9 GPM	5-10 GPM
WITH 1750 RPM MOTOR	1.2-3.1 GPM	2.1-4.8 GPM	3.2-7.3 GPM	8-16 GPM
WITH 3450 RPM MOTOR	2.5-6.2 GPM	4.2-8.5 GPM	6.5-13.0 GPM	N/A
2. VARIABLE SPEED ELECTRIC ADJUSTABLE SL & SPM[4]				
USE ELECTRIC VSD[5]	0.1-6.2 GPM	1.4-8.5 GPM	2.2-13.0 GPM	5-16 GPM
3. VARIABLE SPEED AIR ADJUSTABLE SPM	0.1-6.2 GPM	1.4-8.5 GPM	2.2-13.0 GPM	5-16 GPM

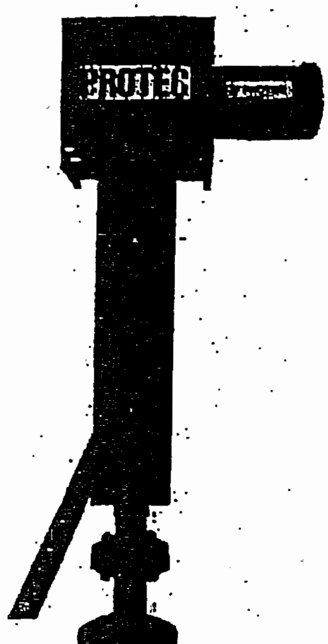
[1] Motor HP can vary depending on operating conditions.
[2] SL: Strokes Length.
[3] 1140 RPM motors available in 3-Phase only.
[4] SPM: Strokes Per Minute.
[5] VSD: Variable Speed Drive.

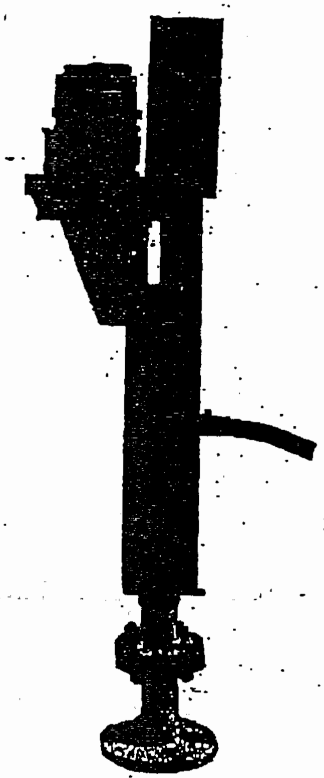
NOTE: Above data is in accordance with the pump curves on the back cover.

PUMPS

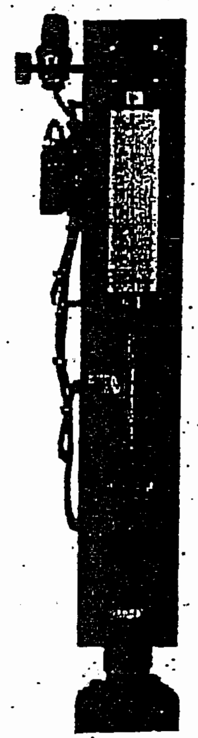


ELECTRIC DRIVE





AIR DRIVE



PROTEC RECIP PUMP
PRICE LIST
(FOR ESTIMATING PURPOSES)
November 1994

The following are estimated prices for complete pumping units including down-hole pump, surface drive assembly and 4 feet of cross-linked polyethylene discharge hose. On Electric Drive units for variable SPM (Strokes Per Minute) add VSD (Variable Speed Drive). Air Drive price includes pneumatic controls and Air Drive units are inherently variable SPM.

				VSD ADD-ON	
PUMP MODEL	AIR DRIVE 316 S.S	FIXED SPM TEFC MOTOR	FIXED SPM X-PROOF MOTOR	NEMA 3R PANEL FOR USE WITH TEFC DC MOTOR	NEMA 3R PANEL FOR USE WITH TEFC OR X-PROOF AC MOTOR
RP1	2,700.00 k	2,975.00	3,175.00	875.00	1,075.00
RP2	2,900.00 3100	3,175.00	3,425.00	1,025.00	1,175.00
RP3	3,100.00	3,375.00	3,625.00	N/A	1,275.00
RP5	3,700.00	3,975.00	4,225.00	N/A	1,325.00

ACCESSORIES

LEVEL CONTROL:
- Dual Probe Level Control....................286.00
- Dual Float Level Control....................305.00
- Level Control Signal Wire....................0.50/FT
  (22 Gauge, Teflon Jacketed)
- Pneumatic Level Control....................275.00
- Pneumatic L/C Tube (3/8" Teflon)....................2.50/FT
- Stroke Counter....................100.00
- Pneumatic Dual Timer....................275.00

WELL TUBULARS

1. FOR USE IN 2" CASING (RP1 ONLY):
   RECIP TUBING : 1/2" CS T&C....................1.23/FT
   1/2" 304SS T&C....................5.22/FT*
   HOLD-DOWN PIPE: 1" CS T&C....................1.81/FT
   1" 304 SS T&C....................8.36/FT*

2. FOR USE IN 3" AND LARGER CASING (RP5 6" AND LARGER CASING):
   RECIP TUBING (RP1, 2, 3) : 3/4" CS T&C....................1.55/FT
   3/4" 304 SS T&C....................6.62/FT* Add 25 %
   (RP5 ONLY): 1" CS T&C....................1.81/FT
   1" 304 SS T&C....................8.36/FT* for 316 S.S.
   HOLD-DOWN PIPE (RP1, 2, 3): 1 1/4" CS T&C....................2.43/FT
   1 1/4" 304 SS T&C....................10.53/FT*
   (RP5 ONLY): 2" CS T&C....................2.96/FT
   2" 304 SS T&C....................13.86/FT*

*SS PRICES CAN FLUCTUATE SIGNIFICANTLY OVER TIME.

WELL HEAD FITTINGS: Standard Carbon Steel....................150.00
Stainless Steel....................price on request

TOP LOADING INLET JACKET (PUMP CAN): Carbon steel....................150.00

CONTROL PANELS - NEMA 3R Enclosure (Contactor, Adjustable Thermal Overload, HOA. Does not include primary disconnect or short circuit protection.)

FIXED SPM: THRU 10 HP, 1-PHASE OR 3-PHASE....................250.00
FOR VARIABLE SPM: PANEL PRICE INCLUDED IN VSD PRICE ABOVE. CONTROL PANELS CAN ALSO BE CUSTOM BUILT PER CUSTOMER REQUIREMENTS.

REF 8

CRC

STANDARD MATHEMATICAL TABLES

28th EDITION

CRC PRESS

REF 8A

Mensuration Formulas

Pyramid

S of regular pyramid $= \frac{1}{2}$(perimeter of base) $\times$ (slant height)
$V = \frac{1}{3}$(area of base) $\times$ (altitude)

Frustum of Pyramid

Let B_1 = area of lower base, B_2 = area of upper base, h = altitude.

S of regular figure $= \frac{1}{2}$(sum of perimeters of bases) $\times$ (slant height)
$V = \frac{1}{3}h(B_1 + B_2 + \sqrt{B_1 B_2})$

Prismatoid

A *prismatoid* is a polyhedron having for bases two polygons in parallel planes, and for lateral faces triangles or trapezoids with one side lying in one base, and the opposite vertex or side lying in the other base, of the polyhedron. Let B_1 = area of lower base, M = area of midsection, B_2 = area of upper base, h = altitude.

$$V = \tfrac{1}{6}h(B_1 + 4M + B_2) \quad \text{(the \textit{prismoidal formula})}$$

Note: Since cubes, rectangular parallelepipeds, prisms, pyramids, and frustums of pyramids are all examples of prismatoids, the formula for the volume of a prismatoid subsumes most of the above volume formulae.

Regular Polyhedra

Let v = number of vertices, e = number of edges, f = number of faces, α = each dihedral angle, a = length of each edge, r = radius of the inscribed sphere, R = radius of the circumscribed sphere, A = area of each face, T = total area, V = volume.

$v - e + f = 2$ (the *Euler-Descartes formula*—actually holds for *any* convex polyhedron)

$$T = fA$$
$$V = \tfrac{1}{3}rfA = \tfrac{1}{3}rT$$

Name	Nature of Surface	T	V
Tetrahedron	4 equilateral triangles	$1.73205a^2$	$0.11785a^3$
Hexahedron (cube)	6 squares	$6.00000a^2$	$1.00000a^3$
Octahedron	8 equilateral triangles	$3.46410a^2$	$0.47140a^3$
Dodecahedron	12 regular pentagons	$20.64573a^2$	$7.66312a^3$
Icosahedron	20 equilateral triangles	$8.66025a^2$	$2.18169a^3$

Name	v	e	f	α	a	r
Tetrahedron	4	6	4	70° 32′	$1.633R$	$0.333R$
Hexahedron	8	12	6	90°	$1.155R$	$0.577R$
Octahedron	6	12	8	109° 28′	$1.414R$	$0.577R$
Dodecahedron	20	30	12	116° 34′	$0.714R$	$0.795R$
Icosahedron	12	30	20	138° 11′	$1.051R$	$0.795R$