APPENDIX B
HYDROLOGY

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1.0 INTRODUCTION

This appendix outlines the hydrologic analysis and evaluation of diversion channels associated with the general configuration of the Primary and Secondary Impoundments. This evaluation has been prepared as an update to the 2005 Decommissioning and Reclamation Plan, associated with revision of the diversion channel alignment (Figure B.1).

2.0 PROBABLE MAXIMUM PRECIPIATION (PMP)

As outlined in NRC (1990) and Johnson (1999), the design event for evaluation of long-term erosional stability of the reclaimed tailings impoundments is the PMP. The PMP events selected by MFG (2005) for calculation of peak runoff were the 6-hour duration PMP (totaling 22.5 inches) and the 1-hour duration PMP (totaling 11.25 inches). The PMP events were determined for the project site using HMR 55A (NOAA, 1988). The PMP storm depths have not changed since the MFG analysis, as the calculation method and references for this area has not changed since 1988.

The SCS Type II precipitation distribution is selected for rainfall-runoff analysis as per MFG (2005). The SCS precipitation distributions were developed by the Natural Resources Conservation Service and are used to estimate peak runoff based on geographic region. The SCS Type II distribution is recommended for the state of Colorado. These selected storm events are the same design events used in the analyses in WWL (1990), ESCI (1995), and MFG (2005).

3.0 CALCULATION OF PEAK DISCHARGE

The peak runoff calculations were performed using the HEC-HMS program (U.S. Army Corps of Engineers, 2010), using basin parameters and antecedent soil moisture conditions consistent with an extreme storm event. A curve number of 83 and an initial abstraction as a function of the curve number were used to represent basin runoff characteristics with low infiltration. A time step of 5 minutes was used in HEC-HMS. These characteristics represent higher runoff quantities and peak flow velocities. The drainage basin delineation is shown in Figure B.1, and is similar to the delineation used in WWL (1990) and MFG (2005).

The drainage basins shown in Figure B.1 would discharge into primary and secondary diversion channels along the edge of the Primary and Secondary Impoundments. The channel configuration presented in the MFG (2005) report effectively splits flows between the primary and secondary diversion channels. The current proposed configuration provides a substantially larger primary diversion channel as the majority of the drainage basin discharge will travel along the inside edge of the Impoundments and only a small portion of the flow will be directed north of the Impoundment. To estimate the peak drainage basin discharge, the 6-hour PMP and 1-hour PMP were used in the HEC-HMS simulations as per MFG (2005). The 6-hour PMP event produced the highest peak discharge of the two duration events and will therefore be used to evaluate the erosional stability and size of the diversion channels.

The peak runoff values for the major drainage basins contributing to the diversion channels resulting from the 6-hour PMP event, are shown on Figure B.2 and are presented in Table B.1.

Table B.1 Drainage Basin Characteristics and Peak Discharges

Drainage Basin	Drainage Area (acres)	Runoff Curve Number	Peak Discharge (cfs)	Time to Peak Discharge (minutes)
S1	18.2	83	895	170
S2	23.0	83	1,151	170
S3	76.0	83	907	220
S4	91.4	83	1,670	195
S5	76.3	83	1,981	180
S6	134.4	83	2,839	190
S7	33.5	83	1,196	175
S8	52.0	83	1,373	180
S9	31.1	83	1,267	170
S10	14.1	83	542	175

The peak runoff values to be used for the diversion channel sizing, resulting from the 6-hour PMP event, are shown on Figure B.2 and are presented in Table B.2. Due to the relatively short length of our proposed channels, routing was not considered in our analysis.

Table B.2 Peak Drainage Basin Discharges

Channel	Peak Discharge (cfs)	Time of Peak Discharge (minutes)
Primary Diversion Channel	9,299	180
Secondary Diversion Channel	895	170

A sensitivity analysis was performed to determine the impact on peak runoff values by 1) modifying the storm distribution to a frequency storm, and 2) increasing the time step to 15 minutes. By using the frequency storm method the peak flows obtained for the primary and secondary diversion channels are 7,510 cfs and 535 cfs, respectively. For a time step of 15 minutes, the peak flows obtained for the primary and secondary diversion channels are 8,379 cfs and 483 cfs, respectively. Therefore the design flows obtained using a time step of 5 minutes (see Table B.2) are conservative as it is expected that the peak runoff should last for less than 15 minutes and then flows should start to attenuate.

4.0 DIVERSION CHANNEL SIZING

The channel depth and erosion protection for the diversion channels will be conservatively based on the peak discharge values from the 6-hour PMP storm presented in Table B.2. The diversion channels with have a minimum bottom width of 40 feet, an inside side slope of 5H:1V (horizontal : vertical), and an outside side slope of 3H:1V. Normal flow depths and velocities will be calculated using Manning's equation. An example calculation method for calculating the Mannings "n" value is the following equation from Hahn et al (1994):

$$n = 0.0395D_{50}^{1/6}$$

For example, a riprap D_{50} of 12" would results in a Manning's n of 0.395 and a riprap D_{50} of 24" would results in a Manning's n of 0.443. The riprap size will be determined using an appropriate calculation method such as the CSU Safety Factor Method as described by Hahn et al (1994). Normal depth and riprap sizing calculations will be provided in Attachment C.2.

Table B.3 Results of Diversion Channel Sizing Calculations

Diversion Channel	Design Discharge (cfs)	Bed Slope (ft/ft)	Maximum Flow Depth (ft)	Velocity (fps)	D50 (ft)	Safety Factor
Primary	9,341	TBD	TBD	TBD	TBD	TBD
Secondary	897	TBD	TBD	TBD	TBD	TBD

Notes: TBD= To Be Determined

Optimization of the channel cross section and riprap sizing will be provided in a future submittal.

5.0 REFERENCES

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Hahn, C.T., Barfield, B.J., Hayes, J.C., 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press Inc., San Diego, CA.

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MFG, Inc., 2005, Cotter Corporation, Appendix C – Erosion Stability Evaluation, August.

U.S. Nuclear Regulatory Commission (NRC), 1990. "Final Staff Technical Position, Design of Erosion Protective Covers for Stabilization of Uranium Mill Tailings Sites." August.

U.S. Army Corps of Engineers, 2010. HEC-HMS Hydrologic Modeling System (Version 3.5), August.

Water, Waste and Land, Inc. (WWL), 1990. "Canon City Tailings Basin Reclamation Plan," prepared for Cotter Corporation, January.

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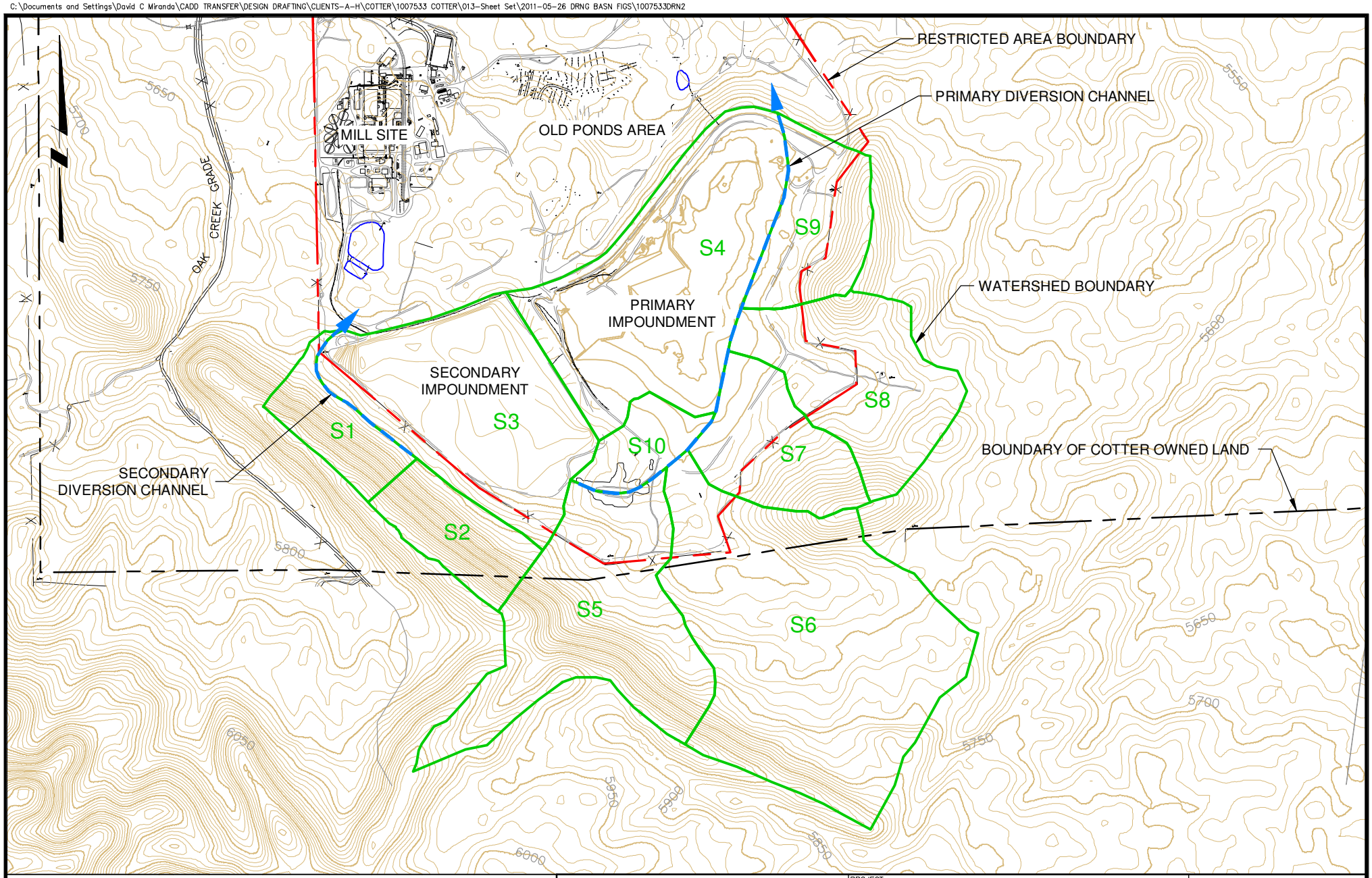

REFERENCE:
- EXISTING GROUND CONTOURS FROM USGS (SEAMLESS.USGS.GOV).
- SITE TOPOGRAPHY FROM COTTER CORPORATION (2007).

SCALE
1200 0 1200 FT

COTTER CORPORATION (N.S.L.)

PROJECT
CANON CITY MILLING FACILITY

TITLE
DRAINAGE BASIN LAYOUT MAP

MWH

DATE MAY 2011

FIGURE B.1

FILE NAME 1007533DRN2

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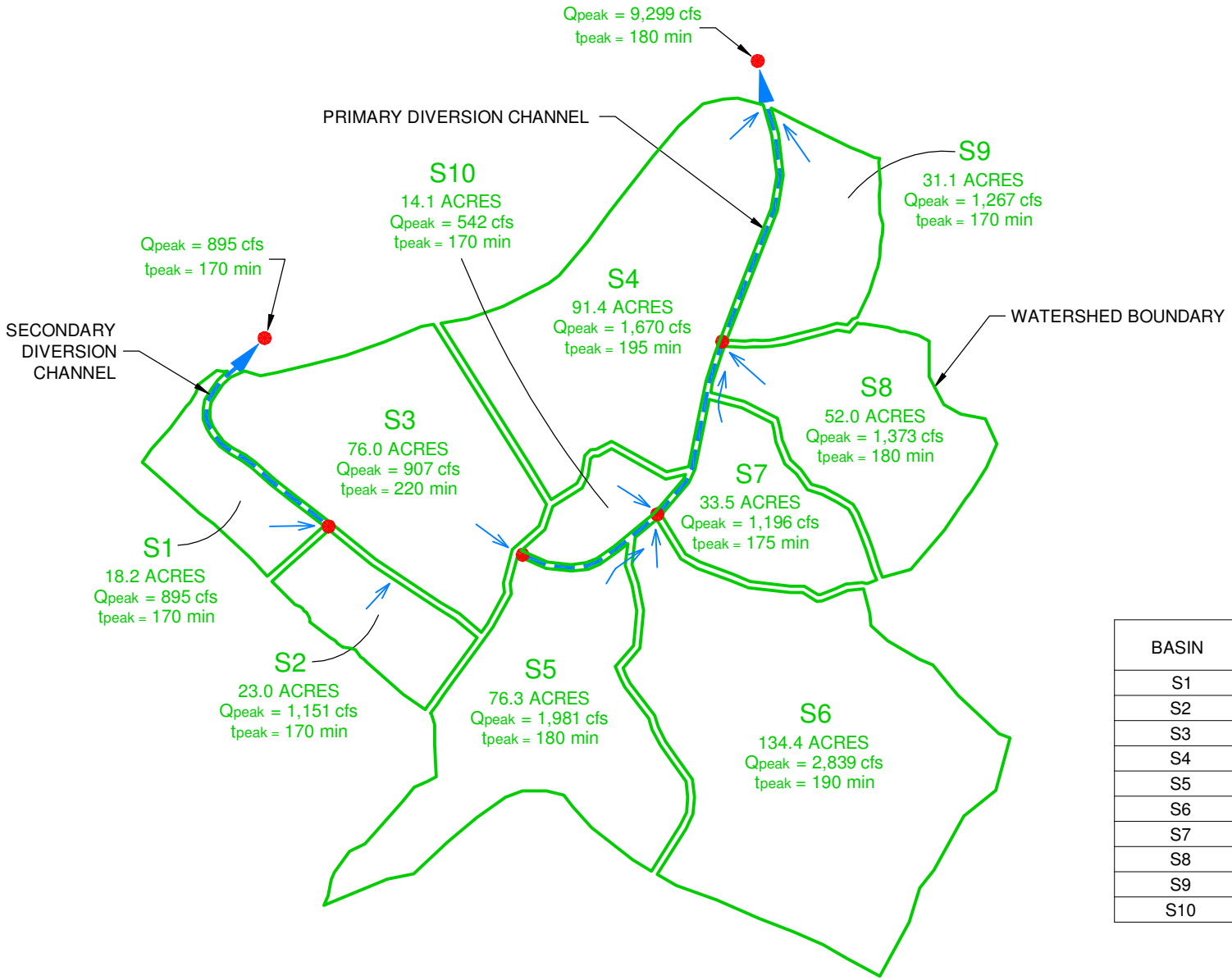


BASIN	AREA	
	SQUARE MILES	ACRES
S1	0.028	18.2
S2	0.036	23.0
S3	0.119	76.0
S4	0.143	91.4
S5	0.119	76.3
S6	0.210	134.4
S7	0.052	33.5
S8	0.081	52.0
S9	.0049	31.1
S10	0.022	14.1

COTTER CORPORATION (N.S.L.)

PROJECT
CANON CITY MILLING FACILITY

TITLE
DRAINAGE BASIN PMP MODEL SCHEMATIC

MWH

DATE MAY 2011

FIGURE B.2

FILE NAME 1007533DRN1

ATTACHMENT B.1

HEC-HMS Calculation Output

Cotter – Canyon City Milling Facility
HEC-HMS Model Input Parameters

Model Assumptions:
* Design storms: 6-hour PMP
* Curve Number: 83
* Initial Abstraction = f(CN)

Site:	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Area (ft2)	792,366	1,001,773	3,311,721	3,982,979	3,324,890	5,855,500	1,461,167	2,266,111	1,355,655	613,567
Area (mi2)	0.028	0.036	0.119	0.143	0.119	0.210	0.052	0.081	0.049	0.022
Area (acres)	18.2	23.0	76.0	91.4	76.3	134.4	33.5	52.0	31.1	14.1
Length (ft)	538	661	2365	2120	3605	4039	1765	2178	1005	828
Max Elev (ft)	5,950	5,995	5,662	5,613	6,070	5,870	5,850	5,710	5,790	5,660
Min Elev (ft)	5,695	5,700	5,650	5,581	5,610	5,595	5,582	5,580	5,590	5,600
Slope (%)	47.40	44.63	0.51	1.51	12.76	6.81	15.18	5.97	19.90	7.25
CN	83.00	83.00	83.00	83.00	83.00	83.00	83.00	83.00	83.00	83.00
S (CN)	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05
Lag Time (hrs)	0.03	0.03	0.81	0.43	0.23	0.34	0.12	0.22	0.06	0.09
Lag Time (minutes)	1.53	1.86	48.37	25.70	13.52	20.26	7.00	13.20	3.90	5.53
Tc (hrs)	0.04	0.05	1.34	0.71	0.38	0.56	0.19	0.37	0.11	0.15
Time Step (min)	0.46	0.56	14.51	7.71	4.05	6.08	2.10	3.96	1.17	1.66

dT = 5 min selected for modeling

SCS Type II Rainfall Distribution
6-hour PMP = 22.5 inches

Time	Distribution	Cum. Precip. (inches)	Time	Distribution	Cum. Precip. (inches)	Time	Distribution	Cum. Precip. (inches)	Time	Distribut ion	Cum. Precip. (inches)
0:00	0	0	1:51	0.1102	2.4795	3:42	0.8554	19.2465	5:33	0.9804	22.059
0:03	0.0024	0.054	1:54	0.1158	2.6055	3:45	0.861	19.3725	5:36	0.9828	22.113
0:06	0.0042	0.0945	1:57	0.1214	2.7315	3:48	0.8658	19.4805	5:39	0.9852	22.167
0:09	0.0062	0.1395	2:00	0.127	2.8575	3:51	0.8706	19.5885	5:42	0.9874	22.2165
0:12	0.0086	0.1935	2:03	0.1326	2.9835	3:54	0.875	19.6875	5:45	0.989	22.2525
0:15	0.011	0.2475	2:06	0.1388	3.123	3:57	0.879	19.7775	5:48	0.9914	22.3065
0:18	0.0126	0.2835	2:09	0.1452	3.267	4:00	0.883	19.8675	5:51	0.9938	22.3605
0:21	0.0148	0.333	2:12	0.1516	3.411	4:03	0.887	19.9575	5:54	0.9958	22.4055
0:24	0.0172	0.387	2:15	0.158	3.555	4:06	0.891	20.0475	5:57	0.9976	22.446
0:27	0.0198	0.4455	2:18	0.1652	3.717	4:09	0.895	20.1375	6:00	1	22.5
0:30	0.023	0.5175	2:21	0.173	3.8925	4:12	0.899	20.2275			
0:33	0.0254	0.5715	2:24	0.1822	4.0995	4:15	0.903	20.3175			
0:36	0.0278	0.6255	2:27	0.1928	4.338	4:18	0.907	20.4075			
0:39	0.0302	0.6795	2:30	0.204	4.59	4:21	0.9104	20.484			
0:42	0.0326	0.7335	2:33	0.2192	4.932	4:24	0.914	20.565			
0:45	0.0353	0.79425	2:36	0.2374	5.3415	4:27	0.9178	20.6505			
0:48	0.0374	0.8415	2:39	0.2622	5.8995	4:30	0.921	20.7225			
0:51	0.0404	0.909	2:42	0.2998	6.7455	4:33	0.925	20.8125			
0:54	0.0432	0.972	2:45	0.359	8.0775	4:36	0.9284	20.889			
0:57	0.0458	1.0305	2:48	0.5174	11.6415	4:39	0.9316	20.961			
1:00	0.049	1.1025	2:51	0.623	14.0175	4:42	0.9348	21.033			
1:03	0.0514	1.1565	2:54	0.6802	15.3045	4:45	0.938	21.105			
1:06	0.0544	1.224	2:57	0.705	15.8625	4:48	0.9412	21.177			
1:09	0.0572	1.287	3:00	0.725	16.3125	4:51	0.9438	21.2355			
1:12	0.0598	1.3455	3:03	0.745	16.7625	4:54	0.9466	21.2985			
1:15	0.063	1.4175	3:06	0.7608	17.118	4:57	0.9496	21.366			
1:18	0.0662	1.4895	3:09	0.7736	17.406	5:00	0.952	21.42			
1:21	0.0694	1.5615	3:12	0.7848	17.658	5:03	0.9552	21.492			
1:24	0.0726	1.6335	3:15	0.796	17.91	5:06	0.9578	21.5505			
1:27	0.076	1.71	3:18	0.8032	18.072	5:09	0.9606	21.6135			
1:30	0.08	1.8	3:21	0.8104	18.234	5:12	0.9636	21.681			
1:33	0.084	1.89	3:24	0.8174	18.3915	5:15	0.966	21.735			
1:36	0.088	1.98	3:27	0.8246	18.5535	5:18	0.9684	21.789			
1:39	0.092	2.07	3:30	0.831	18.6975	5:21	0.9708	21.843			
1:42	0.096	2.16	3:33	0.8374	18.8415	5:24	0.9732	21.897			
1:45	0.1	2.25	3:36	0.8438	18.9855	5:27	0.9756	21.951			
1:48	0.1048	2.358	3:39	0.8498	19.1205	5:30	0.978	22.005			

HEC-HMS Model

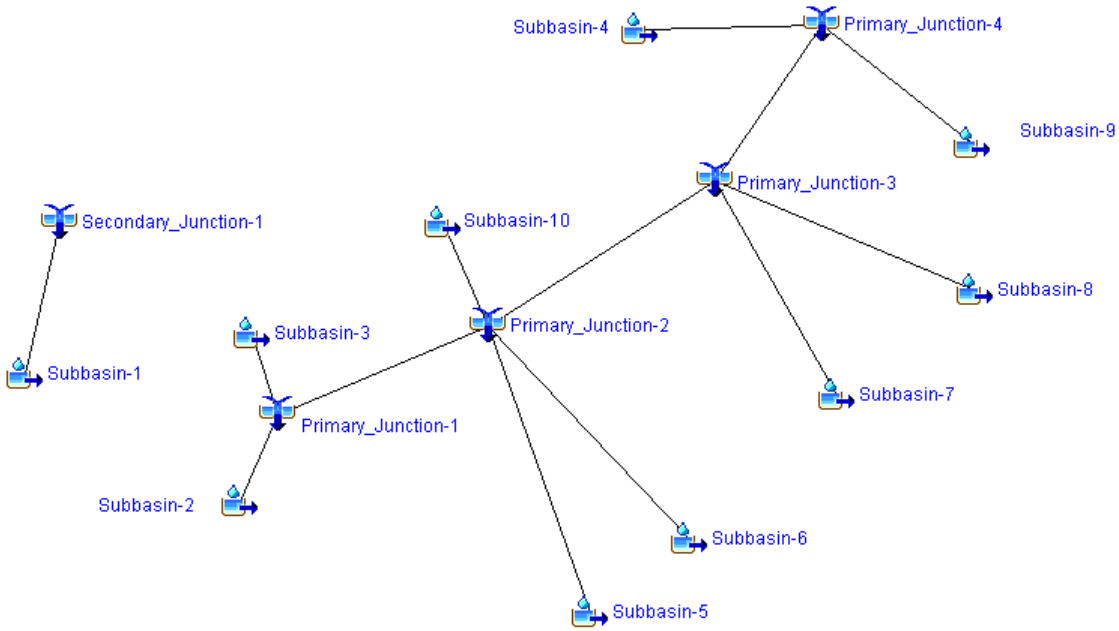


Figure 1. Sub-Basin Schematic

Subbasin Area [Basin 1]

Show Elements: All Elements

Subbasin	Area (MI2)
Subbasin-1	0.028
Subbasin-10	0.022
Subbasin-2	0.036
Subbasin-3	0.119
Subbasin-4	0.143
Subbasin-5	0.119
Subbasin-6	0.210
Subbasin-7	0.052
Subbasin-8	0.081
Subbasin-9	0.049

Figure 2. Sub-basin Areas

Curve Number Loss [Basin 1]

Show Elements: All Elements

Subbasin	Initial Abstraction (IN)	Curve Number	Impervious (%)
Subbasin-6		83	0.0
Subbasin-3		83	0.0
Subbasin-2		83	0.0
Subbasin-5		83	0.0
Subbasin-10		83	0.0
Subbasin-8		83	0.0
Subbasin-7		83	0.0
Subbasin-4		83	0.0
Subbasin-9		83	0.0
Subbasin-1		83	0.0

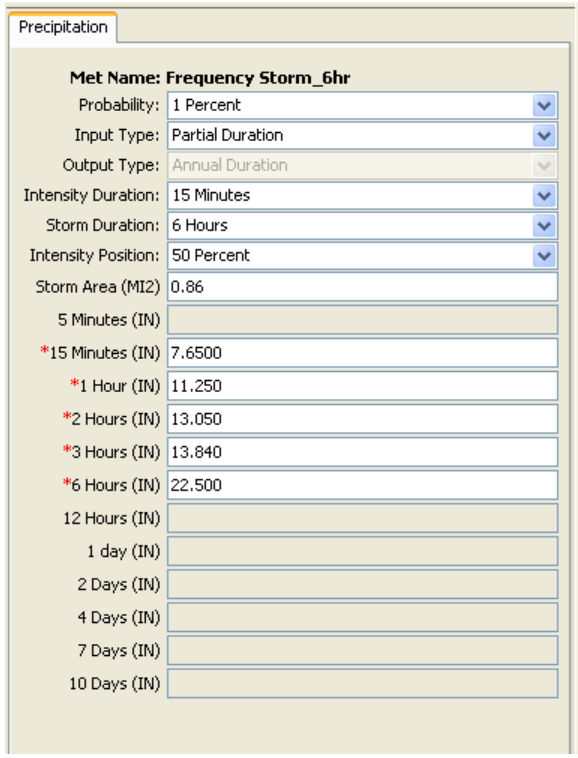
Figure 3. Curve Number Loss

SCS Transform[Basin 1]

Show Elements: All Elements

Subbasin	Lag Time (MIN)
Subbasin-1	1.53
Subbasin-10	5.53
Subbasin-2	1.86
Subbasin-3	48.37
Subbasin-4	25.70
Subbasin-5	13.52
Subbasin-6	20.26
Subbasin-7	7.00
Subbasin-8	13.2
Subbasin-9	3.9

Figure 4. SCS Lag Time

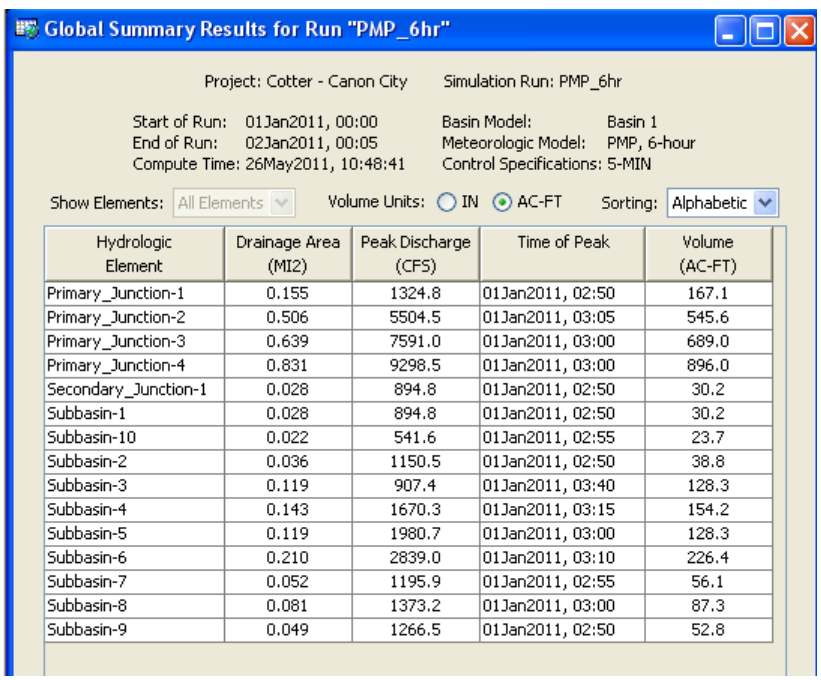


Precipitation

Met Name: Frequency Storm_6hr

Probability:	1 Percent
Input Type:	Partial Duration
Output Type:	Annual Duration
Intensity Duration:	15 Minutes
Storm Duration:	6 Hours
Intensity Position:	50 Percent
Storm Area (MI2)	0.86
5 Minutes (IN)	
*15 Minutes (IN)	7.6500
*1 Hour (IN)	11.250
*2 Hours (IN)	13.050
*3 Hours (IN)	13.840
*6 Hours (IN)	22.500
12 Hours (IN)	
1 day (IN)	
2 Days (IN)	
4 Days (IN)	
7 Days (IN)	
10 Days (IN)	

Figure 5. Frequency Storm Distribution



Global Summary Results for Run "PMP_6hr"

Project: Cotter - Canon City Simulation Run: PMP_6hr

Start of Run: 01Jan2011, 00:00 Basin Model: Basin 1
End of Run: 02Jan2011, 00:05 Meteorologic Model: PMP, 6-hour
Compute Time: 26May2011, 10:48:41 Control Specifications: 5-MIN

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Alphabetic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
Primary_Junction-1	0.155	1324.8	01Jan2011, 02:50	167.1
Primary_Junction-2	0.506	5504.5	01Jan2011, 03:05	545.6
Primary_Junction-3	0.639	7591.0	01Jan2011, 03:00	689.0
Primary_Junction-4	0.831	9298.5	01Jan2011, 03:00	896.0
Secondary_Junction-1	0.028	894.8	01Jan2011, 02:50	30.2
Subbasin-1	0.028	894.8	01Jan2011, 02:50	30.2
Subbasin-10	0.022	541.6	01Jan2011, 02:55	23.7
Subbasin-2	0.036	1150.5	01Jan2011, 02:50	38.8
Subbasin-3	0.119	907.4	01Jan2011, 03:40	128.3
Subbasin-4	0.143	1670.3	01Jan2011, 03:15	154.2
Subbasin-5	0.119	1980.7	01Jan2011, 03:00	128.3
Subbasin-6	0.210	2839.0	01Jan2011, 03:10	226.4
Subbasin-7	0.052	1195.9	01Jan2011, 02:55	56.1
Subbasin-8	0.081	1373.2	01Jan2011, 03:00	87.3
Subbasin-9	0.049	1266.5	01Jan2011, 02:50	52.8

Figure 6. HEC-HMS Output Summary – Design

Global Summary Results for Run "PMP_6hr_15min"

Project: Cotter - Canon City Simulation Run: PMP_6hr_15min

Start of Run: 01Jan2011, 00:00 Basin Model: Basin 1
End of Run: 02Jan2011, 00:15 Meteorologic Model: PMP, 6-hour
Compute Time: 26May2011, 10:48:48 Control Specifications: 15-MIN

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Alphabetic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
Primary_Junction-1	0.155	939.1	01Jan2011, 03:00	167.1
Primary_Junction-2	0.506	4742.1	01Jan2011, 03:15	545.6
Primary_Junction-3	0.639	6598.0	01Jan2011, 03:00	689.0
Primary_Junction-4	0.831	8378.6	01Jan2011, 03:00	896.0
Secondary_Junction-1	0.028	483.1	01Jan2011, 03:00	30.2
Subbasin-1	0.028	483.1	01Jan2011, 03:00	30.2
Subbasin-10	0.022	379.6	01Jan2011, 03:00	23.7
Subbasin-2	0.036	621.2	01Jan2011, 03:00	38.8
Subbasin-3	0.119	835.9	01Jan2011, 03:45	128.3
Subbasin-4	0.143	1472.8	01Jan2011, 03:15	154.2
Subbasin-5	0.119	1507.6	01Jan2011, 03:00	128.3
Subbasin-6	0.210	2400.2	01Jan2011, 03:15	226.4
Subbasin-7	0.052	897.2	01Jan2011, 03:00	56.1
Subbasin-8	0.081	1043.5	01Jan2011, 03:00	87.3
Subbasin-9	0.049	845.5	01Jan2011, 03:00	52.8

Figure 7. HEC-HMS Output Summary – Storm Balance Method

Global Summary Results for Run "PMP_6hr_15min"

Project: Cotter - Canon City Simulation Run: PMP_6hr_15min

Start of Run: 01Jan2011, 00:00 Basin Model: Basin 1
End of Run: 02Jan2011, 00:15 Meteorologic Model: PMP, 6-hour
Compute Time: 26May2011, 10:48:48 Control Specifications: 15-MIN

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Alphabetic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
Primary_Junction-1	0.155	939.1	01Jan2011, 03:00	167.1
Primary_Junction-2	0.506	4742.1	01Jan2011, 03:15	545.6
Primary_Junction-3	0.639	6598.0	01Jan2011, 03:00	689.0
Primary_Junction-4	0.831	8378.6	01Jan2011, 03:00	896.0
Secondary_Junction-1	0.028	483.1	01Jan2011, 03:00	30.2
Subbasin-1	0.028	483.1	01Jan2011, 03:00	30.2
Subbasin-10	0.022	379.6	01Jan2011, 03:00	23.7
Subbasin-2	0.036	621.2	01Jan2011, 03:00	38.8
Subbasin-3	0.119	835.9	01Jan2011, 03:45	128.3
Subbasin-4	0.143	1472.8	01Jan2011, 03:15	154.2
Subbasin-5	0.119	1507.6	01Jan2011, 03:00	128.3
Subbasin-6	0.210	2400.2	01Jan2011, 03:15	226.4
Subbasin-7	0.052	897.2	01Jan2011, 03:00	56.1
Subbasin-8	0.081	1043.5	01Jan2011, 03:00	87.3
Subbasin-9	0.049	845.5	01Jan2011, 03:00	52.8

Figure 8. HEC-HMS Output Summary – Time Step of 15 minutes

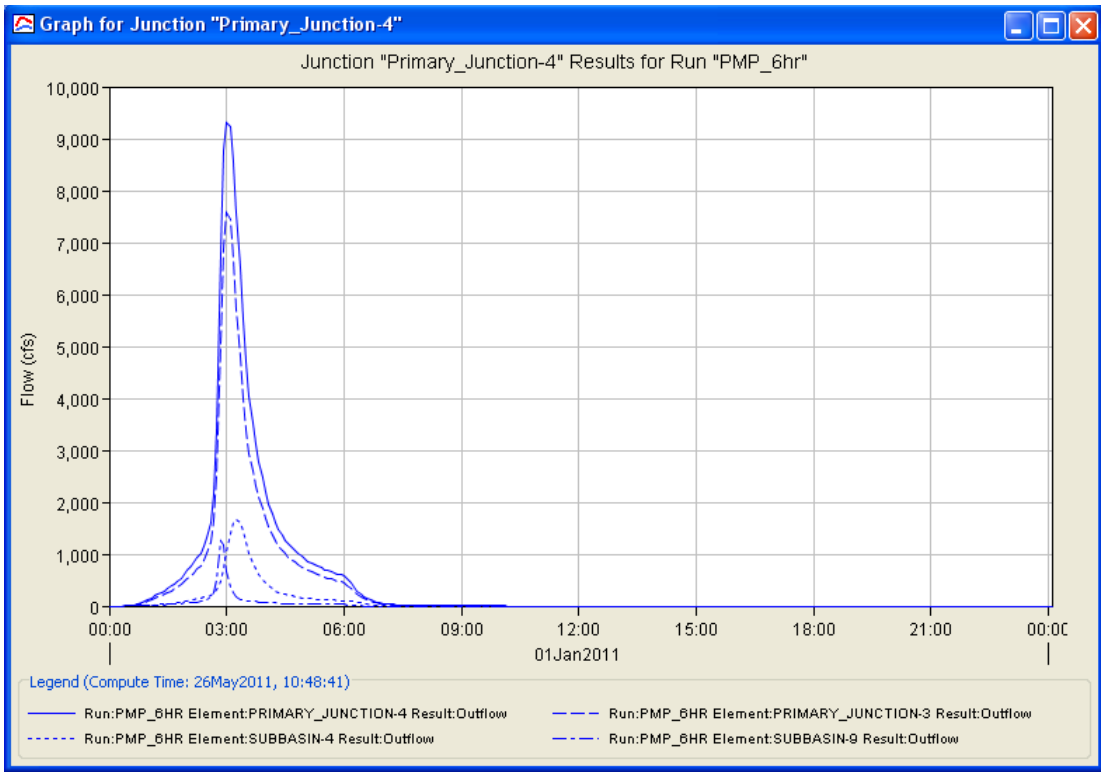


Figure 9. HEC-HMS Output Summary – Primary Diversion Channel Time Series - Design

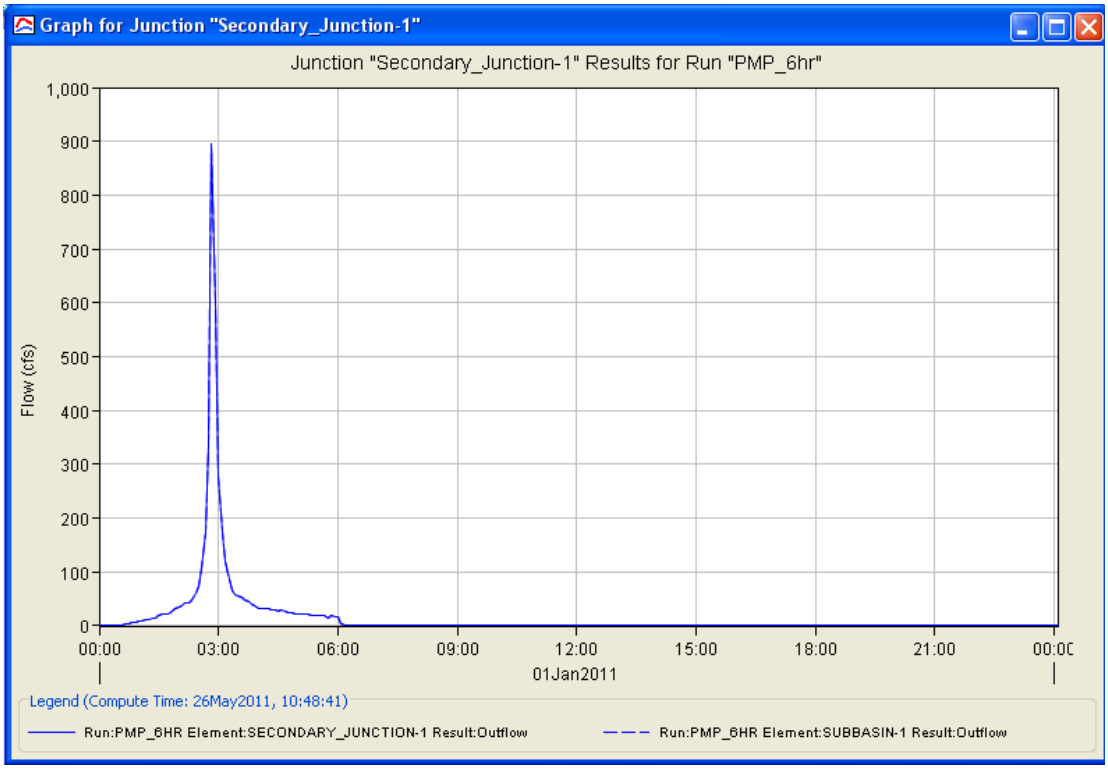


Figure 10. HEC-HMS Output Summary – Secondary Diversion Channel Time Series – Design

ATTACHMENT B.2

Diversion Channels - Hydrologic Calculation Summary

DIVERSION CHANNEL CALCULATIONS TBD