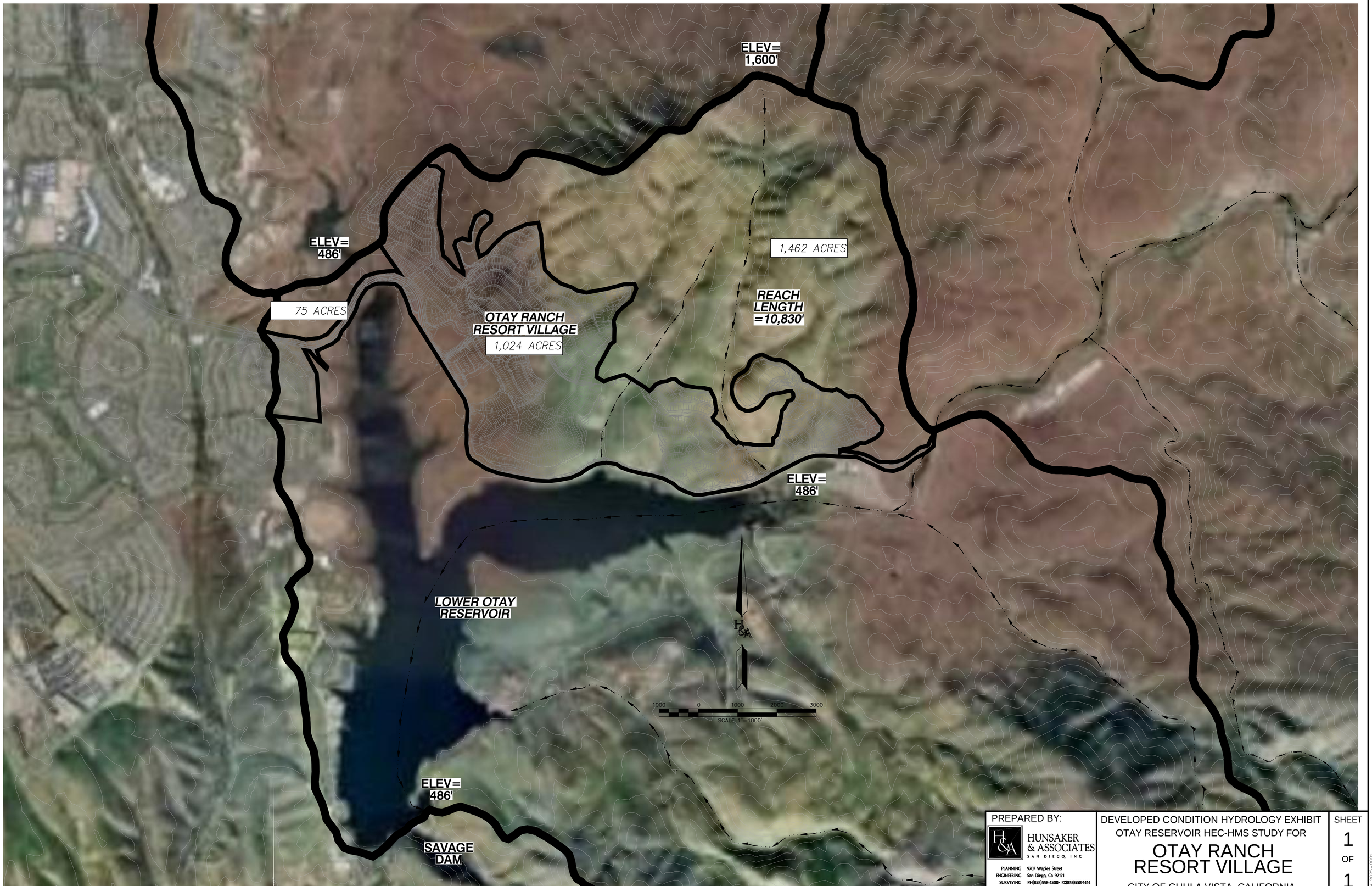

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DEVELOPED CONDITION HYDROLOGY EXHIBIT
OTAY RESERVOIR HEC-HMS STUDY FOR

OTAY RANCH RESORT VILLAGE

CITY OF CHULA VISTA, CALIFORNIA

SHEET 1 OF 1

W.O.# 2825-0001

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CHAPTER 7

HYDRAULIC ANALYSIS

CHAPTER 7

7.1 Culvert Hydraulic Analysis: Existing Condition

Culvert Calculator Report
Culvert 01A Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	530.70	ft	Headwater Depth/Height	5.90	
Computed Headwater Elevation	536.18	ft	Discharge	43.90	cfs
Inlet Control HW Elev.	536.18	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	535.11	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	524.37	ft	Downstream Invert	520.38	ft
Length	57.90	ft	Constructed Slope	0.068912	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.97	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.97	ft
Velocity Downstream	14.02	ft/s	Critical Slope	0.115851	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	535.11	ft	Upstream Velocity Head	3.03	ft
Ke	0.75		Entrance Loss	2.28	ft

Inlet Control Properties					
Inlet Control HW Elev.	536.18	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 01A Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	530.07	ft	Headwater Depth/Height	2.85	
Computed Headwater Elevation	530.07	ft	Discharge	28.93	cfs
Inlet Control HW Elev.	530.07	ft	Tailwater Elevation	494.30	ft
Outlet Control HW Elev.	528.70	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	524.37	ft	Downstream Invert	520.38	ft
Length	57.90	ft	Constructed Slope	0.068912	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.48	ft
Slope Type	Steep		Normal Depth	1.48	ft
Flow Regime	Supercritical		Critical Depth	1.84	ft
Velocity Downstream	11.59	ft/s	Critical Slope	0.048334	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	528.70	ft	Upstream Velocity Head	1.42	ft
Ke	0.75		Entrance Loss	1.06	ft

Inlet Control Properties					
Inlet Control HW Elev.	530.07	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 01B Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	530.70	ft	Headwater Depth/Height	1.03	
Computed Headwater Elevation	526.44	ft	Discharge	11.10	cfs
Inlet Control HW Elev.	526.26	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	526.44	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	524.37	ft	Downstream Invert	520.38	ft
Length	57.90	ft	Constructed Slope	0.068912	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.81	ft
Slope Type	Steep		Normal Depth	0.81	ft
Flow Regime	Supercritical		Critical Depth	1.19	ft
Velocity Downstream	9.30	ft/s	Critical Slope	0.018422	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	526.44	ft	Upstream Velocity Head	0.50	ft
Ke	0.75		Entrance Loss	0.37	ft

Inlet Control Properties					
Inlet Control HW Elev.	526.26	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 01B Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	530.07	ft	Headwater Depth/Height	2.85	
Computed Headwater Elevation	530.07	ft	Discharge	28.93	cfs
Inlet Control HW Elev.	530.07	ft	Tailwater Elevation	494.30	ft
Outlet Control HW Elev.	528.70	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	524.37	ft	Downstream Invert	520.38	ft
Length	57.90	ft	Constructed Slope	0.068912	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.48	ft
Slope Type	Steep		Normal Depth	1.48	ft
Flow Regime	Supercritical		Critical Depth	1.84	ft
Velocity Downstream	11.59	ft/s	Critical Slope	0.048334	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	528.70	ft	Upstream Velocity Head	1.42	ft
Ke	0.75		Entrance Loss	1.06	ft

Inlet Control Properties					
Inlet Control HW Elev.	530.07	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 02 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	510.60	ft	Headwater Depth/Height	11.23	
Computed Headwater Elevation	517.31	ft	Discharge	53.70	cfs
Inlet Control HW Elev.	512.04	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	517.31	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	494.85	ft	Downstream Invert	490.39	ft
Length	88.40	ft	Constructed Slope	0.050452	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.99	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.99	ft
Velocity Downstream	17.11	ft/s	Critical Slope	0.178722	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	517.31	ft	Upstream Velocity Head	4.54	ft
Ke	0.75		Entrance Loss	3.41	ft

Inlet Control Properties					
Inlet Control HW Elev.	512.04	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 02 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	510.60	ft	Headwater Depth/Height	7.87	
Computed Headwater Elevation	510.60	ft	Discharge	45.91	cfs
Inlet Control HW Elev.	507.69	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	510.60	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	494.85	ft	Downstream Invert	490.39	ft
Length	88.40	ft	Constructed Slope	0.050452	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.97	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.97	ft
Velocity Downstream	14.66	ft/s	Critical Slope	0.127649	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	510.60	ft	Upstream Velocity Head	3.32	ft
Ke	0.75		Entrance Loss	2.49	ft

Inlet Control Properties					
Inlet Control HW Elev.	507.69	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 04 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	503.30	ft	Headwater Depth/Height	121.31	
Computed Headwater Elevation	735.14	ft	Discharge	172.02	cfs
Inlet Control HW Elev.	659.37	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	735.14	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	492.52	ft	Downstream Invert	489.99	ft
Length	82.00	ft	Constructed Slope	0.030854	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	2.00	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	2.00	ft
Velocity Downstream	54.76	ft/s	Critical Slope	1.970896	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	735.14	ft	Upstream Velocity Head	46.59	ft
Ke	0.75		Entrance Loss	34.94	ft

Inlet Control Properties					
Inlet Control HW Elev.	659.37	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 04 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	503.30	ft	Headwater Depth/Height	5.39	
Computed Headwater Elevation	503.30	ft	Discharge	37.14	cfs
Inlet Control HW Elev.	501.30	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	503.30	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	492.52	ft	Downstream Invert	489.99	ft
Length	82.00	ft	Constructed Slope	0.030854	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.94	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.94	ft
Velocity Downstream	11.94	ft/s	Critical Slope	0.080684	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	503.30	ft	Upstream Velocity Head	2.17	ft
Ke	0.75		Entrance Loss	1.63	ft

Inlet Control Properties					
Inlet Control HW Elev.	501.30	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 05 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	505.54	ft	Headwater Depth/Height	8.22	
Computed Headwater Elevation	510.57	ft	Discharge	48.40	cfs
Inlet Control HW Elev.	508.29	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	510.57	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	494.13	ft	Downstream Invert	490.64	ft
Length	73.60	ft	Constructed Slope	0.047418	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.98	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.98	ft
Velocity Downstream	15.44	ft/s	Critical Slope	0.143036	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	510.57	ft	Upstream Velocity Head	3.69	ft
Ke	0.75		Entrance Loss	2.77	ft

Inlet Control Properties					
Inlet Control HW Elev.	508.29	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 05 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	505.54	ft	Headwater Depth/Height	5.70	
Computed Headwater Elevation	505.54	ft	Discharge	41.07	cfs
Inlet Control HW Elev.	504.61	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	505.54	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	494.13	ft	Downstream Invert	490.64	ft
Length	73.60	ft	Constructed Slope	0.047418	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.96	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.96	ft
Velocity Downstream	13.14	ft/s	Critical Slope	0.100279	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	505.54	ft	Upstream Velocity Head	2.66	ft
Ke	0.75		Entrance Loss	1.99	ft

Inlet Control Properties					
Inlet Control HW Elev.	504.61	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 06 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	507.78	ft	Headwater Depth/Height	151.89	
Computed Headwater Elevation	797.60	ft	Discharge	194.90	cfs
Inlet Control HW Elev.	707.72	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	797.60	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	493.83	ft	Downstream Invert	491.31	ft
Length	78.90	ft	Constructed Slope	0.031939	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	2.00	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	2.00	ft
Velocity Downstream	62.04	ft/s	Critical Slope	2.530052	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	797.60	ft	Upstream Velocity Head	59.81	ft
Ke	0.75		Entrance Loss	44.86	ft

Inlet Control Properties					
Inlet Control HW Elev.	707.72	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 06 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	507.78	ft	Headwater Depth/Height	6.97	
Computed Headwater Elevation	507.78	ft	Discharge	42.52	cfs
Inlet Control HW Elev.	505.01	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	507.78	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	493.83	ft	Downstream Invert	491.31	ft
Length	78.90	ft	Constructed Slope	0.031939	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.96	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.96	ft
Velocity Downstream	13.59	ft/s	Critical Slope	0.108112	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	507.78	ft	Upstream Velocity Head	2.85	ft
Ke	0.75		Entrance Loss	2.14	ft

Inlet Control Properties					
Inlet Control HW Elev.	505.01	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 07 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	516.55	ft	Headwater Depth/Height	86.50	
Computed Headwater Elevation	759.56	ft	Discharge	568.60	cfs
Inlet Control HW Elev.	759.56	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	711.83	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	500.07	ft	Downstream Invert	497.01	ft
Length	83.90	ft	Constructed Slope	0.036472	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	3.00	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	3.00	ft
Velocity Downstream	80.44	ft/s	Critical Slope	0.726826	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	3.00	ft
Section Size	36 inch		Rise	3.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	711.83	ft	Upstream Velocity Head	100.56	ft
Ke	0.50		Entrance Loss	50.28	ft

Inlet Control Properties					
Inlet Control HW Elev.	759.56	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	7.1	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 07 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	516.55	ft	Headwater Depth/Height	5.49	
Computed Headwater Elevation	516.55	ft	Discharge	135.03	cfs
Inlet Control HW Elev.	516.55	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	512.37	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	500.07	ft	Downstream Invert	497.01	ft
Length	83.90	ft	Constructed Slope	0.036472	ft/ft

Hydraulic Profile					
Profile	MCType22		Depth, Downstream	2.67	ft
Slope Type	Mild		Normal Depth	2.67	ft
Flow Regime	Subcritical		Critical Depth	2.97	ft
Velocity Downstream	20.33	ft/s	Critical Slope	0.037650	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	3.00	ft
Section Size	36 inch		Rise	3.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	512.37	ft	Upstream Velocity Head	6.42	ft
Ke	0.50		Entrance Loss	3.21	ft

Inlet Control Properties					
Inlet Control HW Elev.	516.55	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	7.1	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 08 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	516.03	ft	Headwater Depth/Height	184.01	
Computed Headwater Elevation	697.38	ft	Discharge	34.40	cfs
Inlet Control HW Elev.	620.00	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	697.38	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	513.37	ft	Downstream Invert	513.29	ft
Length	41.20	ft	Constructed Slope	0.001942	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	1.00	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	1.00	ft
Velocity Downstream	43.80	ft/s	Critical Slope	3.177723	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.00	ft
Section Size	12 inch		Rise	1.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	697.38	ft	Upstream Velocity Head	29.81	ft
Ke	0.75		Entrance Loss	22.36	ft

Inlet Control Properties					
Inlet Control HW Elev.	620.00	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	0.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 08 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	516.03	ft	Headwater Depth/Height	2.66	
Computed Headwater Elevation	516.03	ft	Discharge	3.45	cfs
Inlet Control HW Elev.	514.98	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	516.03	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	513.37	ft	Downstream Invert	513.29	ft
Length	41.20	ft	Constructed Slope	0.001942	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	0.79	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	0.79	ft
Velocity Downstream	5.16	ft/s	Critical Slope	0.033950	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.00	ft
Section Size	12 inch		Rise	1.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	516.03	ft	Upstream Velocity Head	0.30	ft
Ke	0.75		Entrance Loss	0.22	ft

Inlet Control Properties					
Inlet Control HW Elev.	514.98	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	0.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 09 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	507.06	ft	Headwater Depth/Height	32.43	
Computed Headwater Elevation	560.90	ft	Discharge	121.90	cfs
Inlet Control HW Elev.	557.28	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	560.90	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	496.05	ft	Downstream Invert	493.39	ft
Length	84.60	ft	Constructed Slope	0.031442	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	2.00	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	2.00	ft
Velocity Downstream	38.80	ft/s	Critical Slope	0.285413	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	560.90	ft	Upstream Velocity Head	23.40	ft
Ke	0.75		Entrance Loss	17.55	ft

Inlet Control Properties					
Inlet Control HW Elev.	557.28	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	3.1	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 09 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	507.06	ft	Headwater Depth/Height	5.51	
Computed Headwater Elevation	507.06	ft	Discharge	49.05	cfs
Inlet Control HW Elev.	507.06	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	505.99	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	496.05	ft	Downstream Invert	493.39	ft
Length	84.60	ft	Constructed Slope	0.031442	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.98	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.98	ft
Velocity Downstream	15.64	ft/s	Critical Slope	0.043187	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	505.99	ft	Upstream Velocity Head	3.79	ft
Ke	0.75		Entrance Loss	2.84	ft

Inlet Control Properties					
Inlet Control HW Elev.	507.06	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	3.1	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 10 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	528.49	ft	Headwater Depth/Height	2.54	
Computed Headwater Elevation	528.08	ft	Discharge	18.80	cfs
Inlet Control HW Elev.	527.94	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	528.08	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	523.64	ft	Downstream Invert	522.40	ft
Length	49.00	ft	Constructed Slope	0.025306	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.57	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.57	ft
Velocity Downstream	8.27	ft/s	Critical Slope	0.042406	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.75	ft
Section Size	21 inch		Rise	1.75	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	528.08	ft	Upstream Velocity Head	0.95	ft
Ke	0.75		Entrance Loss	0.71	ft

Inlet Control Properties					
Inlet Control HW Elev.	527.94	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	2.4	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 10 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	528.49	ft	Headwater Depth/Height	2.77	
Computed Headwater Elevation	528.49	ft	Discharge	19.71	cfs
Inlet Control HW Elev.	528.28	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	528.49	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	523.64	ft	Downstream Invert	522.40	ft
Length	49.00	ft	Constructed Slope	0.025306	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.59	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.59	ft
Velocity Downstream	8.58	ft/s	Critical Slope	0.046083	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.75	ft
Section Size	21 inch		Rise	1.75	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	528.49	ft	Upstream Velocity Head	1.04	ft
Ke	0.75		Entrance Loss	0.78	ft

Inlet Control Properties					
Inlet Control HW Elev.	528.28	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	2.4	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 11 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	516.49	ft	Headwater Depth/Height	1.89	
Computed Headwater Elevation	515.62	ft	Discharge	10.90	cfs
Inlet Control HW Elev.	515.62	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	515.32	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	512.78	ft	Downstream Invert	508.39	ft
Length	45.50	ft	Constructed Slope	0.096484	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.85	ft
Slope Type	Steep		Normal Depth	0.85	ft
Flow Regime	Supercritical		Critical Depth	1.27	ft
Velocity Downstream	10.52	ft/s	Critical Slope	0.034966	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	515.32	ft	Upstream Velocity Head	0.73	ft
Ke	0.75		Entrance Loss	0.55	ft

Inlet Control Properties					
Inlet Control HW Elev.	515.62	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	1.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 11 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	516.49	ft	Headwater Depth/Height	2.47	
Computed Headwater Elevation	516.49	ft	Discharge	12.96	cfs
Inlet Control HW Elev.	516.49	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	515.76	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	512.78	ft	Downstream Invert	508.39	ft
Length	45.50	ft	Constructed Slope	0.096484	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.95	ft
Slope Type	Steep		Normal Depth	0.95	ft
Flow Regime	Supercritical		Critical Depth	1.35	ft
Velocity Downstream	10.93	ft/s	Critical Slope	0.045657	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	515.76	ft	Upstream Velocity Head	0.93	ft
Ke	0.75		Entrance Loss	0.70	ft

Inlet Control Properties					
Inlet Control HW Elev.	516.49	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	1.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 12 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	513.98	ft	Headwater Depth/Height	6.21	
Computed Headwater Elevation	519.26	ft	Discharge	22.08	cfs
Inlet Control HW Elev.	519.26	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	515.70	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	509.95	ft	Downstream Invert	499.28	ft
Length	59.20	ft	Constructed Slope	0.180236	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.13	ft
Slope Type	Steep		Normal Depth	1.13	ft
Flow Regime	Supercritical		Critical Depth	1.48	ft
Velocity Downstream	15.50	ft/s	Critical Slope	0.136653	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	515.70	ft	Upstream Velocity Head	2.44	ft
Ke	0.75		Entrance Loss	1.83	ft

Inlet Control Properties					
Inlet Control HW Elev.	519.26	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	1.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 12 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	513.98	ft	Headwater Depth/Height	2.69	
Computed Headwater Elevation	513.98	ft	Discharge	13.76	cfs
Inlet Control HW Elev.	513.98	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	513.11	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	509.95	ft	Downstream Invert	499.28	ft
Length	59.20	ft	Constructed Slope	0.180236	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.81	ft
Slope Type	Steep		Normal Depth	0.81	ft
Flow Regime	Supercritical		Critical Depth	1.37	ft
Velocity Downstream	14.11	ft/s	Critical Slope	0.050900	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	513.11	ft	Upstream Velocity Head	1.02	ft
Ke	0.75		Entrance Loss	0.77	ft

Inlet Control Properties					
Inlet Control HW Elev.	513.98	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	1.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 13 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	509.12	ft	Headwater Depth/Height	2.52	
Computed Headwater Elevation	508.23	ft	Discharge	14.86	cfs
Inlet Control HW Elev.	508.23	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	507.61	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	504.46	ft	Downstream Invert	501.73	ft
Length	43.90	ft	Constructed Slope	0.062187	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.89	ft
Slope Type	Steep		Normal Depth	0.81	ft
Flow Regime	Supercritical		Critical Depth	1.40	ft
Velocity Downstream	13.66	ft/s	Critical Slope	0.017299	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	507.61	ft	Upstream Velocity Head	1.16	ft
Ke	0.50		Entrance Loss	0.58	ft

Inlet Control Properties					
Inlet Control HW Elev.	508.23	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 13 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	509.12	ft	Headwater Depth/Height	3.11	
Computed Headwater Elevation	509.12	ft	Discharge	17.04	cfs
Inlet Control HW Elev.	509.12	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	508.13	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	504.46	ft	Downstream Invert	501.73	ft
Length	43.90	ft	Constructed Slope	0.062187	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.97	ft
Slope Type	Steep		Normal Depth	0.88	ft
Flow Regime	Supercritical		Critical Depth	1.44	ft
Velocity Downstream	14.12	ft/s	Critical Slope	0.022934	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	508.13	ft	Upstream Velocity Head	1.48	ft
Ke	0.50		Entrance Loss	0.74	ft

Inlet Control Properties					
Inlet Control HW Elev.	509.12	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 14 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	504.77	ft	Headwater Depth/Height	4.18	
Computed Headwater Elevation	505.11	ft	Discharge	20.40	cfs
Inlet Control HW Elev.	505.11	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	503.45	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	498.84	ft	Downstream Invert	496.48	ft
Length	50.00	ft	Constructed Slope	0.047200	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.18	ft
Slope Type	Steep		Normal Depth	1.11	ft
Flow Regime	Supercritical		Critical Depth	1.47	ft
Velocity Downstream	13.68	ft/s	Critical Slope	0.033784	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	503.45	ft	Upstream Velocity Head	2.09	ft
Ke	0.50		Entrance Loss	1.05	ft

Inlet Control Properties					
Inlet Control HW Elev.	505.11	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 14 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	504.77	ft	Headwater Depth/Height	3.95	
Computed Headwater Elevation	504.77	ft	Discharge	19.73	cfs
Inlet Control HW Elev.	504.77	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	503.24	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	498.84	ft	Downstream Invert	496.48	ft
Length	50.00	ft	Constructed Slope	0.047200	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.15	ft
Slope Type	Steep		Normal Depth	1.08	ft
Flow Regime	Supercritical		Critical Depth	1.47	ft
Velocity Downstream	13.56	ft/s	Critical Slope	0.031421	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	503.24	ft	Upstream Velocity Head	1.96	ft
Ke	0.50		Entrance Loss	0.98	ft

Inlet Control Properties					
Inlet Control HW Elev.	504.77	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 15 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	504.43	ft	Headwater Depth/Height	901.27	
Computed Headwater Elevation	1,839.37	ft	Discharge	296.50	cfs
Inlet Control HW Elev.	1,608.89	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	1,839.37	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	487.47	ft	Downstream Invert	484.40	ft
Length	86.90	ft	Constructed Slope	0.035328	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	6.30	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	1.50	ft
Velocity Downstream	167.78	ft/s	Critical Slope	7.968184	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	1,839.37	ft	Upstream Velocity Head	437.49	ft
Ke	0.50		Entrance Loss	218.75	ft

Inlet Control Properties					
Inlet Control HW Elev.	1,608.89	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 15 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	504.43	ft	Headwater Depth/Height	11.31	
Computed Headwater Elevation	504.43	ft	Discharge	25.70	cfs
Inlet Control HW Elev.	496.86	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	504.43	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	487.47	ft	Downstream Invert	484.40	ft
Length	86.90	ft	Constructed Slope	0.035328	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	9.90	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	1.49	ft
Velocity Downstream	14.54	ft/s	Critical Slope	0.055557	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	504.43	ft	Upstream Velocity Head	3.29	ft
Ke	0.50		Entrance Loss	1.64	ft

Inlet Control Properties					
Inlet Control HW Elev.	496.86	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 16 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	505.04	ft	Headwater Depth/Height	42.05	
Computed Headwater Elevation	573.63	ft	Discharge	97.80	cfs
Inlet Control HW Elev.	544.15	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	573.63	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	489.53	ft	Downstream Invert	485.25	ft
Length	88.80	ft	Constructed Slope	0.048198	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	5.45	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	2.00	ft
Velocity Downstream	31.13	ft/s	Critical Slope	0.623063	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	573.63	ft	Upstream Velocity Head	15.06	ft
Ke	0.75		Entrance Loss	11.30	ft

Inlet Control Properties					
Inlet Control HW Elev.	544.15	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 16 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	505.04	ft	Headwater Depth/Height	7.75	
Computed Headwater Elevation	505.04	ft	Discharge	35.20	cfs
Inlet Control HW Elev.	497.50	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	505.04	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	489.53	ft	Downstream Invert	485.25	ft
Length	88.80	ft	Constructed Slope	0.048198	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	9.05	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	1.92	ft
Velocity Downstream	11.20	ft/s	Critical Slope	0.071938	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	505.04	ft	Upstream Velocity Head	1.95	ft
Ke	0.75		Entrance Loss	1.46	ft

Inlet Control Properties					
Inlet Control HW Elev.	497.50	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 16A Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	506.26	ft	Headwater Depth/Height	2.86	
Computed Headwater Elevation	505.63	ft	Discharge	14.18	cfs
Inlet Control HW Elev.	505.63	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	504.61	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	501.34	ft	Downstream Invert	495.20	ft
Length	57.50	ft	Constructed Slope	0.106783	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.98	ft
Slope Type	Steep		Normal Depth	0.98	ft
Flow Regime	Supercritical		Critical Depth	1.39	ft
Velocity Downstream	11.58	ft/s	Critical Slope	0.053824	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	504.61	ft	Upstream Velocity Head	1.07	ft
Ke	0.75		Entrance Loss	0.81	ft

Inlet Control Properties					
Inlet Control HW Elev.	505.63	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	1.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 16A Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	506.26	ft	Headwater Depth/Height	3.28	
Computed Headwater Elevation	506.26	ft	Discharge	15.38	cfs
Inlet Control HW Elev.	506.26	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	504.91	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	501.34	ft	Downstream Invert	495.20	ft
Length	57.50	ft	Constructed Slope	0.106783	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.04	ft
Slope Type	Steep		Normal Depth	1.04	ft
Flow Regime	Supercritical		Critical Depth	1.41	ft
Velocity Downstream	11.76	ft/s	Critical Slope	0.063185	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	504.91	ft	Upstream Velocity Head	1.23	ft
Ke	0.75		Entrance Loss	0.93	ft

Inlet Control Properties					
Inlet Control HW Elev.	506.26	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	1.8	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 17 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	506.30	ft	Headwater Depth/Height	3.32	
Computed Headwater Elevation	501.47	ft	Discharge	30.63	cfs
Inlet Control HW Elev.	499.75	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	501.47	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	494.84	ft	Downstream Invert	489.13	ft
Length	79.30	ft	Constructed Slope	0.072005	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	5.17	ft
Slope Type	Steep		Normal Depth	1.53	ft
Flow Regime	Supercritical		Critical Depth	1.87	ft
Velocity Downstream	9.75	ft/s	Critical Slope	0.054006	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	501.47	ft	Upstream Velocity Head	1.48	ft
Ke	0.50		Entrance Loss	0.74	ft

Inlet Control Properties					
Inlet Control HW Elev.	499.75	ft	Flow Control	N/A	
Inlet Type	Headwall		Area Full	3.1	ft²
K	0.00780		HDS 5 Chart	2	
M	2.00000		HDS 5 Scale	1	
C	0.03790		Equation Form	1	
Y	0.69000				

Culvert Calculator Report
Culvert 17 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	506.30	ft	Headwater Depth/Height	5.73	
Computed Headwater Elevation	506.30	ft	Discharge	44.57	cfs
Inlet Control HW Elev.	503.78	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	506.30	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	494.84	ft	Downstream Invert	489.13	ft
Length	79.30	ft	Constructed Slope	0.072005	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.97	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.97	ft
Velocity Downstream	14.23	ft/s	Critical Slope	0.119694	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	506.30	ft	Upstream Velocity Head	3.13	ft
Ke	0.50		Entrance Loss	1.56	ft

Inlet Control Properties					
Inlet Control HW Elev.	503.78	ft	Flow Control	N/A	
Inlet Type	Headwall		Area Full	3.1	ft²
K	0.00780		HDS 5 Chart	2	
M	2.00000		HDS 5 Scale	1	
C	0.03790		Equation Form	1	
Y	0.69000				

Culvert Calculator Report
Culvert 17A Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	504.78	ft	Headwater Depth/Height	3.21	
Computed Headwater Elevation	505.21	ft	Discharge	11.00	cfs
Inlet Control HW Elev.	505.21	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	504.32	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	501.20	ft	Downstream Invert	498.85	ft
Length	53.90	ft	Constructed Slope	0.043599	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.83	ft
Slope Type	Steep		Normal Depth	0.76	ft
Flow Regime	Supercritical		Critical Depth	1.20	ft
Velocity Downstream	12.76	ft/s	Critical Slope	0.018131	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.011	
Section Material	Corrugated HDPE (Smooth Interior)		Span	1.25	ft
Section Size	15 inch		Rise	1.25	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	504.32	ft	Upstream Velocity Head	1.28	ft
Ke	0.50		Entrance Loss	0.64	ft

Inlet Control Properties					
Inlet Control HW Elev.	505.21	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.2	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 17A Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	504.78	ft	Headwater Depth/Height	2.86	
Computed Headwater Elevation	504.78	ft	Discharge	10.24	cfs
Inlet Control HW Elev.	504.78	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	504.07	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	501.20	ft	Downstream Invert	498.85	ft
Length	53.90	ft	Constructed Slope	0.043599	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.79	ft
Slope Type	Steep		Normal Depth	0.73	ft
Flow Regime	Supercritical		Critical Depth	1.19	ft
Velocity Downstream	12.55	ft/s	Critical Slope	0.015585	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.011	
Section Material	Corrugated HDPE (Smooth Interior)		Span	1.25	ft
Section Size	15 inch		Rise	1.25	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	504.07	ft	Upstream Velocity Head	1.12	ft
Ke	0.50		Entrance Loss	0.56	ft

Inlet Control Properties					
Inlet Control HW Elev.	504.78	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.2	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 18 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	505.84	ft	Headwater Depth/Height	9.56	
Computed Headwater Elevation	537.88	ft	Discharge	896.50	cfs
Inlet Control HW Elev.	524.39	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	537.88	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	485.28	ft	Downstream Invert	483.73	ft
Length	84.90	ft	Constructed Slope	0.018257	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	6.97	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	5.49	ft
Velocity Downstream	37.73	ft/s	Critical Slope	0.233058	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	5.50	ft
Section Size	66 inch		Rise	5.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	537.88	ft	Upstream Velocity Head	22.13	ft
Ke	0.20		Entrance Loss	4.43	ft

Inlet Control Properties					
Inlet Control HW Elev.	524.39	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 33.7° (1.5:1) bevels		Area Full	23.8	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	B	
C	0.02430		Equation Form	1	
Y	0.83000				

Culvert Calculator Report
Culvert 18 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	505.84	ft	Headwater Depth/Height	3.74	
Computed Headwater Elevation	505.84	ft	Discharge	443.38	cfs
Inlet Control HW Elev.	498.26	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	505.84	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	485.28	ft	Downstream Invert	483.73	ft
Length	84.90	ft	Constructed Slope	0.018257	ft/ft

Hydraulic Profile					
Profile	PressureProfile		Depth, Downstream	10.57	ft
Slope Type	N/A		Normal Depth	N/A	ft
Flow Regime	N/A		Critical Depth	5.29	ft
Velocity Downstream	18.66	ft/s	Critical Slope	0.051841	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	5.50	ft
Section Size	66 inch		Rise	5.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	505.84	ft	Upstream Velocity Head	5.41	ft
Ke	0.20		Entrance Loss	1.08	ft

Inlet Control Properties					
Inlet Control HW Elev.	498.26	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 33.7° (1.5:1) bevels		Area Full	23.8	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	B	
C	0.02430		Equation Form	1	
Y	0.83000				

Culvert Calculator Report
Culvert 18A Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	504.99	ft	Headwater Depth/Height	3.59	
Computed Headwater Elevation	507.07	ft	Discharge	16.50	cfs
Inlet Control HW Elev.	506.15	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	507.07	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	501.69	ft	Downstream Invert	500.70	ft
Length	49.10	ft	Constructed Slope	0.020163	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.43	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.43	ft
Velocity Downstream	9.49	ft/s	Critical Slope	0.050710	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.020	
Section Material	HDPE 18-24 inch (Corrugated Interior)		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	507.07	ft	Upstream Velocity Head	1.35	ft
Ke	0.50		Entrance Loss	0.68	ft

Inlet Control Properties					
Inlet Control HW Elev.	506.15	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 18A Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	504.99	ft	Headwater Depth/Height	2.20	
Computed Headwater Elevation	504.99	ft	Discharge	12.63	cfs
Inlet Control HW Elev.	504.71	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	504.99	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	501.69	ft	Downstream Invert	500.70	ft
Length	49.10	ft	Constructed Slope	0.020163	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.34	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.34	ft
Velocity Downstream	7.59	ft/s	Critical Slope	0.030356	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.020	
Section Material	HDPE 18-24 inch (Corrugated Interior)		Span	1.50	ft
Section Size	18 inch		Rise	1.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	504.99	ft	Upstream Velocity Head	0.79	ft
Ke	0.50		Entrance Loss	0.40	ft

Inlet Control Properties					
Inlet Control HW Elev.	504.71	ft	Flow Control	N/A	
Inlet Type	Square edge w/headwall		Area Full	1.8	ft²
K	0.00980		HDS 5 Chart	1	
M	2.00000		HDS 5 Scale	1	
C	0.03980		Equation Form	1	
Y	0.67000				

Culvert Calculator Report
Culvert 19 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	518.05	ft	Headwater Depth/Height	22.13	
Computed Headwater Elevation	551.39	ft	Discharge	85.40	cfs
Inlet Control HW Elev.	549.03	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	551.39	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	507.13	ft	Downstream Invert	505.01	ft
Length	50.00	ft	Constructed Slope	0.042400	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	2.00	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	2.00	ft
Velocity Downstream	27.19	ft/s	Critical Slope	0.471810	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	551.39	ft	Upstream Velocity Head	11.48	ft
Ke	0.75		Entrance Loss	8.61	ft

Inlet Control Properties					
Inlet Control HW Elev.	549.03	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 19 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	518.05	ft	Headwater Depth/Height	5.46	
Computed Headwater Elevation	518.05	ft	Discharge	42.00	cfs
Inlet Control HW Elev.	518.05	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	517.73	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	507.13	ft	Downstream Invert	505.01	ft
Length	50.00	ft	Constructed Slope	0.042400	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.96	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	1.96	ft
Velocity Downstream	13.43	ft/s	Critical Slope	0.105248	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.024	
Section Material	CMP		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	517.73	ft	Upstream Velocity Head	2.78	ft
Ke	0.75		Entrance Loss	2.08	ft

Inlet Control Properties					
Inlet Control HW Elev.	518.05	ft	Flow Control	N/A	
Inlet Type	Projecting		Area Full	3.1	ft²
K	0.03400		HDS 5 Chart	2	
M	1.50000		HDS 5 Scale	3	
C	0.05530		Equation Form	1	
Y	0.54000				

Culvert Calculator Report
Culvert 20 Pre

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	518.17	ft	Headwater Depth/Height	0.50	
Computed Headwater Elevation	512.15	ft	Discharge	86.94	cfs
Inlet Control HW Elev.	511.90	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	512.15	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	509.65	ft	Downstream Invert	507.77	ft
Length	43.10	ft	Constructed Slope	0.043619	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	0.94	ft
Slope Type	Steep		Normal Depth	0.93	ft
Flow Regime	Supercritical		Critical Depth	1.43	ft
Velocity Downstream	10.33	ft/s	Critical Slope	0.011679	ft/ft

Section					
Section Shape	Box		Mannings Coefficient	0.025	
Section Material	Concrete		Span	9.00	ft
Section Size	9 x 5 ft		Rise	5.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	512.15	ft	Upstream Velocity Head	0.71	ft
Ke	0.50		Entrance Loss	0.36	ft

Inlet Control Properties					
Inlet Control HW Elev.	511.90	ft	Flow Control	N/A	
Inlet Type	90° headwall w 45° bevels		Area Full	45.0	ft²
K	0.49500		HDS 5 Chart	10	
M	0.66700		HDS 5 Scale	2	
C	0.03140		Equation Form	2	
Y	0.82000				

Culvert Calculator Report
Culvert 20 Pre Capacity

Solve For: Discharge

Culvert Summary					
Allowable HW Elevation	518.17	ft	Headwater Depth/Height	1.70	
Computed Headwater Elevation	518.17	ft	Discharge	540.44	cfs
Inlet Control HW Elev.	518.17	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	518.09	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	509.65	ft	Downstream Invert	507.77	ft
Length	43.10	ft	Constructed Slope	0.043619	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	3.55	ft
Slope Type	Steep		Normal Depth	3.19	ft
Flow Regime	Supercritical		Critical Depth	4.82	ft
Velocity Downstream	16.89	ft/s	Critical Slope	0.014235	ft/ft

Section					
Section Shape	Box		Mannings Coefficient	0.025	
Section Material	Concrete		Span	9.00	ft
Section Size	9 x 5 ft		Rise	5.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	518.09	ft	Upstream Velocity Head	2.41	ft
Ke	0.50		Entrance Loss	1.21	ft

Inlet Control Properties					
Inlet Control HW Elev.	518.17	ft	Flow Control	N/A	
Inlet Type	90° headwall w 45° bevels		Area Full	45.0	ft²
K	0.49500		HDS 5 Chart	10	
M	0.66700		HDS 5 Scale	2	
C	0.03140		Equation Form	2	
Y	0.82000				

CHAPTER 7

7.2 Culvert Hydraulic Analysis: Developed Condition

Culvert Calculator Report
Culvert 01A

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	530.07	ft	Headwater Depth/Height	1.48	
Computed Headwater Elevation	521.71	ft	Discharge	46.90	cfs
Inlet Control HW Elev.	521.71	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	521.55	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	518.00	ft	Downstream Invert	517.00	ft
Length	100.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	CompositeM2PressureProfile		Depth, Downstream	1.94	ft
Slope Type	Mild		Normal Depth	N/A	ft
Flow Regime	Subcritical		Critical Depth	2.26	ft
Velocity Downstream	11.48	ft/s	Critical Slope	0.011485	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.50	ft
Section Size	30 inch		Rise	2.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	521.55	ft	Upstream Velocity Head	1.20	ft
Ke	0.20		Entrance Loss	0.24	ft

Inlet Control Properties					
Inlet Control HW Elev.	521.71	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 45° bevels		Area Full	4.9	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	A	
C	0.03000		Equation Form	1	
Y	0.74000				

Worksheet for Culvert #1A - 30" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.20	%
Diameter	30.00	in
Discharge	46.85	ft^3/s

Results

Normal Depth	2.16	ft
Flow Area	4.51	ft^2
Wetted Perimeter	5.97	ft
Top Width	1.71	ft
Critical Depth	2.26	ft
Percent Full	86.4	%
Critical Slope	0.01146	ft/ft
Velocity	10.39	ft/s
Velocity Head	1.68	ft
Specific Energy	3.84	ft
Froude Number	1.13	
Maximum Discharge	48.33	ft^3/s
Discharge Full	44.93	ft^3/s
Slope Full	0.01305	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	86.44	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Worksheet for Culvert #1A - 30" RCP

GVF Output Data

Normal Depth	2.16	ft
Critical Depth	2.26	ft
Channel Slope	1.20	%
Critical Slope	0.01146	ft/ft

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #01A Developed Condition

Invert Elev Dn (ft)	= 517.00
Pipe Length (ft)	= 100.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 518.00
Rise (in)	= 30.0
Shape	= Cir
Span (in)	= 30.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5

Embankment

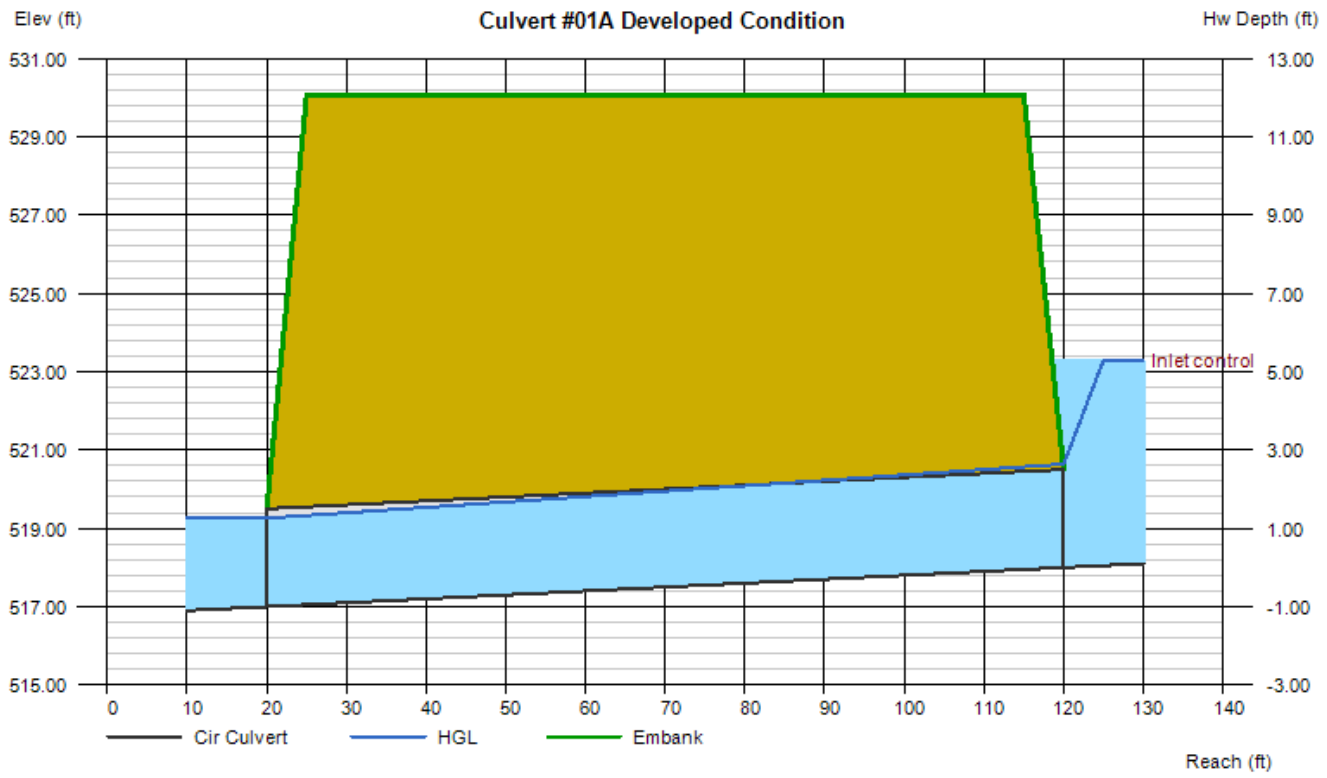
Top Elevation (ft)	= 530.07
Top Width (ft)	= 90.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 46.90
Qmax (cfs)	= 46.90
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 46.90
Qpipe (cfs)	= 46.90
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 10.05
Veloc Up (ft/s)	= 9.55
HGL Dn (ft)	= 519.26
HGL Up (ft)	= 520.64
Hw Elev (ft)	= 523.30
Hw/D (ft)	= 2.12
Flow Regime	= Inlet Control



Culvert Calculator Report
Culvert 01B

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	530.07	ft	Headwater Depth/Height	1.06	
Computed Headwater Elevation	520.11	ft	Discharge	14.50	cfs
Inlet Control HW Elev.	520.05	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	520.11	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	518.00	ft	Downstream Invert	516.80	ft
Length	100.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.16	ft
Slope Type	Steep		Normal Depth	1.16	ft
Flow Regime	Supercritical		Critical Depth	1.37	ft
Velocity Downstream	7.64	ft/s	Critical Slope	0.006181	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	520.11	ft	Upstream Velocity Head	0.62	ft
Ke	0.20		Entrance Loss	0.12	ft

Inlet Control Properties					
Inlet Control HW Elev.	520.05	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 45° bevels		Area Full	3.1	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	A	
C	0.03000		Equation Form	1	
Y	0.74000				

Worksheet for Culvert #1B - 24" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.20	%
Diameter	30.00	in
Discharge	14.50	ft^3/s

Results

Normal Depth	0.98	ft
Flow Area	1.78	ft^2
Wetted Perimeter	3.38	ft
Top Width	2.44	ft
Critical Depth	1.28	ft
Percent Full	39.1	%
Critical Slope	0.00458	ft/ft
Velocity	8.16	ft/s
Velocity Head	1.04	ft
Specific Energy	2.01	ft
Froude Number	1.69	
Maximum Discharge	48.33	ft^3/s
Discharge Full	44.93	ft^3/s
Slope Full	0.00125	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	39.07	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #01B Developed Condition

Invert Elev Dn (ft)	= 516.80
Pipe Length (ft)	= 100.00
Slope (%)	= 1.20
Invert Elev Up (ft)	= 518.00
Rise (in)	= 24.0
Shape	= Cir
Span (in)	= 24.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5

Embankment

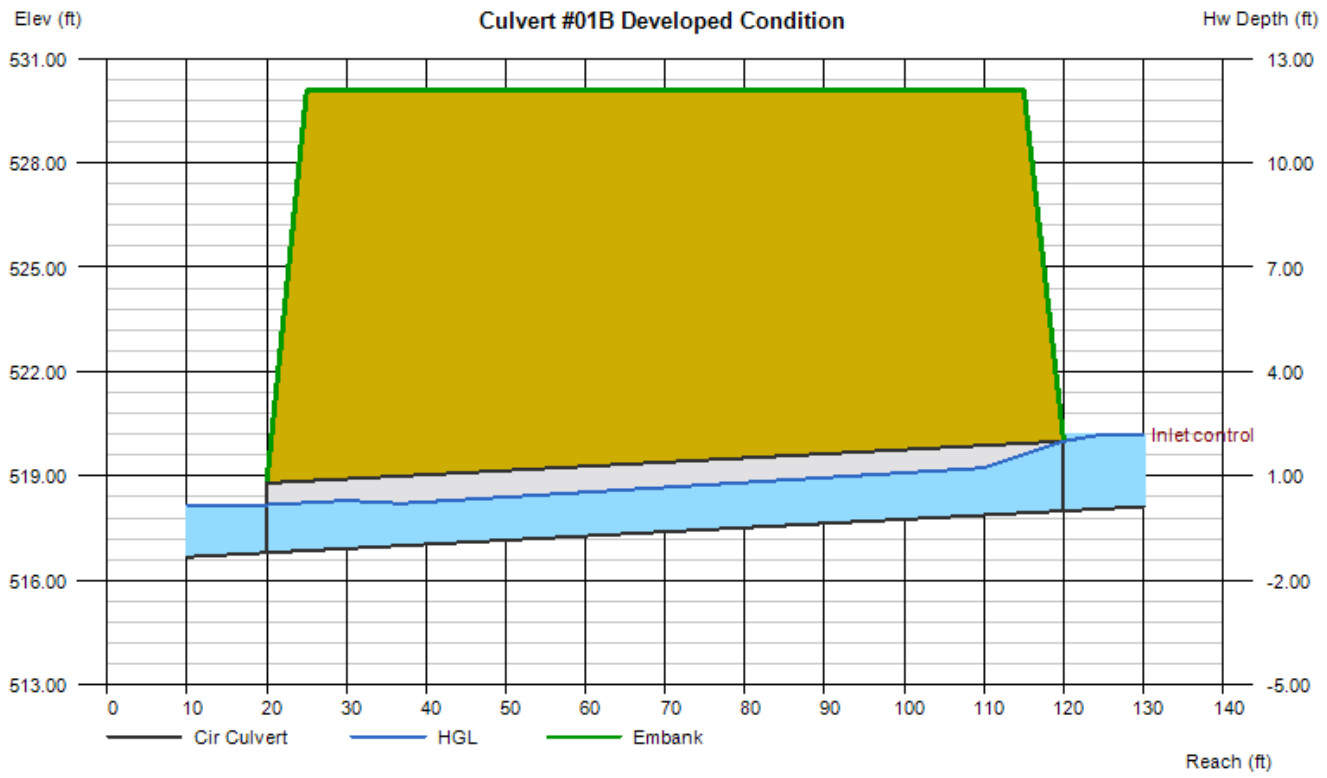
Top Elevation (ft)	= 530.07
Top Width (ft)	= 90.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 14.50
Qmax (cfs)	= 14.50
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 14.50
Qpipe (cfs)	= 14.50
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 6.30
Veloc Up (ft/s)	= 6.30
HGL Dn (ft)	= 518.17
HGL Up (ft)	= 519.37
Hw Elev (ft)	= 520.20
Hw/D (ft)	= 1.10
Flow Regime	= Inlet Control

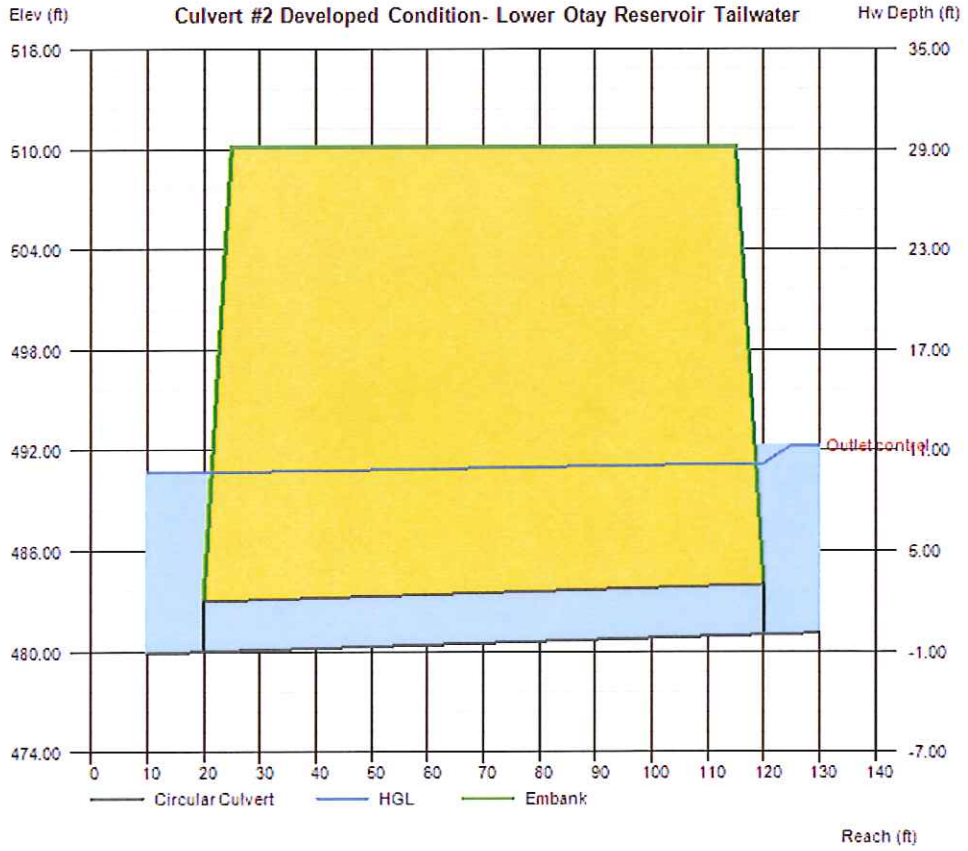


Culvert Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 24 2014

Culvert #2 Developed Condition- Lower Otay Reservoir Tailwater

Invert Elev Dn (ft)	= 480.00	**Calculations**	
Pipe Length (ft)	= 100.00	Qmin (cfs)	= 47.97
Slope (%)	= 1.00	Qmax (cfs)	= 47.97
Invert Elev Up (ft)	= 481.00	Tailwater Elev (ft)	= 490.7
Rise (in)	= 36.0		
Shape	= Circular	**Highlighted**	
Span (in)	= 36.0	Qtotal (cfs)	= 47.97
No. Barrels	= 1	Qpipe (cfs)	= 47.97
n-Value	= 0.013	Qovertop (cfs)	= 0.00
Culvert Type	= Circular Concrete	Veloc Dn (ft/s)	= 6.79
Culvert Entrance	= Square edge w/headwall (C)	Veloc Up (ft/s)	= 6.79
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5	HGL Dn (ft)	= 490.70
		HGL Up (ft)	= 491.22
Embankment		Hw Elev (ft)	= 492.29
Top Elevation (ft)	= 510.14	Hw/D (ft)	= 3.76
Top Width (ft)	= 90.00	Flow Regime	= Outlet Control
Crest Width (ft)	= 50.00		



Worksheet for Culvert #2 - 36" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	36.00	in
Discharge	47.97	ft³/s

Results

Normal Depth	1.88	ft
Flow Area	4.67	ft²
Wetted Perimeter	5.49	ft
Hydraulic Radius	0.85	ft
Top Width	2.90	ft
Critical Depth	2.26	ft
Percent Full	62.8	%
Critical Slope	0.00618	ft/ft
Velocity	10.27	ft/s
Velocity Head	1.64	ft
Specific Energy	3.52	ft
Froude Number	1.43	
Maximum Discharge	71.74	ft³/s
Discharge Full	66.69	ft³/s
Slope Full	0.00517	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	62.78	%
Downstream Velocity	Infinity	ft/s

Worksheet for Culvert #2 - 36" RCP

GVF Output Data

Upstream Velocity	Infinity	ft/s
Normal Depth	1.88	ft
Critical Depth	2.26	ft
Channel Slope	1.00	%
Critical Slope	0.00618	ft/ft

Culvert Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 24 2014

Culvert #2 Developed Condition

Invert Elev Dn (ft)	=	480.00
Pipe Length (ft)	=	100.00
Slope (%)	=	1.00
Invert Elev Up (ft)	=	481.00
Rise (in)	=	36.0
Shape	=	Circular
Span (in)	=	36.0
No. Barrels	=	1
n-Value	=	0.013
Culvert Type	=	Circular Concrete
Culvert Entrance	=	Square edge w/headwall (C)
Coeff. K,M,c,Y,k	=	0.0098, 2, 0.0398, 0.67, 0.5

Embankment

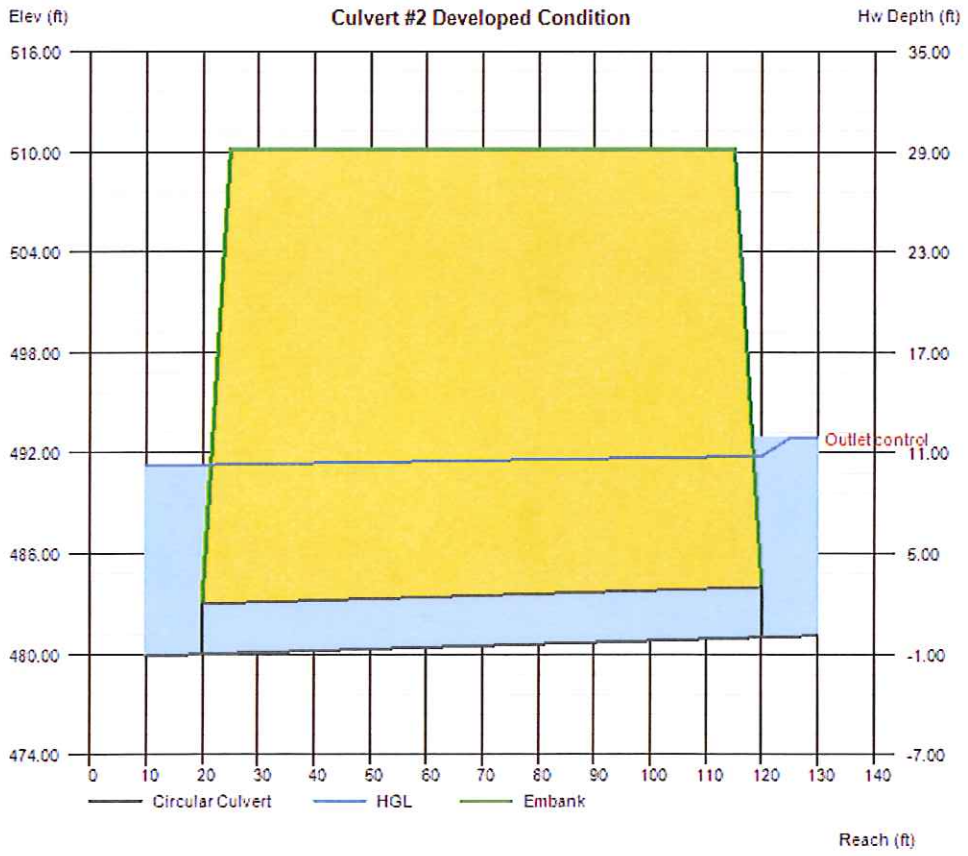
Top Elevation (ft)	=	510.14
Top Width (ft)	=	90.00
Crest Width (ft)	=	50.00

Calculations

Qmin (cfs)	=	47.97
Qmax (cfs)	=	47.97
Tailwater Elev (ft)	=	491.3

Highlighted

Qtotal (cfs)	=	47.97
Qpipe (cfs)	=	47.97
Qovertop (cfs)	=	0.00
Veloc Dn (ft/s)	=	6.79
Veloc Up (ft/s)	=	6.79
HGL Dn (ft)	=	491.30
HGL Up (ft)	=	491.82
Hw Elev (ft)	=	492.89
Hw/D (ft)	=	3.96
Flow Regime	=	Outlet Control

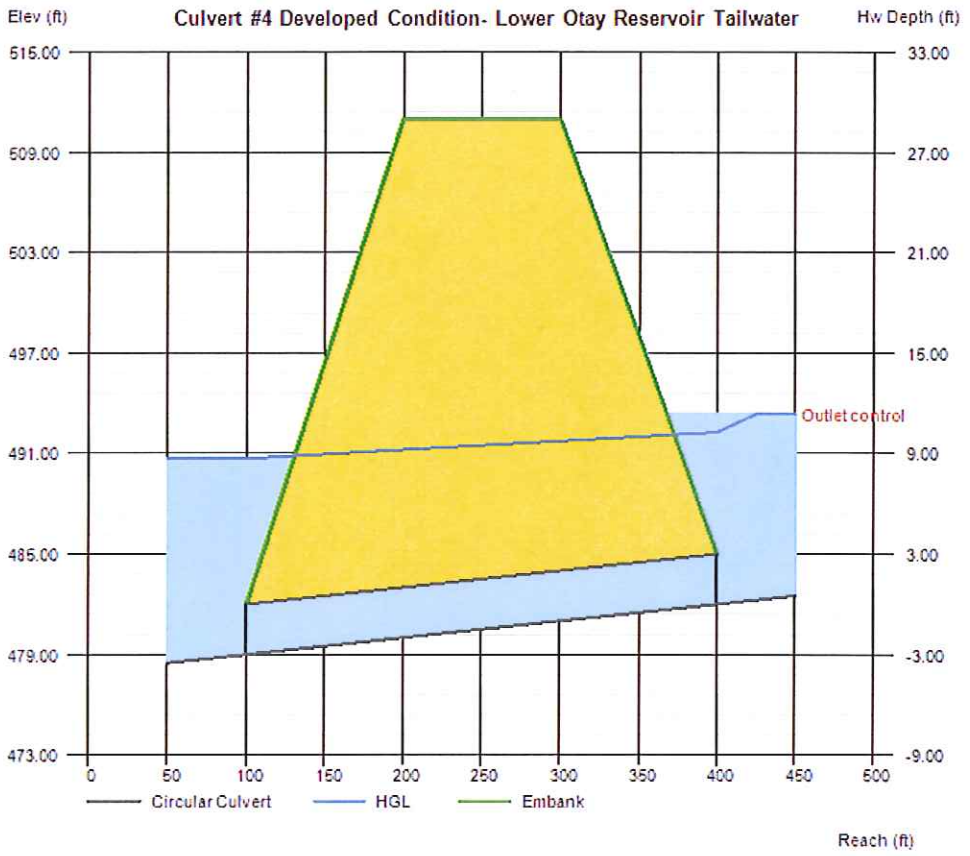


Culvert Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 24 2014

Culvert #4 Developed Condition- Lower Otay Reservoir Tailwater

Invert Elev Dn (ft)	= 479.00	**Calculations**	
Pipe Length (ft)	= 300.00	Qmin (cfs)	= 48.22
Slope (%)	= 1.00	Qmax (cfs)	= 48.22
Invert Elev Up (ft)	= 482.00	Tailwater Elev (ft)	= 490.7
Rise (in)	= 36.0		
Shape	= Circular	**Highlighted**	
Span (in)	= 36.0	Qtotal (cfs)	= 48.22
No. Barrels	= 1	Qpipe (cfs)	= 48.22
n-Value	= 0.013	Qovertop (cfs)	= 0.00
Culvert Type	= Circular Concrete	Veloc Dn (ft/s)	= 6.82
Culvert Entrance	= Square edge w/headwall (C)	Veloc Up (ft/s)	= 6.82
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5	HGL Dn (ft)	= 490.70
		HGL Up (ft)	= 492.27
Embankment		Hw Elev (ft)	= 493.35
Top Elevation (ft)	= 511.00	Hw/D (ft)	= 3.78
Top Width (ft)	= 100.00	Flow Regime	= Outlet Control
Crest Width (ft)	= 50.00		



Worksheet for Culvert #4 - 36" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	36.00	in
Discharge	48.22	ft³/s

Results

Normal Depth	1.89	ft
Flow Area	4.69	ft²
Wetted Perimeter	5.50	ft
Hydraulic Radius	0.85	ft
Top Width	2.90	ft
Critical Depth	2.26	ft
Percent Full	63.0	%
Critical Slope	0.00621	ft/ft
Velocity	10.28	ft/s
Velocity Head	1.64	ft
Specific Energy	3.53	ft
Froude Number	1.42	
Maximum Discharge	71.74	ft³/s
Discharge Full	66.69	ft³/s
Slope Full	0.00523	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	63.01	%
Downstream Velocity	Infinity	ft/s

Worksheet for Culvert #4 - 36" RCP

GVF Output Data

Upstream Velocity	Infinity	ft/s
Normal Depth	1.89	ft
Critical Depth	2.26	ft
Channel Slope	1.00	%
Critical Slope	0.00621	ft/ft

Culvert Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 24 2014

Culvert #4 Developed Condition

Invert Elev Dn (ft)	=	479.00
Pipe Length (ft)	=	300.00
Slope (%)	=	1.00
Invert Elev Up (ft)	=	482.00
Rise (in)	=	36.0
Shape	=	Circular
Span (in)	=	36.0
No. Barrels	=	1
n-Value	=	0.013
Culvert Type	=	Circular Concrete
Culvert Entrance	=	Square edge w/headwall (C)
Coeff. K,M,c,Y,k	=	0.0098, 2, 0.0398, 0.67, 0.5

Embankment

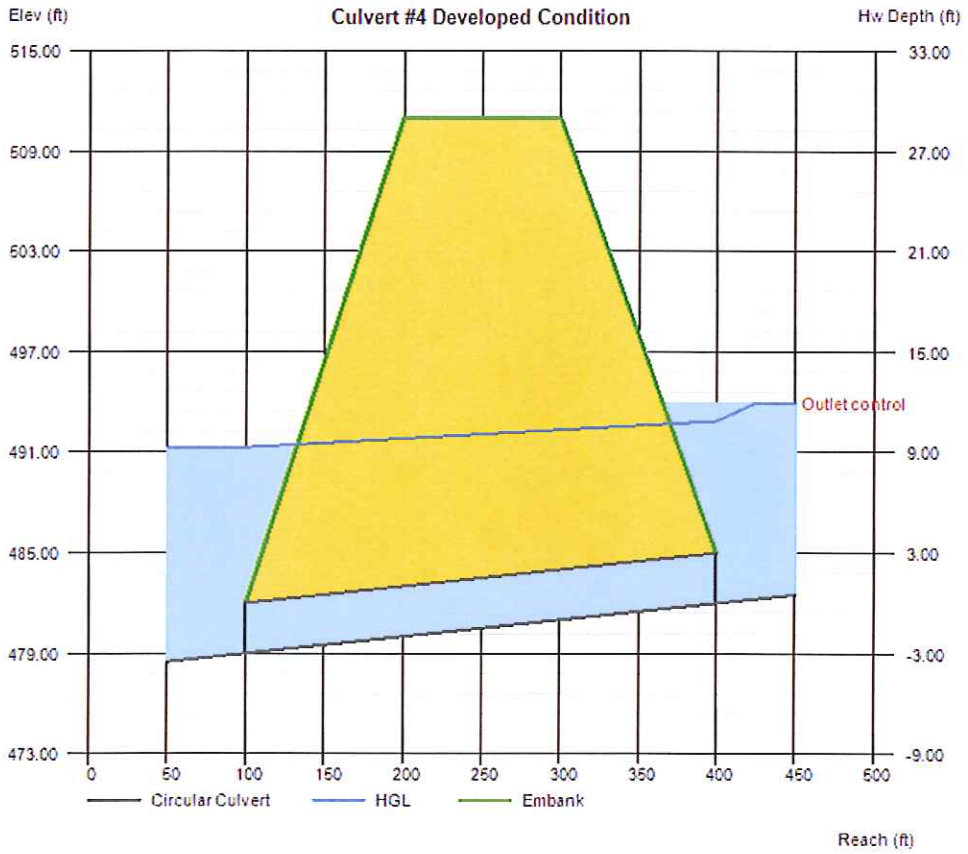
Top Elevation (ft)	=	511.00
Top Width (ft)	=	100.00
Crest Width (ft)	=	50.00

Calculations

Qmin (cfs)	=	48.22
Qmax (cfs)	=	48.22
Tailwater Elev (ft)	=	491.3

Highlighted

Qtotal (cfs)	=	48.22
Qpipe (cfs)	=	48.22
Qovertop (cfs)	=	0.00
Veloc Dn (ft/s)	=	6.82
Veloc Up (ft/s)	=	6.82
HGL Dn (ft)	=	491.30
HGL Up (ft)	=	492.87
Hw Elev (ft)	=	493.95
Hw/D (ft)	=	3.98
Flow Regime	=	Outlet Control



Culvert Report

Culvert #6 Developed Condition- Lower Otay Reservoir Tailwater

Invert Elev Dn (ft)	=	480.00
Pipe Length (ft)	=	100.00
Slope (%)	=	1.00
Invert Elev Up (ft)	=	481.00
Rise (in)	=	72.0
Shape	=	Circular
Span (in)	=	72.0
No. Barrels	=	1
n-Value	=	0.013
Culvert Type	=	Circular Concrete
Culvert Entrance	=	Square edge w/headwall (C)
Coeff. K,M,c,Y,k	=	0.0098, 2, 0.0398, 0.67, 0.5

Embankment

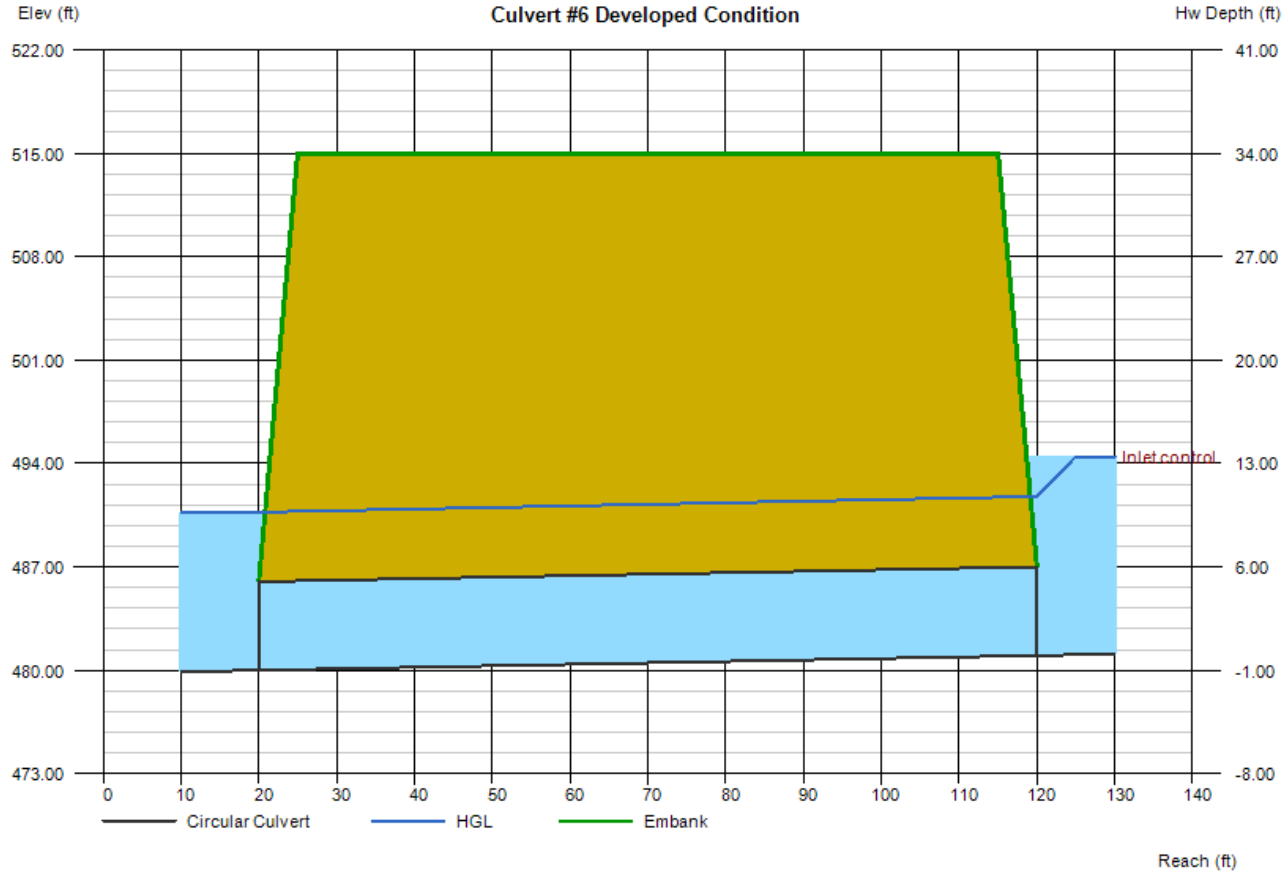
Top Elevation (ft)	=	515.00
Top Width (ft)	=	90.00
Crest Width (ft)	=	50.00

Calculations

Qmin (cfs)	=	436.30
Qmax (cfs)	=	436.30
Tailwater Elev (ft)	=	490.7

Highlighted

Qtotal (cfs)	=	436.30
Qpipe (cfs)	=	436.30
Qovertop (cfs)	=	0.00
Veloc Dn (ft/s)	=	15.43
Veloc Up (ft/s)	=	15.43
HGL Dn (ft)	=	490.70
HGL Up (ft)	=	491.76
Hw Elev (ft)	=	494.47
Hw/D (ft)	=	2.24
Flow Regime	=	Inlet Control



Worksheet for Culvert #6 - 72" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	72.00	in
Discharge	436.30	ft^3/s

Results

Normal Depth	5.10	ft
Flow Area	25.61	ft^2
Wetted Perimeter	14.07	ft
Hydraulic Radius	1.82	ft
Top Width	4.29	ft
Critical Depth	5.48	ft
Percent Full	85.0	%
Critical Slope	0.00924	ft/ft
Velocity	17.04	ft/s
Velocity Head	4.51	ft
Specific Energy	9.61	ft
Froude Number	1.23	
Maximum Discharge	455.55	ft^3/s
Discharge Full	423.49	ft^3/s
Slope Full	0.01061	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	84.98	%
Downstream Velocity	Infinity	ft/s

Worksheet for Culvert #6 - 72" RCP

GVF Output Data

Upstream Velocity	Infinity	ft/s
Normal Depth	5.10	ft
Critical Depth	5.48	ft
Channel Slope	1.00	%
Critical Slope	0.00924	ft/ft

Culvert Report

Culvert #6 Developed Condition

Invert Elev Dn (ft)	=	480.00
Pipe Length (ft)	=	100.00
Slope (%)	=	1.00
Invert Elev Up (ft)	=	481.00
Rise (in)	=	72.0
Shape	=	Circular
Span (in)	=	72.0
No. Barrels	=	1
n-Value	=	0.013
Culvert Type	=	Circular Concrete
Culvert Entrance	=	Square edge w/headwall (C)
Coeff. K,M,c,Y,k	=	0.0098, 2, 0.0398, 0.67, 0.5

Embankment

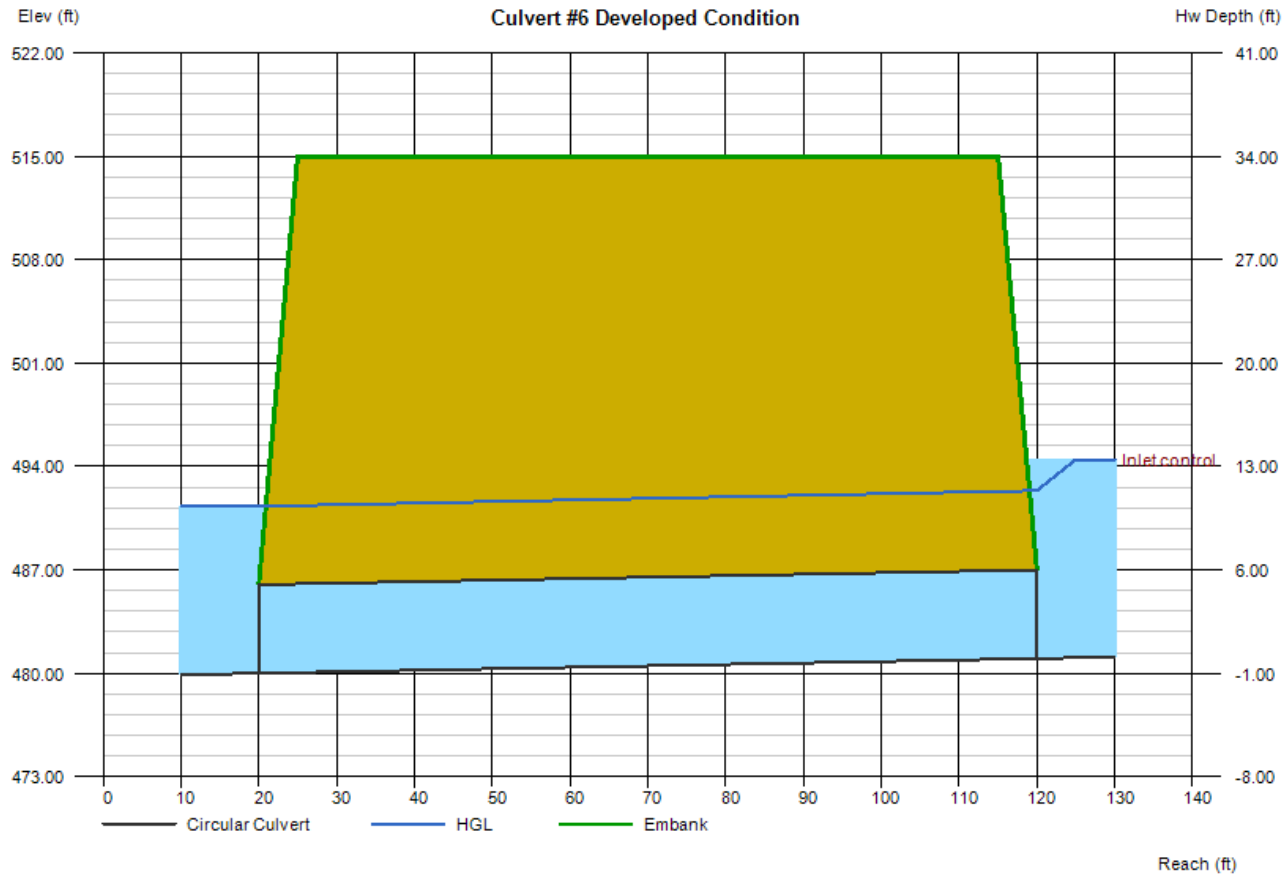
Top Elevation (ft)	=	515.00
Top Width (ft)	=	90.00
Crest Width (ft)	=	50.00

Calculations

Qmin (cfs)	=	436.30
Qmax (cfs)	=	436.30
Tailwater Elev (ft)	=	491.3

Highlighted

Qtotal (cfs)	=	436.30
Qpipe (cfs)	=	436.30
Qovertop (cfs)	=	0.00
Veloc Dn (ft/s)	=	15.43
Veloc Up (ft/s)	=	15.43
HGL Dn (ft)	=	491.30
HGL Up (ft)	=	492.36
Hw Elev (ft)	=	494.47
Hw/D (ft)	=	2.24
Flow Regime	=	Inlet Control



Culvert Calculator Report
Culvert 07

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	515.00	ft	Headwater Depth/Height	1.45	
Computed Headwater Elevation	512.08	ft	Discharge	937.90	cfs
Inlet Control HW Elev.	512.08	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	511.89	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	500.50	ft	Downstream Invert	500.00	ft
Length	50.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	6.17	ft
Slope Type	Steep		Normal Depth	4.59	ft
Flow Regime	Supercritical		Critical Depth	6.49	ft
Velocity Downstream	15.20	ft/s	Critical Slope	0.004004	ft/ft

Section					
Section Shape	Box		Mannings Coefficient	0.013	
Section Material	Concrete		Span	10.00	ft
Section Size	10 x 8 ft		Rise	8.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	511.89	ft	Upstream Velocity Head	3.56	ft
Ke	0.20		Entrance Loss	0.71	ft

Inlet Control Properties					
Inlet Control HW Elev.	512.08	ft	Flow Control	N/A	
Inlet Type	33.7° wingwall flares - offset		Area Full	80.0	ft²
K	0.49500		HDS 5 Chart	13	
M	0.66700		HDS 5 Scale	2	
C	0.02520		Equation Form	2	
Y	0.88100				

Worksheet for Culvert #7 - 8'x10' Box

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Height	8.00	ft
Bottom Width	10.00	ft
Discharge	937.90	ft³/s

Results

Normal Depth	4.59	ft
Flow Area	45.87	ft²
Wetted Perimeter	19.17	ft
Top Width	10.00	ft
Critical Depth	6.49	ft
Percent Full	57.3	%
Critical Slope	0.00400	ft/ft
Velocity	20.45	ft/s
Velocity Head	6.50	ft
Specific Energy	11.08	ft
Froude Number	1.68	
Discharge Full	1557.16	ft³/s
Slope Full	0.02756	ft/ft
Flow Type	Supercritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	57.34	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Worksheet for Culvert #7 - 8'x10' Box

GVF Output Data

Normal Depth	4.59	ft
Critical Depth	6.49	ft
Channel Slope	1.00	%
Critical Slope	0.00400	ft/ft

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #07 Developed Condition

Invert Elev Dn (ft)	= 500.00
Pipe Length (ft)	= 50.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 500.50
Rise (in)	= 96.0
Shape	= Box
Span (in)	= 120.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.061, 0.75, 0.04, 0.8, 0.5

Embankment

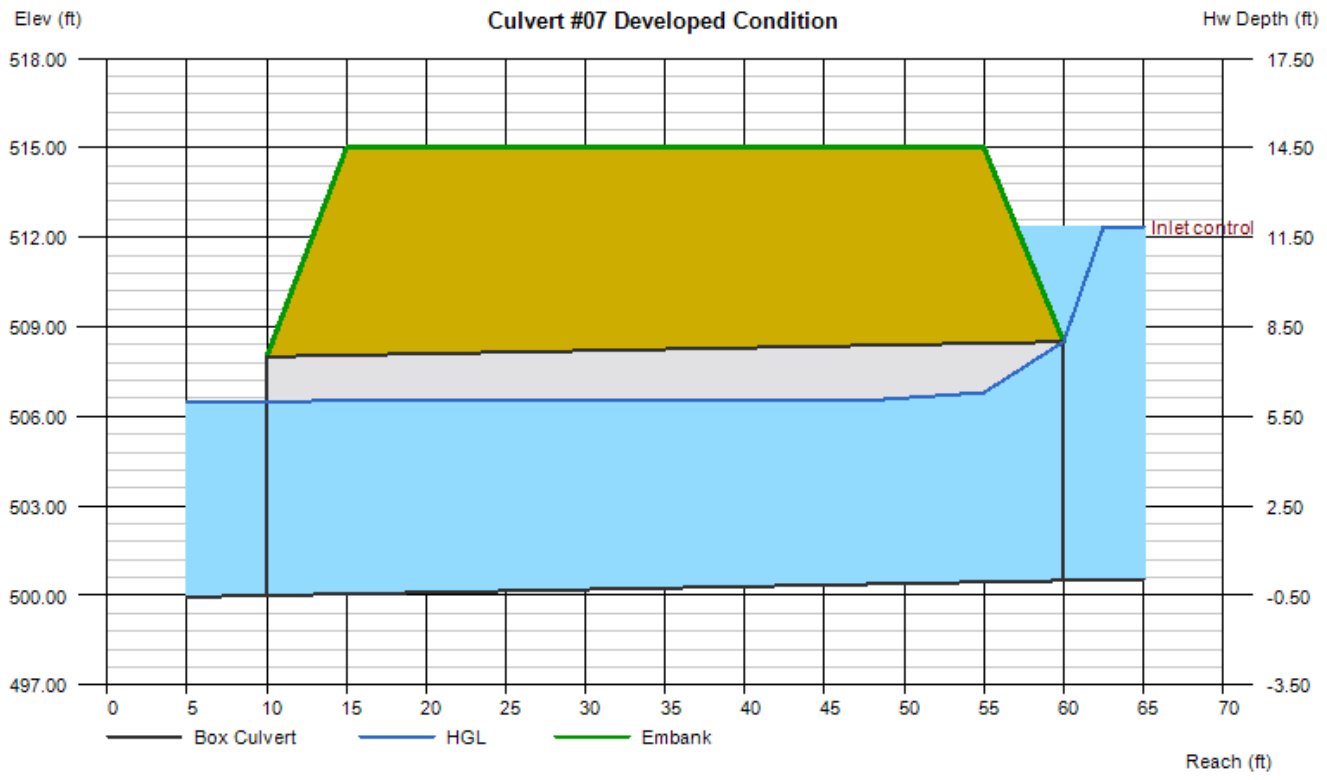
Top Elevation (ft)	= 515.00
Top Width (ft)	= 40.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 937.90
Qmax (cfs)	= 937.90
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 937.90
Qpipe (cfs)	= 937.90
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 14.48
Veloc Up (ft/s)	= 14.48
HGL Dn (ft)	= 506.48
HGL Up (ft)	= 506.98
Hw Elev (ft)	= 512.36
Hw/D (ft)	= 1.48
Flow Regime	= Inlet Control



Culvert Calculator Report
Culvert 09

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	510.00	ft	Headwater Depth/Height	1.68	
Computed Headwater Elevation	503.06	ft	Discharge	200.00	cfs
Inlet Control HW Elev.	503.06	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	502.83	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	495.50	ft	Downstream Invert	495.00	ft
Length	50.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	3.85	ft
Slope Type	Steep		Normal Depth	3.76	ft
Flow Regime	Supercritical		Critical Depth	4.04	ft
Velocity Downstream	13.80	ft/s	Critical Slope	0.009133	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	4.50	ft
Section Size	54 inch		Rise	4.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	502.83	ft	Upstream Velocity Head	2.75	ft
Ke	0.20		Entrance Loss	0.55	ft

Inlet Control Properties					
Inlet Control HW Elev.	503.06	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 33.7° bevels		Area Full	15.9	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	B	
C	0.02430		Equation Form	1	
Y	0.83000				

Worksheet for Culvert #9 - 54" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	54.00	in
Discharge	200.00	ft^3/s

Results

Normal Depth	3.76	ft
Flow Area	14.20	ft^2
Wetted Perimeter	10.38	ft
Top Width	3.33	ft
Critical Depth	4.04	ft
Percent Full	83.6	%
Critical Slope	0.00913	ft/ft
Velocity	14.08	ft/s
Velocity Head	3.08	ft
Specific Energy	6.84	ft
Froude Number	1.20	
Maximum Discharge	211.53	ft^3/s
Discharge Full	196.64	ft^3/s
Slope Full	0.01034	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	83.60	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Worksheet for Culvert #9 - 54" RCP

GVF Output Data

Normal Depth	3.76	ft
Critical Depth	4.04	ft
Channel Slope	1.00	%
Critical Slope	0.00913	ft/ft

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #09 Developed Condition

Invert Elev Dn (ft)	= 495.00
Pipe Length (ft)	= 50.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 495.50
Rise (in)	= 54.0
Shape	= Cir
Span (in)	= 54.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5

Embankment

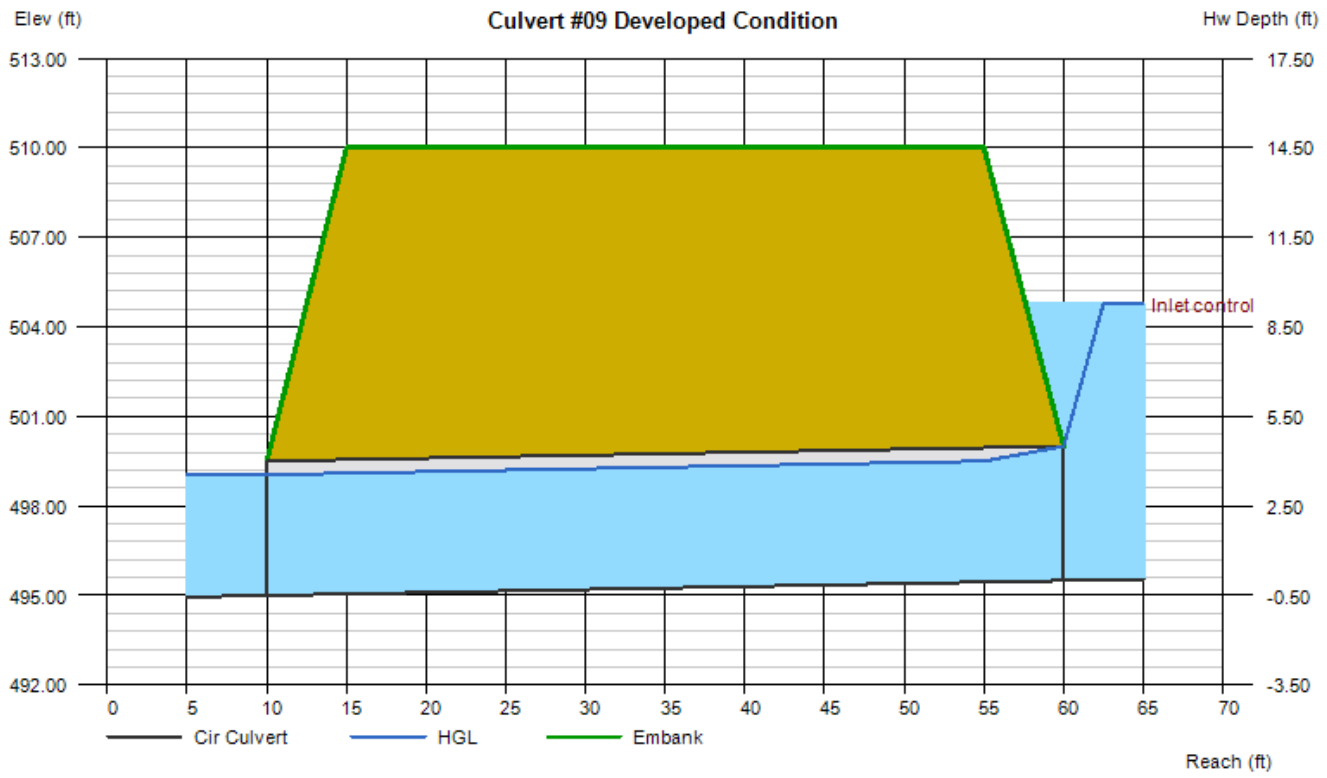
Top Elevation (ft)	= 510.00
Top Width (ft)	= 40.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 200.00
Qmax (cfs)	= 200.00
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 200.00
Qpipe (cfs)	= 200.00
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 13.28
Veloc Up (ft/s)	= 13.26
HGL Dn (ft)	= 499.05
HGL Up (ft)	= 499.55
Hw Elev (ft)	= 504.79
Hw/D (ft)	= 2.06
Flow Regime	= Inlet Control



Culvert Calculator Report
Culvert 12

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	510.50	ft	Headwater Depth/Height	1.36	
Computed Headwater Elevation	503.22	ft	Discharge	20.30	cfs
Inlet Control HW Elev.	503.22	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	503.15	ft	Control Type	Inlet Control	

Grades					
Upstream Invert	500.50	ft	Downstream Invert	500.00	ft
Length	50.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.49	ft
Slope Type	Steep		Normal Depth	1.48	ft
Flow Regime	Supercritical		Critical Depth	1.62	ft
Velocity Downstream	8.10	ft/s	Critical Slope	0.008257	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	503.15	ft	Upstream Velocity Head	0.86	ft
Ke	0.20		Entrance Loss	0.17	ft

Inlet Control Properties					
Inlet Control HW Elev.	503.22	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 45° bevels		Area Full	3.1	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	A	
C	0.03000		Equation Form	1	
Y	0.74000				

Worksheet for Culvert #12 - 24" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	24.00	in
Discharge	20.35	ft³/s

Results

Normal Depth	1.48	ft
Flow Area	2.50	ft²
Wetted Perimeter	4.15	ft
Top Width	1.75	ft
Critical Depth	1.62	ft
Percent Full	74.1	%
Critical Slope	0.00828	ft/ft
Velocity	8.15	ft/s
Velocity Head	1.03	ft
Specific Energy	2.51	ft
Froude Number	1.20	
Maximum Discharge	24.33	ft³/s
Discharge Full	22.62	ft³/s
Slope Full	0.00809	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	74.14	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Worksheet for Culvert #12 - 24" RCP

GVF Output Data

Normal Depth	1.48	ft
Critical Depth	1.62	ft
Channel Slope	1.00	%
Critical Slope	0.00828	ft/ft

Culvert Report

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Culvert #12 Developed Condition

Invert Elev Dn (ft)	= 500.00
Pipe Length (ft)	= 50.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 500.50
Rise (in)	= 24.0
Shape	= Cir
Span (in)	= 24.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5

Embankment

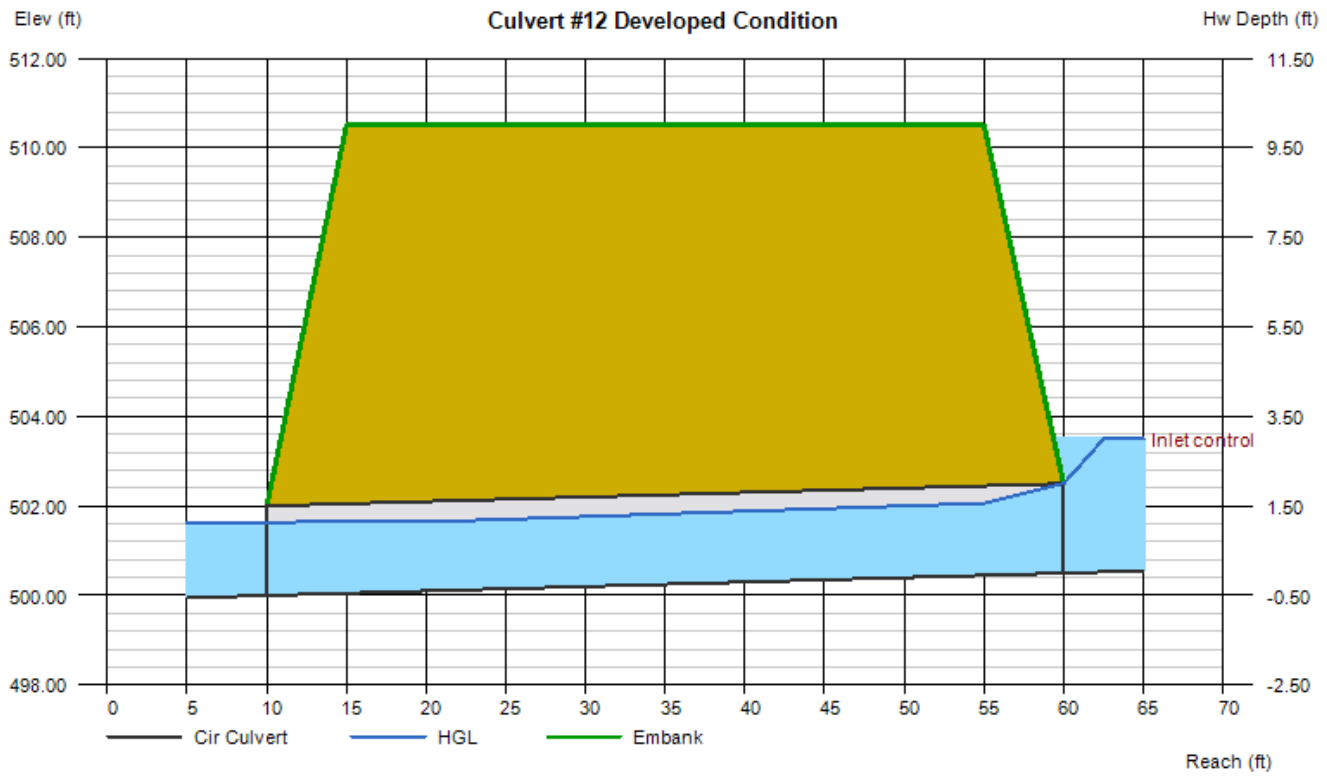
Top Elevation (ft)	= 510.50
Top Width (ft)	= 40.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 20.30
Qmax (cfs)	= 20.30
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 20.30
Qpipe (cfs)	= 20.30
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 7.45
Veloc Up (ft/s)	= 7.45
HGL Dn (ft)	= 501.62
HGL Up (ft)	= 502.12
Hw Elev (ft)	= 503.49
Hw/D (ft)	= 1.50
Flow Regime	= Inlet Control



Culvert Calculator Report
Culvert 14

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	501.50	ft	Headwater Depth/Height	1.19	
Computed Headwater Elevation	498.47	ft	Discharge	30.20	cfs
Inlet Control HW Elev.	498.46	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	498.47	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	495.50	ft	Downstream Invert	495.00	ft
Length	50.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.64	ft
Slope Type	Steep		Normal Depth	1.59	ft
Flow Regime	Supercritical		Critical Depth	1.87	ft
Velocity Downstream	8.87	ft/s	Critical Slope	0.006531	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.50	ft
Section Size	30 inch		Rise	2.50	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	498.47	ft	Upstream Velocity Head	0.91	ft
Ke	0.20		Entrance Loss	0.18	ft

Inlet Control Properties					
Inlet Control HW Elev.	498.46	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 45° bevels		Area Full	4.9	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	A	
C	0.03000		Equation Form	1	
Y	0.74000				

Worksheet for Culvert #14 - 24" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	30.00	in
Discharge	30.19	ft³/s

Results

Normal Depth	1.59	ft
Flow Area	3.30	ft²
Wetted Perimeter	4.63	ft
Top Width	2.40	ft
Critical Depth	1.87	ft
Percent Full	63.8	%
Critical Slope	0.00653	ft/ft
Velocity	9.14	ft/s
Velocity Head	1.30	ft
Specific Energy	2.89	ft
Froude Number	1.37	
Maximum Discharge	44.12	ft³/s
Discharge Full	41.01	ft³/s
Slope Full	0.00542	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	63.78	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Worksheet for Culvert #14 - 24" RCP

GVF Output Data

Normal Depth	1.59	ft
Critical Depth	1.87	ft
Channel Slope	1.00	%
Critical Slope	0.00653	ft/ft

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #14 Developed Condition

Invert Elev Dn (ft)	= 495.00
Pipe Length (ft)	= 50.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 495.50
Rise (in)	= 30.0
Shape	= Cir
Span (in)	= 30.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5

Embankment

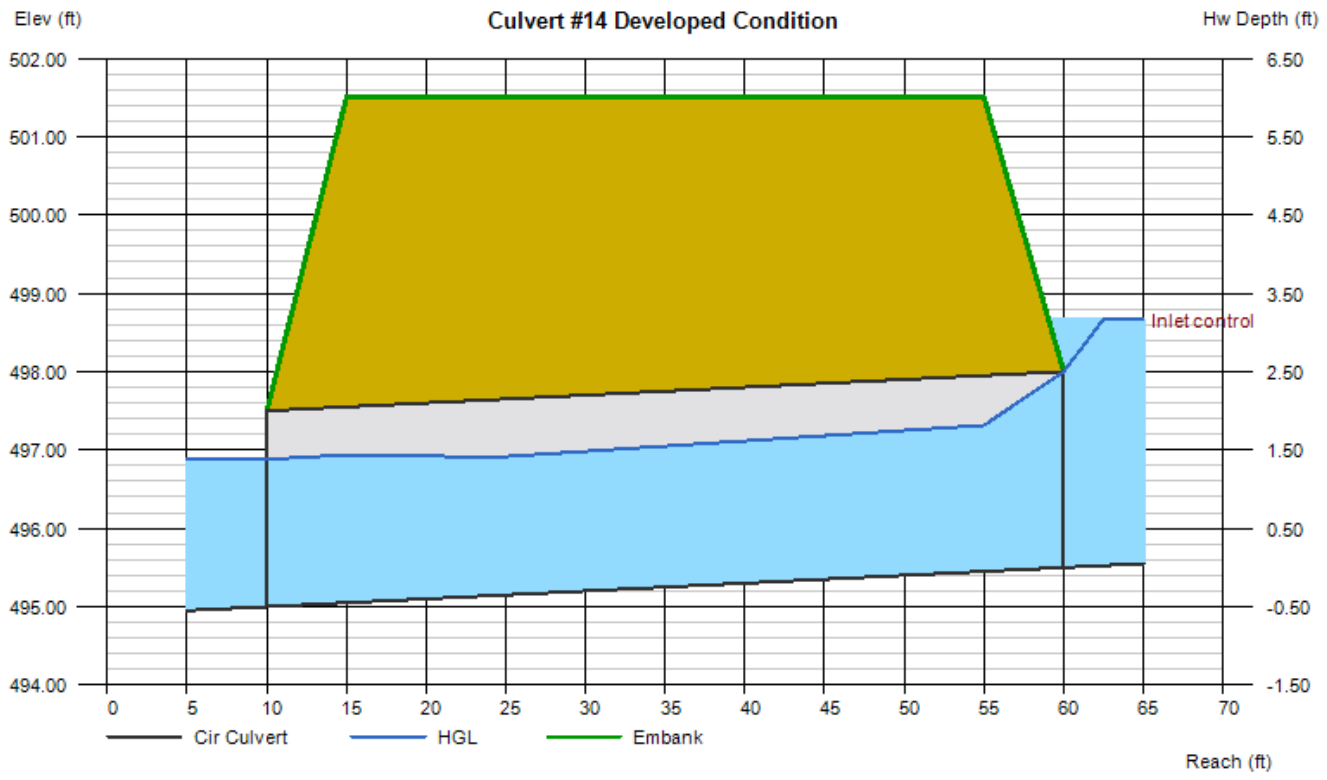
Top Elevation (ft)	= 501.50
Top Width (ft)	= 40.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 30.20
Qmax (cfs)	= 30.20
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 30.20
Qpipe (cfs)	= 30.20
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 7.62
Veloc Up (ft/s)	= 7.62
HGL Dn (ft)	= 496.88
HGL Up (ft)	= 497.38
Hw Elev (ft)	= 498.67
Hw/D (ft)	= 1.27
Flow Regime	= Inlet Control



Culvert Calculator Report
Culvert 15

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	506.00	ft	Headwater Depth/Height	0.89	
Computed Headwater Elevation	490.74	ft	Discharge	256.00	cfs
Inlet Control HW Elev.	490.70	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	490.74	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	479.00	ft	Downstream Invert	478.00	ft
Length	100.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	M1		Depth, Downstream	12.70	ft
Slope Type	Mild		Normal Depth	2.54	ft
Flow Regime	Subcritical		Critical Depth	2.30	ft
Velocity Downstream	1.21	ft/s	Critical Slope	0.015082	ft/ft

Section					
Section Shape	Arch		Mannings Coefficient	0.034	
Section Material	Steel structural plate 31 In CR		Span	20.58	ft
Section Size	247 x 158.6 inch		Rise	13.22	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	490.74	ft	Upstream Velocity Head	0.02	ft
Ke	0.20		Entrance Loss	0.00	ft

Inlet Control Properties					
Inlet Control HW Elev.	490.70	ft	Flow Control	N/A	
Inlet Type31 inch CR structural plate, 33.7° bevels			Area Full	213.8	ft²
K	0.00300		HDS 5 Chart	36	
M	2.00000		HDS 5 Scale	3	
C	0.02690		Equation Form	1	
Y	0.77000				

Worksheet for Culvert #15 - Contech 23A6

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Channel Slope	1.00	%
Discharge	256.00	ft³/s

Section Definitions

Station (ft)	Elevation (ft)
0+00	0.00
0+01	3.00
0+04	6.00
0+08	7.25
0+10	7.50
0+12	7.25
0+16	6.00
0+19	3.00
0+20	0.00

Roughness Segment Definitions

Start Station	Ending Station	Roughness Coefficient
(0+00, 0.00)	(0+20, 0.00)	0.035

Results

Normal Depth		8.34	ft
Elevation Range	0.00 to 7.50 ft		
Flow Area		53.08	ft²
Wetted Perimeter		43.85	ft
Top Width		19.83	ft
Normal Depth		8.34	ft
Critical Depth		7.23	ft
Critical Slope		0.04499	ft/ft
Velocity		4.82	ft/s

Worksheet for Culvert #15 - Contech 23A6

Results

Velocity Head		0.36	ft
Specific Energy		8.70	ft
Froude Number		0.52	
Flow Type	Subcritical		

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	8.34	ft
Critical Depth	7.23	ft
Channel Slope	0.01000	ft/ft
Critical Slope	0.04499	ft/ft

Culvert Report

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Culvert #15 Developed Condition

Invert Elev Dn (ft)	= 478.00
Pipe Length (ft)	= 100.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 479.00
Rise (in)	= 125.0
Shape	= Arch
Span (in)	= 250.0
No. Barrels	= 1
n-Value	= 0.024
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0083, 2, 0.0379, 0.69, 0.5

Embankment

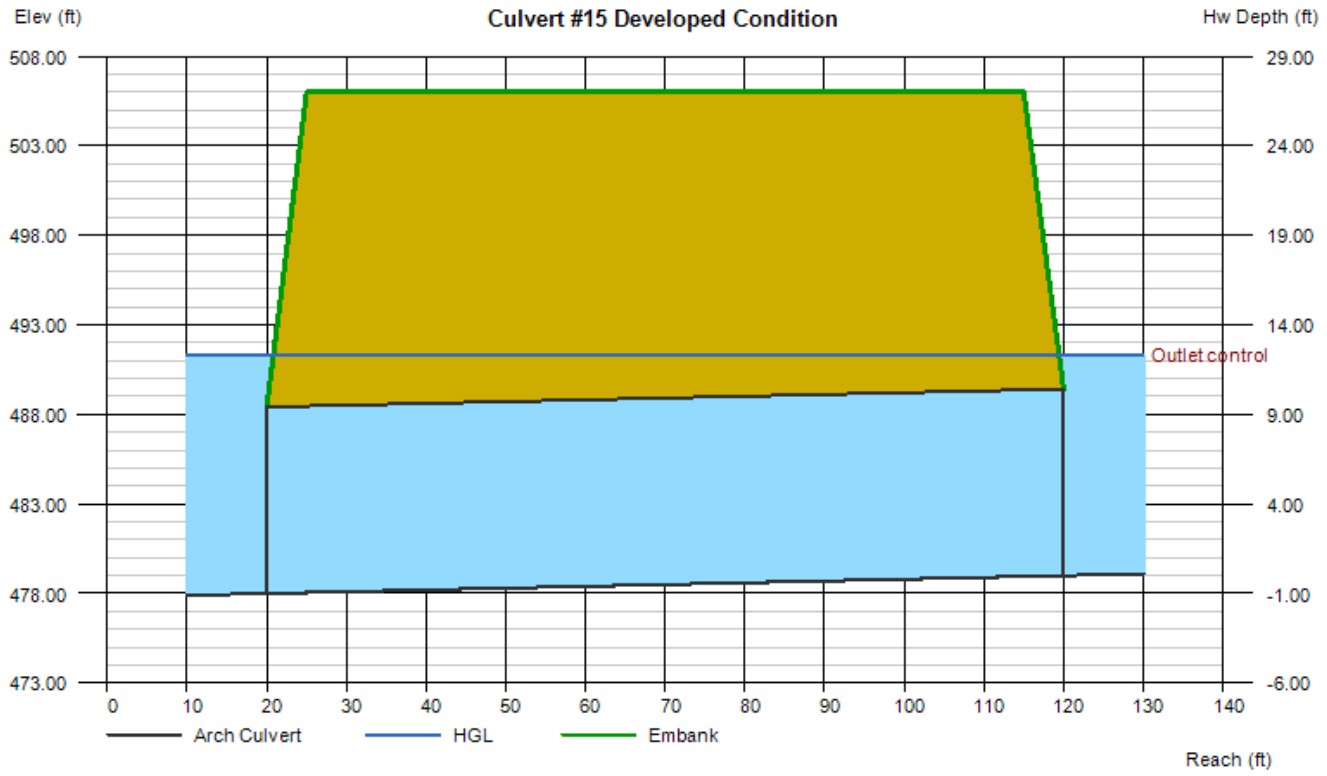
Top Elevation (ft)	= 506.00
Top Width (ft)	= 90.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 256.00
Qmax (cfs)	= 256.00
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 256.00
Qpipe (cfs)	= 256.00
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 1.50
Veloc Up (ft/s)	= 1.50
HGL Dn (ft)	= 491.30
HGL Up (ft)	= 491.31
Hw Elev (ft)	= 491.33
Hw/D (ft)	= 1.18
Flow Regime	= Outlet Control



Culvert Report

Culvert #16 Developed Condition- Lower Otay Resvoir Tailwater

Invert Elev Dn (ft)	=	485.00
Pipe Length (ft)	=	50.00
Slope (%)	=	1.00
Invert Elev Up (ft)	=	485.50
Rise (in)	=	60.0
Shape	=	Circular
Span (in)	=	60.0
No. Barrels	=	1
n-Value	=	0.013
Culvert Type	=	Circular Concrete
Culvert Entrance	=	Square edge w/headwall (C)
Coeff. K,M,c,Y,k	=	0.0098, 2, 0.0398, 0.67, 0.5

Embankment

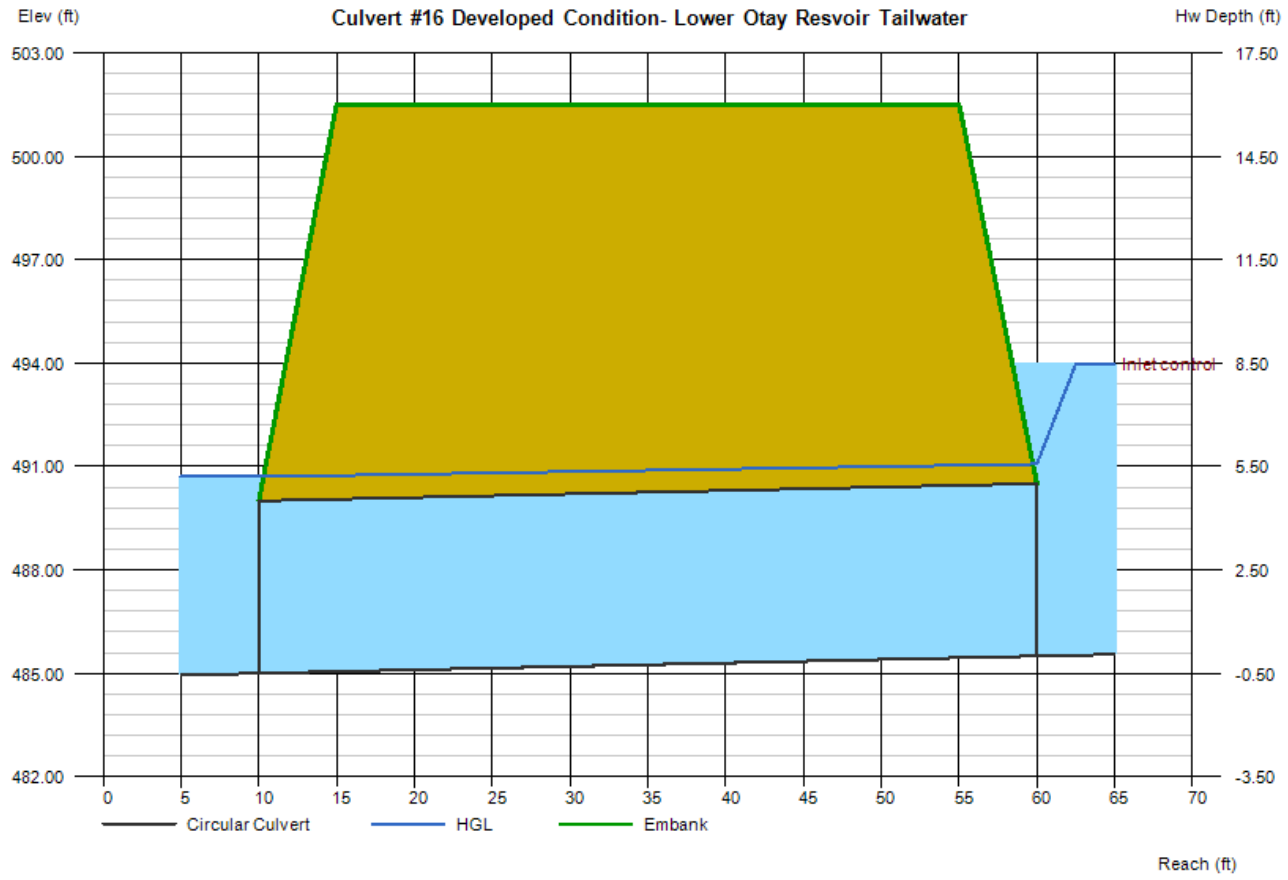
Top Elevation (ft)	=	501.50
Top Width (ft)	=	40.00
Crest Width (ft)	=	50.00

Calculations

Qmin (cfs)	=	223.30
Qmax (cfs)	=	223.30
Tailwater Elev (ft)	=	490.7

Highlighted

Qtotal (cfs)	=	223.30
Qpipe (cfs)	=	223.30
Qovertop (cfs)	=	0.00
Veloc Dn (ft/s)	=	11.37
Veloc Up (ft/s)	=	11.37
HGL Dn (ft)	=	490.70
HGL Up (ft)	=	491.07
Hw Elev (ft)	=	493.97
Hw/D (ft)	=	1.69
Flow Regime	=	Inlet Control



Worksheet for Culvert #16 - 60" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	60.00	in
Discharge	223.30	ft³/s

Results

Normal Depth	3.57	ft
Flow Area	14.98	ft²
Wetted Perimeter	10.05	ft
Hydraulic Radius	1.49	ft
Top Width	4.52	ft
Critical Depth	4.24	ft
Percent Full	71.3	%
Critical Slope	0.00696	ft/ft
Velocity	14.91	ft/s
Velocity Head	3.45	ft
Specific Energy	7.02	ft
Froude Number	1.44	
Maximum Discharge	280.14	ft³/s
Discharge Full	260.43	ft³/s
Slope Full	0.00735	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	71.31	%
Downstream Velocity	Infinity	ft/s

Worksheet for Culvert #16 - 60" RCP

GVF Output Data

Upstream Velocity	Infinity	ft/s
Normal Depth	3.57	ft
Critical Depth	4.24	ft
Channel Slope	1.00	%
Critical Slope	0.00696	ft/ft

Culvert Report

Culvert #16 Developed Condition

Invert Elev Dn (ft)	=	485.00
Pipe Length (ft)	=	50.00
Slope (%)	=	1.00
Invert Elev Up (ft)	=	485.50
Rise (in)	=	60.0
Shape	=	Circular
Span (in)	=	60.0
No. Barrels	=	1
n-Value	=	0.013
Culvert Type	=	Circular Concrete
Culvert Entrance	=	Square edge w/headwall (C)
Coeff. K,M,c,Y,k	=	0.0098, 2, 0.0398, 0.67, 0.5

Embankment

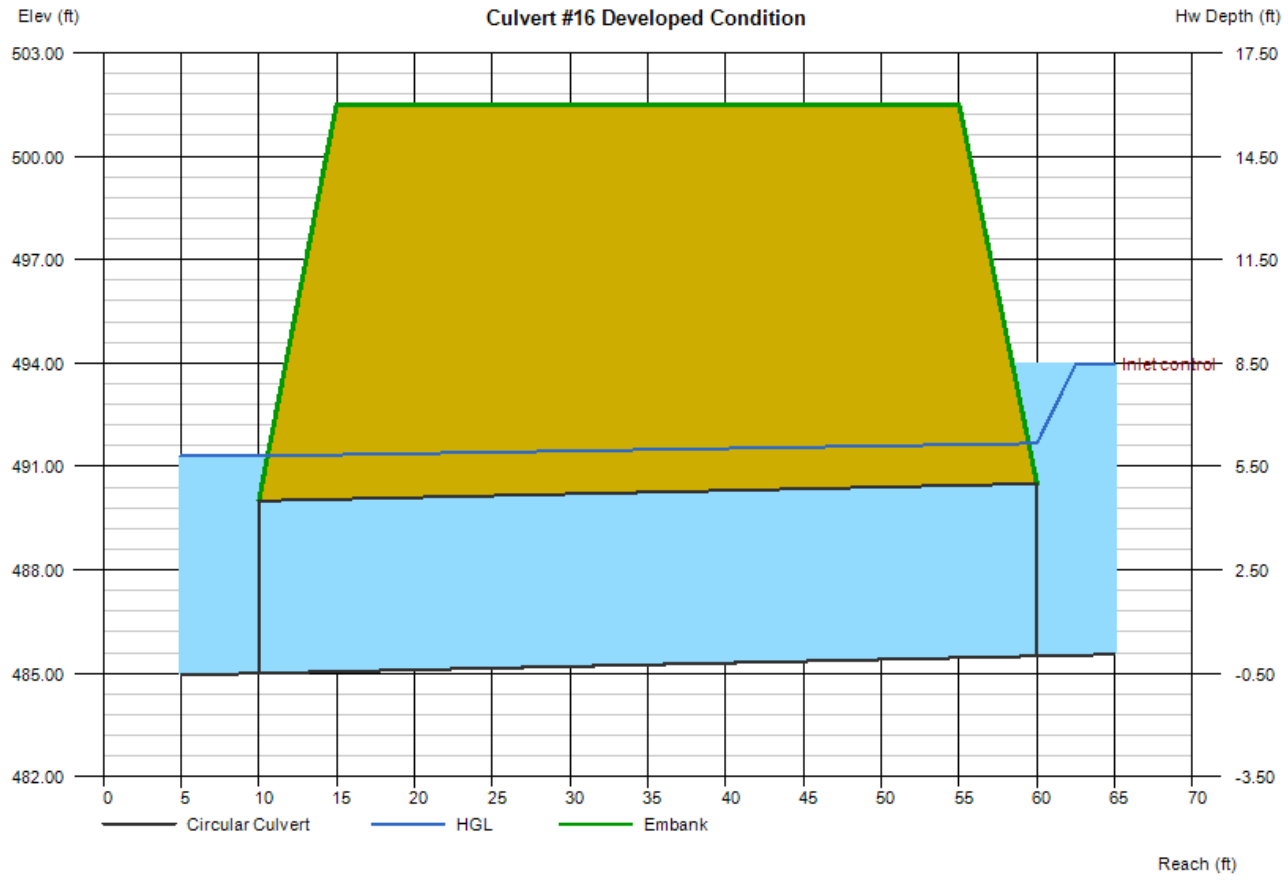
Top Elevation (ft)	=	501.50
Top Width (ft)	=	40.00
Crest Width (ft)	=	50.00

Calculations

Qmin (cfs)	=	223.30
Qmax (cfs)	=	223.30
Tailwater Elev (ft)	=	491.3

Highlighted

Qtotal (cfs)	=	223.30
Qpipe (cfs)	=	223.30
Qovertop (cfs)	=	0.00
Veloc Dn (ft/s)	=	11.37
Veloc Up (ft/s)	=	11.37
HGL Dn (ft)	=	491.30
HGL Up (ft)	=	491.67
Hw Elev (ft)	=	493.97
Hw/D (ft)	=	1.69
Flow Regime	=	Inlet Control



Culvert Calculator Report
Culvert 18

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	504.00	ft	Headwater Depth/Height	0.72	
Computed Headwater Elevation	495.00	ft	Discharge	1,198.50	cfs
Inlet Control HW Elev.	493.97	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	495.00	ft	Control Type	Outlet Control	

Grades					
Upstream Invert	485.50	ft	Downstream Invert	485.00	ft
Length	100.00	ft	Constructed Slope	0.005000	ft/ft

Hydraulic Profile					
Profile	M2		Depth, Downstream	5.70	ft
Slope Type	Mild		Normal Depth	7.81	ft
Flow Regime	Subcritical		Critical Depth	5.34	ft
Velocity Downstream	11.58	ft/s	Critical Slope	0.014978	ft/ft

Section					
Section Shape	Arch		Mannings Coefficient	0.034	
Section Material	Steel structural plate 31 In CR		Span	20.58	ft
Section Size	247 x 158.6 inch		Rise	13.22	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	495.00	ft	Upstream Velocity Head	1.46	ft
Ke	0.90		Entrance Loss	1.32	ft

Inlet Control Properties					
Inlet Control HW Elev.	493.97	ft	Flow Control	N/A	
Inlet Type	31 inch CR structural plate, projecting		Area Full	213.8	ft²
K	0.03000		HDS 5 Chart	36	
M	1.50000		HDS 5 Scale	1	
C	0.04960		Equation Form	1	
Y	0.57000				

Worksheet for Culvert #18 - Contech 23A6 -6

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Channel Slope	1.00	%
Discharge	1198.50	ft³/s

Section Definitions

Station (ft)	Elevation (ft)
0+00	0.00
0+01	4.00
0+04	9.00
0+09	11.50
0+11	12.00
0+13	11.50
0+18	9.00
0+21	4.00
0+22	0.00

Roughness Segment Definitions

Start Station	Ending Station	Roughness Coefficient
(0+00, 0.00)	(0+22, 0.00)	0.013

Results

Normal Depth		12.57	ft
Elevation Range	0.00 to 12.00 ft		
Flow Area		84.07	ft²
Wetted Perimeter		60.35	ft
Top Width		22.00	ft
Normal Depth		12.57	ft
Critical Depth		13.27	ft
Critical Slope		0.00590	ft/ft
Velocity		14.26	ft/s

Worksheet for Culvert #18 - Contech 23A6 -6

Results

Velocity Head		3.16	ft
Specific Energy		15.73	ft
Froude Number		1.29	
Flow Type	Supercritical		

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	12.57	ft
Critical Depth	13.27	ft
Channel Slope	0.01000	ft/ft
Critical Slope	0.00590	ft/ft

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #18 Developed Condition

Invert Elev Dn (ft)	= 485.00
Pipe Length (ft)	= 100.00
Slope (%)	= 0.50
Invert Elev Up (ft)	= 485.50
Rise (in)	= 125.0
Shape	= Arch
Span (in)	= 250.0
No. Barrels	= 1
n-Value	= 0.024
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0083, 2, 0.0379, 0.69, 0.5

Embankment

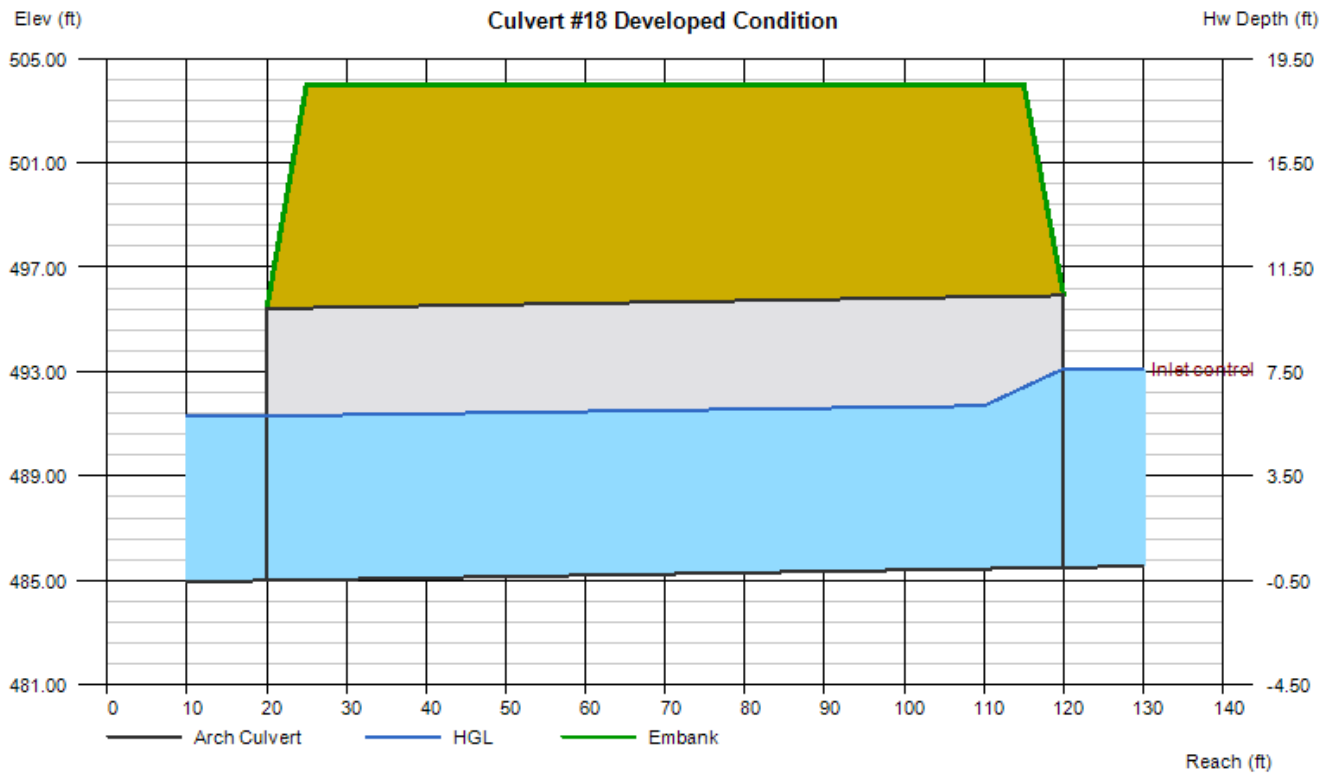
Top Elevation (ft)	= 504.00
Top Width (ft)	= 90.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 1198.50
Qmax (cfs)	= 1198.50
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 1198.50
Qpipe (cfs)	= 1198.50
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 9.76
Veloc Up (ft/s)	= 9.86
HGL Dn (ft)	= 491.30
HGL Up (ft)	= 491.73
Hw Elev (ft)	= 493.11
Hw/D (ft)	= 0.73
Flow Regime	= Inlet Control



Culvert Calculator Report
Culvert 19

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	522.00	ft	Headwater Depth/Height	0.93	
Computed Headwater Elevation	507.35	ft	Discharge	11.70	cfs
Inlet Control HW Elev.	507.28	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	507.35	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	505.50	ft	Downstream Invert	505.00	ft
Length	50.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.04	ft
Slope Type	Steep		Normal Depth	1.02	ft
Flow Regime	Supercritical		Critical Depth	1.23	ft
Velocity Downstream	7.13	ft/s	Critical Slope	0.005525	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	2.00	ft
Section Size	24 inch		Rise	2.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	507.35	ft	Upstream Velocity Head	0.52	ft
Ke	0.20		Entrance Loss	0.10	ft

Inlet Control Properties					
Inlet Control HW Elev.	507.28	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 45° bevels		Area Full	3.1	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	A	
C	0.03000		Equation Form	1	
Y	0.74000				

Worksheet for Culvert #19 - 18" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	24.00	in
Discharge	12.30	ft³/s

Results

Normal Depth	1.05	ft
Flow Area	1.67	ft²
Wetted Perimeter	3.24	ft
Top Width	2.00	ft
Critical Depth	1.26	ft
Percent Full	52.6	%
Critical Slope	0.00565	ft/ft
Velocity	7.35	ft/s
Velocity Head	0.84	ft
Specific Energy	1.89	ft
Froude Number	1.42	
Maximum Discharge	24.33	ft³/s
Discharge Full	22.62	ft³/s
Slope Full	0.00296	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	52.56	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Worksheet for Culvert #19 - 18" RCP

GVF Output Data

Normal Depth	1.05	ft
Critical Depth	1.26	ft
Channel Slope	1.00	%
Critical Slope	0.00565	ft/ft

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #19 Developed Condition

Invert Elev Dn (ft)	= 505.00
Pipe Length (ft)	= 50.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 505.50
Rise (in)	= 24.0
Shape	= Cir
Span (in)	= 24.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5

Embankment

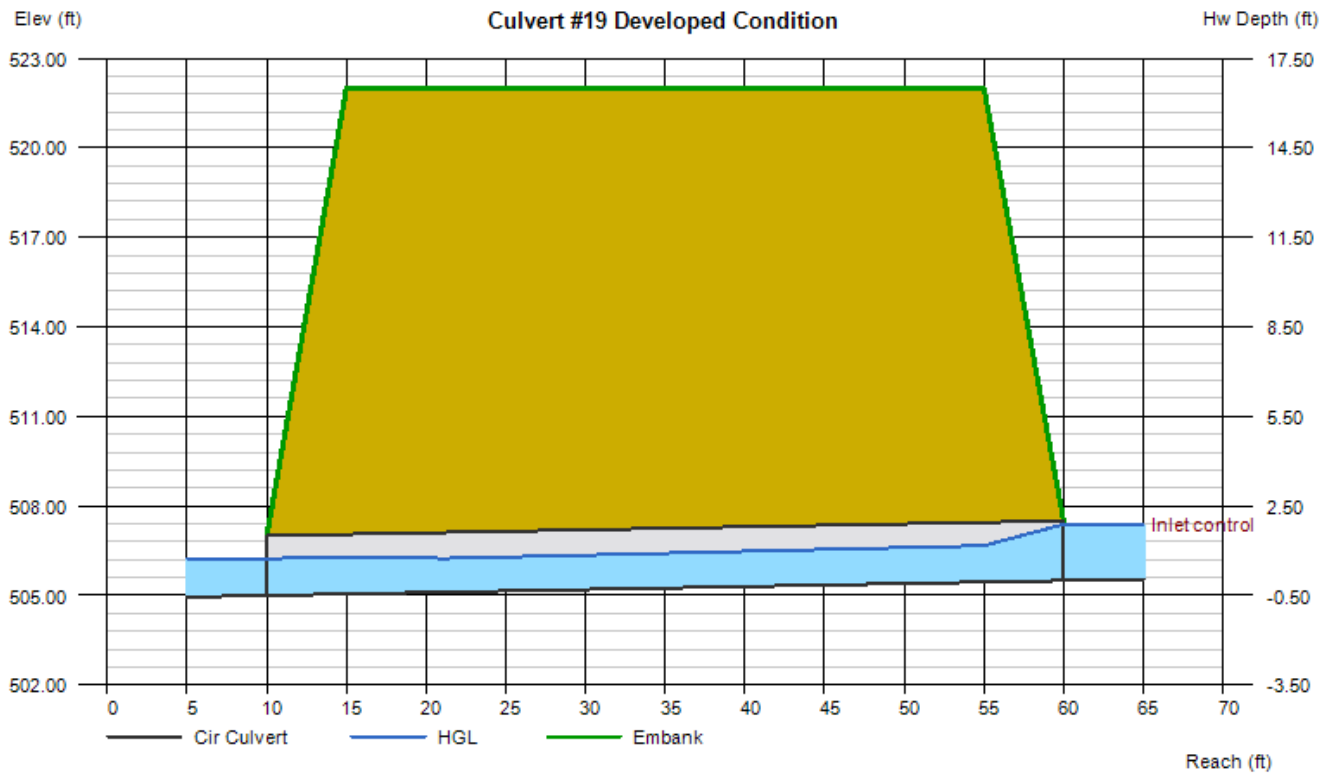
Top Elevation (ft)	= 522.00
Top Width (ft)	= 40.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 11.70
Qmax (cfs)	= 11.70
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 11.70
Qpipe (cfs)	= 11.70
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 5.76
Veloc Up (ft/s)	= 5.76
HGL Dn (ft)	= 506.23
HGL Up (ft)	= 506.73
Hw Elev (ft)	= 507.38
Hw/D (ft)	= 0.94
Flow Regime	= Inlet Control



Culvert Calculator Report
Culvert 20

Solve For: Headwater Elevation

Culvert Summary					
Allowable HW Elevation	522.00	ft	Headwater Depth/Height	1.14	
Computed Headwater Elevation	513.92	ft	Discharge	44.80	cfs
Inlet Control HW Elev.	513.86	ft	Tailwater Elevation	490.70	ft
Outlet Control HW Elev.	513.92	ft	Control Type	Entrance Control	

Grades					
Upstream Invert	510.50	ft	Downstream Invert	510.00	ft
Length	50.00	ft	Constructed Slope	0.010000	ft/ft

Hydraulic Profile					
Profile	S2		Depth, Downstream	1.88	ft
Slope Type	Steep		Normal Depth	1.80	ft
Flow Regime	Supercritical		Critical Depth	2.18	ft
Velocity Downstream	9.63	ft/s	Critical Slope	0.005848	ft/ft

Section					
Section Shape	Circular		Mannings Coefficient	0.013	
Section Material	Concrete		Span	3.00	ft
Section Size	36 inch		Rise	3.00	ft
Number Sections	1				

Outlet Control Properties					
Outlet Control HW Elev.	513.92	ft	Upstream Velocity Head	1.03	ft
Ke	0.20		Entrance Loss	0.21	ft

Inlet Control Properties					
Inlet Control HW Elev.	513.86	ft	Flow Control	N/A	
Inlet Type	Beveled ring, 45° bevels		Area Full	7.1	ft²
K	0.00180		HDS 5 Chart	3	
M	2.50000		HDS 5 Scale	A	
C	0.03000		Equation Form	1	
Y	0.74000				

Worksheet for Culvert #20 - 36" RCP

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.013	
Channel Slope	1.00	%
Diameter	36.00	in
Discharge	44.80	ft^3/s

Results

Normal Depth	1.80	ft
Flow Area	4.43	ft^2
Wetted Perimeter	5.32	ft
Top Width	2.94	ft
Critical Depth	2.18	ft
Percent Full	60.0	%
Critical Slope	0.00585	ft/ft
Velocity	10.12	ft/s
Velocity Head	1.59	ft
Specific Energy	3.39	ft
Froude Number	1.45	
Maximum Discharge	71.74	ft^3/s
Discharge Full	66.69	ft^3/s
Slope Full	0.00451	ft/ft
Flow Type	SuperCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%
Normal Depth Over Rise	60.00	%
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s

Worksheet for Culvert #20 - 36" RCP

GVF Output Data

Normal Depth	1.80	ft
Critical Depth	2.18	ft
Channel Slope	1.00	%
Critical Slope	0.00585	ft/ft

Culvert Report

2011 Hydraflow Express Extension for AutoCAD® Civil 3D® 2011 by Autodesk, Inc.

Culvert #20 Developed Condition

Invert Elev Dn (ft)	= 510.00
Pipe Length (ft)	= 50.00
Slope (%)	= 1.00
Invert Elev Up (ft)	= 510.50
Rise (in)	= 36.0
Shape	= Cir
Span (in)	= 36.0
No. Barrels	= 1
n-Value	= 0.013
Inlet Edge	= 0
Coeff. K,M,c,Y,k	= 0.0098, 2, 0.0398, 0.67, 0.5

Embankment

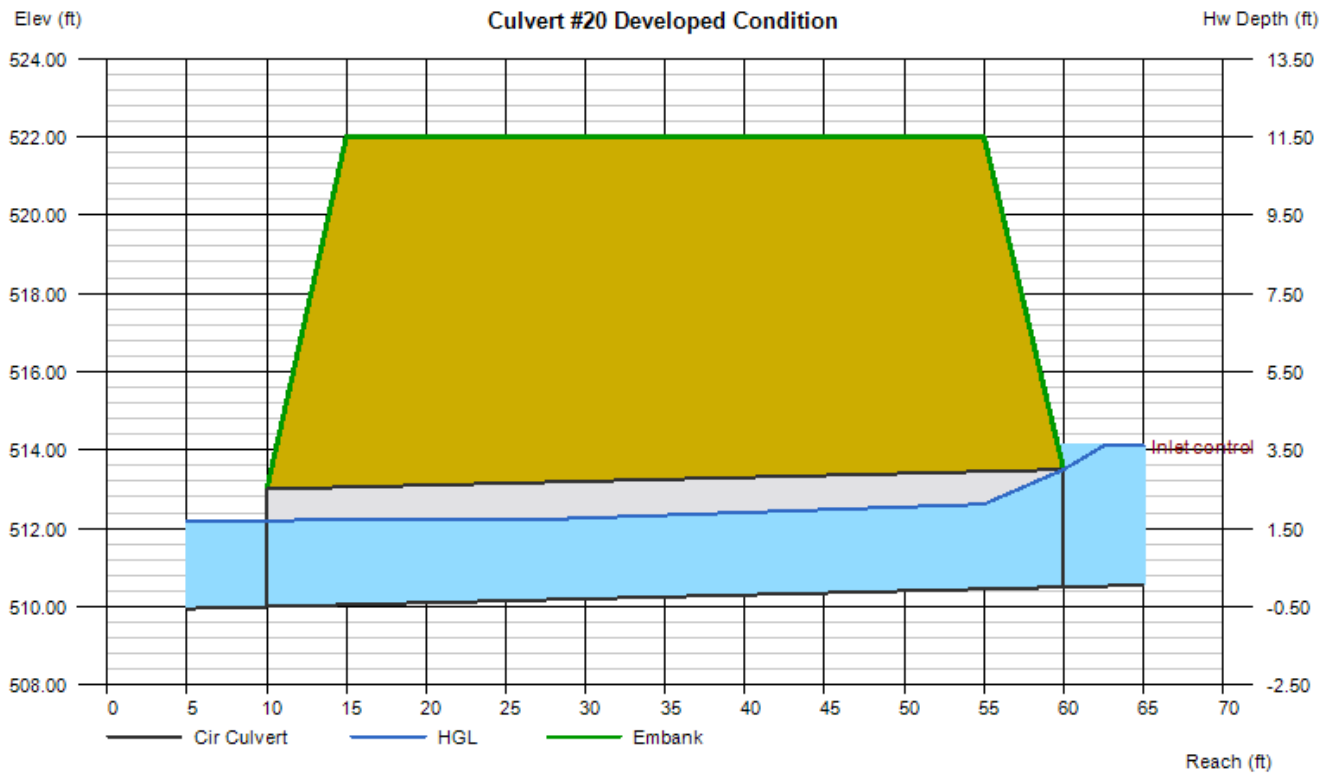
Top Elevation (ft)	= 522.00
Top Width (ft)	= 40.00
Crest Width (ft)	= 50.00

Calculations

Qmin (cfs)	= 44.80
Qmax (cfs)	= 44.80
Tailwater Elev (ft)	= 491.3

Highlighted

Qtotal (cfs)	= 44.80
Qpipe (cfs)	= 44.80
Qovertop (cfs)	= 0.00
Veloc Dn (ft/s)	= 8.12
Veloc Up (ft/s)	= 8.12
HGL Dn (ft)	= 512.18
HGL Up (ft)	= 512.68
Hw Elev (ft)	= 514.10
Hw/D (ft)	= 1.20
Flow Regime	= Inlet Control



CHAPTER 7

7.3 Freeboard of Proposed Culverts and Dam Considerations

FREEBOARD TABLE FOR PROPOSED CULVERTS AND WATER DEPTHS [1]

Culvert	Headwater Elevation	Allowable Elevation	Freeboard	Upstream Flowline	Upstream depth of Water	Downstream Flowline	Total depth[2]
1A	521.71	530.07	8.36	518.00	3.71	517.00	4.71
1B	520.11	530.07	9.96	518.00	2.11	516.80	3.31
2	492.20	510.14	17.94	481.00	11.20	480.00	12.20
4	493.80	511.00	17.20	482.00	11.80	479.00	14.80
6	494.47	515.00	20.53	481.00	13.47	480.00	14.47
7	512.08	515.00	2.92	500.50	11.58	500.00	12.08
9	503.06	510.00	6.94	495.50	7.56	495.00	8.06
12	503.22	510.50	7.28	500.50	2.72	500.00	3.22
14	498.47	501.50	3.03	495.50	2.97	495.00	3.47
15	490.74	506.00	15.26	479.00	11.74	478.00	12.74
16	493.97	501.50	7.53	485.50	8.47	485.00	8.97
18	495.00	504.00	9.00	485.50	9.50	485.00	10.00
19	507.35	522.00	14.65	505.50	1.85	505.00	2.35
20	513.92	522.00	8.08	510.50	3.42	510.00	3.92

(1) : All values are in ft

(2) : Total depth refers to the difference in elevation from downstream toe of filling to water max-elev upstream during a 100 yr storm event

DAM CONSIDERATIONS

Per the Statutes and Regulations pertaining to Supervition of Dams and Reservoirs, Department of Water Resources, Division of Safety of Dams (DSOS), Chapter 1 : Definitions, section 6004 a), shown in the next page after this explanation, *" ... no railroad fill or structure, and no road or highway fill or structure, ... shall be considered a dam"* . Therefore, culverts where ponding is in excess of 25' measured from upstream maximum elevation to downstream toe, shall not be considered as dams. Additionally, in this project the total depth does not exceed 25' in any culvert.

STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

Division of Safety of Dams

STATUTES AND REGULATIONS

PERTAINING TO

SUPERVISION OF

DAMS AND RESERVOIRS

CALIFORNIA WATER CODE
Division 3. Dams and Reservoirs

DIVISION 3. DAMS AND RESERVOIRS

PART 1. SUPERVISION OF DAMS AND RESERVOIRS

Chapter 1. Definitions

6000. Unless the context otherwise requires, the definitions in this chapter govern the construction of this part.

6002. "Dam" means any artificial barrier, together with appurtenant works, which does or may impound or divert water, and which either (a) is or will be 25 feet or more in height from the natural bed of the stream or watercourse at the downstream toe of the barrier, as determined by the department, or from the lowest elevation of the outside limit of the barrier, as determined by the department, if it is not across a stream channel or watercourse, to the maximum possible water storage elevation or (b) has or will have an impounding capacity of 50 acre-feet or more.

6003. Any such barrier which is or will be not in excess of 6 feet in height, regardless of storage capacity, or which has or will have a storage capacity not in excess of 15 acre-feet, regardless of height, shall not be considered a dam.

6004. a) No obstruction in a canal used to raise or lower water therein or divert water therefrom, no levee, including but not limited to a levee on the bed of a natural lake the primary purpose of which levee is to control floodwaters, no railroad fill or structure, and no road or highway fill or structure, no circular tank constructed of steel or concrete, or both, no tank elevated above the ground, and no barrier which is not across a stream channel, watercourse, or natural drainage area and which has the principal purpose of impounding water for agricultural use shall be considered a dam.

b) No obstruction in the channel of astream or watercourse which is 15 feet or less in height from the lowest elevation of the obstruction and which has the single purpose of spreading water within the bed of the stream or watercourse upstream from the obstruction for percolation underground shall be considered a dam.

c) The levee of an island adjacent to tidal waters in the Sacramento-San Joaquin Delta, as defined in Section 12220, even when used to impound water, shall not be considered a dam and the impoundment shall not be considered a reservoir if the maximum possible water storage elevation of the impounded water does not

exceed four feet above mean sea level, as established by the United Stated Geological Survey 1929 datum.

d) No noncircular tank, constructed of steel or concrete, or both, that is constructed in a county of the third class by a public agency, under the supervision of a civil engineer registered in the state, that does not exceed 75 acre-feet in capacity or 30 feet in height, and no barrier that is not across a stream channel, watercourse, or natural drainage area and that has the principal use as a sewage sludge drying facility shall be considered a dam.

6004.5. "Reservoir" means any reservoir which contains or will contain the water impounded by a dam.

6005. "Owner" includes any of the following who own, control, operate, maintain, manage, or propose to construct a dam or reservoir:

(a) The State and its departments, institutions, agencies, and political subdivisions.

(b) Every municipal or quasi-municipal corporation.

(c) Every public utility.

(d) Every district.

(e) Every person.

(f) The duly authorized agents, lessees, or trustees of any of the foregoing.

(g) Receivers or trustees appointed by any court for any of the foregoing.

"Owner" does not include the United States.

6006. "Alterations", "repairs", or either of them, mean only such alterations or repairs as may affect the safety of the dam or reservoir.

6007. "Enlargement" means any change in or addition to an existing dam or reservoir, which raises or may raise the water storage elevation of the water impounded by the dam or reservoir.

6008. Water storage elevation means that elevation of water surface which could be obtained by the existing dam or reservoir, as previously operated, were there no outflow and were the reservoir full of water.

CHAPTER 7

7.4 Lower Otay Reservoir Tailwater Calculations

Worksheet for Savage Dam

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Channel Slope	0.50	%
Discharge	17571.00	ft³/s

Section Definitions

Reference Savage Dam Data sheet for Spillway Information

Station (ft)	Elevation (ft)
0+00	492.90
0+01	486.40
2+25	486.40
2+26	489.40
4+25	489.40
4+26	493.50

Roughness Segment Definitions

Start Station	Ending Station	Roughness Coefficient
(0+00, 492.90)	(4+26, 493.50)	0.015

Results

Normal Depth		4.33	ft
Elevation Range	486.40 to 493.50 ft		
Flow Area		1241.11	ft²
Wetted Perimeter		431.92	ft
Top Width		424.99	ft
Normal Depth		4.33	ft
Critical Depth		5.17	ft
Critical Slope		0.00216	ft/ft
Velocity		14.16	ft/s
Velocity Head		3.11	ft
Specific Energy		7.45	ft
Froude Number		1.46	

486.4' (Dam Spillway)
+ 4.33' Flow Depth
= 490.7'

Lower Otay Reservoir Calculated Tail Water

Worksheet for Savage Dam

Results

Flow Type	Supercritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	4.33	ft
Critical Depth	5.17	ft
Channel Slope	0.00500	ft/ft
Critical Slope	0.00216	ft/ft

SAVAGE DAM (LOWER OTAY)

LOCATION OR APPURTENANCE:	RESERVOIR GAUGE:	USGS DATUM:	AREA (ACRES):	CAPACITY ACRE FEET:	CAPACITY M.G.'s:
Top of Dam, Road	145.00	492.20	1,256.8	58,380.9	19,023.5
Top of Gates (16) Indep. Spill.	144.10	491.30			
Top of Gates (18) In Dam Spill.	143.50	490.70	1,227.0	56,518.6	18,416.6
Crest Ind. Spillway	140.00	487.20	1,157.8	52,345.3	17,056.8
Crest Dam Spillway	137.50	484.20	1,110.3	49,510.7	16,133.1
Outlet # 7, Top	117.00	464.20	794.5	30,281.8	9,867.3
Outlet # 6, Top	106.00	453.20	654.4	22,315.6	7,271.6
Outlet # 5, Top	95.00	442.20	532.6	15,812.2	5,152.4
Outlet # 4, Top	84.00	431.20	418.9	10,580.9	3,451.0
Outlet # 3, Top	73.00	420.20	325.7	6,517.3	2,123.7
Outlet # 2, Top	63.00	410.20	230.2	3,734.4	1,216.9
Tunnel Invert	48.85	396.05	120.2	1,271.2	412.2
Outlet # 1, Top (silted)	47.85	395.05	113.5	1,154.1	376.1
Streambed	0.00	347.20	0.0	0.0	0.0

COMMENTS: Silt level @ gauge 81 + or - (1993)

DSOD CODE NO.: 8-4

STREAM: Otay River, San Diego Bay

LOCATION: 20 miles southeast of San Diego, in Section 18, T18S, R1E (SBBM);
Lat.: 32° 36' 40" N.
Long.: 116° 55' 40" W.

WATER RIGHTS: Pre-1914 right. No application required.

Spillway Elevation
484.2'
+ 2.2' (Datum Conversion)
= 486.4'

DAM STRUCTURE

TYPE: Curved concrete gravity (base of original dam is included in the foundation of the present structure).

HEIGHT ABOVE STREAMBED: 145' (plus a 4' parapet)

DEPTH BELOW STREAMBED: 37'

TOTAL HEIGHT: 182'

LENGTH OF CREST: 741'

WIDTH OF CREST: 15'

WIDTH OF FOUNDATION AT STREAMBED: 150'

PLAN: Curved - Ranges from 225' to 325' radius.

INSTRUMENTATION: Micrometers: 2, Leak Weir: 1, Monuments: 2.

$Q_{100} = \frac{98}{122.7}(22,000)$
$= 17,571$ cfs

100 year flow at Lower Otay Reservoir. Interpolated from FEMA Flood Insurance Study

SPILLWAY INFORMATION

SPILLWAY TYPE: Gated overpour on dam section (18 gates: each 12.63' long) and independent gated channel (16 gates : 11 at 12.25' and 5 at 13.70' long).

SPILLWAY CAPACITY: 49,400 cfs (combined)

SPILLWAY CREST LENGTH: Overpour Section - 225'; Independent Section - 201'.

SPILLWAY CHANNEL LENGTH: Independent channel: 325'

SPILLWAY GATES OPERATION: Gates must be fully open between Nov. 1 & April 1.

FLOOD STAGE ABOVE SPILLWAY: 100-YR: N/A PMF: 11.4'

OUTLET WORKS

DESCRIPTION: An independent wet tower, with seven 36" saucer valves on the outside and one inoperable 48" gate valve at the base of the tower.

MAXIMUM DRAFT RATE: To treatment plant: 74 cfs (48 MGD);
To blowoff and treatment plant: 349 cfs (225 Mgd)

GENERAL INFORMATION

AREA OF WATERSHED: 98 square miles (including Upper Otay)

CONSTRUCTION PERIOD: 1917-1919

CONSTRUCTED BY: City of San Diego

COST: $733,157

AVERAGE ANNUAL RUNOFF (1888-1990): 6,427 ac.-ft.

MEDIAN ANNUAL RUNOFF (1888-1990): 2,052 ac.-ft.

AVERAGE ANNUAL RAINFALL at reservoir: (1888-1990): 11.36 inches (1983-1993): 11.66 inches

AVERAGE ANNUAL EVAPORATION (1888-1990): 50.63 inches

YEARS SPILLED: 1927, 1932, 1938, 1941, 1980-83, 1993

HISTORICAL INFORMATION SUMMARY

The original Lower Otay Dam was started in 1886-1887 by the Otay Water Company & was completed by the Southern California Mountain Water Company between 1894-1897.

1913: The City of San Diego purchased the dam.

Jan 27, 1916: Dam failed due to overtopping during the "Hatfield Flood".

1917-1919: Dam was reconstructed.

1934: Named Savage Dam in honor of the chief engineer.

FLOOD INSURANCE STUDY

SAN DIEGO COUNTY, CALIFORNIA
AND INCORPORATED AREAS

VOLUME 1 OF 7

Community Name	Community Number
CARLSBAD, CITY OF	060285
CHULA VISTA, CITY OF	065021
CORONADO, CITY OF	060287
DEL MAR, CITY OF	060288
EL CAJON, CITY OF	060289
ENCINITAS, CITY OF	060726
ESCONDIDO, CITY OF	060290
IMPERIAL BEACH, CITY OF	060291
LA MESA, CITY OF	060292
LEMON GROVE, CITY OF	060723
NATIONAL CITY, CITY OF	060293
OCEANSIDE, CITY OF	060294
POWAY, CITY OF	060702
SAN DIEGO, CITY OF	060295
SAN DIEGO COUNTY UNINCORPORATED AREAS	060284
SAN MARCOS, CITY OF	060296
SANTEE, CITY OF	060703
SOLANA BEACH, CITY OF	060725
VISTA, CITY OF	060297

REVISED:
SEPTEMBER 29, 2006

Federal Emergency Management Agency
FLOOD INSURANCE STUDY NUMBER
06073CV001B

Fema, Flood Insurance Study, San Diego County, California 06073CV001B pg 63

Table 4. Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Year	50-Year	100-Year	500-Year
Nestor Creek					
At Palm Avenue	2.75	--[1]	--[1]	1,093	--[1]
At 19th Street	--[1]	--[1]	--[1]	864[2]	--[1]
At Elm Avenue	2.45	--[1]	--[1]	796[2]	--[1]
At Coronado Avenue	2.33	--[1]	--[1]	698[2]	--[1]
At Hollister Street	1.99	--[1]	--[1]	496[2]	--[1]
At 25th Street/Interstate 5	1.71	--[1]	--[1]	456[2]	--[1]
At San Diego and Arizona Eastern Railroad	1.40	515	800	945	2,155
North Branch Poway Creek					
At Sycamore Canyon Road	4.5	650	2,000	3,000	7,200
North Tributary to Santa Maria Creek					
At Mouth	1.6	100	600	1,100	2,900
Olive Creek					
At Mouth	1.0	--[1]	--[1]	1,370	--[1]
Otay River					
At Otay Valley Road	122.7	1,200	12,000	22,000	50,000
Pala Mesa Creek					
Approximately 265 Feet Upstream of Interstate Highway 15	2.1	--[1]	--[1]	1,700	--[1]
Pauma Creek					
At Apex of Alluvial Fan	14.7	1,550	6,270	10,480	30,460
Pilgrim Creek					
Upstream End of Oceanside Golf Course	14.0	--[1]	--[1]	5,775	--[1]
Downstream End of Oceanside Golf Course	14.0	--[1]	--[1]	1,440	
Just Upstream of the Confluence with Windmill Creek	15.8	--[1]	--[1]	2,020	--[1]
At Mouth	19.0	--[1]	--[1]	2,810	--[1]
Poggi Canyon Creek					
At City of Chula Vista Corporate Limit	3.74	180	830	1,280	2,470
At Confluence with Otay River	4.63	220	930	1,400	2,630

[1]Data Not Available
[2]Decrease Due to Construction of "Lot 6 Detention Basin" Upstream of Railroad

These discharge parameters used to interpolate flow at Lower Otay Reservoir.

CHAPTER 7

7.5 Open Channel Inundation Calculations

CHANNEL INUNDATION Report

Label	Roughness Coefficient	Channel Slope (%)	Normal Depth (ft)	Left Side Slope (ft/ft (H:V))	Right Side Slope (ft/ft (H:V))	Bottom Width (ft)	Discharge (ft^3/s)	Velocity (ft/s)
CHANNEL AT NODE 1211	0.045	8.30	1.89	2.80	2.80	2.00	134.67	9.77
CHANNEL AT NODE 1311	0.045	2.70	2.08	2.50	2.50	3.00	104.14	6.12
CHANNEL AT NODE 1364	0.045	2.70	3.55	1.50	1.50	3.60	266.90	8.42
CHANNEL AT NODE 1408	0.045	4.50	1.37	4.80	4.80	13.00	189.39	7.07
CHANNEL AT NODE 1416	0.045	2.70	2.44	4.80	4.80	4.00	256.25	6.70
CHANNEL AT NODE 1504	0.045	12.00	0.83	4.00	4.00	5.00	55.48	8.00
CHANNEL AT NODE 1633	0.045	10.00	4.14	2.00	2.00	2.00	723.05	16.99
CHANNEL AT NODE 1635	0.045	3.00	3.37	4.60	4.60	20.00	1198.50	10.01
CHANNEL AT NODE 1642	0.045	16.00	1.55	4.80	4.80	2.00	174.65	11.88
CHANNEL AT NODE 1708	0.045	15.00	0.83	2.60	2.60	4.00	45.64	8.99
CHANNEL AT NODE 1712	0.045	15.00	0.75	2.80	2.80	4.00	38.52	8.47
CHANNEL AT NODE 2403	0.045	6.90	0.65	5.00	5.00	7.00	35.72	5.38
CHANNEL AT NODE 2503	0.045	9.30	0.66	3.60	3.60	7.00	40.17	6.49

CHAPTER 8

APPENDIXES

CHAPTER 8

8.1. City of San Diego Letter Regarding Opposition to Reduction of Runoff, Review of SWMP, and Review of all Maps

THE CITY OF SAN DIEGO

May 18, 2009

Mr. Rob Cameron
Otay Ranch Company
610 West Ash Street, Suite 1500
San Diego, CA 92101

Reference: Otay Ranch Village 13 and the Lower Otay Reservoir catchment

Dear Mr. Cameron:

Pursuant to our meeting with Hunsaker and Associates San Diego, Inc. on April 30, 2009, we would like to clarify a few items with respect to the Lower Otay Reservoir catchment in general and the Otay Ranch Village 13 Community in particular.

- The City of San Diego Water Department will oppose any reductions in the volume of runoff into the Lower Otay Reservoir, including storm water discharges, which might result from the Village 13 projects. The Water Department desires that the project area produce the same or greater runoff volumes as long as the quality of the runoff is acceptable and the Source Protection Guidelines for New Development [January, 2004] are used to address water quality matters.

- The City of San Diego will review and comment on the Storm Water Management Plan for Village 13 with regard to its compliance with the Source Water Protection Guidelines.

- The City of San Diego will review and comment on the Tentative Map, Grading and Improvement Plans, and Final Maps for all work on Water Department property, including road alignments, wildlife crossings, storm drains, and rip rap energy dissipaters.

If you have any questions or require additional information, please do not hesitate to contact me at (619) 533-7599 or jpasek@sandiego.gov.

Sincerely,

Jeffery Pasek
Watershed Manager

JP/cj

Water Department
600 B Street, Suite 600, MS 906 • San Diego, CA 92101
Tel (619) 533-7595 Fax (619) 533-5325

CHAPTER 8

8.2. Final Hydromodification Management Plan – Exemptions for Otay River and Lower Otay Reservoir.

FINAL

HYDROMODIFICATION MANAGEMENT PLAN

Prepared for
County of San Diego, California
March 2011

Brown AND Caldwell
9665 Chesapeake Drive, Suite 201
San Diego, California 92123

6. REQUIREMENTS AND STANDARDS FOR PROJECTS

Priority Development Projects are required to implement hydrologic control measures so that post-project runoff flow rates and durations do not exceed pre-project flow rates and durations where they would result in an increased potential for erosion or significant impacts to beneficial uses or violate the channel standard (Permit Section D.1.g(1)(c)). The purpose of this chapter is to detail HMP applicability requirements, present hydromodification mitigation criteria and implementation options, and provide a framework for in-stream rehabilitation options.

6.1 HMP Applicability Requirements

To determine if a proposed project must implement hydromodification controls, refer to the HMP Decision Matrix in Figure 6-1 on the following page.

The HMP Decision Matrix can be used for all projects. For redevelopment projects, flow controls would only be required if the redevelopment project increases impervious area or peak flow rates as compared to pre-project conditions.

It should be noted that all Priority Development Projects will be subject to the Permit's LID and water quality treatment requirements even if hydromodification flow controls are not required.

As noted in Figure 6-1, projects may be exempt from HMP criteria under the following conditions.

- If the project is not a Priority Development Project
- If the proposed project does not increase the impervious area or peak flows to any discharge location.
- If the proposed project discharges runoff directly to an exempt receiving water such as the Pacific Ocean, San Diego Bay, an exempt river reach, an exempt reservoir, or a tidally-influenced area.
- If the proposed project discharges to a stabilized conveyance system that extends to the Pacific Ocean, San Diego Bay, a tidally-influenced area, an exempt river reach or reservoir.
- If the contributing watershed area to which the project discharges has an impervious area percentage greater than 70 percent
- If an urban infill project discharges to an existing hardened or rehabilitated conveyance system that extends beyond the "domain of analysis," the potential for cumulative impacts in the watershed are low, and the ultimate receiving channel has a Low susceptibility to erosion as defined in the SCCWRP channel assessment tool.

If the proposed project decreases the pre-project impervious area and peak flows to each discharge location, then a flow-duration analysis is implicitly not required. If continuous simulation flow-frequency and flow duration curves were developed for such a scenario, the unmitigated post-project flows and durations would be less as compared to pre-project curves.

Proposed exemptions for projects discharging runoff directly to the Pacific Ocean, San Diego Bay or to hardened conveyance systems which transport runoff directly to the Pacific Ocean or San Diego Bay are referred to the 2007 Municipal Permit. Per the Permit, hardened conveyance systems can include existing concrete channels, storm drain systems, etc.

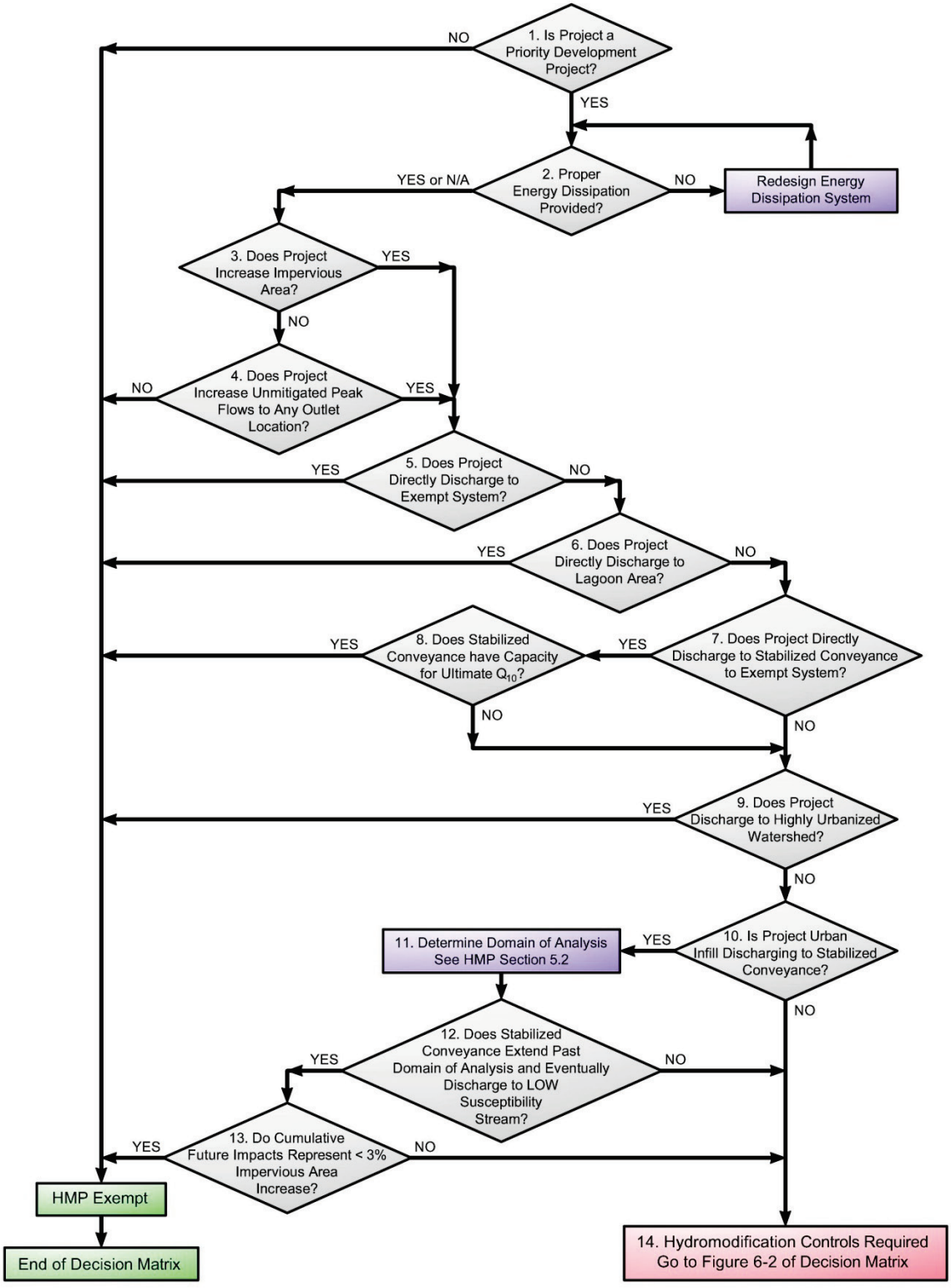


Figure 6-1. HMP Applicability Determination

The Municipal Permit also contains language to support exemptions for projects located in highly urbanized areas where the impervious percentage exceeds 70 percent (as calculated for the sub-watershed between the project outfall downstream to the exempt receiving water).

- Figure 6-1, Node 1 – Hydromodification mitigation measures are only required if the proposed project is a Priority Development Project.
- Figure 6-1, Node 2 – Properly designed energy dissipation systems are required for all project outfalls to unlined channels. Such systems should be designed in accordance with the County of San Diego's Drainage Design Manual to ensure downstream channel protection from concentrated outfalls.
- Figure 6-1, Nodes 3 and 4 – Projects may be exempt from hydromodification criteria if the proposed project reduces the pre-project impervious area and if unmitigated post-project outflows (outflows without detention routing) to each outlet location are less as compared to the pre-project condition. The pre and post-project hydrologic analysis should be conducted for the 2 and 10-year design storms and follow single-event methodology set forth in the San Diego Hydrology Manual. This scenario may apply to redevelopment projects in particular.
- Figure 6-1, Node 5 – Potential exemptions may be granted for projects discharging runoff directly to an exempt receiving water, such as the Pacific Ocean, San Diego Bay, an exempt river system (detailed in Table 6-1), or an exempt reservoir system (detailed in Table 6-2).
- Figure 6-1, Node 6 – For projects discharging runoff directly to a tidally-influenced lagoon, potential exemptions may also be granted. Exemptions related to runoff discharging directly to tidally-influenced areas were drafted based upon precedent set in the Santa Clara HMP. Regarding the potential exemption, additional analysis would be required to assess the effects of the freshwater / saltwater balance and the resultant effects on lagoon-system biology. This assessment, which would be required by other permitting processes such as the Army Corps of Engineers, California Department of Fish and Game, etc., must be provided by a certified biologist or other specialist as approved by the governing municipality. Such discharges would include an energy dissipation system (riprap, etc.) designed to mitigate 100-year outlet velocities based upon a free outfall condition. Such a design would be protective of the channel bed and bank from an erosion standpoint.
- Figure 6-1, Nodes 7 and 8 – For projects discharging runoff directly to a hardened conveyance or rehabilitated stream system that extends to exempt receiving waters detailed in Node 5, potential exemptions from hydromodification criteria may be granted. Such hardened or rehabilitated systems could include existing storm drain systems, existing concrete channels, or stable engineered unlined channels. To qualify for this exemption, the existing hardened or rehabilitated conveyance system must continue uninterrupted to the exempt system. In other words, the hardened or rehabilitated conveyance system cannot discharge to an unlined, non-engineered channel segment prior to discharge to the exempt system. Additionally, the project proponent must demonstrate that the hardened or rehabilitated conveyance system has capacity to convey the 10-year ultimate condition flow through the conveyance system. The 10-year flow should be calculated based upon single-event hydrologic criteria as detailed in the San Diego County Hydrology Manual.
- Figure 6-1, Node 9 – As allowed per the Municipal Permit, projects discharging runoff to a highly urbanized watershed (defined as an existing, pre-project impervious percentage greater than 70 percent) may be eligible for an exemption from hydromodification criteria.

Watershed impervious area calculations for this potential exemption will be measured between the project site discharge location and the connection to a downstream exempt receiving conveyance system, such as the Pacific Ocean, San Diego Bay, or an exempt river system. If a tributary area connects with the main line drainage path between the project site and the exempt system, then the entire watershed area contributing to the tributary shall be included in the calculation. Initial review of County land use indicates that this exemption will likely only apply in a limited number of urbanized coastal areas.

Percent imperviousness will be calculated based on an area-weighted average of impervious areas associated with commercial, industrial, single-family residential, multi-family residential, open space, and other miscellaneous areas (schools, churches, etc.) representative for the watershed. Representative percent imperviousness values for each land use type may correspond to values recommended in Table 3-1 of the County of San Diego's Hydrology Manual and detailed below or by more specific representative percent impervious calculations (using GIS, etc.), which are often required to represent impervious area percentages for park, school and church sites.

- Figure 6-1, Nodes 10 through 13 – For urban infill projects discharging runoff to an existing hardened or rehabilitated conveyance system, potential limited exemptions from hydromodification criteria may apply where the existing impervious area percentage in the watershed exceeds 40 percent. For the potential exemption application, the domain of analysis must be determined and the existing hardened or rehabilitated conveyance system must extend beyond the downstream terminus of the domain of analysis. The hardened or rehabilitated conveyance system must discharge to a receiving channel with a Low potential for channel susceptibility for this exemption to be granted (channel susceptibility determined using SCCWRP tool). Finally, continuous simulation sensitivity analysis shows that an exemption could only be granted if the potential future development impacts in the watershed would increase the watershed's impervious area percentage by less than 3 percent (as compared to the existing condition in the year 2010). If the potential future cumulative impacts in the watershed could increase the impervious area percentage by more than 3 percent (as compared to existing condition), then no exemption could be granted based on this item. Watershed impervious area calculations for this potential exemption, in which a project discharges to a watershed with an existing impervious areas greater than 40 percent, will be measured upstream from the outfall of the urban conveyance system (to a non-concrete, non-riprap-lined or non-engineered channel) to the contributing watershed boundary (the entire watershed contributing to the discharge outfall).

  Percent imperviousness will be calculated based on an area-weighted average of impervious areas associated with commercial, industrial, single-family residential, multi-family residential, open space, and other miscellaneous areas (schools, churches, etc.) representative for the watershed. Representative percent imperviousness values for each land use type may correspond to values recommended in Table 3-1 of the County of San Diego's Hydrology Manual and detailed below or by more specific representative percent impervious calculations (using GIS, etc.), which are often required to represent impervious area percentages for park, school and church sites.

Exemptions related to runoff discharging directly to certain river reaches were initially based upon the majority TAC opinion that such river reaches were depositional (aggrading) and that the effects of cumulative watershed impacts to these reaches is minimal. Subsequent justifications for the river reach exemptions were the result of a flow duration curve analysis for the San Diego River.

Potential river reaches that would be exempt from hydromodification criteria include only those reaches for which the contributing drainage area exceeds 100 square miles and which have a 100-year design flow in excess of 20,000 cfs. For reference, proposed Caltrans HMP criteria allows for river/creek exemptions for drainage areas of only 10 square miles.

Per recommendations from members of the TAC, San Diego river systems meeting the drainage area and peak flow criteria are typically aggrading (depositional) and have very wide floodplain areas when in the natural condition. In all cases, river reaches meeting the drainage area and peak flow criteria are located downstream of large reservoir systems which effectively block outflows for most storm events. In addition, the river systems meeting these criteria typically have very low gradients. The combination of low gradients, significant peak flow attenuation, and wide floodplain areas translate to a low potential for channel erosion at the upper limit of the proposed geomorphic flow range (10-year flow event).

The intent of the San Diego River flow duration analysis was to determine the level of cumulative watershed impacts that would result in a significant alteration to the San Diego River's flow duration curve. Both the Fashion Valley and Mast Boulevard USGS stream gauge stations were used to develop long-term flow duration curves for the San Diego River. Data from this analysis will be used to determine exemption criteria for similar-sized river systems in San Diego County, since detailed long-term hourly streamflow data is not available for most of those rivers. Since the findings of the sensitivity analysis are planned to be extrapolated to other large river systems, implementation of additional gauging stations along other major river systems is recommended to analyze the differences in watershed response between the major watershed systems.

Assumptions related to the San Diego River sensitivity analysis are provided below:

- The flow duration charts show the San Diego River flow durations, plus simulated river flows durations for additional development scenarios.
- HSPF models were built to simulate converting existing undeveloped areas in the watershed into development with no stormwater flow controls.
- Increasing drainage area increments were modeled.
- To produce the 'simulated development' flow duration curves, the difference between developed and undeveloped flow duration curves was calculated for proposed hypothetical development .sites of varying sizes Then, the "difference hydrograph" was added to the San Diego River flow duration curve. This approach was used to avoid the potential problem of double-counting areas.

Tasks Related to Development of Flow Duration Analysis of San Diego River:

- Acquired 15-minute stream flow data from USGS (available from 1988 to present)
- Aggregated to 1-hour historical record
- Computed flow duration statistics for both records and determined if there is any substantial difference between the records (this is a QA step that allowed for removal any high flow 'outliers' in the record that could affect the results).
- Prepared a simple, characteristic HSPF model for the lower watershed for "existing conditions in an undeveloped area" – assumed Group D soils with sparse vegetation.
- Prepared a simple, parallel HSPF model for "developed conditions"

- Ran both models and examined the difference between the resulting hydrographs (the hydromodification). A couple of different pre- and post-development models were generated to analyze the differences on a per unit area basis.
- Using the "difference hydrograph" created from the model simulations, progressively added development and recomputed the flow duration statistics.
- Examined the modified flow duration statistics and determined at what level of increased development the statistics became noticeably altered.

Results showed that increasing levels of development, in excess of 1,000 acres assumed to occur at the same location as the stream gauge station, would produce a very minor influence on the river's flow duration curve. These results demonstrated that certain portions of the San Diego River could be exempt from hydromodification requirements. Such HMP exemptions would only be granted for projects discharging runoff directly to the exempt river reach. Each municipality must define "direct discharge" based on the project site conditions. To qualify for the potential exemption, the outlet elevation must be between the river bottom elevation and the 100-year floodplain elevation and properly designed energy dissipation must be provided The supporting HSPF continuous modeling analysis results are summarized in a Technical Memo in Appendix F.

All exempt river reaches, which are presented in Table 6-1, have drainage areas in excess of 100 square miles and 100-year flow rates in excess of 20,000 cfs. In addition, all proposed river reaches are subject to significant upstream reservoir flow regulation, have wide floodplain or stabilized channel areas, and low gradients. This combination of factors, in association with field observations and years of historical perspective from the TAC members, justifies exemptions for direct discharges to the exempt river reaches provided that properly sized energy dissipation is provided at the outfall location.

Table 6-1. Summary of Exempt River Reaches in San Diego County

River	Downstream Limit	Upstream Limit
Otay River	Outfall to San Diego Bay	Lower Otay Reservoir Dam
San Diego River	Outfall to Pacific Ocean	Confluence with San Vicente Creek
San Dieguito River	Outfall to Pacific Ocean	Lake Hodges Dam
San Luis Rey River	Outfall to Pacific Ocean	Upstream river limit of Basin Plan subwatershed 903.1 upstream of Bonsall and near Interstate 15
Sweetwater River	Outfall to San Diego Bay	Sweetwater Reservoir Dam

Table 6-2 provides a summary of exempt reservoirs in San Diego County. Large reservoirs can be exempt systems from a hydromodification standpoint since reservoir storm water inflow velocities are naturally mitigated by the significant tailwater condition in the reservoir. HMP exemptions would only be granted for projects discharging runoff directly to the exempt reservoirs. Each municipality must define "direct discharge" based on the project site conditions. To qualify for the potential exemption, the outlet elevation of the conveyance system must be within (or below) the normal operating water surface elevations of the reservoir and properly designed energy dissipation must be provided.

Table 6-2. Summary of Exempt Reservoirs in San Diego County	
Reservoir	**Watershed**
Barrett Lake	Tijuana River
El Capitain Reservoir	San Diego River
Lake Dixon	Escondido Creek
Lake Heneshaw	San Luis Rey River
Lake Hodges	San Dieguito River
Lake Jennings	San Diego River
Lake Murray	San Diego River
Lake Poway	San Dieguito River
Lake San Marcos	San Marcos Creek
Lake Wohlford	Escondido Creek
Loveland Reservoir	Sweetwater River
Lower Otay Reservoir	Otay River
Miramar Lake	Los Penasquitos Creek
San Vicente Reservoir	San Diego River
Sweetwater Reservoir	Sweetwater River
Upper Otay Reservoir	Otay River

The final exemption category focuses on small urban infill projects where the potential for future cumulative watershed impacts is minimal. Continuous simulation models have been prepared for subwatershed areas containing between 40 and 70 percent existing imperviousness (as measured from the project site downstream to existing storm drain outfall) with the following assumptions.

Sensitivity Analysis for Urban Watersheds:

- Prepared HSPF models for 10-, 100-, and 500-acre watersheds with 40, 50, 60 percent imperviousness. Ran simulations and computed flow duration statistics for each of the urban watershed scenarios.
- Progressively increased the level of imperviousness to simulate infill development for the 10-, 100-, 500-acre watersheds.
- Ran infill scenario simulations and computed flow duration statistics
- Examined the infill flow duration statistics and determined at what level of increased development the statistics became noticeably altered.

Per results of the continuous simulation modeling and analysis of the resultant flow duration curves, urban infill projects have a relatively minor effect on the overall watershed's flow duration curve if the future cumulative additional impacts have the potential to increase the existing watershed impervious area by less than 3 percent. Potential urban infill project exemptions are only considered if the existing impervious area percentage of the sub-watersheds is at least 40 percent. For sub-watersheds containing less than 40 percent existing impervious area, continuous simulation models indicated a more pronounced response to the flow duration curve with small urban infill developments.

CHAPTER 8

8.3. Reference Regarding Sediment Transport Capacity

Sediment Transport Capacity of Overland Flow

P. Y. Julien, D. B. Simons

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Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

ABSTRACT

OVERLAND flow runoff can be either laminar or turbulent depending on the Reynolds number. The rate of soil erosion may be limited by the sediment transport capacity which depends on the type of flow. Sediment transport equations based on velocity were found to give different results than those based on shear stress. Most of the sediment transport equations developed for turbulent streams should not be applied to soil erosion by overland flow. A general relationship supported by dimensional analysis was derived. The recommended sediment transport capacity relationship can be written as a power function of slope and discharge and the range of exponents was defined from empirical relationships.

INTRODUCTION

Soil erosion by rainfall is one of the major hazards threatening the productivity of farmlands. The physical processes governing the movement of sediments by rainfall are very complex. The rate of soil erosion depends mainly on the detachment of soil particles and on the transporting capacity of overland runoff. Several sediment transport equations and soil loss relationships have been developed both from experimental studies in laboratories under simulated rainfall (Kilinc, 1972) and from statistical and regression analysis using field data (Wischmeier and Smith, 1978). Recently, some researchers have recommended the use of well-known bed-load equations to predict soil erosion losses from overland flow. For example, Komura (1976) used the Kalinske-Brown relationship and obtained fair agreement with observed data though his data set was relatively limited. The Meyer-Peter and Muller equation has also been suggested by Li (1979) for overland flow. Several sediment transport equations have been examined by Alonso, Neibling and Foster (1981) to determine how well they fit observed data on concave slopes.

Fundamental relationships for sediment transport in turbulent stream flows have been used as a basis for the analysis of sediment transport capacity by overland flow. However, since sheet flows are generally classified as laminar a theoretical analysis is required in order to determine if a sediment transport formula derived for turbulent streamflow is also applicable to laminar sheet flow.

Article was submitted for publication in July, 1984; reviewed and approved for publication by the Soil and Water Div. of ASAE in December, 1984.

The contribution of the first author was supported by the Natural Sciences and Engineering Research Council of Canada.

The authors are: P. Y. JULIEN, Fac. Affiliate, Dept. of Civil Engineering, and D. B. SIMONS, Professor, Dept. of Civil Engineering, Colorado State University, Fort Collins.

Therefore, the purpose of this study was to investigate the applicability of several sediment transport equations under various hydraulic conditions, including laminar sheet flow. In the first part of this paper, the hydraulic characteristics relevant to sediment transport are summarized to clearly point out the differences between turbulent and laminar flows. Then several sediment transport formulas valid for turbulent streamflow are examined under laminar sheet flow conditions. These transformed relationships are compared with regression equations obtained from experimental studies of soil erosion.

OVERLAND FLOW CHARACTERISTICS

In natural fields, overland flow occurs when the rainfall intensity is in excess of the infiltration rate of the soil. A very thin film of water covers the soil surface and it is referred to as the laminar sheet flow. As the runoff rate increases downslope, the flow converges into micro-scale channels called rills which gradually develop until they form large-scale channels called gullies. In a recent study, Thorne (1984) also defined ephemeral gullies in arable fields. These gullies are formed by the concentraiton of surface runoff and are obliterated each year by normal tillage.

Gully, rill and sheet runoff have different hydraulic properties depending on the relative magnitude of inertia and viscous forces. The ratio of these two types of forces defines the Reynolds number Re. When the inertia forces largely overcome the viscous forces, such as flows in rivers and gullies, the Reynolds number is large and the flow is turbulent. In the case of thin overland runoff, the viscous forces overcome the inertia forces and the flow is called laminar. In sheet flows, perturbations induced by raindrop impact and surface roughness are greatly attenuated due to the large magnitude of viscous forces at low Reynolds numbers. These forces damp out the velocity fluctuations caused by these disturbances and sheet flows over rough boundaries remain laminar until a critical value of the Reynolds number is exceeded.

Another major difference between stream flow and sheet flow is related to the flow depth. For a given particle size, the transport of sediments by saltation and suspension in overland flow is very limited due to the reduced flow depth. The bed load movement, however, may predominate and the most accurate sediment transport rates might be given by bed-load equations, the validity of this statement being precisely the purpose of this investigation.

The principal variables describing overland flow are shown in Fig. 1. The main geometric variables are slope length L and gradient S. The hydraulic variables are rainfall intensity i, flow depth h, mean velocity $\bar{u}$, unit water discharge q and thickness of the laminar sublayer δ'. The parameter generally associated with the sediment discharge q_s is bed shear stress τ_o; the other properties

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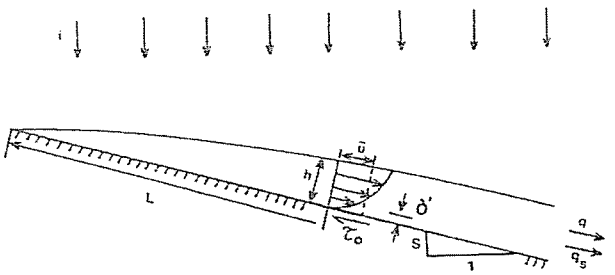

Fig. 1—Overland flow variables.

being gravitational acceleration g, kinematic viscosity ν and specific mass of water ρ.

Fundamental Equations

Two nonlinear partial differential equations derived by de Saint-Venant are generally used to solve the problem of gradually varied unsteady flows. These are the continuity relationship describing the conservation of mass and the momentum equation which is a force equilibrium relationship. In the case of steady overland flow, the continuity equation reduces to:

$$q = \bar{u}\, h \quad \ldots\ldots [1]$$

Considering the principal terms of the momentum equation, the kinematic wave approximation has been recommended by Wooding (1965) and Woolhiser (1975). This approximation states that the slope of the energy line is equal to the soil surface slope, or:

$$S = S_f \quad \ldots\ldots [2]$$

in which S_f is the slope of the energy line or friction slope.

The slope of the energy line can be defined by the Darcy-Weisbach relationship:

$$S_f = \frac{f}{8}\frac{\bar{u}^2}{gh} \quad \ldots\ldots [3]$$

where f is the Darcy-Weisbach friction factor.

The friction factor f is a function of the Reynolds number and the relative roughness for turbulent flows. The Reynolds number is defined as:

$$Re = \frac{\bar{u}\, h}{\nu} \quad \ldots\ldots [4]$$

As the Reynolds number increases, the flow becomes turbulent and the friction factor is then a function of the roughness of the surface. The roughness of the boundary depends on the sediment size d_s and the thickness of the laminar sublayer δ'. Two important variables are associated with the thickness of the boundary sublayer δ'. These are bed shear stress τ_o and shear velocity U_*. These variables are defined as:

$$\tau_o = \rho g h S_f \quad \ldots\ldots [5]$$

$$U_* = \sqrt{\frac{\tau_o}{\rho}} \quad \ldots\ldots [6]$$

$$\delta' = \frac{11.6\,\nu}{U_*} \quad \ldots\ldots [7]$$

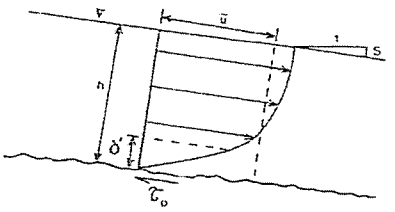

Fig. 2—Turbulent flow over a smooth surface.

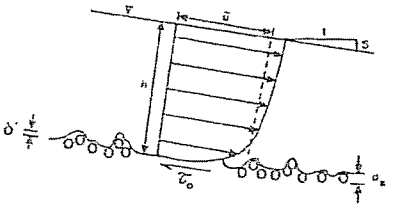

Fig. 3—Turbulent flow over a rough surface.

The ratio of sediment size d_s to the thickness of the laminar sublayer δ' delineates two types of turbulent flow conditions shown in Figs. 2 and 3 for smooth and rough boundaries respectively.

From combining equations [5], [6], and [7], the ratio δ'/d_s is:

$$\frac{\delta'}{d_s} = \frac{11.6\,\nu}{d_s\sqrt{ghS_f}} \quad \ldots\ldots [8]$$

This parameter and the Reynolds number are used to define the type of overland flow.

Overland Flow Types

The four principal types of flow relevant to this investigation on soil erosion by overland flow are: (a) laminar sheet flow; (b) turbulent smooth flow governed by the Blasius equation; (c) turbulent rough flow (Manning equation); and (d) turbulent rough flow with very small relative roughness (Chezy equation). This last flow type is not very likely to occur in overland flow. However, it has been included in this analysis since it represents a limiting case for which the Darcy-Weisbach friction factor remains constant. For steady flow conditions, the principal variables related to soil erosion ($\bar{u}$, h and τ_o) are defined as a function of slope and water discharge.

Laminar Flow

In laminar flows with raindrop impact the Darcy-Weisbach friction factor f is related to: (a) the Reynolds number Re, (b) the surface friction coefficient k_o without raindrop impact, and (c) two empirical coefficients A and b for raindrop impact. The following relationship is generally used:

$$f = \frac{K}{Re} = \frac{k_o + Ai^b}{Re} \quad \ldots\ldots [9]$$

The values of k_o have been tabulated by Woolhiser (1975) for various surface types and the value $k_o = 24$ is representative of the smooth surface condition. Experimental coefficients A and b have been obtained by Izzard (1944), Li (1972), and Fawkes (1972), and these