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Golder Associates

March 8, 1996

Project No.: 923-6058

Mr. Roger Duwart
Remedial Project Manager
New Hampshire/RI Superfund Section
U.S. EPA New England
J.F.K. Federal Building
Boston, MA 02203-2211

RE: USE OF PASSIVE GAS VENTING TO CONTROL LANDFILL GAS MIGRATION, COAKLEY LANDFILL SUPERFUND SITE

Dear Mr. Duwart:

As you are aware, Golder Associates Inc. (Golder) on behalf of the Coakley Landfill Group (the Group) is modifying the Final (100%) Design Report (FDR) for the Coakley Landfill Superfund Site to incorporate the design of a passive gas venting system in place of the currently designed active gas collection and treatment system. In December 1995 Golder submitted a report entitled Evaluation of Passive Landfill Gas Collection and Venting, Coakley Landfill, which demonstrated that passive gas collection and venting at the Coakley Landfill will meet Applicable or Relevant and Appropriate Regulations (ARARs). As per your January 25, 1996 letter, we have prepared the following additional information to demonstrate the effectiveness of passive gas collection and venting in controlling the migration of Landfill Gas (LFG). This letter also includes a summary of the cost savings that will be realized through the use of the passive gas venting.

<u>Summary of Passive Gas Collection and Venting System Design</u>

The passive gas collection and venting system currently being designed will include the following major components:

- a 12-inch thick sand gas collection layer located beneath the flexible membrane liner (FML);
- gas vents located within the capped landfill area which intersect the gas collection layer and allow gas pressure beneath the FML to be released;
- gas vents located between the edge of the landfill and the property line to provide additional protection against LFG migration; and

- gas-migration monitoring probes located around the perimeter of the landfill which will be monitored on a regular basis.

Calculations supporting the design of the gas collection layer and gas vent spacing will be provided as part of the modified design package.

Use of Passive Gas Venting to Control LFG Migration

Passive LFG collection and venting systems are commonly designed and constructed to control the buildup of gas pressure beneath a landfill cap system and to control LFG migration. To assess the effectiveness of these systems, the New Hampshire Department of Environmental Services' (NHDES) Waste Management Division was contacted to determine how many landfills in New Hampshire have been closed with passive gas collection and venting system. File reviews were then completed for selected the sites which are similar to Coakley Landfill to assess whether the installed systems are meeting design requirements.

Mr. Carl Woodbury of NHDES provided a list of twenty-five landfills in New Hampshire which have been closed with passive gas collection and venting systems (see Table 1). These twenty-five landfills represent the majority of landfill closures in New Hampshire. Further, additional pending landfill designs incorporate passive gas venting. In general only a few, very large landfills which have recently been closed or are still operational have active gas collection systems. Nineteen of the twenty-five landfills are capped with an FML (HDPE, VLDPE or PVC). The landfills with passive gas venting range in size from 1.2 acres to 34 acres. Coakley Landfill, which will have an FML cap, is approximately 27 acres in size.

Mr. Woodbury indicated he was not aware of any gas migration problems associated with the landfills listed in Table 1. To further assess effectiveness of the passive gas collection and venting systems NHDES file reviews were completed for the Laconia Disposal Gardens Landfill (34 acres), Hudson Municipal Landfill (14 acres), Exeter Cross Road Landfill (11 acres), and Windham Landfill (2.7 acres). These landfills were selected due to their size and similarities to the Coakley Landfill. During the file reviews, particular attention was paid to number of vents installed at each site, the LFG monitoring programs in place at each site, and any information regarding monitoring results and/or system operational difficulties. Table 2 summarizes passive gas designs and monitoring requirements at each of these sites. Table 2 also includes the proposed design and monitoring requirements for the Coakley Landfill. The landfill site file review did not disclose information indicating that additional measures were required at any of the sites to address LFG migration.

As shown on Table 2, the proposed passive gas collection and venting system design and the proposed LFG monitoring system for the Coakley Landfill exceeds those of the four landfills reviewed by Golder. Based on NHDES' continued approval of passive gas designs and the apparent lack of problems at existing sites with passive gas venting, it is concluded that passive gas collection and venting is appropriate and effective for the control of LFG migration at closed municipal waste landfills.

Cost Comparison

A comparison of the costs for active gas collection and treatment and passive gas collection and venting was completed. The comparison included capital costs as well as long term (30 year post closure period) operation and maintenance (O&M) costs.

The following summarizes the capital and O&M cost estimates respectively for the two types of systems:

Capital Costs

Active Gas Collection and Treatment

Gas Extraction Wells	$ 201,300
Gas Conveyance System	$ 197,200
Gas Treatment System	$ 287,500
TOTAL:	$ 686,000

Passive Gas Collection Venting

Gas Vents	$ 50,000
Gas Collection Layer	$ 480,600
Additional Refuse Excavation	$ 37,700
Reduction in Grading Fill	$(228,800)
TOTAL:	$ 339,500

O&M Costs (Present Worth, 7% Interest, No Inflation)

Active Gas Collection and Treatment	$360,600
Passive Gas Collection and Treatment	$ 40,200

Based on these costs, the combined capital and O&M cost comparison is as follows:

	Capital	O&M	Total
Active System	$686,000	$360,600	$1,046,600
Passive System	$339,500	$ 40,200	$ 379,700
Difference	$346,500	$320,400	$ 666,900

As shown, a significant portion of the cost savings are associated with long term O&M costs. The calculated O&M costs for the active gas collection and treatment system are considered to be conservatively low. Actual costs savings associated with the passive gas collection and venting system could be significantly higher than calculated.

Summary

Based on a review of landfill closures in New Hampshire, it is concluded that passive LFG gas collection and venting is an effective means of controlling LFG migration from closed landfill facilities with FML caps. Implementation of passive LFG collection and venting at the Coakley Landfill will result in combined capital and O&M cost savings of approximately $700,000 through the closure and post closure period as compared to active LFG collection and treatment.

Should you have any questions or require additional information, please do not hesitate to call.

Very truly yours,

GOLDER ASSOCIATES INC.

Alistair P.T. Macdonald, LSP
Project Director and Associate

APTM/ljl

Enclosures

cc: T. Hubbard, NHDES
T. Roy, Aries
Coakley Technical Committee
Coakley Executive Committee

TABLE 1

NEW HAMPSHIRE LANDFILLS

CLOSED WITH PASSIVE GAS COLLECTION AND VENTING SYSTEMS

FACILITY	YR. CLSR. DESIGN APPROVED	YR. CLSR. CNSTRTN. BEGAN	YR. CLSR. CNSTRTN. COMPLT.	SIZE (ACRE)	CAP TYPE
Franklin	-	-	1985	13	HDPE/Clay
Derry	-	-	1986	6.5	PVC
Plaistow	-	-	1987	14	Clay
Rye	-	-	1988	7	Clay
New Boston	-	-	1989	4	HDPE
Andover	-	-	1989	2.3	HDPE
Laconia	1989	1989	1990	34	HDPE
Weare (PT2)	1989	1989	1990	2.8	HDPE
Soughegan (PT2)	1991	1991	1991	4	HDPE
Hudson	1989	1991	1991	14	HDPE
Jaffrey	1992	1992	1992	11	HDPE
New London	1991	1992	1992	3.5	VLDPE
Peterboro	1991	1992	1992	4	HDPE
Bennington	1992	1993	1993	8.5	HDPE
Salisbury	1992	1993	1993	1.2	HDPE
Windham	1994	-	-	2.7	HDPE
Exeter	1994	1994	1994	11	VLDPE/HDPE
Shelburne	1994	1994	1994	1.2	PVC
Whitefield	1994	-	-	6.0	VLDPE
Belmont	1994	1994	1994	3.5	VLDPE
Marlboro	1994	1994	1994	1.5	PS
Alton	1994	1994	1994	1.2	Clay/VLDPE
Ossipee	1994	1994	-	3.4	Till
Freedom	1994	1994	1994	1.2	Till
Effingham	1984	1994	-	2	Till

HDPE = High Density Polyethylene
VLDPE = Very Low Density Polyethylene
PVC = Polyvinyl Chloride
Till = 10^5 Soil
PS = Paper Sludge
\- = Unavailable
From NHDES Waste Management Division

TABLE 2

SUMMARY OF PASSIVE GAS COLLECTION AND VENTING SYSTEM DESIGNS AT SELECTED NEW HAMPSHIRE LANDFILLS

LANDFILL	LANDFILL AREA	NO. OF GAS VENTS	GAS VENTS PER ACRE	GAS COLLECTION LAYER	MONITORING REQUIREMENTS
Laconia	34 acres	8	0.24	6" granular fill	Not available
Exeter	11 acres	5	1.4	6" sand	Tri-annual monitoring at 6 gas migration probes located on two sides of the landfill 50' to 100' from edge of cap
Hudson	14 acres	12	0.85	Not available	None - no potential receptors
Windham	2.7 acres	6	2.2	None	Annual monitoring at 6 gas migration monitoring probes around perimeter of the landfill
Coakley	27 acres	68*	2.5	12" sand*	Tri-annual monitoring at 7 gas migration monitoring probes, annual ambient air monitoring at 4 monitoring stations*

*Proposed

APPENDIX G

PASSIVE GAS COLLECTION AND VENTING SYSTEM DESIGN CALCULATIONS

PASSIVE GAS VENT SPACING CALCULATION

Golder Associates	SUBJECT: PASSIVE GAS WELL SPACING		
	Job No. 923 6058 Ref.	Made by MRT Checked DC Reviewed [illegible]	Date 02-02-96 Sheet 1 of 3

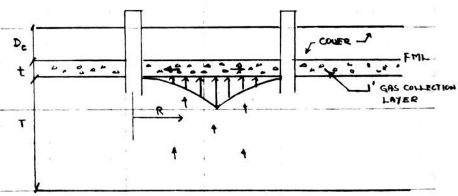
OBJECTIVE: TO CALCULATE THE SPACING OF THE PASSIVE GAS VENTS TO PROTECT CAP FROM LIFTING.

REFERENCE: 1 DESIGN CONSTRUCTION AND MONITORING OF LANDFILLS — AMALENDU BAGCHI

METHOD: HEAD LOSS FOR A GAS WELL IS GIVEN BY (REF 1)

$$\Delta p_w = \frac{T}{t} \frac{\mu_g F_g D_r}{2 k_s g} \left[R^2 \ln\left(\frac{R}{r_w}\right) + \frac{r_w^2}{2} - \frac{R^2}{2} \right]$$ (SEE ATTACHMENT-A)

WHERE, μ_g = ABSOLUTE VISCOSITY
F_g = GAS GENERATION RATE / UNIT MASS
D_r = REFUSE DENSITY
k_s = INTRINSIC PERMEABILITY
g = ACCELERATION DUE TO GRAVITY
R = A DISTANCE FROM WELL (POINT OF INTEREST)
r_w = WELL RADIUS
Δp_w = PRESSURE DROP AT DISTANCE 'R'



Golder Associates	SUBJECT: PASSIVE GAS VENT SPACING		
	Job No. 923 605 B	Made by MRT	Date 02-02-96
	Ref.	Checked DC	Sheet 2 of 3
		Reviewed [illegible]	

- THE LOCATION OF MAXIMUM PRESSURE ON FML WOULD BE AT MIDPOINT BETWEEN GAS WELLS.
- TO PREVENT LIFTING OF CAP, THE PRESSURE DEVELOPED UNDER THE FML SHOULD BE LESS THAN THE WEIGHT OF CAP

WEIGHT OF THE CAP $= D_c \times \gamma_m$

D_c - CAP THICKNESS

γ_m - SOIL DENSITY

TO INCLUDE A FOS OF F, THE WEIGHT OF THE CAP IS TAKEN AS $\frac{D_c \gamma_w}{F}$.

$$\frac{D_c \gamma_w}{F} = \frac{T}{t} \frac{\mu_g F_g D_r}{2 k_s \cdot g} \left[R^2 \ln\left(\frac{R}{r_w}\right) + \frac{r_w^2}{2} - \frac{R^2}{2} \right]$$

FROM WHICH R CAN BE CALCULATED

ASSUMPTIONS:

$\mu_g = 0.0293$ lb/ft-hr (REF-1)

$F_g = 390$ cfm FROM WHOLE LANDFILL (PDIR)

$= \frac{390}{} \times \frac{1}{60} \times \frac{1}{2{,}049{,}840{,}000 \text{ lbs}}$ (APPENDIX O - PDIR)

$= 3.17 \times 10^{-9}$ cf/lb/sec

$D_r = 60$ lb/cf CONSERVATIVE VALUE

$r_w = 0.5$ ft

$k_s = 6.02 \times 10^{-11}$ ft² (K $= 5 \times 10^{-3}$ cm/s FOR SAND - HELP MODEL)

$T = 30$ TO 50 ft

$t = 1$ ft

$\gamma_w = 120$ pcf

$D_c = 2.5$ ft

Golder Associates	SUBJECT: PASSIVE VENT SPACING		
	Job No. 923 6058 Ref.	Made by: MRT Checked: [illegible] Reviewed: [illegible]	Date 02-02-96 Sheet 3 of 3

CALCULATION

- $\frac{T}{t}\frac{\mu_g F_g D_r}{2 k_s g} = \frac{30'}{1'} \times \frac{0.0293 \frac{lb}{ft\text{-}hr} \times \frac{1 hr}{3600 sec} \times 3.17 \times 10^{-9} \frac{cf}{ft\text{-}sec} \times 60 \frac{lb}{cf}}{2 \times 6.02 \times 10^{-11} ft^2 \times 32.2 \frac{ft}{sec^2} \times 144 \frac{in^2}{ft^2}}$

  $= 8.32 \times 10^{-5} \frac{psi}{ft^2}$

- $\frac{D_c \gamma_w}{F} = \frac{2.5 \times 120}{F} = \frac{300 \text{ psf}}{F} = \frac{2.08}{F}$

- $\frac{2.08}{F} = 8.32 \times 10^{-5} \left[R^2 \ln\left(\frac{R}{0.5}\right) + \frac{0.5^2}{2} - \frac{R^2}{2} \right]$

FOR F = 1.5 AND T = 30, R = 63 (SEE ATTACHMENT-B)

CONCLUSION

THE ROI CALCULATED FOR DIFFERENT REFUSE THICKNESS ARE SHOWN IN ATTACHMENT-B. IN THE WELL LAYOUT (DRAWING 7-1) FOLLOWING ROI'S WILL BE USED

DEPTH	ROI
AVE 20'	75'
AVE 35'	59'
AVE 50	50'

ATTACHMENT A

Golder Associates	SUBJECT PRESSURE DROP IN GASWELL.		
	Job No. 923 6058 Ref.	Made by MRT Checked DC Reviewed pec	Date 02-02-96 Sheet 1 of 1

OBJECTIVE: TO DEVELOP A EQUATION FOR RADIAL PRESSURE DROP IN A GAS WELL.

REFERENCE: EMCON REPORT, PG 91-95

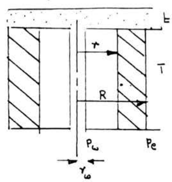
THEORY: DARCY'S LAW,

$$V_r = -\frac{k_s \gamma}{\mu}\frac{dh}{dr}$$

$$h = \frac{p}{\gamma} + z$$

$$\frac{dh}{dr} = \frac{1}{\gamma}\frac{dp}{dr} \quad \text{ASSUMING} \quad \frac{d\gamma}{dr} = 0, \quad \frac{dz}{dr} = 0$$

$$\therefore \quad V_r = -\frac{k_s g}{\mu} \cdot \frac{dp}{dr}$$



V_r - Velocity at r towards well
k_s - Specific or Intrinsic Perm.
μ - Absolute viscosity
p - pressure at Distance r
h - Static head
γ - Specific weight
F_G - Gas prod rate per unit mass
D - Refuse density
t - Refuse thickness
P_ω - Pressure at well
Pe - Pressure at Radius of Infl
T - Thickness of refuse

BUT
$$V_r = -\frac{(\pi R^2 - \pi r^2)T \cdot F_G \cdot D}{2\pi r \cdot t}$$

$$= -\frac{(R^2 - r^2)}{r}\frac{T}{t}\frac{F_G}{2} \cdot D$$

THEREFORE,

$$\frac{dp}{dr} \cdot \left(-\frac{g k_s}{\mu}\right) = -\frac{R^2 - r^2}{r}\frac{T}{t}\frac{F_G}{2} \cdot D$$

$$\int_{P_\omega}^{P_e} dp = \frac{\mu D F_G}{2 k_s g}\frac{T}{t}\int_{r_\omega}^{R}\left(\frac{R^2 - r^2}{r}\right) dr.$$

$$\boxed{p_e - p_\omega = \frac{T}{t}\frac{\mu D F_G}{2 k_s g}\left[R^2 \ln\left(\frac{R}{r_\omega}\right) + \frac{r_\omega^2}{2} - \frac{R^2}{2}\right]}$$

ATTACHMENT- B

TABLE1: ROI CALCULATION

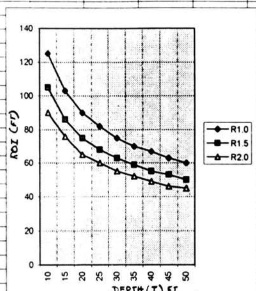
GAS TRAVELS UPWARDS TO GAS COLLECTION LAYER AND THEN LATERALLY TOWARD WELL (t=1)

(1) Gas absolute viscosity =0.0293 lb/ft-hr

(2) Hydraulic Conductivity of Sand = 0.005cm/s

FOS	T	k	ROI	
1	10	6.20E-11	125	1.009959
1.5	10	6.20E-11	105	1.031826
2	10	6.20E-11	90	0.978624
1	15	6.20E-11	103	0.988954
1.5	15	6.20E-11	86	0.995527
2	15	6.20E-11	76	1.009055
1	20	6.20E-11	90	0.978624
1.5	20	6.20E-11	75	0.979798
2	20	6.20E-11	65	0.950121
1	25	6.20E-11	82	0.995332
1.5	25	6.20E-11	68	0.984929
2	25	6.20E-11	60	0.993419
1	30	6.20E-11	75	0.979798
1.5	30	6.20E-11	63	0.996936
2	30	6.20E-11	55	0.98137
1	35	6.20E-11	70	0.980535
1.5	35	6.20E-11	59	1.004656
2	35	6.20E-11	52	1.009772
1	40	6.20E-11	67	1.016494
1.5	40	6.20E-11	55	0.98137
2	40	6.20E-11	49	1.010019
1	45	6.20E-11	63	0.996936
1.5	45	6.20E-11	53	1.016168
2	45	6.20E-11	46	0.985909
1	50	6.20E-11	60	0.993419
1.5	50	6.20E-11	50	0.990811
2	50	6.20E-11	45	1.042615

T	$R_{1.0}$	$R_{1.5}$	$R_{2.0}$
10	125	105	90
15	103	86	76
20	90	75	65
25	82	68	60
30	75	63	55
35	70	59	52
40	67	55	49
45	63	53	46
50	60	50	45



CHANNEL CAPACITY RE-EVALUATION

Golder Associates	SUBJECT: ADDENDUM TO 100% RDR SURFACE WATER RUNOFF CALCULATION		
	Job No. 923-6658 Ref. 525	Made by DC Checked MRT Reviewed [illegible]	Date 2/29/96 Sheet 1 of 2

OBJECTIVE; RE-EVALUATE THE CHANNEL VELOCITIES AND CAPACITIES PER THE POST 100% RDR MODIFICATION OF A PASSIVE GAS SYSTEM. AS A RESULT OF THE MODIFICATION, THE FINAL GRADES WERE REVISED AND CHANNEL WIDTHS WERE REDUCED REQUIRING RE-EVALATION.

REFERENCE;

1) COAKLEY LANDFILL 100% REMEDIAL DESIGN REPORT. GOLDER ASSOCIATES, NOVEMBER 1995.

METHOD; 1) THE SPREADSHEET DEVELOPED FOR REF. 1 WAS REVISITED AND THE CHANNEL BOTTOM WIDTHS WERE REDUCED FROM 5 FT TO 4 FT. (SEE TABLE A, sheet 2 of 2)

2) BY TRIAL AND ERROR, THE FLOW DEPTH IS ADJUSTED SO THAT "ACTUAL Q" APPROACHES PEAK DISCHARGE.

3) COMPARE DEPTH OF FLOW, FLOW VELOCITY, Q AVAILABLE, CHANNEL LINING AND FREEBOARD. IF CHANNEL VELOCITIES FOR GRASS ARE GREATER THAN 3 FT/SEC THAN CHANGE CHANNEL LINING AND RETURN TO 2).

CALCULATIONS: (SEE TABLE A, sheet 2 of 2 AND ATTACHMENT A)

CONCLUSIONS; RIPRAP WAS ADDED TO THE FINAL LEGS OF CHANNELS D-1 AND D-4 AND CHANNEL D-3 WAS CHANGED TO RIPRAP ENTIRELY.

TABLE A

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Client COAKLEY LANDFILL GROUP date 2/29/96
Project No 923-6058 time 12 00

Title COAKLEY LANDFILL		Site NORTH HAMPTON, NH		
Prepared by VEF/DC	Checked by	Telephone Number		Sheet of

Design Calculations. CHANNEL/BENCH/DOWNCHUTE DESIGN

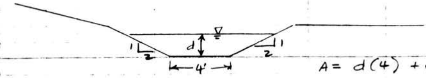
																				With Freeboard		
Channel Name	Contributing Watersheds	Design Storm (years)	Riprap Lining d50 (in)	Riprap Lining hicknes	Curve No.	Peak Discharge (cfs)	Channel Bed Slope (ft/ft)	Freeboard (ft)	Channel Lining	Manning Coeff.	Channel Bottom Width (ft)	Left Side Slopes (ave.)	Right Side Slopes (ave.)	Flow Area (sq.ft.)	Flow Depth (ft)	Top Flo Width (ft.)	Flow Velocity (ft/s)	Actual Q (cfs)	Channel Depth (ft)	Top Channel Width (ft)	Q Available (cfs)
B-1	B-1	25	N/A	N/A	71	1	0.020	0.53	GRASS	0.045	0	20	20	0 97	0 22	8 80	1 07	1 0	0 75	30 0	27.3
B-2	B-2	25	N/A	N/A	71	2	0.010	0.43	GRASS	0.045	0	20	20	2.05	0.32	12 80	0 97	2 0	0 75	30 0	19 3
B-3	B-3	25	N/A	N/A	71	5	0.020	0.28	GRASS	0.045	0	6	20	2 87	0 47	12.22	1 77	5 1	0 75	19 5	17 7
B-4	B-4	25	N/A	N/A	71	3	0.030	0 40	GRASS	0.045	0	8	20	1 72	0 35	9 80	1 79	3 1	0 75	21 0	23 4
B-5	B-5	25	N/A	N/A	71	2	0.015	0.41	GRASS	0.045	0	8	20	1 62	0 34	9 52	1 24	2 0	0 75	21 0	16 5
D-1	D-1	25	N/A	N/A	71	8	0.015	1 38	GRASS	0.045	4	2	2	3 25	0 62	6 48	2 48	8 1	2 00	12 0	74 5
D-1	D-1	25	6	18	71	8	0.030	1.43	RIPRAP	0.055	4	2	2	2 93	0 57	6 28	2 74	8 0	2 00	12 0	86 2
D-2	D-2	25	N/A	N/A	71	2	0.015	1.72	GRASS	0.045	4	2	2	1 28	0 28	5 12	1 58	2 0	2 00	12 0	74 5
D-3	D-3	25	N/A	N/A	71	4	0.050	1 67	RIPRAP	0.055	4	2	2	1 54	0 33	5 32	2 59	4 0	2 00	12 0	111 3
D-4	D-4	25	6	18	71	8	0.030	1 43	RIPRAP	0.055	4	2	2	2 93	0 57	6 28	2 74	8 0	2 00	12 0	86 2
D-4	D-4	25	N/A	N/A	71	8	0.015	1.38	GRASS	0.045	4	2	2	3 25	0 62	6 48	2 48	8 1	2 00	12 0	74 5
D-5	D-5	25	N/A	N/A	71	6	0.010	1.41	GRASS	0.045	4	2	2	3 06	0 59	6 36	1 97	6 0	2 00	12 0	60 9
DS-1	B-5 *	25	N/A	N/A	71	2	0.080	1 83	GRASS	0.045	4	2	2	0 74	0 17	4 68	2 69	2 0	2 00	12 0	172 1
DS-2	B-1 thru B-4	25	6	18	71	11	0.126	1.59	RIPRAP	0.055	4	2	2	1 98	0 41	5 64	4 66	9 2	2 00	12 0	176 7
DS-2	B-1 thru B-4	25	6	18	71	11	0.050	1 47	RIPRAP	0.055	4	2	2	2 68	0.53	6 12	3 39	9 1	2 00	12 0	111 3

* SEE ATTACHMENT A FOR HAND CALCULATION OF CHANNEL VELOCITY AND Q AVAILABLE

Golder Associates	SUBJECT: ADDENDUM TO 100 % RDR SURFACE WATER RUNOFF CALCULATION		
	Job No. 923-6058	Made by DC	Date 2/29/96
	Ref. .525	Checked MRT	Sheet 1 of 1
		Reviewed pee	

CHECK CHANNEL FLOW VELOCITY: **ATTACHMENT A**

$$V = \frac{1.486\, R^{2/3}\, S^{1/2}}{n}$$



$A = d(4) + d^2(2)$

$P = 4 + 2\sqrt{d^2 + (2d)^2}$

$R = \frac{A}{P}$

CHECK DOWNCHUTE DS-1:

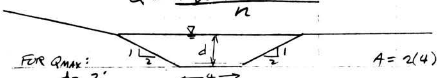
FOR $d = 0.17$ $n = 0.045$
$S = 0.08$
$A = 0.738$
$P = 4.76$
$R = 0.155$

$$V = \frac{1.486\,(.155)^{2/3}\,(0.08)^{1/2}}{0.045} = 2.7 \text{ FT/sec}$$

OK

AVAILABLE Q CHECK:

$$Q = \frac{1.486\, R^{2/3}\, S^{1/2}\, A}{n}$$



FOR Q_{MAX}:
$d = 2'$
$S = 0.08$
$A = 16$
$P = 12.94$
$R = 1.236$

$A = 2(4) + 2^2(2) = 16$

$P = 4 + 2\sqrt{2^2 + 4^2}$
$= 12.94$

$$Q = \frac{1.486\,(1.236)^{2/3}\,(0.08)\,16}{0.045} = 172.1$$

OK