Subject GEOMEMBRANE / ACCESS ROAD
B&L LANDFILL

Project No. 13488.131.1
Task No. 1
File No.
Sheet 1 of 3

By KT
Checked By MZ
Date 6/10/09
Date 6/15/09

THIS CALCULATION EVALUATES THE SAFETY OF GEOMEMBRANE CAP AGAINST TEARING DUE TO ACCESS ROAD AND ANTICIPATED TRUCK TRAFFIC.

LANDFILL CAP WILL BE APPROXIMATELY 8 H:1 V SLOPE OR 7.5°. APPROXIMATELY 3.5' OF SOIL AND ROCK WILL COVER THE GEOMEMBRANE WITH AVG DENSITY OF 120 POUNDS PER CUBIC FOOT. THEREFORE,

DEAD LOAD = 3.5' x 120 = 420 PSF

MAXIMUM LIVE LOAD WILL BE A SEMI TRACTOR TRAILER WITH 18 WHEELS AND GROSS VEHICLE WEIGHT OF 80,000 LBS.

THE TANDEM WHEELS AXLE WILL WEIGH:

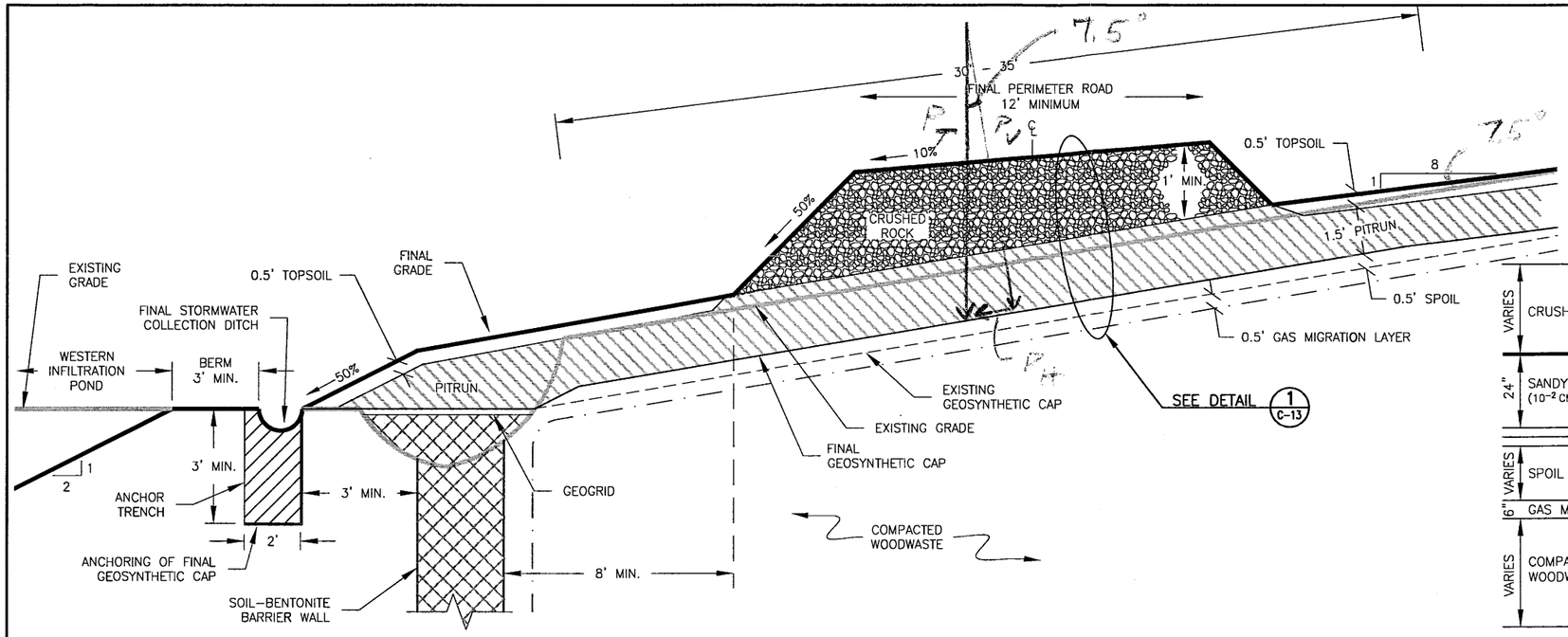
80,000 LBS ÷ 18 ≈ 4,500 LBS

4 WHEELS = 4 x 4,500 = 18,000 LBS

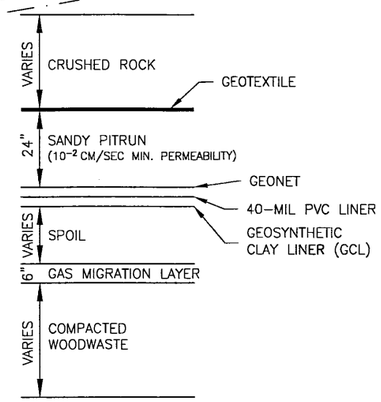
TOTAL DEAD AND LIVE LOAD WILL BE ABOUT 18,500 LBS.

SHEET 2 OF 3

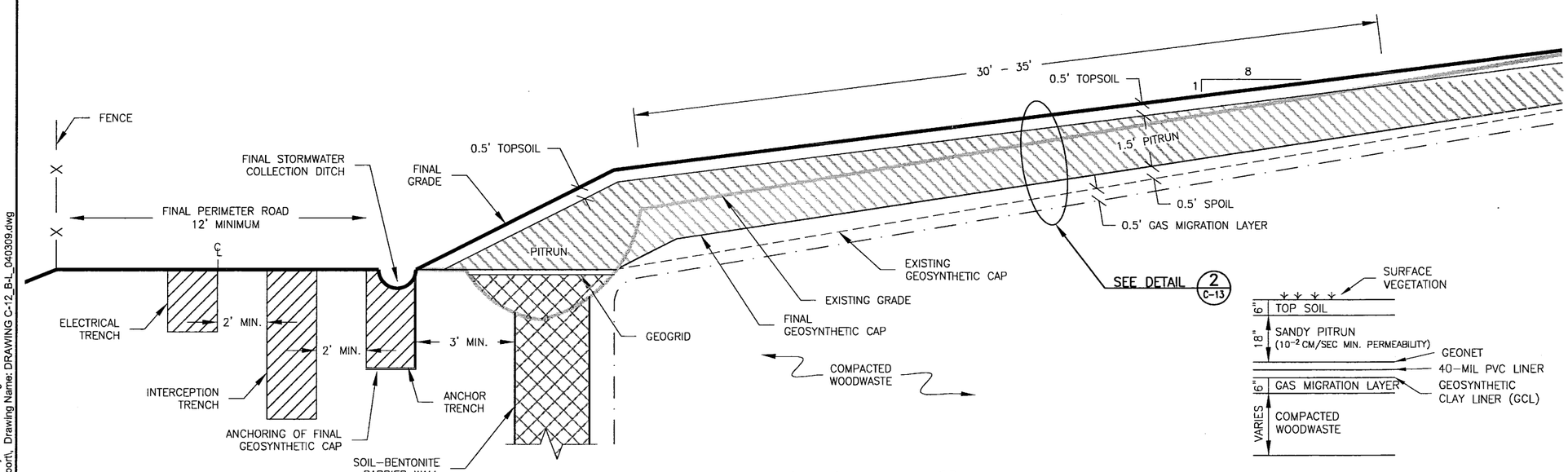
GEOMEMBRANE/ACCESS ROAD



LANDFILL CAP RESTORATION (TYP.) — A C-12
NOT TO SCALE — SIDE VIEW



LANDFILL CAP DETAIL — 1 C-13
NOT TO SCALE — SIDE VIEW



LANDFILL CAP RESTORATION (TYP.) — B C-12
NOT TO SCALE — SIDE VIEW

LANDFILL CAP DETAIL — 2 C-13
NOT TO SCALE — SIDE VIEW

NOTES:

1. RESTORE LANDFILL CAP IN LAYERS FROM BOTTOM UP TO MATCH THE EXISTING CAP. USE MANUFACTURER-APPROVED EQUIPMENT AND TECHNIQUES TO INSTALL GEOSYNTHETIC MATERIAL (GCL, GEOMEMBRANE, AND GEONET).
2. SUBGARDE SURFACE MUST BE FREE OF ROCKS OR OTHER SHARP OBJECTS TO PREVENT DAMAGE TO GEOSYNTHETIC MATERIAL.
3. ANY NEW GCL SHALL BE CLAYMAX 200R OR APPROVED EQUIVALENT. GCL SECTIONS MUST OVERLAP A MINIMUM DISTANCE OF 1 FOOT AND BE SHINGLED TOWARD THE TOE OF THE LANDFILL. REMOVE HYDRATED GCL AND REPLACED WITH DRY GCL. REPAIRS TO THE GCL SHALL BE MADE WITH DRY GCL WITH 1 FOOT MINIMUM OVERLAP.
4. ANY NEW GEOMEMBRANE SHALL BE 40 MIL PVC AND GLUE-BONDED PER MANUFACTURER'S RECOMMENDATION. OVERLAPS SHALL BE A MINIMUM OF 2 FT AND BE SHINGLED TOWARD THE TOE OF THE LANDFILL. TEST 100% OF THE BONDS/WELDS IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATION; REMOVE LEAKY OR DAMAGED SECTIONS AND BOND/WELD PATCHES WITH 2 FOOT MINIMUM OVERLAP.
5. PVC GEOMEMBRANE SHALL BE INSTALLED IN A RELAXED CONDITION, FREE FROM STRESS, TENSION, AND WRINKLES.
6. ANY NEW GEONET SHALL BE GSE HYPERNET HF OR APPROVED EQUIVALENT, WITH A BONDED LAYER OF FILTER GEOTEXTILE FACING UP. SECTIONS SHALL OVERLAP A MINIMUM OF 1 FOOT AND BE SHINGLED TOWARD THE TOE OF THE LANDFILL.
7. TERMINATE THE GCL AT THE NEW STORMWATER COLLECTION DITCH. TERMINATE THE GEOMEMBRANE INSIDE A 3-FT DEEP ANCHOR TRENCH. GEOMEMBRANE SHALL COVER THE BOTTOM OF ANCHOR TRENCH. TERMINATE THE GEONET AT THE STORMWATER COLLECTION DITCH SO THAT GEONET DRAINS INTO THE DITCH.
8. BACKFILL ANCHOR TRENCH WITH EXCAVATED SOIL IN 8-INCH LIFTS AND COMPACT TO A FIRM, NON-YIELDING SURFACE.
9. THE FINAL STORMWATER COLLECTION DITCH SHALL BE 18-INCH DIAMETER CORRUGATED HDPE, SDR 17 HALFPIPE. CONNECTIONS SHALL BE WELDED OR EQUAL TO MAINTAIN CONTINUITY. PIPING SHALL BE A CULVERT WHERE ACCESS ROAD CROSSES OVER.
10. PLACE COVER SOIL IN ONE 18-INCH LIFT OVER THE GEONET USING LOW CONTACT PRESSURE EQUIPMENT. CONSTRUCTION EQUIPMENT SHALL NOT OPERATE ON OR ABOVE THE GEOSYNTHETICS UNTIL AT LEAST 15 INCHES OF MATERIAL IS PLACED.
11. TOPSOIL SHALL HAVE A MINIMUM THICKNESS OF 6 INCHES AND SHALL BE TRACK-WALKED WITH LOW PRESSURE TRACKED EQUIPMENT TO ACHIEVE IN FINAL GRADES WITHIN 0.1 FOOT OF THE GRADES SHOWN ON THE PLANS.
12. CONSTRUCT PERIMETER ROAD ON THE LANDFILLBY PLACING 2-INCH DIAMETER CRUDHED ROCK (BALLAST) OVER GEOTEXTILE IN 2 LIFTS AND TRACK-COMPACTING.
13. SALVAGED CRUSHED ROCK FROM THE EXISTING DITCH USED IN CONSTRUCTION OF CONTAINMENT BERMS SHALL BE USED FOR TRANSITION FROM PERIMETER ROAD TO ACCESS ROAD ON LANDFILL. ENGINEER WILL DETERMINE ADDITIONAL USEAGE IN THE FIELD.

DRAFT
CONSTRUCTION

Plot Date: 04/23/09 - 1:58pm, Plotted by: adam.stenberg
Drawing Path: S:\13488\005_EDR Report\, Drawing Name: DRAWING C-12_B-L_040309.dwg

REFERENCES:	NO.	REVISION	DATE	APRVD
PLANS				
DATUM HORIZONTAL: WASP-NAD83-S FEET VERTICAL: NAVD88 FEET				

DRAWN ??
DESIGNED ??
CHECKED ??
REVIEWED ??

FLOYD | SNIDER
AMEC Geomatrix

LANDFILL CAP RESTORATION DETAILS
ADDENDUM 1

B&L WOODWASTE SITE
PIERCE COUNTY, WASHINGTON

DATE: 04/23/09
PROJECT NO.: 13488
DRAWING C-13

Subject GEOMEMBRANE / ACCESS ROAD B&L LANDFILL
By KT
Date 6/10/09
Checked By MZ
Date 6/15/09
Project No. 13488.131.1
Task No. 1
File No.
Sheet 3 of 3

P_T = TOTAL LOAD = 18,500 LBS

P_H = HORIZONTAL LOAD ALONG GEOMEMBRANE

$= \sin 7.5° = \frac{P_H}{P_T} \Rightarrow$

$P_H = 18{,}500 \times 0.13 = 2{,}400$ LBS ~~/LF~~

BASED CONTACT SURFACE WIDTH OF THE ROAD OF ABOUT 15 FT, THE PULL FORCE WILL BE:

2,400 LBS/LF ÷ 15 FT = 160 ~~PSF~~ LBS/LF

$\Rightarrow$ 160 ÷ 12 = 13.5 LBS/INCH

GEOMEMBRANE TEAR RESISTANCE

= 300 LBS/IN

FACTOR OF SAFETY = $\frac{300}{13.5}$ = 22 ✓

DESIGN MEMORANDUM

Client: B&L Woodwaste Site Trust Sheet 1 Of 4

Project: Phase 1 Part 1 Cleanup Action Design Date: 6/15/09

Data For: Work Order:

Prepared By: MZ Checked By: GD File No:

Note: This form must be used for project calculations and original filed in project files

Objective: calculate lifting requirement for pump in lift station

Known Parameters and Assumptions.

① 4-inch nominal diameter schedule 40 HDPE pipe:

Internal diameter: $D = 0.3355$ ft $\boxed{\text{App 16.B}}$

Internal area: $A = 0.08841$ ft^2

Design Flow Rate: $Q = 30$ gpm

Flow Velocity:

$$V = Q/A = (30 \text{ gpm})\left(\frac{0.002228 \text{ ft}^3/\text{s}}{1 \text{ gpm}}\right) / (0.08841 \text{ ft}^2)$$

$$= 0.76 \text{ ft/s}$$

Viscosity @ 50°F: $\mu = 1.41 \times 10^{-5}$ ft^2/s $\boxed{\text{App 14. A}}$

Renolds Number:

$$Re = \frac{D \cdot V}{\mu} = \frac{(0.3355 \text{ ft})(0.76 \text{ ft/s})}{1.41 \times 10^{-5} \text{ ft}^2/\text{s}} = 1.8 \times 10^4$$

Roughness: $\epsilon = 5 \times 10^{-6}$ ft $\boxed{\text{App17. A}}$

Relative Roughness $\frac{\epsilon}{D} = \frac{5 \times 10^{-6} \text{ ft}}{0.3355 \text{ ft}} = 1.5 \times 10^{-5}$

Darcy Friction Factor (from lookup table) $\boxed{\text{App17. B}}$

$$f = (0.0278 + 0.0259)/2 = 0.0269$$

4" Pipe length: $L = 800$ ft

DESIGN MEMORANDUM

Client: B&L | Sheet 2 Of 4
Project: | Date: 6/15/09
Data For: | Work Order:
Prepared By: MZ | Checked By: SD | File No:

Note: This form must be used for project calculations and original filed in project files

② 2-inch nominal diameter pipe :

$$d = 0.1723 \text{ ft}$$

$$a = 0.02330 \text{ ft}^2$$

$$v = \frac{Q}{a} = (30 \text{ gpm})\left(\frac{0.002228 \text{ ft}^3/\text{s}}{1 \text{ gpm}}\right) / (0.02330 \text{ ft}^2)$$

$$= 2.87 \text{ ft/s}$$

$$Re = \frac{(0.1723 \text{ ft})(2.87 \text{ ft/s})}{1.41 \times 10^{-5} \text{ ft}^2/\text{s}} = 3.5 \times 10^4$$

Relative Roughness : $\frac{\epsilon}{D} = \frac{5 \times 10^{-6} \text{ ft}}{0.1723 \text{ ft}} = 2.9 \times 10^{-5}$

Darcy Friction Factor (from lookup table)

$$f = \frac{(0.0236 + 0.0221)}{2} = 0.0229$$

2" pipe length $l = 3$ ft

DESIGN MEMORANDUM

Client: B&L | Sheet 3 Of 4
Project: | Date: 6/15/09
Data For: | Work Order:
Prepared By: MZ | Checked By: SD | File No:

Note: This form must be used for project calculations and original filed in project files

Head Loss Calculations:

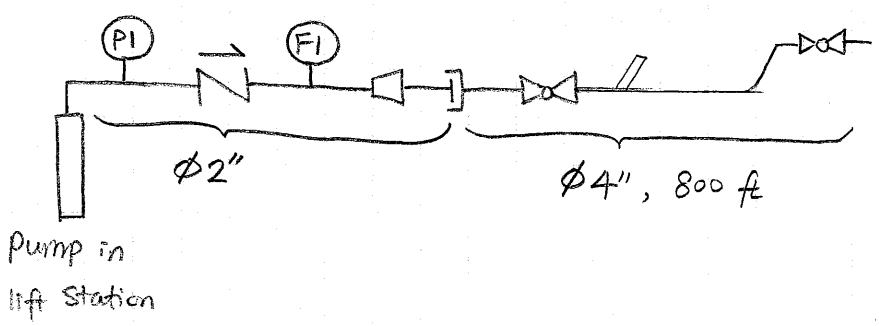
1. Friction Loss in Pipe: Darcy Equation.

$$h_f = \frac{f \cdot L \cdot v^2}{2 \cdot D \cdot g}$$

$$h_{f,4''} = \frac{(0.0269)(800\ ft)(0.76\ ft/s)^2}{(2)(0.3355\ ft)(32.2\ ft/s^2)} = 0.58\ ft$$

$$h_{f,2''} = \frac{(0.0229)(3\ ft)(2.87\ ft/s)^2}{(2)(0.1723\ ft)(32.2\ ft/s^2)} = 0.02\ ft$$

2. Minor Loss:



Item	Number	Typical Loss Coefficient, K (Table 17.4 unless noted otherwise)
45° Elbow	3	0.42
Pressure Indicator	1	assume = 1
Check Valve	1	2.3
Flow meter	1	10
Enlargement	1	$\left[1-\left(\frac{2''}{4''}\right)\right]^2 = 0.25$
Quick Connect Coupling	1	assume = 1
Ball Valve	2	0.19
pipe Exit	1	1

DESIGN MEMORANDUM

Client: B&L | Sheet 4 Of 4
Project: | Date: 6/15/09
Data For: | Work Order:
Prepared By: MZ | Checked By: SL | File No:

Note: This form must be used for project calculations and original filed in project files

Sum of minor loss coefficient:

for 2" pipe: $\sum K_{2''} = (1)(0.42) + (1) + (2.3) + (10) + (0.25) + 1 = 15$

for 4" pipe $\sum K_{4''} = (2)(0.42) + (2)(0.19) + 1 = 2.2$

Minor Head Loss:

2" pipe $h_{m,2''} = \sum K_{2''} \cdot \frac{v^2}{2g} = (15)\frac{(2.87\ ft/s)^2}{(2)(32.2\ ft/s^2)} = 1.9\ ft$ ✓

4" pipe $h_{m,4''} = \sum K_{4''} \cdot \frac{v^2}{2g} = (2.2)\frac{(0.76\ ft/s)^2}{(2)(32.2\ ft/s)} = 0.02\ ft$ ✓

3. Assume water level in lift station = 15 ft

Elevation at discharge = 20 ft

Elevation change $h_e = (20\ ft) - (15\ ft) = 5\ ft$ ✓

4 Total Lifting Required

$$H = \sum h_f + \sum h_m + h_e$$

$$= (0.58\ ft) + (0.02\ ft) + (1.9\ ft) + (0.02\ ft) + (5\ ft)$$

$$= 7.5\ ft$$ ✓

Reference:

Civil Engineering Reference Manual for the PE Exam, 8th Edition
M.R. Lindeburg.

Civil Engineering Reference Manual

for the PE Exam

Eighth Edition

Michael R. Lindeburg, PE

Professional Publications, Inc. • Belmont, CA

APPENDIX 16.B

Dimensions of Welded and Seamless Steel Pipe[a,b]
(selected sizes)[c]
(English units)

nominal diameter (in)	schedule	outside diameter (in)	wall thickness (in)	internal diameter (in)	internal area (in^2)	internal diameter (ft)	internal area (ft^2)
$\frac{1}{8}$	40 (S)	0.405	0.068	0.269	0.0568	0.0224	0.00039
	80 (X)		0.095	0.215	0.0363	0.0179	0.00025
$\frac{1}{4}$	40 (S)	0.540	0.088	0.364	0.1041	0.0303	0.00072
	80 (X)		0.119	0.302	0.0716	0.0252	0.00050
$\frac{3}{8}$	40 (S)	0.675	0.091	0.493	0.1909	0.0411	0.00133
	80 (X)		0.126	0.423	0.1405	0.0353	0.00098
$\frac{1}{2}$	40 (S)	0.840	0.109	0.622	0.3039	0.0518	0.00211
	80 (X)		0.147	0.546	0.2341	0.0455	0.00163
	160		0.187	0.466	0.1706	0.0388	0.00118
	(XX)		0.294	0.252	0.0499	0.0210	0.00035
$\frac{3}{4}$	40 (S)	1.050	0.113	0.824	0.5333	0.0687	0.00370
	80 (X)		0.154	0.742	0.4324	0.0618	0.00300
	160		0.218	0.614	0.2961	0.0512	0.00206
	(XX)		0.308	0.434	0.1479	0.0362	0.00103
1	40 (S)	1.315	0.133	1.049	0.8643	0.0874	0.00600
	80 (X)		0.179	0.957	0.7193	0.0798	0.00500
	160		0.250	0.815	0.5217	0.0679	0.00362
	(XX)		0.358	0.599	0.2818	0.0499	0.00196
$1\frac{1}{4}$	40 (S)	1.660	0.140	1.380	1.496	0.1150	0.01039
	80 (X)		0.191	1.278	1.283	0.1065	0.00890
	160		0.250	1.160	1.057	0.0967	0.00734
	(XX)		0.382	0.896	0.6305	0.0747	0.00438
$1\frac{1}{2}$	40 (S)	1.900	0.145	1.610	2.036	0.1342	0.01414
	80 (X)		0.200	1.500	1.767	0.1250	0.01227
	160		0.281	1.338	1.406	0.1115	0.00976
	(XX)		0.400	1.100	0.9503	0.0917	0.00660
2	40 (S)	2.375	0.154	2.067	3.356	0.1723	0.02330
	80 (X)		0.218	1.939	2.953	0.1616	0.02051
	160		0.343	1.689	2.240	0.1408	0.01556
	(XX)		0.436	1.503	1.774	0.1253	0.01232
$2\frac{1}{2}$	40 (S)	2.875	0.203	2.469	4.788	0.2058	0.03325
	80 (X)		0.276	2.323	4.238	0.1936	0.02943
	160		0.375	2.125	3.547	0.1771	0.02463
	(XX)		0.552	1.771	2.464	0.1476	0.01711
3	40 (S)	3.500	0.216	3.068	7.393	0.2557	0.05134
	80 (X)		0.300	2.900	6.605	0.2417	0.04587
	160		0.437	2.626	5.416	0.2188	0.03761
	(XX)		0.600	2.300	4.155	0.1917	0.02885
$3\frac{1}{2}$	40 (S)	4.000	0.226	3.548	9.887	0.2957	0.06866
	80 (X)		0.318	3.364	8.888	0.2803	0.06172
4	40 (S)	4.500	0.237	4.026	12.73	0.3355	0.08841
	80 (X)		0.337	3.826	11.50	0.3188	0.07984
	120		0.437	3.626	10.33	0.3022	0.07171
	160		0.531	3.438	9.283	0.2865	0.06447
	(XX)		0.674	3.152	7.803	0.2627	0.05419
5	40 (S)	5.563	0.258	5.047	20.01	0.4206	0.1389
	80 (X)		0.375	4.813	18.19	0.4011	0.1263
	120		0.500	4.563	16.35	0.3803	0.1136
	160		0.625	4.313	14.61	0.3594	0.1015
	(XX)		0.750	4.063	12.97	0.3386	0.09004

(continued)

Water Properties

APPENDIX 14.A
Properties of Water at Atmospheric Pressure
(English Units)

temperature (°F)	density (lbm/ft^3)	absolute viscosity ($lbf\text{-}sec/ft^2$)	kinematic viscosity (ft^2/sec)	surface tension (lbf/ft)	vapor pressure head[a,b,c] (ft)	bulk modulus (lbf/in^2)
32	62.42	3.746×10^{-5}	1.931×10^{-5}	0.518×10^{-2}	0.20	293×10^3
40	62.43	3.229×10^{-5}	1.664×10^{-5}	0.514×10^{-2}	0.28	294×10^3
50	62.41	2.735×10^{-5}	1.410×10^{-5}	0.509×10^{-2}	0.41	305×10^3
60	62.37	2.359×10^{-5}	1.217×10^{-5}	0.504×10^{-2}	0.59	311×10^3
70	62.30	2.050×10^{-5}	1.059×10^{-5}	0.500×10^{-2}	0.84	320×10^3
80	62.22	1.799×10^{-5}	0.930×10^{-5}	0.492×10^{-2}	1.17	322×10^3
90	62.11	1.595×10^{-5}	0.826×10^{-5}	0.486×10^{-2}	1.62	323×10^3
100	62.00	1.424×10^{-5}	0.739×10^{-5}	0.480×10^{-2}	2.21	327×10^3
110	61.86	1.284×10^{-5}	0.667×10^{-5}	0.473×10^{-2}	2.97	331×10^3
120	61.71	1.168×10^{-5}	0.609×10^{-5}	0.465×10^{-2}	3.96	333×10^3
130	61.55	1.069×10^{-5}	0.558×10^{-5}	0.460×10^{-2}	5.21	334×10^3
140	61.38	0.981×10^{-5}	0.514×10^{-5}	0.454×10^{-2}	6.78	330×10^3
150	61.20	0.905×10^{-5}	0.476×10^{-5}	0.447×10^{-2}	8.76	328×10^3
160	61.00	0.838×10^{-5}	0.442×10^{-5}	0.441×10^{-2}	11.21	326×10^3
170	60.80	0.780×10^{-5}	0.413×10^{-5}	0.433×10^{-2}	14.20	322×10^3
180	60.58	0.726×10^{-5}	0.385×10^{-5}	0.426×10^{-2}	17.87	313×10^3
190	60.36	0.678×10^{-5}	0.362×10^{-5}	0.419×10^{-2}	22.29	313×10^3
200	60.12	0.637×10^{-5}	0.341×10^{-5}	0.412×10^{-2}	27.61	308×10^3
212	59.83	0.593×10^{-5}	0.319×10^{-5}	0.404×10^{-2}	35.38	300×10^3

[a]Based on actual densities, not on standard "cold, clear water."
[b]Can also be calculated from steam tables as $(p_{saturation})$ $(144\ in^2/ft^2)$ (v) (g/g_c).
[c]Multiply the vapor pressure head by the density and divide by $144\ in^2/ft^2$ to obtain psi.

APPENDIX 14.B
Properties of Water at Atmospheric Pressure
(SI Units)

temperature (°C)	density (kg/m^3)	absolute viscosity (Pa·s)	kinematic viscosity (m^2/s)	vapor pressure (kPa)	bulk modulus (kPa)
0	999.87	1.7921×10^{-3}	1.792×10^{-6}	0.611	204×10^4
4	1000.00	1.5674×10^{-3}	1.567×10^{-6}	0.813	206×10^4
10	999.73	1.3077×10^{-3}	1.371×10^{-6}	1.228	211×10^4
20	998.23	1.0050×10^{-3}	1.007×10^{-6}	2.338	220×10^4
25	997.08	0.8937×10^{-3}	8.963×10^{-7}	3.168	221×10^4
30	995.68	0.8007×10^{-3}	8.042×10^{-7}	4.242	223×10^4
40	992.25	0.6560×10^{-3}	6.611×10^{-7}	7.375	227×10^4
50	988.07	0.5494×10^{-3}	5.560×10^{-7}	12.333	230×10^4
60	983.24	0.4688×10^{-3}	4.768×10^{-7}	19.92	228×10^4
70	977.81	0.4061×10^{-3}	4.153×10^{-7}	31.16	225×10^4
80	971.83	0.3565×10^{-3}	3.668×10^{-7}	47.34	221×10^4
90	965.34	0.3165×10^{-3}	3.279×10^{-7}	70.10	216×10^4
100	958.38	0.2838×10^{-3}	2.961×10^{-7}	101.325	207×10^4

Compiled from various sources.

Support Material

APPENDIX 17.A

Specific Roughness and Hazen-Williams Constants for Various Water Pipe Materials[b]

ε , C

type of pipe or surface	ε (ft) range	ε (ft) design	C range	C clean	C design[a]
steel					
welded and seamless	0.0001–0.0003	0.0002	150–80	140	100
interior riveted, no projecting rivets				139	100
projecting girth rivets				130	100
projecting girth and horizontal rivets				115	100
vitrified, spiral-riveted, flow with lap				110	100
vitrified, spiral-riveted, flow against lap				100	90
corrugated				60	60
mineral					
concrete	0.001–0.01	0.004	152–85	120	100
cement-asbestos			160–140	150	140
vitrified clays					110
brick sewer					100
iron					
cast, plain	0.0004–0.002	0.0008	150–80	130	100
cast, tar (asphalt) coated	0.0002–0.0006	0.0004	145–50	130	100
cast, cement lined	0.000008	0.000008		150	140
cast, bituminous lined	0.000008	0.000008	160–130	148	140
cast, centrifugally spun	0.00001	0.00001			
galvanized, plain	0.0002–0.0008	0.0005			
wrought, plain	0.0001–0.0003	0.0002	150–80	130	100
miscellaneous					
copper and brass	0.000005	0.000005	150–120	140	130
wood stave	0.0006–0.003	0.002	145–110	120	110
transite	0.000008	0.000008			
lead, tin, glass		0.000005	150–120	140	130
plastic (PVC and ABS)		0.000005	150–120	140	130
fiberglass	0.000017	0.000017	160–150	150	150

(Multiply ft by 0.3 to obtain m.)

[a]The following guidelines are provided for selecting Hazen-Williams coefficients for cast-iron pipes of different ages. Values for welded steel pipe are similar to those of cast-iron pipe 5 years older. New pipe, all sizes: $C = 130$. 5 year-old pipe: $C = 120$ (d < 24 in); $C = 115$ (d $\geq$ 24 in). 10 year-old pipe: $C = 105$ (d = 4 in); $C = 110$ (d = 12 in); $C = 85$ (d $\geq$ 30 in). 40 year-old pipe: $C = 65$ (d = 4 in); $C = 80$ (d = 16 in).

[b]C values for sludge are 20 to 40% less than the corresponding water pipe values.

Support Material

B&L Eng. Calculation #4
Appendix 1C-4

APPENDIX 17.B
Darcy Friction Factors
(turbulent flow)

	relative roughness (ϵ/D)								
Reynolds no.	0.00000	0.000001	0.0000015	0.00001	0.00002	0.00004	0.00005	0.00006	0.00008
2×10^3	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495
2.5×10^3	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461	0.0461
3×10^3	0.0435	0.0435	0.0435	0.0435	0.0435	0.0436	0.0436	0.0436	0.0436
4×10^3	0.0399	0.0399	0.0399	0.0399	0.0399	0.0399	0.0400	0.0400	0.0400
5×10^3	0.0374	0.0374	0.0374	0.0374	0.0374	0.0374	0.0374	0.0375	0.0375
6×10^3	0.0355	0.0355	0.0355	0.0355	0.0355	0.0356	0.0356	0.0356	0.0356
7×10^3	0.0340	0.0340	0.0340	0.0340	0.0340	0.0341	0.0341	0.0341	0.0341
8×10^3	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0329	0.0329	0.0329
9×10^3	0.0318	0.0318	0.0318	0.0318	0.0318	0.0318	0.0318	0.0319	0.0319
1×10^4	0.0309	0.0309	0.0309	0.0309	0.0309	0.0309	0.0310	0.0310	0.0310
1.5×10^4	0.0278	0.0278	0.0278	0.0278	0.0278	0.0279	0.0279	0.0279	0.0280
2×10^4	0.0259	0.0259	0.0259	0.0259	0.0259	0.0260	0.0260	0.0260	0.0261
2.5×10^4	0.0245	0.0245	0.0245	0.0245	0.0246	0.0246	0.0246	0.0247	0.0247
3×10^4	0.0235	0.0235	0.0235	0.0235	0.0235	0.0236	0.0236	0.0236	0.0237
4×10^4	0.0220	0.0220	0.0220	0.0220	0.0220	0.0221	0.0221	0.0222	0.0222
5×10^4	0.0209	0.0209	0.0209	0.0209	0.0210	0.0210	0.0211	0.0211	0.0212
6×10^4	0.0201	0.0201	0.0201	0.0201	0.0201	0.0202	0.0203	0.0203	0.0204
7×10^4	0.0194	0.0194	0.0194	0.0194	0.0195	0.0196	0.0196	0.0197	0.0197
8×10^4	0.0189	0.0189	0.0189	0.0189	0.0190	0.0190	0.0191	0.0191	0.0192
9×10^4	0.0184	0.0184	0.0184	0.0184	0.0185	0.0186	0.0186	0.0187	0.0188
1×10^5	0.0180	0.0180	0.0180	0.0180	0.0181	0.0182	0.0183	0.0183	0.0184
1.5×10^5	0.0166	0.0166	0.0166	0.0166	0.0167	0.0168	0.0169	0.0170	0.0171
2×10^5	0.0156	0.0156	0.0156	0.0157	0.0158	0.0160	0.0160	0.0161	0.0163
2.5×10^5	0.0150	0.0150	0.0150	0.0151	0.0152	0.0153	0.0154	0.0155	0.0157
3×10^5	0.0145	0.0145	0.0145	0.0146	0.0147	0.0149	0.0150	0.0151	0.0153
4×10^5	0.0137	0.0137	0.0137	0.0138	0.0140	0.0142	0.0143	0.0144	0.0146
5×10^5	0.0132	0.0132	0.0132	0.0133	0.0134	0.0137	0.0138	0.0140	0.0142
6×10^5	0.0127	0.0128	0.0128	0.0129	0.0131	0.0133	0.0135	0.0136	0.0139
7×10^5	0.0124	0.0124	0.0124	0.0126	0.0127	0.0131	0.0132	0.0134	0.0136
8×10^5	0.0121	0.0121	0.0121	0.0123	0.0125	0.0128	0.0130	0.0131	0.0134
9×10^5	0.0119	0.0119	0.0119	0.0121	0.0123	0.0126	0.0128	0.0130	0.0133
1×10^6	0.0116	0.0117	0.0117	0.0119	0.0121	0.0125	0.0126	0.0128	0.0131
1.5×10^6	0.0109	0.0109	0.0109	0.0112	0.0114	0.0119	0.0121	0.0123	0.0127
2×10^6	0.0104	0.0104	0.0104	0.0107	0.0110	0.0116	0.0118	0.0120	0.0124
2.5×10^6	0.0100	0.0100	0.0101	0.0104	0.0108	0.0113	0.0116	0.0118	0.0123
3×10^6	0.0097	0.0098	0.0098	0.0102	0.0105	0.0112	0.0115	0.0117	0.0122
4×10^6	0.0093	0.0094	0.0094	0.0098	0.0103	0.0110	0.0113	0.0115	0.0120
5×10^6	0.0090	0.0091	0.0091	0.0096	0.0101	0.0108	0.0111	0.0114	0.0119
6×10^6	0.0087	0.0088	0.0089	0.0094	0.0099	0.0107	0.0110	0.0113	0.0118
7×10^6	0.0085	0.0086	0.0087	0.0093	0.0098	0.0106	0.0110	0.0113	0.0118
8×10^6	0.0084	0.0085	0.0085	0.0092	0.0097	0.0106	0.0109	0.0112	0.0118
9×10^6	0.0082	0.0083	0.0084	0.0091	0.0097	0.0105	0.0109	0.0112	0.0117
1×10^7	0.0081	0.0082	0.0083	0.0090	0.0096	0.0105	0.0109	0.0112	0.0117
1.5×10^7	0.0076	0.0078	0.0079	0.0087	0.0094	0.0104	0.0108	0.0111	0.0116
2×10^7	0.0073	0.0075	0.0076	0.0086	0.0093	0.0103	0.0107	0.0110	0.0116
2.5×10^7	0.0071	0.0073	0.0074	0.0085	0.0093	0.0103	0.0107	0.0110	0.0116
3×10^7	0.0069	0.0072	0.0073	0.0084	0.0092	0.0103	0.0107	0.0110	0.0116
4×10^7	0.0067	0.0070	0.0071	0.0084	0.0092	0.0102	0.0106	0.0110	0.0115
5×10^7	0.0065	0.0068	0.0070	0.0083	0.0092	0.0102	0.0106	0.0110	0.0115

(continued)

weld, thread, or flange).[15] Because of these many variations, it may be necessary to use a "generic table" of equivalent lengths during the initial design stages. (See Table 17.3 and App. 17.D.)

Table 17.3 *Typical Equivalent Lengths (schedule-40, screwed steel fittings)*

fitting type	pipe size 1 in	2 in	4 in
	equivalent length, ft		
angle valve	17.0	18.0	18.0
coupling or union	0.29	0.45	0.65
gate valve	0.84	1.5	2.5
globe valve	29.0	54.0	110.0
long radius 90° elbow	2.7	3.6	4.6
regular 45° elbow	1.3	2.7	5.5
regular 90° elbow	5.2	8.5	13.0
swing check valve	11.0	19.0	38.0
tee, flow through line (run)	3.2	7.7	17.0
tee, flow through stem	6.6	12.0	21.0
180° return bend	5.2	8.5	13.0

An alternative method of calculating the minor loss for a fitting is to use the *method of loss coefficients*. Each fitting has a *loss coefficient*, K, associated with it, which, when multiplied by the kinetic energy, gives the loss. Thus, a loss coefficient is the minor loss expressed in fractions (or multiples) of the velocity head.

$$h_m = Kh_v \qquad 17.41$$

The loss coefficient for any minor loss can be calculated if the equivalent length is known. However, there is no advantage to using one method over the other, except for consistency in calculations.

$$K = \frac{fL_e}{D}$$

Exact friction loss coefficients for bends, fittings, and valves are unique to each manufacturer. Furthermore, except for contractions, enlargements, exits, and entrances, the coefficients decrease fairly significantly (according to the fourth power of the diameter ratio) with increases in valve size. Therefore, a single K value is seldom applicable to an entire family of valves. Nevertheless, generic tables and charts have been developed. These compilations can be used for initial estimates as long as the general nature of the data is recognized.

pipe fittings, a *threaded fitting* is known as
n though no screws are used.

Table 17.4 *Typical Loss Coefficients*[a]

device	K
angle valve	5
bend, close return	2.2
butterfly valve[b]	
2 to 8 in	$45f_t$
10 to 14 in	$35f_t$
16 to 24 in	$25f_t$
check valve, swing, fully open	2.3
corrugated bends	1.3 to 1.6 times value for smooth bend
standard 90° elbow	0.9
long radius 90° elbow	0.6
45° elbow	0.42
gate valve	
fully open	0.19
1/4 closed	1.15
1/2 closed	5.6
3/4 closed	24
globe valve	10
meter	
disk or wobble	3.4 to 10
rotary (star or cog-wheel piston)	10
reciprocating piston	15
turbine wheel (double flow)	5 to 7.5
tee, standard	1.8

[a]The actual loss coefficient will usually depend on the size of the valve. Average values are given.
[b]Loss coefficients for butterfly valves are calculated from the friction factors for the pipes with complete turbulent flow.

Loss coefficients for specific fittings and valves must be known in order to be used. They cannot be derived theoretically. However, the loss coefficients for certain changes in flow area can be calculated from the following equations.[16]

- *sudden enlargements:* (D_1 is the smaller of the two diameters)

$$K = \left(1 - \left(\frac{D_1}{D_2}\right)^2\right)^2 \qquad 17.43$$

- *sudden contractions:* (D_1 is the smaller of the two diameters)

$$K = \tfrac{1}{2}\left(1 - \left(\frac{D_1}{D_2}\right)^2\right) \qquad 17.44$$

- *pipe exit:* (projecting exit, sharp-edged or rounded)

$$K = 1.0 \qquad 17.45$$

[16]No attempt is made to imply great accuracy with these equations. Correlation between actual and theoretical losses is fair.

DESIGN MEMORANDUM

Client: Floyd | Snider
Sheet 1 Of 6
Project: B&L Landfill (13488)
Date: 5/8/09
Data For:
Work Order:
Prepared By: RW/MZ Checked By: DLS
File No:

Note: This form must be used for project calculations and original filed in project files

- Contributing Area for the Southwest portion

1.) Use Pierce County Methodology for Sheet Flow Travel Time (Pierce Co. Stormwater Management and Site Development Manual Vol III Appendix III-B → Ref#1.)

$$T_1 = \frac{(0.42)(n_s \cdot L)^{0.8}}{(P^{0.527})(S_o^{0.4})}$$

n_s = Manning's "n" for sheet flow (Ref #1 Table B-2 p. B-9)
L = 300 ft, maximum sheet flow
P = 2 yr 24 hr rainfall (in.)
2.0 in from Ref#1 Table B.1 p B-5
S_o = land slope = $\frac{54-19.7}{511} = 0.06712$ from CAD Drawing C-12

$$T_1 = \frac{(0.42)(0.24 \cdot 300)^{0.8}}{(2^{0.527})(0.06712)^{0.4}} = 26.29 \text{ min.}$$

2.) Use Pierce County Methodology for Shallow Conc. Flow (Ref #1)

V = Velocity (ft/s)
K = Time of Concentration velocity factor (Ref #1 Table B-2 p. B-9)
S_o = land slope

$$V = K\sqrt{S_o}$$

$$V = 11\sqrt{0.06712} = 2.85 \frac{ft}{s}$$

Remaining Distance to Ditch = 511 ft − 300 ft = 211 ft

$$T_2 = 211 \text{ ft} \cdot \frac{s}{2.85 \text{ ft}} \cdot \frac{1 \text{ min}}{60 s} = 1.23 \text{ min.}$$

$$T_c = T_1 + T_2 = 26.29 \text{ min} + 1.23 \text{ min} = 27.5 \text{ min.}$$

3) Use WSDOT Hydraulics Manual (M23-03.01) March 2007 (Ref #2) to derive I

$$I = \frac{m}{(T_c)^n}$$

I = Rainfall (in/hr)
T_c = Time of Concentration (min)
m and n = dimensionless coefficient (Ref #2 Figure 2-5.4A)

$$I = \frac{6.93}{(27.5)^{0.539}}$$

$$= 1.16 \frac{in.}{hr}$$

DESIGN MEMORANDUM

Client: Floyd | Snider
Sheet 2 Of 6
Project: B&L Landfill (13488)
Date: 5/8/09
Data For:
Work Order:
Prepared By: RW/MZ Checked By: DLS
File No:

Note: This form must be used for project calculations and original filed in project files

4a) 10 yr Return Interval, Turf Only, WSDOT Hydraulics Methodology for I_{10} & Q_p (Ref #2)

For 10 year return... (Ref #2 Figure 2-5.4A)

$m = 5.70$
$n = 0.533$
$T_c = 27.5$ min (See Calculations #1 and #2)

$$I_{10} = \frac{m}{T_c^n}$$

$$I_{10} = \frac{5.70}{(27.5)^{0.533}} = 0.97 \frac{in}{hr}$$

$$Q_p = \frac{I\,C\,X\,A}{K_c} = (0.97\ in/hr)(0.3)(1.0)\left(221021.5\ ft^2 \cdot \frac{1ac}{43,560\ ft^2}\right)$$

$$= 1.48 \frac{ft^3}{s}$$

4b) 25 yr Return Interval, Turf Only, WSDOT Hydraulics Methodology for I_{25} & Q_p (Ref #2)

For 25 yr return... (Ref #2 Fig 2-2.5 4A)

$m = 6.93$
$n = 0.539$
$T_c = 27.5$ min.

$$I_{25} = \frac{m}{T_c^n} = \frac{6.93}{(27.5)^{0.539}} = 1.16 \frac{in}{hr}$$

$$Q_p = \frac{I\,C\,X\,A}{K_c} = (1.16\ in/hr)(0.3)(1.1)\left(221021.5\ ft^2 \cdot \frac{1ac}{43,560\ ft^2}\right)$$

$$= 1.94 \frac{ft^3}{s}$$

Q_p = Peak Discharge (ft^3/s)
C = Coefficient (unitless) Ref#2 Figure 2-5.2 p2-10
X = multiplier for storm event other than 10-year frequency (unitless) Ref#2 p2-8
A = Area (acre)
I = Rainfall Intensity (in/hr)
K_c = 1 for English units

DESIGN MEMORANDUM

Client: Floyd | Snider
Sheet 3 Of 6
Project: B&L Woodinville Site
Date: 6/9/09
Data For:
Work Order:
Prepared By: RW/MZ Checked By: DLS
File No:

Note: This form must be used for project calculations and original filed in project files

- Contributing Area for the East / Southeast portion of Landfill = 209,939.9 ft^2 (CAD Drawing G12)

1.) Use Pierce County Methodology for Sheet Flow Travel Time
(Pierce Co. Stormwater Management and Site Development Manual Vol III Appendix III-B → Ref. #1)

$$T_1 = \frac{(0.42)(n_s \cdot L)^{0.8}}{(P^{0.527})(S_o^{0.4})}$$

n_s = Manning's "n" for sheet flow (Ref #1 Table B-2 p. B-9)
L = 300 ft, maximum sheet flow length
P = 2 yr 24 hr Rainfall (in.)
2.0 in. from Ref #1 Table B-1 p. B-5
S_o = land slope = $\frac{54\ ft - 19.9\ ft}{402\ ft}$ = 0.0848
(values from CAD Drawing G12)

$$\therefore T_1 = \frac{(0.42)(0.24 \cdot 300)^{0.8}}{(2^{0.527})(0.0848)^{0.4}} = 23.94 \text{ min.}$$

2.) Use Pierce County Methodology for Shallow Conc. Flow (Ref #1)

$$V = K\sqrt{S_o}$$

V = Velocity (ft/s)
K = Time of Concentration Velocity Factor (Ref #1 Table B-2 pB-9)
S_o = Land Slope

$$V = 11\sqrt{0.0848} = 3.20\ ft/s$$

Remaining Distance to Ditch = 402 ft - 300 ft = 102 ft

$$T_2 = 102\ ft \cdot \frac{s}{3.20\ ft} \cdot \frac{1\ min}{60\ s} = 0.53 \text{ min.}$$

$$T_c = T_1 + T_2 = 23.94\ min + 0.53\ min. = 24.47\ min$$

3.) Use WSDOT Hydraulics Manual (M23-03.01) March 2007 (Ref #2) to derive I

$$I = \frac{m}{(T_c)^n}$$

I = Rainfall (in/hr)
T_c = Time of Concentration (min)
m an = dimensionless coefficients (Ref #2 Fig. 2-5.4A)

$$I = \frac{6.93}{(24.47)^{0.539}} = 1.24\ \frac{in}{hr}$$

DESIGN MEMORANDUM

Client: Floyd | Snider
Sheet 4 Of 6
Project: B+L Woodinville Site
Date: 6/9/09
Data For:
Work Order:
Prepared By: RW/MZ Checked By: DLS
File No:

Note: This form must be used for project calculations and original filed in project files

4a) 10 yr Return Interval, Turf Only, WSDOT Hydraulics Methodology for I_{10} & Q_p (Ref #2)

For 10 year return ... (Ref #2 Figure 2-5.4 A)

$$I_{10} = \frac{m}{T_c^{\,n}}$$ where $m = 5.70$
$n = 0.533$
$T_c = 24.47$ min. (See Calculations #1 and #2)

$$I_{10} = \frac{5.70}{(24.47)^{0.533}} = 1.04 \ \frac{in}{hr}$$

$$Q_p = \frac{I_{10} C \times A}{K_c}$$ where Q_p = Peak Discharge (ft^3/s)
C = Coefficient (–), Ref #2 Fig 2-5.2 p.2-10
X = multiplier for storm event other than 10-yr frequency (–) Ref #2 p. 2-8
A = Area (acre)
I_{10} = Rainfall Intensity for 10-year return interval
K_c = 1 for English units

$$\therefore Q_p = \left(1.04 \ \frac{in}{hr}\right)(0.3)(1.0)\left(209{,}939.9 \ ft^2 \cdot \frac{1 \ ac}{43{,}560 \ ft^2}\right) = 1.50 \ \frac{ft^3}{s}$$

4b) 25 year return interval, Turf Only, WSDOT Hydraulics Method for I_{25} and Q_p (Ref #2)

For 25 year return (Ref #2 Fig 2-2.5 4A)

$m = 6.93$
$n = 0.539$
$T_c = 24.47$ min

$$I_{25} = \frac{6.93}{(24.47)^{0.539}} = 1.24 \ \frac{in}{hr}$$

Using Q_p (See 4a) and using I_{25} instead of I_{10}

$$Q_p = \frac{I_{25} C \times A}{K_c} = \left(1.24 \ \frac{in}{hr}\right)(0.3)(1.1)\left(209{,}939.9 \ ft^2 \cdot \frac{1 \ ac}{43{,}560 \ ft^2}\right) = 1.97 \ \frac{ft^3}{s}$$

DESIGN MEMORANDUM

Client: Floyd | Snider
Sheet 5 Of 6
Project: B+L Woodwaste Site
Date: 6/9/09
Data For:
Work Order:
Prepared By: RW/MZ Checked By: DLS
File No:

Note: This form must be used for project calculations and original filed in project files

- Contributing Area for North portion of Landfill = 90,359.4 ft^2 (CAD Drawing C-12)

1.) Use Pierce County Methodology for Sheet Flow Travel Time
(Pierce County Stormwater Management and Site Development Manual Vol III Appendix III-B → Ref #1)

$$T_1 = \frac{(0.42)(n_s \cdot L)^{0.8}}{(P^{0.527})(S_o^{0.4})}$$

n_s = Manning's "n" for sheet flow (Ref #1 Table B-2 p B-9)
L = 300 ft, maximum sheet flow length
P = 2yr 24 hr Rainfall (in.) ; 2.0 in. from Ref #1 Table B-1 p.B-5
S_o = land surface = $\frac{54ft - 19ft}{335ft}$ = 0.1045
(values from CAD Drawing C-12)

$$\therefore T_1 = \frac{(0.42)(0.24 \cdot 300)^{0.8}}{(2^{0.527})(0.1045^{0.4})} = 22.02 \text{ min}$$

2.) Use Pierce County Methodology for Shallow Conc. Flow (Ref #1)
V = Velocity (ft/s)
K = Time of Concentration velocity factor (Ref #1 Table B-2 p B-9)
S_o = Land Slope

$$V = K\sqrt{S_o} = 11\sqrt{0.1045} = 3.56 \text{ ft/s}$$

Remaining Distance to Ditch = 335 ft − 300 ft = 35 ft

$$T_2 = 35 \text{ ft} \cdot \frac{s}{3.56 \text{ ft}} \cdot \frac{1 \text{ min}}{60 \text{ sec}} = 0.16 \text{ min.}$$

$$T_c = 22.02 \text{ min.} + 0.16 \text{ min.} = 22.18 \text{ min.}$$

3.) Use WSDOT Hydraulics Manual (M23-03.01) March 2007 (Ref #2) to derive I

$$I = \frac{m}{(T_c)^n}$$

I = Rainfall (in/hr)
T_c = Time of Concentration (min)
m & n = dimensionless coefficients (Ref #2 Figure 2-54A)

$$I = \frac{6.93}{(22.18)^{0.539}} = 1.30 \frac{in}{hr}$$

DESIGN MEMORANDUM

Client: Floyd | Snider
Sheet 6 Of 6
Project: B+L Woodinville Site
Date: 6/9/09
Data For:
Work Order:
Prepared By: RJ/MZ Checked By: DLS
File No:

Note: This form must be used for project calculations and original filed in project files

4a) 10yr Return Interval, Turf Only, WSDOT Hydraulics Methodology for I_{10} & Q_p (Ref #2)

For 10yr return ... (Ref #2 Figure 2-5.4 A)

$I_{10} = \frac{m}{T_c^n}$ where $m = 5.70$
$n = 0.533$
$T_c = 22.18$ min

$I_{10} = \frac{5.70}{(22.18)^{0.533}} = 1.09 \frac{in}{hr}$

$Q_p = \frac{I_{10} C x A}{K_c}$ Where Q_p = peak discharge (ft^3/s)
C = Coefficient (-), Ref #2 Fig 2-5.2 p 2-10
x = multiplier for storm event other than 10-yr frequency (-), Ref #2 p. 2-8
A = Area (acre)
I_{10} = Rainfall Intensity for 10-year return interval

$Q_p = \left(1.09 \frac{in}{hr}\right)(0.3)(1.0)\left(90,359.4\ ft^2 \cdot \frac{1\ ac}{43,560\ ft^2}\right) = 0.68 \frac{ft^3}{s}$

4b) 25 year return interval, Turf only, WSDOT Hydraulics Method for I_{25} and Q_p (Ref#2)

For 25 year return (Ref #2 Fig 2-25 4A)

$m = 6.93$
$n = 0.539$
$T_c = 22.18$ min

$I_{25} = \frac{m}{T_c^n} = \frac{6.93}{(22.18)^{0.539}} = 1.30 \frac{in}{hr}$

$Q_p = \frac{I_{25} C x A}{K_c} = \left(1.30 \frac{in}{hr}\right)(0.3)(1.1)\left(90,359.4\ ft^2 \cdot \frac{1\ ac}{43,560\ ft^2}\right)$

$= 0.89 \frac{ft^3}{s}$

Appendix III-B – Design Aids: Design Storm Precipitation Values, Isopluvial Maps, SCS Curve Numbers, Roughness Coefficients, and Soil Types

Ref #1

Single Event Model Guidance

The only approved use of a single event model is for the sizing of conveyance systems. Approved continuous simulation runoff models will be used for the design of water quality and quantity BMPs.

SBUH or SCS Methods

The applicant shall use the western Washington SCS curve numbers, not the SCS national curve numbers. These have been included in Table B.4. Individual curve numbers for a drainage area may be averaged into a "composite" curve number for use in either the SCS or SBUH methods. The NRCS (formerly SCS) has, for many years, conducted studies of the runoff characteristics for various land types. After gathering and analyzing extensive data, NRCS has developed relationships between land use, soil type, vegetation cover, interception, infiltration, surface storage, and runoff. The relationships have been characterized by a single runoff coefficient called a "curve number." The National Engineering Handbook – Section 4: Hydrology (NEH-4, SCS, August 1972) contains a detailed description of the development and use of the curve number method.

NRCS has developed "curve number" (CN) values based on soil type and land use. They can be found in "Urban Hydrology for Small Watersheds", Technical Release 55 (TR-55), June 1986, published by the NRCS. The combination of these two factors is called the "soil-cover complex." The soil-cover complexes have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. NRCS has classified over 4,000 soil types into these four soil groups. Table B.5 shows the hydrologic soil group of most soils in Pierce County and provides a brief description of the four groups. For details on other soil types refer to the NRCS publication mentioned above (TR-55, 1986).

Isopluvial Maps

National Oceanic and Atmospheric Administration (NOAA) isopluvial maps for Pierce County and Tacoma are included below. The professional engineer shall use the best engineering judgment in selecting the runoff totals for the project site.

Time of Concentration

Time of concentration is the sum of the travel times for sheet flow, shallow concentrated flow, and channel flow. For lakes and submerged wetlands, the travel time can be determined with storage routing techniques if the stage-storage versus discharge relationship is known or it may be assumed to be "zero."

Sheet Flow

With sheet flow, the friction value (n_s) (a modified Manning's effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges and rocks; and erosion and transportation of sediment) is used. These n_s values are for very shallow flow depths of about 0.1 foot and are only used for travel lengths up to 300 feet. Table B.2 gives Manning's n_s values for sheet flow for various surface conditions.

For sheet flow of up to 300 feet, use Manning's kinematic solution to directly compute T_t.

$$T_t = \frac{0.42\,(n_s L)^{0.8}}{(P_2)^{0.527}(S_o)^{0.4}}$$

where:

T_t = travel time (min),

n_s = sheet flow Manning's effective roughness coefficient (Table B.2).

L = flow length (ft),

P_2 = 2-year, 24-hour rainfall (in), and

s_o = slope of hydraulic grade line (land slope, ft/ft)

The maximum allowable distance for sheet flow shall be 300 feet, the remaining overland flow distance shall be shallow concentrated flow until the water reaches a channel.

Shallow Concentrated Flow

After a maximum of 300 feet, sheet flow is assumed to become shallow concentrated flow. The average velocity for this flow can be calculated using the k_s values from Table B.2 in which average velocity is a function of watercourse slope and type of channel.

The average velocity of flow, once it has measurable depth, shall be computed using the following equation:

$$V = k\sqrt{s_o}$$

where:

V = velocity (ft/s)

k = time of concentration velocity factor (ft/s)

s_o = slope of flow path (ft/ft)

"k" is computed for various land covers and channel characteristics with assumptions made for hydraulic radius using the following rearrangement of Manning's equation:

$$k = (1.49(R)^{0.667})/n$$

where:

R = an assumed hydraulic radius

n = Manning's roughness coefficient for open channel flow (see Table B.3)

Open Channel Flow

Open channels are assumed to begin where surveyed cross-section information has been obtained, where channels are visible on aerial photographs, or where lines indicating streams appear (in blue) on United States Geological Survey (USGS) quadrangle sheets. The k_c values from Table B.2 used in the Velocity Equation above or water surface profile information can be used to estimate average flow velocity.

Lakes or Wetlands

This travel time is normally very small and can be assumed as zero. Where significant attenuation may occur due to storage effects, the flows should be routed using a "level pool routing" technique.

Limitations

The following limitations apply in estimating travel time (T_t).

- Manning's kinematic solution should not be used for sheet flow longer than 300 feet.
- In watersheds with storm drains, carefully identify the appropriate hydraulic flow path to estimate T_c.
- Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or nonpressure flow.

Table B.2. "n" and "k" Values Used in Time Calculations for Hydrographs.

"n" Sheet Flow Equation Manning's Values (for the initial 300 ft. of travel)	n_s*
Smooth surfaces (concrete, asphalt, gravel, or bare hand packed soil)	0.011
Fallow fields or loose soil surface (no residue)	0.05
Cultivated soil with residue cover (s≤ 0.20 ft/ft)	0.06
Cultivated soil with residue cover (s> 0.20 ft/ft)	0.17
Short prairie grass and lawns	0.15
Dense grasses	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods or forest with light underbrush	0.40
Woods or forest with dense underbrush	0.80

*Manning values for sheet flow only, from Overton and Meadows 1976 (See TR-55, 1986)

"k" Values Used in Travel Time/Time of Concentration Calculations

Shallow Concentrated Flow (After the initial 300 ft. of sheet flow, R = 0.1)	k_s
1. Forest with heavy ground litter and meadows (n = 0.10)	3
2. Brushy ground with some trees (n = 0.060)	5
3. Fallow or minimum tillage cultivation (n = 0.040)	8
4. High grass (n = 0.035)	9
5. Short grass, pasture and lawns (n = 0.030)	11
6. Nearly bare ground (n = 0.25)	13
7. Paved and gravel areas (n = 0.012)	27

Channel Flow (intermittent) (At the beginning of visible channels R = 0.2)	k_c
1. Forested swale with heavy ground litter (n = 0.10)	5
2. Forested drainage course/ravine with defined channel bed (n = 0.050)	10
3. Rock-lined waterway (n = 0.035)	15
4. Grassed waterway (n = 0.030)	17
5. Earth-lined waterway (n = 0.025)	20
6. CMP pipe (n = 0.024)	21
7. Concrete pipe (0.012)	42
8. Other waterways and pipe	0.508/n

Channel Flow (Continuous stream, R = 0.4)	k_c
9. Meandering stream with some pools (n = 0.040)	20
10. Rock-lined stream (n = 0.035)	23
11. Grass-lined stream (n = 0.030)	27
12. Other streams, man-made channels and pipe n** determined from Table B.3	0.807/n**

Ref: DOE Stormwater Management Manual for the Puget Sound Basin, February 1992.

Hydrograph Phasing Analysis

Where flows from multiple basins or subbasins having different runoff characteristics and/or travel times combine, the design engineer shall sum the hydrographs after shifting each hydrograph according to its travel time to the discharge point of interest. The resultant hydrograph shall be either routed downstream as required in the downstream analysis, or routed through the control facility.

Included in this appendix are the 2-, 10-, and 100-year, 24-hour design storm and mean annual precipitation isopluvial maps for western Washington. These have been taken from NOAA Atlas 2 "Precipitation - Frequency Atlas of the Western United States, Volume IX, Washington. The applicant has the option of using the National Oceanic and Atmospheric Administration (NOAA) isopluvials for design purposes or utilizing the design storm precipitation values listed in Table B.1 below. The listed values can be used to an elevation of 650 feet, Mean Sea Level (MSL). Above 650 feet, MSL, the applicant shall use the NOAA isopluvials for selection of the design storm precipitation.

Table B.1. Design Storm Precipitation Values

Return Frequency 24-Hour Storm Event (Years)	Tacoma/Puyallup Southern Pierce County inches	Gig Harbor	KPN*
0.5	1.28	1.6	1.92
2	2.0	2.5	3.0
5	2.5	3.0	3.5
10	3.0	3.5	4.3
25	3.5	4.0	4.5-5.0
50	3.8	4.5	5.0-5.5
100	4.1	4.8	5.5-6.0

* KPN = Key Peninsula, North