Run-On and Run-Off Control System Plan, Revision 1

Upstream Raise 91 CCR Surface Impoundment, Coal Creek Station

Submitted to:

Great River Energy

Coal Creek Station, 2875 Third Street SW, Underwood, North Dakota 58576

Submitted by:

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1.0 INTRODUCTION

Golder Associates Inc. (Golder) has prepared this run-on and run-off control system plan for the Upstream Raise 91 Coal Combustion Residual (CCR) Surface Impoundment (Upstream Raise 91) at Great River Energy's (GRE's) Coal Creek Station (CCS). The United States Environmental Protection Agency's (USEPA's) Coal Combustion Residual Rule, 40 Code of Federal Regulations (CFR) Part 257 (USEPA 2015), requires a run-on and run-off control system plan be completed as specified in 40 CFR 257.81(c)(3) for all existing CCR landfills. Although Upstream Raise 91 is a surface impoundment and not a landfill, the facility is constructed with slopes extending above the original earthen embankments and will be closed with CCR in place above those original earthen embankments. Per 40 CFR 257.81(c)(4), run-on and run-off control system plans must be revisited every five years. This document serves as the current version of the run-on and run-off control system plan.

Upstream Raise 91 is also regulated by the North Dakota Department of Environmental Quality (NDDEQ) under Permit 0033. The NDDEQ requires a run-on and run-off control system plan as part of the application for a permit as described in Section 33.1-20-08-05.2.c. of the North Dakota Administrative Code (NDAC 2020). This run-on and run-off control system plan satisfies the state-specific requirement.

2.0 REQUIREMENTS FOR RUN-ON AND RUN-OFF CONTROL SYSTEMS

In accordance with 40 CFR 257.81(c)(1) and NDAC Section 33.1-20-08-05.2.c.(1), the run-on and run-off control systems plans must document how the run-on and run-off control systems have been designed and constructed to meet the following criteria, as supported by appropriate engineering calculations, for CCR landfills:

- The run-on control system must be designed to prevent flow onto the active portion of the CCR unit during the peak discharge from a 24-hour, 25-year storm.
- The run-off control system from the active portion of the CCR unit must be designed to collect and control at least the water volume resulting from a 24-hour, 25-year storm.

Further clarification on the intent of the rule is provided in the text of the Preamble for the federal CCR Rule:

> *The owner or operator must design, construct, operate, and maintain the CCR landfill in such a way that any run-off generated from at least a 24-hour, 25-year storm must be collected through hydraulic structures, such as drainage ditches, toe drains, swales, or other means, and controlled so as to not adversely affect the condition of the CCR landfill. EPA has promulgated these requirements to minimize the detention time of run-off on the CCR landfill and minimize infiltration into the CCR landfill, to dissipate storm water run-off velocity, and to minimize erosion of CCR landfill slopes. An additional concern with run-off from CCR landfills is the water quality of the run-off, which may collect suspended solids from the landfill slopes.*

The run-on and run-off control systems designed for and operated at Upstream Raise 91 are described below.

3.0 RUN-ON CONTROL

Run-on is defined as stormwater that may flow towards the active portions of the facility. The run-on control system for Upstream Raise 91 consists of the perimeter embankments, ditches, and grading, with slopes directing water away from the facility to prevent stormwater run-on.

The Upstream Raise 92 CCR Surface Impoundment (Upstream Raise 92) buttresses Upstream Raise 91 along the east side of Upstream Raise 91. Water that might run-on from this facility is handled in the same way that run-off is handled from Upstream Raise 91 (Section 4.1). Contact water run-off controls for Upstream Raise 91 and Upstream Raise 92 work in concert with each other.

An earthen embankment separates the facility on the north side from existing ground and Samuelson Slough. The embankment has a height of approximately 20 feet, and the surrounding ground slopes north, directing stormwater away from Upstream Raise 91.

An earthen embankment separates the facility on the south and west sides from a surface water drainage ditch. The embankment has a height of approximately 20 feet, and water collected and/or flowing through the surface water drainage ditch is directed south and east along the side and away from the facility. The surface water drainage ditch is graded and maintained along the toe of the embankment of the facility.

4.0 RUN-OFF CONTROL

Run-off at Upstream Raise 91 consists of both contact water (namely water having directly contacted CCR within the active area of the facility) and non-contact stormwater (water that has contacted temporary or final cover).

4.1 Contact Water Run-Off Controls

Contact water run-off is contained and directed to one of two main areas described below:

1) The active pool within Upstream Raise 91 (when operating as a surface impoundment).

2) The adjacent Drains Pond System CCR Surface Impoundment (Drains Pond System) via the perimeter ditches and crossover pipes.

Contact water run-off is directed using berms, channels, ditches, and culverts contained within the lined footprint of the facility. Calculations supporting the design of the contact water controls are included in Appendix A (Golder 2015). Contact water run-off calculations are based on a 24-hour, 25-year storm event for two different time periods over the life of the facility. Both phases are designed to contain and passively convey contact water to the Drains Pond System through crossover culverts, without ponding in the perimeter ditches above the Upstream Raise 91 composite liner.

4.2 Non-Contact Water Run-Off Controls

Non-contact run-off is collected in grass-lined terrace channels and is directed toward armored down-chute and outlet channels. Down-chute and outlet channels direct non-contact stormwater off the facility and into surrounding surface water drainage ditches or areas generally sloped away from the facility. Calculations supporting the design of non-contact surface water controls are included in Appendix B (Golder 2015). Non-contact surface water run-off calculations are based on a 24-hour, 100-year storm event when the landfill is developed to final grades.

These surface water calculations are based on current permitted grades for Upstream Raise 91, including how the final grades on the east side of Upstream Raise 91 work in concert with Upstream Raise 92. Changes to 40 CFR Part 257 since original promulgation in 2015 (related to a liner demonstration specific to Coal Creek Station that requires review by the USEPA) may require that the final cover grades be updated for the facility, particularly at the connection with Upstream Raise 92. Consequently, the run-off surface water controls and calculations will be required to be updated at that time.

5.0 REVISION HISTORY

A history of revisions to this document:

Revision 0 – Published October 13, 2016.

Revision 1 – 5-Year Update: Published October 13, 2021.

1) New CCR unit naming convention (Ash Pond 91 to Upstream Raise 91 and Upstream Raise to Upstream Raise 92).

2) Reflect that final grades (and surface water controls), particularly related to the tie-in between Upstream Raise 91 and Upstream Raise 92, may change due to changes to 40 CFR Part 257 since original rule promulgation in 2015 (pending USEPA review).

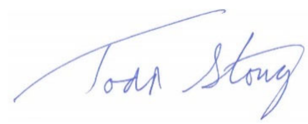
6.0 CERTIFICATION

The undersigned attest to the completeness and accuracy of the above written run-on and run-off control plans, and certify that the plans meet the requirements detailed in 40 CFR 257.81(c) and Section 33.1-20-08-05.2.c. of the NDAC.

Signature Page

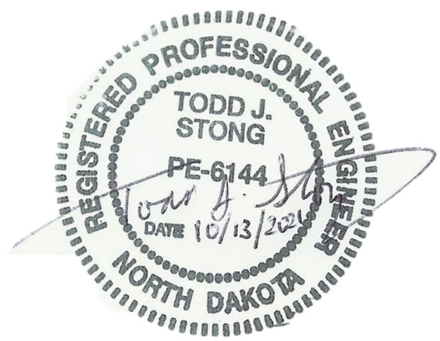
Golder Associates Inc.

Craig Schuettpelz, PE
Senior Engineer



Todd Stong, PE
Associate and Senior Consultant

CS/TS/df



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7.0 REFERENCES

Golder (Golder Associates Inc). 2015. Permit Modification Document, Permit No. SP-033. February.

NDAC (North Dakota Administrative Code). 2020. Chapter 33.1-20-08 – Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments.

USEPA (United States Environmental Protection Agency). 2015. Code of Federal Regulations Title 40 Part 257: Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities. April 17.

APPENDIX A

Contact Water Controls Calculations

1.0 OBJECTIVE

Design contact water controls to contain/convey runoff from the Ash Pond 91 (AP91) facility during the 25-year 24-hour design storm event.

2.0 METHOD

Golder delineated subbasins for the proposed contact water control system based on planned and existing grades, shown in Figures 1 and 2. Times of concentration were calculated using the methodology described in TR-55 (U. S. Soil Conservation Service, 1986) for sheet and shallow concentrated flow and Manning's equation for channel flow. HEC-HMS modeling software (U.S. Army Corps of Engineers Hydrologic Engineering Center, 2010) was used to determine the routing of surface runoff from the landfill slopes and the peak inflows that will report to the control structures. All contact water will be directed to the Drains Pond.

The analysis was performed for two phases of construction. Phase A (Figure 1) considers runoff from the 15% and 20% slopes around the landfill at maximum FGD material deposition height. Runoff from side slopes reports to a perimeter ditch at the toe and rainfall on the cap of the landfill is contained within the FGD working pool. This phase represents the maximum contributing area prior to placement of the crown and final cover. Phase B (Figure 2) assumes that a large portion of the 15% and 20% slopes are covered, and contact water runoff originates from the landfill cap/crown and the northwest slopes between the construction access roads. This phase considers a smaller collection pond on the northwest corner AP91. Both the phases are designed to contain contact water and convey it to the Drains Pond through cross-over culverts.

Outflow from AP91 to the Drains Pond was modeled using head loss estimates assuming full pipe flow conditions. The culverts were sized to convey contact water from AP91 to the Drains Pond without ponding above the pond liner and to maintain two feet of freeboard per North Dakota Administrative Code Rule 33-20-08.1.

North Dakota Department of Environmental Quality

3.0 ASSUMPTIONS

- North Dakota Department of Health regulations require that "The landfill must be designed and operated to prevent the run-on and runoff of surface waters resulting from a maximum flow of a twenty-five year, twenty-four-hour storm." The 24-hour, 25-year storm depth is 3.75 inches and was obtained from the "Rainfall Frequency Atlas of the United States" (Hershfield, 1961). The atlas section relevant to North Dakota is included in Attachment A.

Ash Pond 91 is now referred to as Upstream Raise 91,
Ash Pond 92 is now referred to as Upstream Raise 92 (10/13/2021).

- The 2-year, 24-hour storm depth, which is used in the TR-55 time of concentration method, is 1.9 inches (Hershfield, 1961). The relevant "Rainfall Frequency Atlas of the United States" section is included in Attachment A.
- The design storm is distributed in time as an SCS Type II synthetic distribution.
- Lag time is equal to 60% of the time of concentration.
- The minimum lag time is 3.6 minutes (a time of concentration of 6 minutes per TR-55).
- Maximum length of sheet flow is 300 feet.
- An SCS curve number of 94 was assumed for all sub-basins, reflecting hardened fly ash.
- An overland flow surface roughness of 0.011 was assumed for fly ash (Attachment B).
- A shallow concentrated flow coefficient of 20.33 was assumed for the surface of the raise (Attachment B) to reflect hardened fly ash.
- The perimeter ditch and northwest pond are treated as "reservoir" elements in the HEC-HMS program. Elevation and area relationships for the control ditches were estimated using proposed topography as shown in Attachment C.
- The Drains Pond water elevation is maintained at elevation 1917 during the design storm event.
- The composite liner for Ash Pond 91 ties into the embankment at an elevation of approximately 1920 feet.

4.0 CALCULATIONS

Hydraulic parameters for the basins (Tables 1 and 2) and cross-over pipelines (Table 3) were entered into the HEC-HMS modeling software and routed to estimate peak flows and volumes (Table 4). The number and size of pipelines was evaluated to keep the headwater depth below the elevation of the liner during the design storm event. Additionally, the HEC-HMS model schematic, reservoir element inputs, and reservoir element results are included as Attachment C.

5.0 RESULTS/CONCLUSIONS

The critical phase for the pipe sizing calculations is Phase B; despite the larger contributing area in Phase A, the smaller AP91 perimeter ditch/northwest pond area in Phase B results in a greater peak flow that must be conveyed to the Drains Pond. Calculations suggest that three 24-inch HDPE pipes between AP91 and the Drains Pond can convey the design storm event without ponding above the AP91 liner (elevation 1920 feet). The peak headwater elevations are estimated at 1919.4 feet for Phase A and 1919.9 feet for Phase B. The combined capacity of the AP91 pond (perimeter ditch or northwest pond) and the Drains Pond is sufficient to contain the runoff volume from the design storm event.

6.0 REFERENCES

Hershfield, D. M. (1961). *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years.* U.S. Department of Agriculture, Soil Conservation Service. Washington D. C.: U.S. Government Printing Office.

U. S. Soil Conservation Service. (1986). *Urban hydrology for small watersheds.* Washington D. C.: United States Department of Agriculture.

U.S. Army Corps of Engineers Hydrologic Engineering Center. (2010, August 10). Hydrologic Modeling System (HEC-HMS). (3.5). Davis, California, USA: U.S. Army Corps of Engineers.

TABLES

GRE CCS AP91 Permit
Contact Water Calculations
PROJECT NO.: 1400644

TABLE 1
SUBBASIN SUMMARY TABLE

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

Design Storm 25 -Year Reccurence Interval

Storm Duration (hours)	2-Year Depth (inches)	25 -Year Depth (inches)	Storm Distribution
24	1.9	3.75	II

Subbasin ID	Subbasin Area (ft^2)	Subbasin Area (acres)	Subbasin Area (sq mile)	CN = 94 Fly Ash (newly graded areas, no vegetation) (acres)	Composite SCS Curve No.	S = $\frac{1000}{CN}$ - 10	Unit Runoff Q (in)	Runoff Volume (ac-ft)	Runoff Volume (ft^3)
Phase A	2,996,893	68.80	0.1075	68.80	CN = 94	0.64	3.08	17.66	769,120
Phase B Cap	1,170,233	26.86	0.0420	26.86	CN = 94	0.64	3.08	6.89	300,327
Phase B Side	872,906	20.04	0.0313	20.04	CN = 94	0.64	3.08	5.14	224,022

TABLE 2
BASIN HYDRAULIC PARAMETER SUMMARY TABLE

GRE CCS AP91 Permit
Contact Water Calculations
Project Number: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

Subbasin ID	Subbasin Area (sq mile)	Composite Curve Number	Total Lag (0.6*Tc) (min)	Total Travel Time (min)	Flow Segment 1: Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Travel Time (min)
Phase A	0.1075	94	3.6	2.2	Sheet	300	0.140	A	Fly Ash	1.7
Phase B Cap	0.0420	94	3.6	5.1	Sheet	282	0.050	A	Fly Ash	2.5
Phase B Side	0.0313	94	3.6	2.3	Sheet	225	0.150	A	Fly Ash	1.3

Subbasin ID	Flow Segment 2: Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)
Phase A	Shallow	239	0.190	P	Paved		0.4
Phase B Cap	Channel	1826	0.010	C	Concrete	0.93	2.6
Phase B Side	Sheet	75	0.200	A	Fly Ash		0.5

Subbasin ID	Flow Segment 3: Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)
Phase A							
Phase B Cap							
Phase B Side	Shallow	126	0.200	P	Paved		0.2

Subbasin ID	Flow Segment 4: Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)
Phase A							
Phase B Cap							
Phase B Side	Channel	267	0.070	C	Concrete	0.62	0.2

TABLE 3
PIPE CALCULATIONS

GRE CCS AP91 Permit
Contact Water Calculations
PROJECT NO.: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

Static Head Loss			**Friction Head Loss**										**Minor Head Loss**				**Total**			
Starting Elevation (ft)	Ending Elevation (ft)	Static Head Loss (ft)	Nominal Pipe Diameter (in)	HDPE DR21 Pipe ID (in)	Pipe Area (ft^2)	No. of pipes	Total Flow (cfs)	Flow per pipe (cfs)	Pipe Velocity (fps)	Velocity Head (ft)	Total Pipe Length (ft)	Hazen-Williams C Value	Friction Head Loss (ft)	Entrance	Exit	Total Coefficient per Pipe	Minor Head Loss (ft)	Minor + Friction (ft)	Total Head Loss (ft)	Drains Pond Water Elevation (ft)	**Headwater Elevation (ft)**
														0.5	1						
1915.0	1915.0	0.0	24	23.2	2.94	3	0	0.00	0.00	0.00	105	120	0.00	1	1	1.50	0.00	0.00	0.00	1917	**1917.00**
1915.0	1915.0	0.0	24	23.2	2.94	3	0.01	0.00	0.00	0.00	105	120	0.00	1	1	1.50	0.00	0.00	0.00	1917	**1917.00**
1915.0	1915.0	0.0	24	23.2	2.94	3	25	8.33	2.84	0.13	105	120	0.14	1	1	1.50	0.19	0.33	0.33	1917	**1917.33**
1915.0	1915.0	0.0	24	23.2	2.94	3	50	16.67	5.68	0.50	105	120	0.52	1	1	1.50	0.75	1.27	1.27	1917	**1918.27**
1915.0	1915.0	0.0	24	23.2	2.94	3	75	25.00	8.52	1.13	105	120	1.09	1	1	1.50	1.69	2.78	2.78	1917	**1919.78**
1915.0	1915.0	0.0	24	23.2	2.94	3	100	33.33	11.35	2.00	105	120	1.86	1	1	1.50	3.00	4.87	4.87	1917	**1921.87**

TABLE 4
FLOW RESULTS FROM HEC-HMS

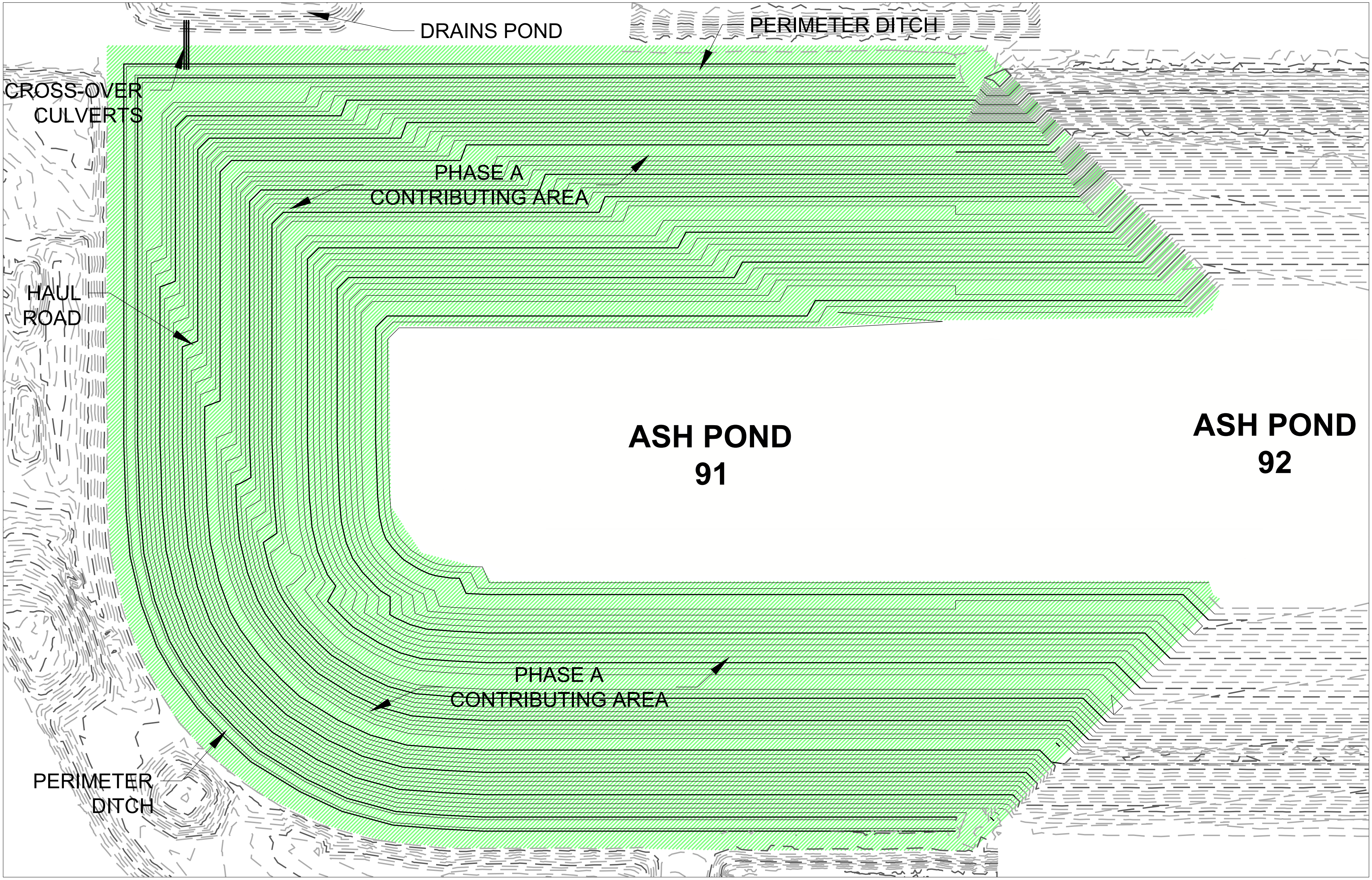
GRE CCS AP91 Permit
Contact Water Calculations
PROJECT NO.: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

HEC-HMS Basin Model:	AP91 Contact
HEC-HMS Met. Model:	25yr24hr
HEC-HMS Control Specs:	36 Hour, 5 Minute

Hydrologic Element	Drainage Area (sq mile)	Peak Discharge (cfs)	Time of Peak	Total Volume (ac-ft)
Phase A	0.1075	286.1	01Jan2050, 12:55	17.7
Phase A Perimeter Ditch	0.1075	68.9	01Jan2050, 13:10	17.7
Phase A Drains Pond	0.1075	68.9	01Jan2050, 13:10	17.7
Phase B Cap	0.042	111.8	01Jan2050, 12:55	6.9
Phase B Side	0.0313	83.3	01Jan2050, 12:55	5.1
Phase B NW Pond	0.0733	76.7	01Jan2050, 13:05	12
Phase B Drains Pond	0.0733	76.7	01Jan2050, 13:05	12

FIGURES

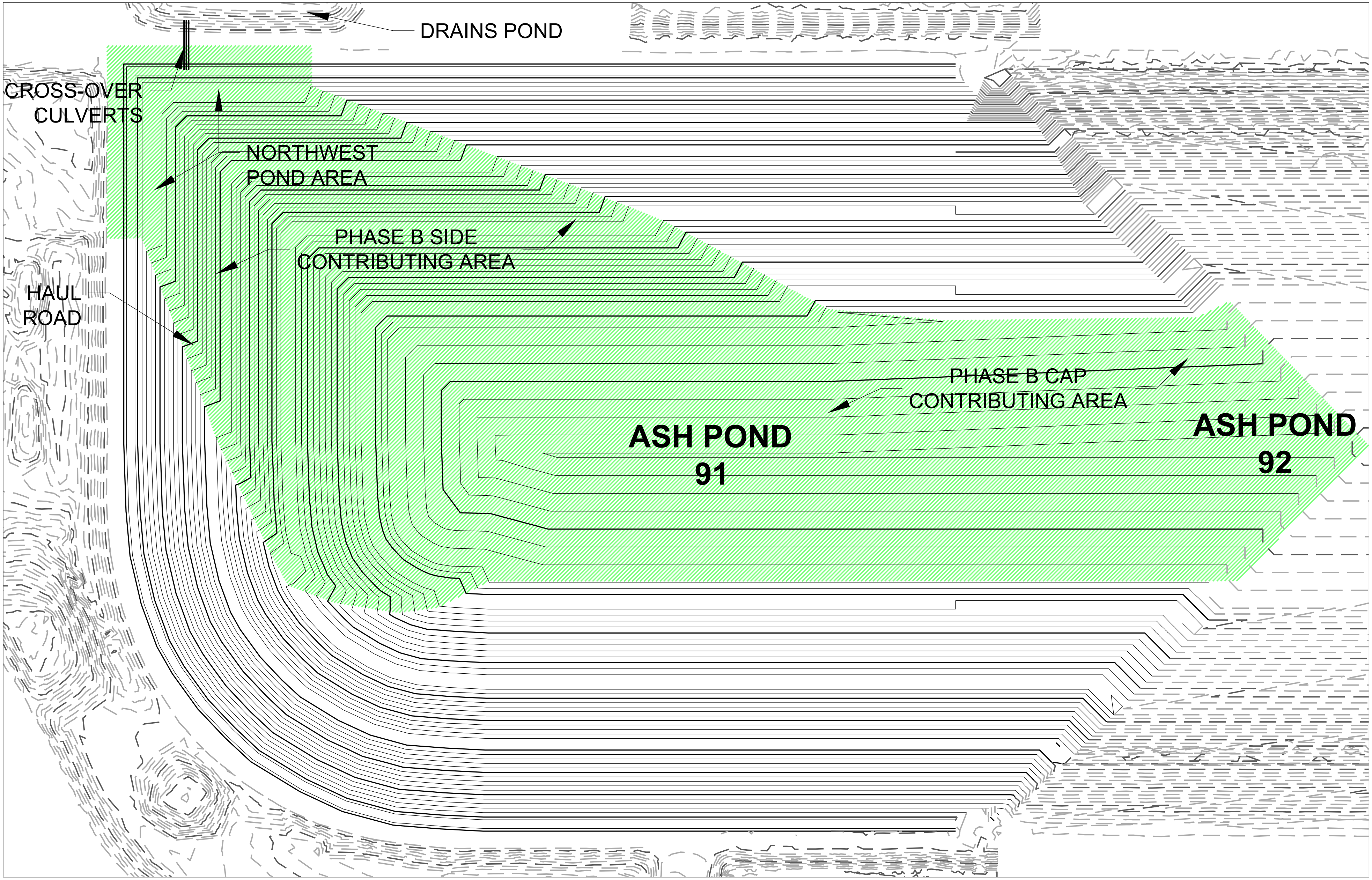


ASH POND 91 PERMIT SP-033
CONTACT WATER CONTROLS, PHASE A

Golder Associates

FIGURE 1

Path: \\Denver.golder.gds\projects\14JOBS\1400644 - GRE\Ash Pond 91_Appendix C\C-8 Contact Water\ | File Name: AP91 contact.dwg



ASH POND 91 PERMIT SP-033
CONTACT WATER CONTROLS, PHASE B

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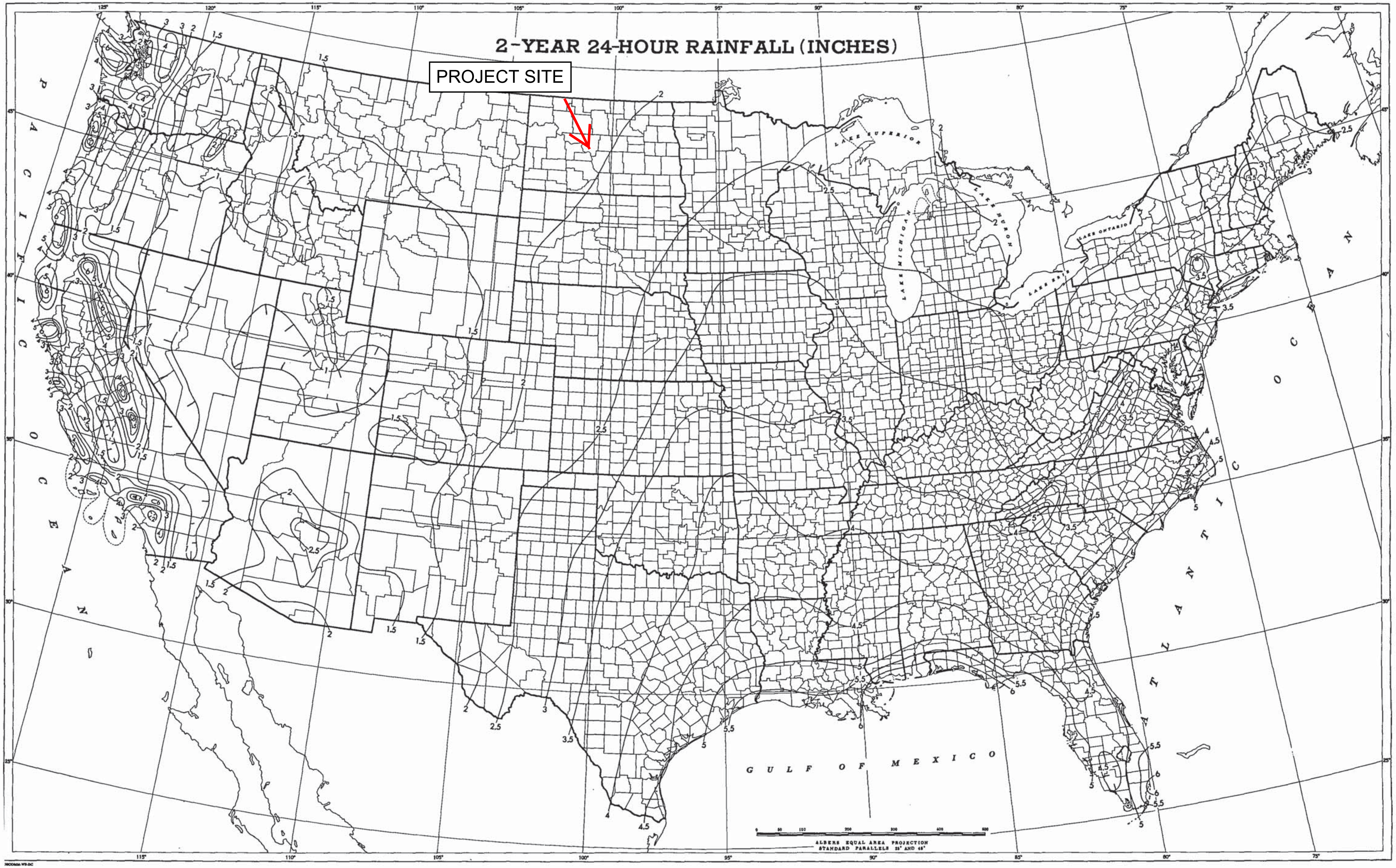
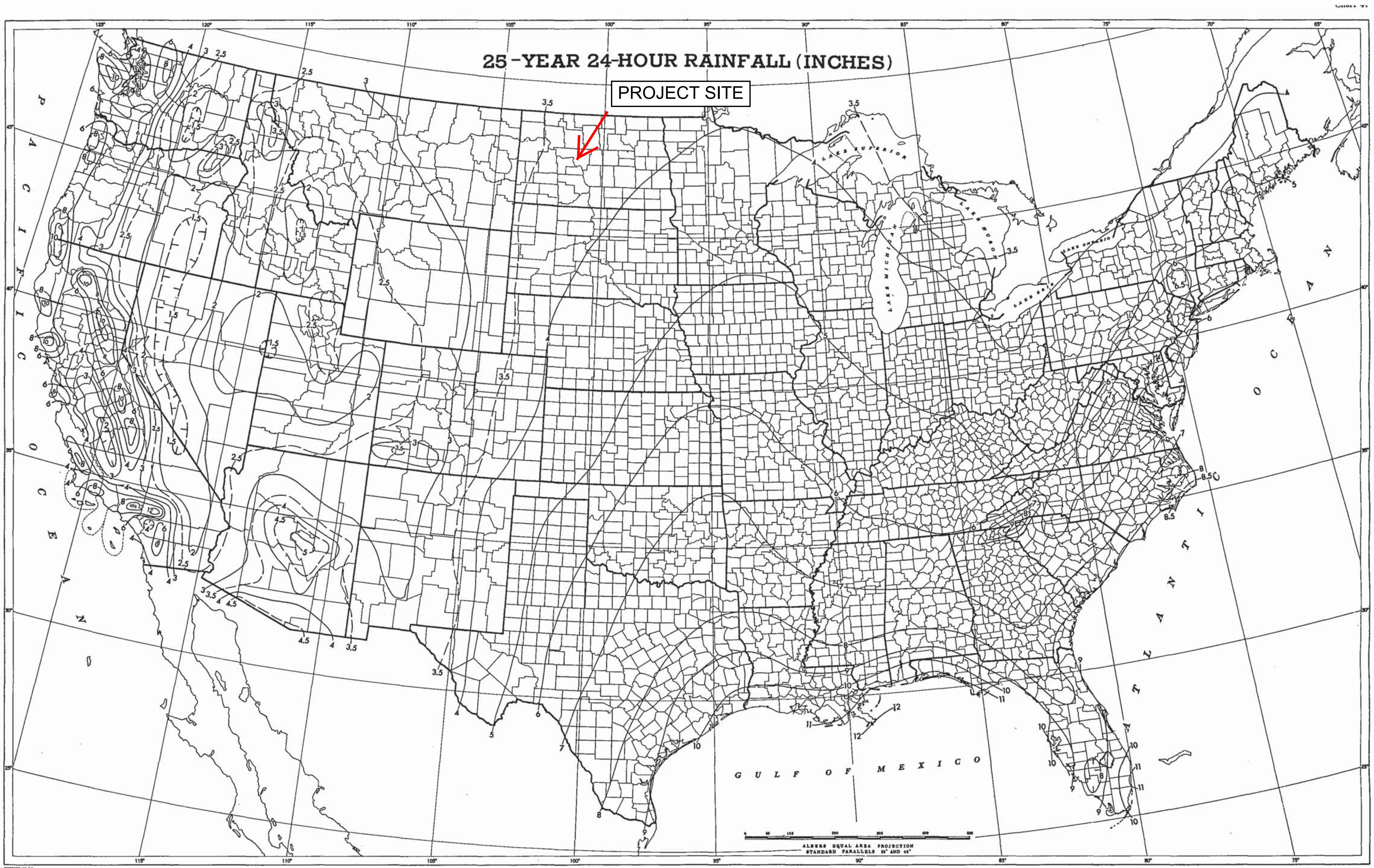
FIGURE 2

ATTACHMENT A
RAINFALL FREQUENCY ATLAS (TP-40)
25-YEAR, 24-HOUR RAINFALL AND
2-YEAR, 24-HOUR RAINFALL


2-YEAR 24-HOUR RAINFALL (INCHES)
PROJECT SITE
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°



25-YEAR 24-HOUR RAINFALL (INCHES)
PROJECT SITE
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

ATTACHMENT B
TIME OF CONCENTRATION CALCULATION AND COEFFICIENTS

ATTACHMENT B
TIME OF CONCENTRATION CALCULATION EQUATIONS AND COEFFICIENTS

TR-55 (1986)

Sheet Flow Travel time (SCS Upland Method)

$$T_t = \frac{0.007\,(n'\,L)^{0.8}}{(P_2)^{0.5}\;S^{0.4}}$$

Where: T_t = travel time (hr); n' = roughness coefficient; L = flow length (ft);

P_2 = 2-yr storm depth (inches); s = slope (ft/ft)

flow velocity = L/(60T_t)

Flow Type	Surface Type	roughness n	Surface Description	Short Description
Sheet/Overland Flow	A	0.011	Fly Ash	Fly Ash
	B	0.05	Fallow (no residue)	Fallow
	C	0.06	Cultivated soils: Residue cover <= 20%	Cover<20%
	D	0.17	Cultivated soils: Residue cover > 20%	Cover>20%
	E	0.15	Grass: Short grass prairie	Short Grass
	F	0.24	Grass: Dense grasses	Dense Grass
	G	0.41	Grass: Bermuda grass	Bermuda Grass
	H	0.13	Range (natural)	Range
	I	0.40	Woods: Light underbrush	Light woods
	J	0.80	Woods: Heavy underbrush	Heavy Woods

Shallow Concentrated Flow Velocity (SCS Upland Method)

$v = mS^{0.5}$

Where: v = velocity (fps); m = roughness coeffient; S = slope (ft/ft)

Flow Type	Surface Type	Roughness m	Surface Description	Short Description
Shallow Conc. Flow	P	20.3282	Paved Surfaces	Paved
	U	16.1345	Unpaved Surfaces	Unpaved

Channel Flow Velocity (Mannings Velocity)

$v = 1.49/n\ Rh^{2/3} S^{1/2}$

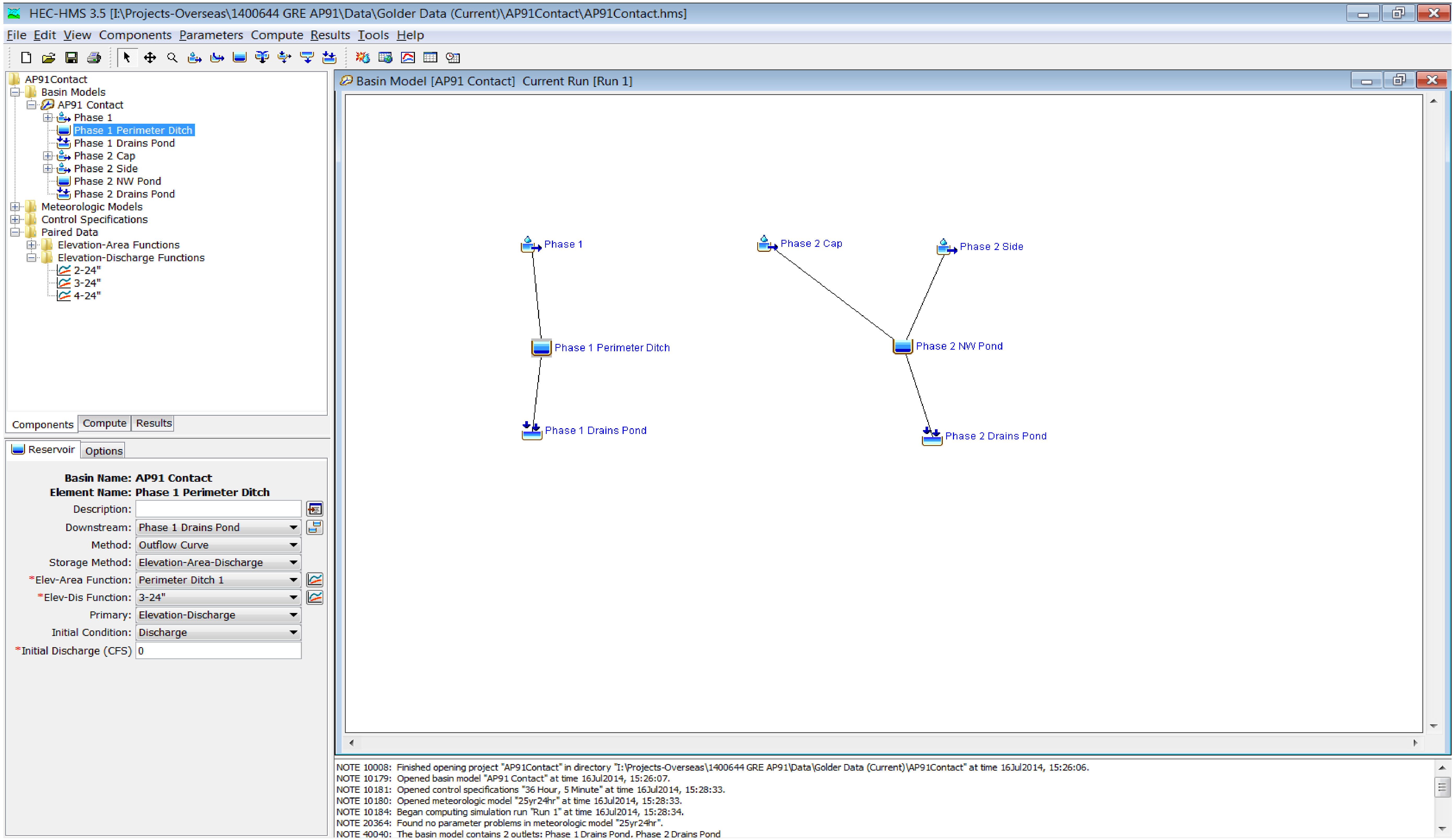
Where: v = velocity (fps); n = roughness coeffient; Rh = Hydraulic Radius (ft), S = slope (ft/ft)

Lining Type	Mannings n for Depth	Mannings n for Velocity	Material	Maximum Velocity	Maximum Shear Stress
A	0.026	0.026	ACB	25	
C	0.012	0.011	Concrete	50	
E	0.025	0.022	Earth-lined	3	
G	0.035	0.030	Grass-lined	5	
I	0.017	0.013	Ductile Iron	50	
P	0.012	0.009	Plastic	25	
R	0.040	0.035	Riprap	16	
T	0.035	0.030	Turf Reinf.	10	1.5
Z	0.058	0.026	Flexamat	19	24

ATTACHMENT C
HEC-HMS SCREEN CAPTURES AND INPUTS

ATTACHMENT C
HEC-HMS SCREEN CAPTURES AND INPUTS

HEC-HMS Basin Model Schematic

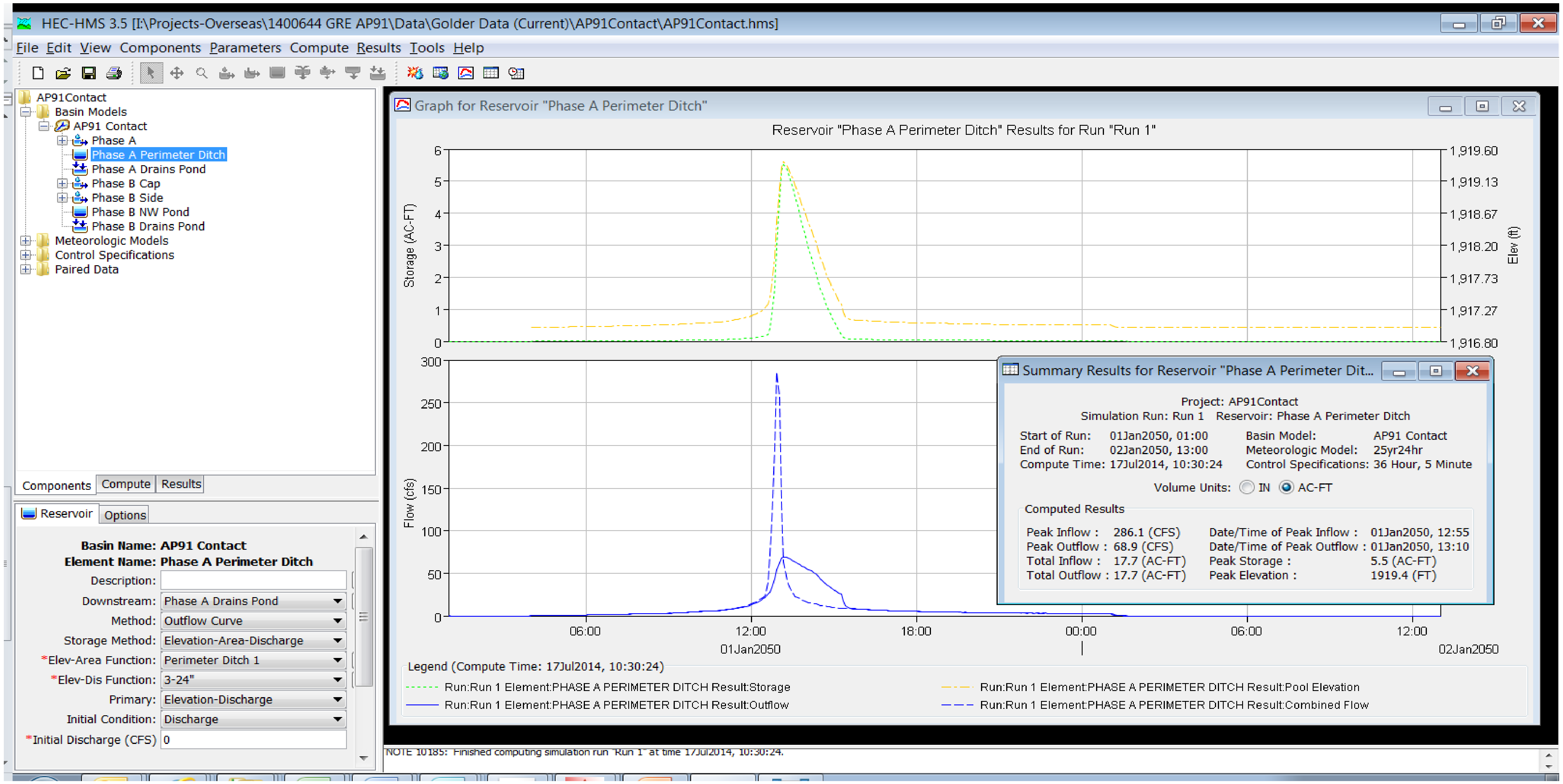


ATTACHMENT C
HEC-HMS SCREEN CAPTURES AND INPUTS

Stage-Storage Evaluation for Phase A (Perimeter Ditch) and Phase B (Northwest Corner Pond)

Ponds		
Elevation (ft)	Area (ft2)	Area (ac)
Perimeter Ditch (Phase A)		
1917	67080	1.54
1918	97578	2.24
1919	128148	2.94
1920	158790	3.65
1921	189504	4.35
1922	220289	5.06
NW Pond (Phase B)		
1915	185	0.00
1917	38509	0.88
1918	42994	0.99
1919	47551	1.09
1920	52129	1.20
1921	56822	1.30
1922	61548	1.41

ATTACHMENT C
HEC-HMS SCREEN CAPTURES AND INPUTS



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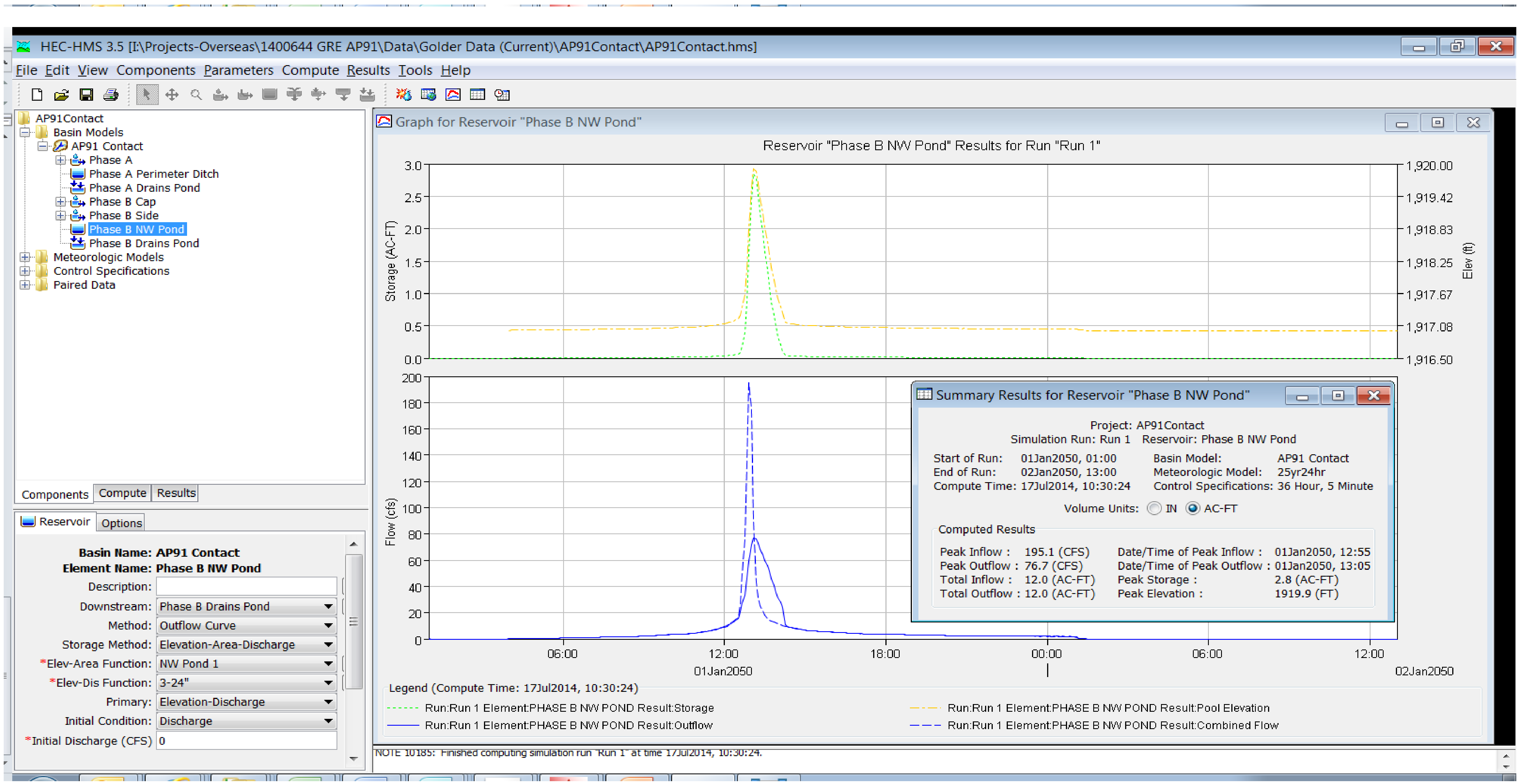
HEC-HMS SCREEN CAPTURES AND INPUTS



APPENDIX B

Surface Water Controls Calculations

1.0 OBJECTIVE

Determine the size of terrace channels, down-chute channels and hydraulic jump basins needed to convey the design storm event.

2.0 METHOD

Golder delineated subbasins for the proposed surface water control system based on the design grades shown in Figure 1. Times of concentration were calculated using the methodology described in TR-55 (U. S. Soil Conservation Service, 1986) for sheet and shallow concentrated flow and Manning's equation for channel flow. Using the HEC-HMS modeling software (U.S. Army Corps of Engineers Hydrologic Engineering Center, 2010), Golder determined the routing of surface runoff from the final cover system and the peak flows that will occur in each runoff channel. Peak flows are used to size the channels, assuming normal depths, as well as determine the required channel lining.

North Dakota Department of Environmental Quality

3.0 ASSUMPTIONS

- North Dakota Department of Health regulations do not specify a design storm event for the evaluation of final cover surface water controls. A design storm event of 4.75 inches was used in this analysis. This event is the 24-hour, 100-year storm event from the "Rainfall Frequency Atlas of the United States" (Hershfield, 1961). The atlas section relevant to North Dakota is included in Attachment A.
- The 2-year, 24-hour storm depth, which is used in the TR-55 time of concentration method, is 1.9 inches (Hershfield, 1961). The relevant "Rainfall Frequency Atlas of the United States" section is included in Attachment A.
- The design storm is distributed in time as an SCS Type II synthetic distribution.
- Lag time is equal to 60% of the time of concentration.
- The minimum lag time is 3.6 minutes (a time of concentration of 6 minutes per TR-55).
- Maximum length of sheet flow is 300 feet.
- An SCS curve number of 81 was assumed for all sub-basins, reflecting fair coverage of prairie grasses.
- An overland flow surface roughness of 0.15 was assumed for short grass prairie cover (Attachment B).
- A shallow concentrated flow coefficient of 16.13 was assumed for the unpaved surface of the raise (Attachment B) to reflect vegetative cover.
- A Manning roughness coefficient of 0.035 (for capacity) was assumed for grass lined channels and a Manning roughness coefficient of 0.026 was assumed for articulated concrete block lined channels (Attachment B).

Ash Pond 91 is now referred to as Upstream Raise 91,
Ash Pond 92 is now referred to as Upstream Raise 92 (10/13/2021).

4.0 CALCULATIONS

Hydraulic parameters for the basins (Tables 1 and 2) were entered into the HEC-HMS modeling software and routed to calculate peak flows for each basin and channel (Table 3). Peak flows were used to size channels and determine the appropriate channel linings.

Output from the HEC-HMS modeling, channel sizing calculations (Table 4), and hydraulic jump basin sizing are attached (Table 5). Additionally, the HEC-HMS model schematic is included as Attachment C.

5.0 RESULTS/CONCLUSIONS

Individual terrace channel reaches are summarized in Table 4, with peak flows, depths and velocities associated with the design storm event. Terrace channels are designed as grass lined v-notch channels with outside slopes of 3H:1V, inside slopes from 20H:1V to 5H:1V, bed slopes of either 1% or 2%, and approximately 24 inches deep.

Perimeter channels are summarized in Table 4, with peak flows, depths and velocities associated with the design storm event. Perimeter channels are designed as grass lined v-notch channels with side slopes of 3H:1V, bed slopes of 1%, and 24 to 30 inches deep.

Channels along the landfill access road are summarized in Table 4, with peak flows, depths and velocities associated with the design storm event. Access road channels are designed as grass or turf-reinforcement mat lined v-notch channels with side slopes of 3H:1V, bed slopes of 7%, and 18 to 24 inches deep.

The down-chute and outlet channel reaches are also summarized in Table 4, with peak flows, depths and velocities associated with the design storm event. The down-chute and outlet channels are designed as trapezoidal with 3H:1V side slopes, a 10 - 12 foot wide bottom and 2.0 foot depth. These channels will be lined with articulated concrete block. Special attention must be given to the installation of this lining to prevent the creation of erosion pathways at the interfaces between terrace channels and down-chute channels.

At the end of the outlet channels, the slope changes from steep to 0% and hydraulic jump basins are required to dissipate energy. The minimum hydraulic jump length is summarized in Table 5 and ranges from approximately 12 to 17 feet. The hydraulic jump basin will be constructed of articulated concrete block or a concrete slab. After the hydraulic jump basin, the existing grass-lined channels will convey the water further from the site.

6.0 REFERENCES

Hershfield, D. M. (1961). *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years.* U.S. Department of Agriculture, Soil Conservation Service. Washington D. C.: U.S. Government Printing Office.

U. S. Soil Conservation Service. (1986). *Urban hydrology for small watersheds.* Washington D. C.: United States Department of Agriculture.

U.S. Army Corps of Engineers Hydrologic Engineering Center. (2010, August 10). Hydrologic Modeling System (HEC-HMS). (3.5). Davis, California, USA: U.S. Army Corps of Engineers.

TABLES

TABLE 1
SUBBASIN SUMMARY TABLE

GRE CCS AP91
Surface Water Calculations
PROJECT NO.: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

Design Storm 100 -Year Reccurence Interval

Storm Duration (hours)	2-Year Depth (inches)	100 -Year Depth (inches)	Storm Distribution
24	1.9	4.8	II

Subbasin ID	Subbasin Area (ft^2)	Subbasin Area (acres)	Subbasin Area (sq mile)	CN = 81 Fair Coverage of Prairie Grasses	Composite SCS Curve No.	S = 1000/CN - 10	Unit Runoff Q (in)	Runoff Volume (ac-ft)	Runoff Volume (ft^3)
C1	258,519	5.93	0.0093	5.93	CN = 81	2.35	2.77	1.37	59,578
C2	131,242	3.01	0.0047	3.01	CN = 81	2.35	2.77	0.69	30,246
C3	117,779	2.70	0.0042	2.70	CN = 81	2.35	2.77	0.62	27,143
C4	139,243	3.20	0.0050	3.20	CN = 81	2.35	2.77	0.74	32,090
C5	73,559	1.69	0.0026	1.69	CN = 81	2.35	2.77	0.39	16,952
D1	271,247	6.23	0.0097	6.23	CN = 81	2.35	2.77	1.44	62,511
D2	139,385	3.20	0.0050	3.20	CN = 81	2.35	2.77	0.74	32,123
D3	120,288	2.76	0.0043	2.76	CN = 81	2.35	2.77	0.64	27,722
D4	153,861	3.53	0.0055	3.53	CN = 81	2.35	2.77	0.81	35,459
D5	79,981	1.84	0.0029	1.84	CN = 81	2.35	2.77	0.42	18,432
N1	286,419	6.58	0.0103	6.58	CN = 81	2.35	2.77	1.52	66,008
N2	228,752	5.25	0.0082	5.25	CN = 81	2.35	2.77	1.21	52,718
N3	169,769	3.90	0.0061	3.90	CN = 81	2.35	2.77	0.90	39,125
N4	191,281	4.39	0.0069	4.39	CN = 81	2.35	2.77	1.01	44,083
N5	71,728	1.65	0.0026	1.65	CN = 81	2.35	2.77	0.38	16,530
O1	167,213	3.84	0.0060	3.84	CN = 81	2.35	2.77	0.88	38,536
O2	136,066	3.12	0.0049	3.12	CN = 81	2.35	2.77	0.72	31,358
O3	131,102	3.01	0.0047	3.01	CN = 81	2.35	2.77	0.69	30,214
O4	132,593	3.04	0.0048	3.04	CN = 81	2.35	2.77	0.70	30,557
O5	83,929	1.93	0.0030	1.93	CN = 81	2.35	2.77	0.44	19,342
P1	100,141	2.30	0.0036	2.30	CN = 81	2.35	2.77	0.53	23,078
P2	118,547	2.72	0.0043	2.72	CN = 81	2.35	2.77	0.63	27,320
P3	98,003	2.25	0.0035	2.25	CN = 81	2.35	2.77	0.52	22,586
P4	50,788	1.17	0.0018	1.17	CN = 81	2.35	2.77	0.27	11,705
P5	21,176	0.49	0.0008	0.49	CN = 81	2.35	2.77	0.11	4,880
Q1	20,030	0.46	0.0007	0.46	CN = 81	2.35	2.77	0.11	4,616
Q2	36,553	0.84	0.0013	0.84	CN = 81	2.35	2.77	0.19	8,424
Q3	58,220	1.34	0.0021	1.34	CN = 81	2.35	2.77	0.31	13,417
Q4	9,875	0.23	0.0004	0.23	CN = 81	2.35	2.77	0.05	2,276
R1	42,789	0.98	0.0015	0.98	CN = 81	2.35	2.77	0.23	9,861
R2	82,703	1.90	0.0030	1.90	CN = 81	2.35	2.77	0.44	19,060
R3	166,849	3.83	0.0060	3.83	CN = 81	2.35	2.77	0.88	38,452
R4	157,044	3.61	0.0056	3.61	CN = 81	2.35	2.77	0.83	36,192
S1	201,021	4.61	0.0072	4.61	CN = 81	2.35	2.77	1.06	46,327
S2	127,294	2.92	0.0046	2.92	CN = 81	2.35	2.77	0.67	29,336
S3	95,455	2.19	0.0034	2.19	CN = 81	2.35	2.77	0.51	21,999
S4	93,785	2.15	0.0034	2.15	CN = 81	2.35	2.77	0.50	21,614
S5	29,555	0.68	0.0011	0.68	CN = 81	2.35	2.77	0.16	6,811
T1	233,770	5.37	0.0084	5.37	CN = 81	2.35	2.77	1.24	53,875
T2	173,480	3.98	0.0062	3.98	CN = 81	2.35	2.77	0.92	39,980
T3	115,429	2.65	0.0041	2.65	CN = 81	2.35	2.77	0.61	26,602
T4	116,073	2.66	0.0042	2.66	CN = 81	2.35	2.77	0.61	26,750
T5	29,295	0.67	0.0011	0.67	CN = 81	2.35	2.77	0.15	6,751

TABLE 2
SUBBASIN TIME OF CONCENTRATION CALCULATIONS

GRE CCS AP91
Surface Water Calculations
Project Number: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

					Flow Segment 1						Flow Segment 2						
Subbasin ID	Subbasin Area (sq mile)	Composite Curve Number	Total Lag (0.6*Tc) (min)	Total Travel Time (min)	Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Travel Time (min)	Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)
C1	0.0093	81	14.7	24.6	Sheet	300	0.050	E	Short Grass	21.2	Shallow	20	0.050	P	Paved		0.1
C2	0.0047	81	10.4	17.3	Sheet	78	0.050	E	Short Grass	7.2	Sheet	86	0.150	E	Short Grass		5.0
C3	0.0042	81	7.7	12.9	Sheet	130	0.150	E	Short Grass	7.0	Sheet	16	0.250	E	Short Grass		1.1
C4	0.0050	81	7.0	11.7	Sheet	132	0.220	E	Short Grass	6.1	Channel	1197	0.020	G	Grass-lined	0.46	5.6
C5	0.0026	81	7.4	12.3	Sheet	91	0.250	E	Short Grass	4.3	Channel	1106	0.010	G	Grass-lined	0.40	8.0
D1	0.0097	81	14.7	24.6	Sheet	300	0.050	E	Short Grass	21.2	Shallow	16	0.050	P	Paved		0.1
D2	0.0050	81	11.1	18.5	Sheet	96	0.050	E	Short Grass	8.5	Sheet	85	0.150	E	Short Grass		5.0
D3	0.0043	81	7.9	13.1	Sheet	130	0.150	E	Short Grass	7.0	Sheet	18	0.250	E	Short Grass		1.2
D4	0.0055	81	6.3	10.4	Sheet	93	0.250	E	Short Grass	4.4	Channel	1337	0.020	G	Grass-lined	0.48	6.1
D5	0.0029	81	8.1	13.5	Sheet	95	0.250	E	Short Grass	4.4	Channel	1279	0.010	G	Grass-lined	0.42	9.0
N1	0.0103	81	14.2	23.7	Sheet	300	0.050	E	Short Grass	21.2	Channel	166	0.010	G	Grass-lined	0.40	1.2
N2	0.0082	81	12.3	20.5	Sheet	111	0.050	E	Short Grass	9.6	Sheet	125	0.150	E	Short Grass		6.8
N3	0.0061	81	7.6	12.7	Sheet	202	0.200	E	Short Grass	8.9	Channel	848	0.020	G	Grass-lined	0.48	3.8
N4	0.0069	81	6.8	11.3	Sheet	173	0.200	E	Short Grass	7.8	Channel	791	0.020	G	Grass-lined	0.51	3.4
N5	0.0026	81	7.8	13.0	Sheet	122	0.200	E	Short Grass	5.9	Channel	971	0.010	G	Grass-lined	0.40	7.0
O1	0.0060	81	12.9	21.6	Sheet	262	0.050	E	Short Grass	19.0	Channel	147	0.010	G	Grass-lined	0.33	1.2
O2	0.0049	81	10.9	18.2	Sheet	90	0.050	E	Short Grass	8.1	Sheet	93	0.150	E	Short Grass		5.4
O3	0.0047	81	7.7	12.9	Sheet	189	0.200	E	Short Grass	8.4	Channel	934	0.020	G	Grass-lined	0.44	4.5
O4	0.0048	81	6.6	10.9	Sheet	144	0.200	E	Short Grass	6.8	Channel	880	0.020	G	Grass-lined	0.45	4.2
O5	0.0030	81	7.6	12.7	Sheet	122	0.200	E	Short Grass	5.9	Channel	963	0.010	G	Grass-lined	0.42	6.7
P1	0.0036	81	12.6	21.0	Sheet	267	0.050	E	Short Grass	19.3	Channel	313	0.020	G	Grass-lined	0.37	1.7
P2	0.0043	81	8.1	13.5	Sheet	142	0.150	E	Short Grass	7.5	Channel	896	0.020	G	Grass-lined	0.27	6.0
P3	0.0035	81	6.9	11.5	Sheet	135	0.150	E	Short Grass	7.2	Channel	773	0.020	G	Grass-lined	0.36	4.2
P4	0.0018	81	5.3	8.9	Sheet	135	0.200	E	Short Grass	6.4	Channel	415	0.020	G	Grass-lined	0.32	2.5
P5	0.0008	81	4.0	6.7	Sheet	73	0.200	E	Short Grass	3.9	Channel	298	0.010	G	Grass-lined	0.27	2.8
Q1	0.0007	81	5.4	9.0	Sheet	146	0.100	E	Short Grass	9.0							
Q2	0.0013	81	4.6	7.7	Sheet	147	0.150	E	Short Grass	7.7							
Q3	0.0021	81	4.1	6.8	Sheet	144	0.200	E	Short Grass	6.8							
Q4	0.0004	81	3.6	2.7	Sheet	46	0.200	E	Short Grass	2.7							
R1	0.0015	81	6.1	10.1	Sheet	199	0.150	E	Short Grass	9.8	Channel	44	0.020	G	Grass-lined	0.30	0.3
R2	0.0030	81	5.5	9.1	Sheet	133	0.200	E	Short Grass	6.4	Channel	509	0.020	G	Grass-lined	0.37	2.7
R3	0.0060	81	6.8	11.3	Sheet	136	0.200	E	Short Grass	6.5	Channel	1046	0.020	G	Grass-lined	0.47	4.8
R4	0.0056	81	9.8	16.3	Sheet	147	0.200	E	Short Grass	6.9	Channel	1497	0.010	G	Grass-lined	0.49	9.5
S1	0.0072	81	13.2	22.0	Sheet	300	0.050	E	Short Grass	21.2	Shallow	8	0.150	P	Paved		0.0
S2	0.0046	81	10.7	17.8	Sheet	83	0.050	E	Short Grass	7.6	Sheet	118	0.150	E	Short Grass		6.5
S3	0.0034	81	6.9	11.5	Sheet	153	0.150	E	Short Grass	8.0	Channel	635	0.020	G	Grass-lined	0.35	3.5
S4	0.0034	81	6.2	10.3	Sheet	159	0.200	E	Short Grass	7.3	Channel	568	0.020	G	Grass-lined	0.38	3.0
S5	0.0011	81	5.6	9.3	Sheet	81	0.200	E	Short Grass	4.3	Channel	566	0.010	G	Grass-lined	0.29	5.1
T1	0.0084	81	13.6	22.6	Sheet	298	0.050	E	Short Grass	21.1	Channel	308	0.020	G	Grass-lined	0.44	1.5
T2	0.0062	81	11.3	18.9	Sheet	101	0.050	E	Short Grass	8.9	Sheet	126	0.150	E	Short Grass		6.8
T3	0.0041	81	6.9	11.6	Sheet	163	0.150	E	Short Grass	8.4	Channel	599	0.020	G	Grass-lined	0.38	3.2
T4	0.0042	81	6.1	10.2	Sheet	172	0.200	E	Short Grass	7.8	Channel	481	0.020	G	Grass-lined	0.41	2.4
T5	0.0011	81	5.4	9.0	Sheet	81	0.200	E	Short Grass	4.3	Channel	530	0.010	G	Grass-lined	0.29	4.7

	Flow Segment 3							Flow Segment 4						
Subbasin ID	Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)	Type of Flow	Length (ft)	Slope (ft/ft)	Roughness Condition[1]		Typical Hydraulic Radius (Channel Only) (ft)	Travel Time (min)
C1	Channel	281	0.010	G	Grass-lined	0.38	2.1	Channel	245	0.020	G	Grass-lined	0.45	1.2
C2	Channel	941	0.020	G	Grass-lined	0.38	5.0							
C3	Channel	972	0.020	G	Grass-lined	0.42	4.8							
C4														
C5														
D1	Channel	279	0.010	G	Grass-lined	0.39	2.1	Channel	266	0.020	G	Grass-lined	0.46	1.2
D2	Channel	949	0.020	G	Grass-lined	0.38	5.0							
D3	Channel	1002	0.020	G	Grass-lined	0.42	4.9							
D4														
D5														
N1	Channel	289	0.020	G	Grass-lined	0.48	1.3							
N2	Channel	884	0.020	G	Grass-lined	0.45	4.2							
N3														
N4														
N5														
O1	Channel	257	0.020	G	Grass-lined	0.40	1.3							
O2	Channel	900	0.020	G	Grass-lined	0.38	4.8							
O3														
O4														
O5														
P1														
P2														
P3														
P4														
P5														
Q1														
Q2														
Q3														
Q4														
R1														
R2														
R3														
R4														
S1	Channel	152	0.020	G	Grass-lined	0.42	0.8							
S2	Channel	684	0.020	G	Grass-lined	0.37	3.7							
S3														
S4														
S5														
T1														
T2	Channel	630	0.020	G	Grass-lined	0.41	3.2							
T3														
T4														
T5														

TABLE 3
FLOW RESULTS FROM HEC-HMS

GRE CCS AP91
Surface Water Calculations
PROJECT NO.: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

HEC-HMS Basin Model:	AP91finalcover
HEC-HMS Met. Model:	100 Year, 24 Hour
HEC-HMS Control Specs:	36 Hour, 5 Minute

Hydrologic Element	Drainage Area (sq mile)	Peak Discharge (cfs)	Time of Peak	Total Volume (ac-ft)
N1	0.0103	17.3	01Jan2050, 13:05	1.5
C1	0.0093	15.2	01Jan2050, 13:10	1.4
J-N1C1	0.0196	32.5	01Jan2050, 13:05	2.9
N2	0.0082	15	01Jan2050, 13:05	1.2
C2	0.0047	9.1	01Jan2050, 13:05	0.7
J-N2C2J1	0.0325	56.7	01Jan2050, 13:05	4.8
N3	0.0061	13.3	01Jan2050, 13:00	0.9
C3	0.0042	9.1	01Jan2050, 13:00	0.6
J-N3C3J2	0.0428	76.8	01Jan2050, 13:05	6.3
N4	0.0069	15.7	01Jan2050, 13:00	1
C4	0.005	11.2	01Jan2050, 13:00	0.7
C5	0.0026	5.7	01Jan2050, 13:00	0.4
N5	0.0026	5.6	01Jan2050, 13:00	0.4
J-N5C5J4	0.0599	109.2	01Jan2050, 13:05	8.8
S-NC	0.0599	109.2	01Jan2050, 13:05	8.8
D1	0.0097	15.9	01Jan2050, 13:10	1.4
T1	0.0084	14.5	01Jan2050, 13:05	1.2
J-T1D1	0.0181	30.4	01Jan2050, 13:05	2.7
T2	0.0062	11.8	01Jan2050, 13:05	0.9
D2	0.005	9.6	01Jan2050, 13:05	0.7
J-T2D2J1	0.0293	51.7	01Jan2050, 13:05	4.3
D3	0.0043	9.2	01Jan2050, 13:00	0.6
T3	0.0041	9.3	01Jan2050, 13:00	0.6
J-T3D3J2	0.0377	67.9	01Jan2050, 13:05	5.6
D4	0.0055	12.8	01Jan2050, 13:00	0.8
T4	0.0042	9.8	01Jan2050, 13:00	0.6
D5	0.0029	6.2	01Jan2050, 13:00	0.4
T5	0.0011	2.6	01Jan2050, 13:00	0.2
J-T5D5J4	0.0514	93.7	01Jan2050, 13:00	7.6
S-TD	0.0514	93.7	01Jan2050, 13:00	7.6
O1	0.006	10.7	01Jan2050, 13:05	0.9
P1	0.0036	6.5	01Jan2050, 13:05	0.5
J-O1P1	0.0096	17.2	01Jan2050, 13:05	1.4
O2	0.0049	9.4	01Jan2050, 13:05	0.7
P2	0.0043	9.1	01Jan2050, 13:00	0.6
J-O2P2	0.0188	35.1	01Jan2050, 13:05	2.8

TABLE 3
FLOW RESULTS FROM HEC-HMS

GRE CCS AP91
Surface Water Calculations
PROJECT NO.: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

HEC-HMS Basin Model:	AP91finalcover
HEC-HMS Met. Model:	100 Year, 24 Hour
HEC-HMS Control Specs:	36 Hour, 5 Minute

Hydrologic Element	Drainage Area (sq mile)	Peak Discharge (cfs)	Time of Peak	Total Volume (ac-ft)
O3	0.0047	10.2	01Jan2050, 13:00	0.7
P3	0.0035	7.9	01Jan2050, 13:00	0.5
J-O3P3	0.027	50.9	01Jan2050, 13:05	4
O4	0.0048	11	01Jan2050, 13:00	0.7
O5	0.003	6.6	01Jan2050, 13:00	0.4
P4	0.0018	4.3	01Jan2050, 13:00	0.3
J-O5P5	0.0366	72.3	01Jan2050, 13:00	5.4
Q3	0.0021	5	01Jan2050, 13:00	0.3
Q2	0.0013	3.1	01Jan2050, 13:00	0.2
Q1	0.0007	1.7	01Jan2050, 13:00	0.1
J-Q2	0.002	4.8	01Jan2050, 13:00	0.3
J-Q3	0.0041	9.8	01Jan2050, 13:00	0.6
Q4	0.0004	1	01Jan2050, 12:55	0.1
J-Q4	0.0045	10.7	01Jan2050, 13:00	0.7
P5	0.0008	1.9	01Jan2050, 12:55	0.1
J-QP	0.0053	12.6	01Jan2050, 13:00	0.8
J-QOP	0.0419	85	01Jan2050, 13:00	6.2
S-OP	0.0419	85	01Jan2050, 13:00	6.2
S1	0.0072	12.7	01Jan2050, 13:05	1.1
S2	0.0046	8.9	01Jan2050, 13:05	0.7
R1	0.0015	3.5	01Jan2050, 13:00	0.2
J-S1R1S2	0.0133	24.2	01Jan2050, 13:05	2
S3	0.0034	7.7	01Jan2050, 13:00	0.5
R2	0.003	7.1	01Jan2050, 13:00	0.4
J-R2S3	0.0197	37.1	01Jan2050, 13:00	2.9
R3	0.006	13.6	01Jan2050, 13:00	0.9
R4	0.0056	11	01Jan2050, 13:05	0.8
S4	0.0034	7.9	01Jan2050, 13:00	0.5
S5	0.0011	2.6	01Jan2050, 13:00	0.2
J-R4S5	0.0358	71.9	01Jan2050, 13:00	5.3
S-RS	0.0358	71.9	01Jan2050, 13:00	5.3

TABLE 4
CHANNEL HYDRAULIC CALCULATIONS

GRE CCS AP91
Surface Water Calculations
PROJECT NO.: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

			Channel Design Geometry					Channel Roughness Parameters				Hydraulic Calculations					
Reach Designation	Q100 from HEC-HMS (cfs)	HEC HMS Element ID for Q	Bed Slope (ft/ft)	Left Side Slope (H:1V)	Right Side Slope (H:1V)	Bottom Width (ft)	Minimum Channel Depth (ft)	Design Channel Lining		Mannings 'n' for Capacity (Depth Calculation)	Mannings 'n' for Stability (Velocity Calculation)	Maximum Velocity (ft/sec)	Maximum Normal Flow Depth (ft)	Froude Number	Top Width of Flow (ft)	Top Width of Channel (ft)	Available Freeboard (ft)
Terrace Channels																	
RC1	15.2	C1	0.020	6.7	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.6	0.94	0.92	9.1	19.4	1.1
RC1	15.2	C1	0.010	20.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	2.2	0.77	0.64	17.7	46.0	1.2
RC2	9.1	C2	0.020	6.7	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.1	0.77	0.89	7.5	19.4	1.2
RC3	9.1	C3	0.020	4.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.4	0.88	0.90	6.1	14.0	1.1
RC4	11.2	C4	0.020	4.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.6	0.95	0.91	6.6	14.0	1.1
RC5	5.7	C5	0.010	4.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	2.3	0.84	0.63	5.9	14.0	1.2
RD1	15.9	D1	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	3.6	0.95	0.92	9.2	19.4	1.0
RD1	15.9	D1	0.010	3.0	20.0	0	2.0	G	Grass-lined	0.035	0.030	2.3	0.78	0.64	18.0	46.0	1.2
RD2	9.6	D2	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	3.2	0.79	0.89	7.6	19.4	1.2
RD3	9.2	D3	0.020	3.0	4.0	0	2.0	G	Grass-lined	0.035	0.030	3.4	0.88	0.90	6.2	14.0	1.1
RD4	12.8	D4	0.020	3.0	4.0	0	2.0	G	Grass-lined	0.035	0.030	3.7	1.00	0.92	7.0	14.0	1.0
RD5	6.2	D5	0.010	3.0	4.0	0	2.0	G	Grass-lined	0.035	0.030	2.4	0.86	0.64	6.1	14.0	1.1
RN1	17.3	N1	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	3.7	0.98	0.93	9.5	19.4	1.0
RN1	17.3	N1	0.010	3.0	20.0	0	2.0	G	Grass-lined	0.035	0.030	2.3	0.81	0.64	18.6	46.0	1.2
RN2	15.0	N2	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	3.6	0.93	0.92	9.0	19.4	1.1
RN3	13.3	N3	0.020	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	3.6	0.96	0.92	7.7	16.0	1.0
RN4	15.7	N4	0.020	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	3.8	1.02	0.93	8.2	16.0	1.0
RO1	10.7	O1	0.020	6.7	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.3	0.82	0.90	8.0	19.4	1.2
RO1	10.7	O1	0.010	20.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	2.0	0.67	0.62	15.5	46.0	1.3
RO2	9.4	O2	0.020	6.7	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.2	0.78	0.89	7.6	19.4	1.2
RO3	10.2	O3	0.020	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.4	0.87	0.90	6.9	16.0	1.1
RO4	11.0	O4	0.020	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.4	0.89	0.91	7.1	16.0	1.1
RP1	6.5	P1	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	2.9	0.68	0.87	6.6	19.4	1.3
RP1	6.5	P1	0.010	3.0	20.0	0	2.0	G	Grass-lined	0.035	0.030	1.8	0.56	0.60	12.9	46.0	1.4
RP2	9.1	P2	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	3.1	0.77	0.89	7.5	19.4	1.2
RP3	7.9	P3	0.020	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	3.2	0.79	0.89	6.3	16.0	1.2
RP4	4.3	P4	0.020	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	2.7	0.63	0.86	5.0	16.0	1.4
RR1	3.5	R1	0.020	6.7	3.0	0	2.0	G	Grass-lined	0.035	0.030	2.5	0.54	0.84	5.2	19.4	1.5
RR2	7.1	R2	0.020	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.1	0.76	0.88	6.1	16.0	1.2
RR3	13.6	R3	0.020	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.6	0.97	0.92	7.7	16.0	1.0
RS1	12.7	S1	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	3.4	0.88	0.91	8.5	19.4	1.1
RS1	12.7	S1	0.010	3.0	20.0	0	2.0	G	Grass-lined	0.035	0.030	2.1	0.72	0.63	16.5	46.0	1.3
RS2	8.9	S2	0.020	3.0	6.7	0	2.0	G	Grass-lined	0.035	0.030	3.1	0.77	0.89	7.4	19.4	1.2
RS3	7.7	S3	0.020	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	3.2	0.78	0.89	6.3	16.0	1.2
RS4	7.9	S4	0.020	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	3.2	0.79	0.89	6.3	16.0	1.2
RT1	14.5	T1	0.020	6.7	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.5	0.92	0.92	8.9	19.4	1.1
RT1	14.5	T1	0.010	20.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	2.2	0.76	0.63	17.4	46.0	1.2
RT2	11.8	T2	0.020	6.7	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.4	0.85	0.91	8.3	19.4	1.1
RT3	9.3	T3	0.020	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.3	0.84	0.90	6.7	16.0	1.2
RT4	9.8	T4	0.020	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	3.3	0.86	0.90	6.8	16.0	1.1

Note: Side slopes for downchutes measured in line with flow.

TABLE 4
CHANNEL HYDRAULIC CALCULATIONS

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

Reach Designation	Q100 from HEC-HMS (cfs)	HEC HMS Element ID for Q	Channel Design Geometry: Bed Slope (ft/ft)	Left Side Slope (H:1V)	Right Side Slope (H:1V)	Bottom Width (ft)	Minimum Channel Depth (ft)	Channel Roughness Parameters: Design Channel Lining		Mannings 'n' for Capacity (Depth Calculation)	Mannings 'n' for Stability (Velocity Calculation)	Hydraulic Calculations: Maximum Velocity (ft/sec)	Maximum Normal Flow Depth (ft)	Froude Number	Top Width of Flow (ft)	Top Width of Channel (ft)	Available Freeboard (ft)
Downchute and Outlet Channels																	
NC DOWN 1	32.5	J-N1C1	0.110	4.0	4.0	10	2.0	A	ACB	0.026	0.026	8.5	0.34	2.73	12.7	26.0	1.7
NC DOWN 2	56.7	J-N2C2J1	0.180	4.0	4.0	10	2.0	A	ACB	0.026	0.026	12.1	0.40	3.59	13.2	26.0	1.6
NC DOWN 3	76.8	J-N3C3J2	0.180	4.0	4.0	10	2.0	A	ACB	0.026	0.026	13.4	0.48	3.68	13.8	26.0	1.5
NC OUT	109.2	J-N5C5J4	0.360	4.0	4.0	12	2.0	A	ACB	0.026	0.026	18.2	0.44	5.15	15.5	28.0	1.6
OP DOWN 1	17.2	J-O1P1	0.110	4.0	4.0	10	2.0	A	ACB	0.026	0.026	6.8	0.23	2.58	11.9	26.0	1.8
OP DOWN 2	35.1	J-O2P2	0.140	4.0	4.0	10	2.0	A	ACB	0.026	0.026	9.4	0.33	3.07	12.6	26.0	1.7
OP DOWN 3	50.9	J-O3P3	0.140	4.0	4.0	10	2.0	A	ACB	0.026	0.026	10.7	0.41	3.17	13.3	26.0	1.6
OP OUT	85.0	S-OP	0.320	4.0	4.0	12	2.0	A	ACB	0.026	0.026	16.0	0.39	4.78	15.1	28.0	1.6
RS DOWN 1	12.7	S1	0.150	4.0	4.0	10	2.0	A	ACB	0.026	0.026	6.7	0.18	2.89	11.4	26.0	1.8
RS DOWN 2	24.2	J-S1R1S2	0.200	4.0	4.0	10	2.0	A	ACB	0.026	0.026	9.3	0.24	3.50	11.9	26.0	1.8
RS DOWN 3	37.1	J-R2S3	0.200	4.0	4.0	10	2.0	A	ACB	0.026	0.026	10.8	0.31	3.63	12.4	26.0	1.7
RS OUT	71.9	J-R4S5	0.310	4.0	4.0	12	2.0	A	ACB	0.026	0.026	15.0	0.36	4.64	14.9	28.0	1.6
TD DOWN 1	30.4	J-T1D1	0.110	4.0	4.0	10	2.0	A	ACB	0.026	0.026	8.3	0.32	2.71	12.6	26.0	1.7
TD DOWN 2	51.7	J-T2D2J1	0.180	4.0	4.0	10	2.0	A	ACB	0.026	0.026	11.7	0.38	3.56	13.1	26.0	1.6
TD DOWN 3	67.9	J-T3D3J2	0.180	4.0	4.0	12	2.0	A	ACB	0.026	0.026	12.3	0.41	3.60	15.2	28.0	1.6
TD OUT	93.7	J-T5D5J4	0.400	4.0	4.0	12	2.0	A	ACB	0.026	0.026	17.8	0.39	5.33	15.1	28.0	1.6
Perimeter Channels																	
RN5	5.6	N5	0.010	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	2.5	0.79	0.73	6.3	16.0	1.2
RO5	6.6	O5	0.010	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	2.6	0.84	0.73	6.7	16.0	1.2
RP5	12.6	J-QP	0.010	3.0	5.0	0	2.5	G	Grass-lined	0.035	0.030	3.1	1.07	0.76	8.6	20.0	1.4
RR4	11.0	R4	0.010	5.0	3.0	0	2.5	G	Grass-lined	0.035	0.030	3.0	1.02	0.76	8.1	20.0	1.5
RS5	2.6	S5	0.010	3.0	5.0	0	2.0	G	Grass-lined	0.035	0.030	2.1	0.59	0.69	4.7	16.0	1.4
RT5	2.6	T5	0.010	5.0	3.0	0	2.0	G	Grass-lined	0.035	0.030	2.1	0.59	0.69	4.7	16.0	1.4
Access Road Channels																	
RQ1	1.7	Q1	0.070	3.0	3.0	0	1.5	G	Grass-lined	0.035	0.030	4.1	0.39	1.69	2.4	9.0	1.1
RQ2	4.8	J-Q2	0.070	3.0	3.0	0	2.0	T	Turf Reinf.	0.035	0.030	5.3	0.58	1.80	3.5	12.0	1.4
RQ3	9.8	J-Q3	0.070	3.0	3.0	0	2.0	T	Turf Reinf.	0.035	0.030	6.4	0.76	1.88	4.5	12.0	1.2
RQ4	10.7	J-Q4	0.070	3.0	3.0	0	2.0	T	Turf Reinf.	0.035	0.030	6.5	0.78	1.89	4.7	12.0	1.2

Note: Side slopes for downchutes measured in line with flow.

TABLE 5
HYDRAULIC JUMP (STILLING BASIN) CALCULATIONS

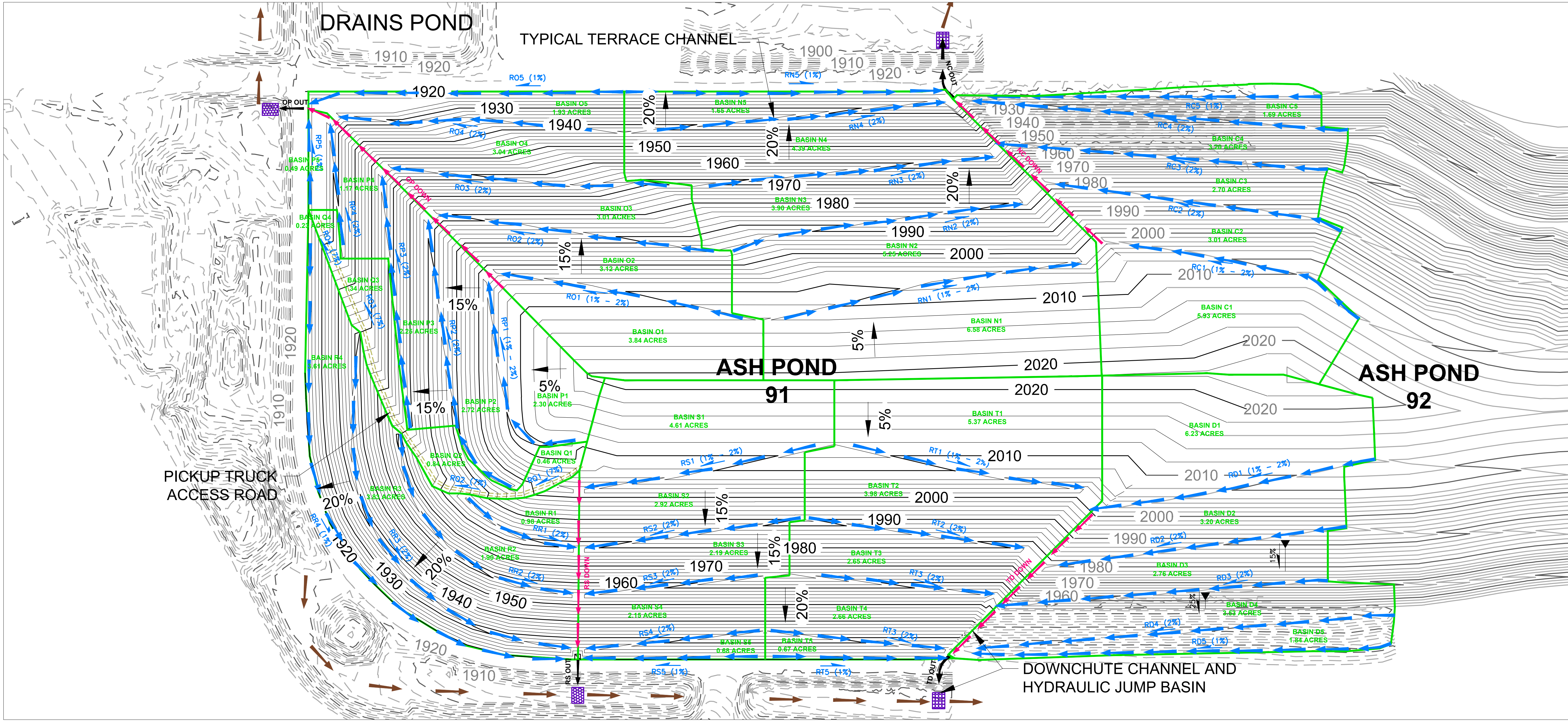
GRE CCS AP91
Surface Water Calculations
PROJECT NO.: 1400644

Date:	2/17/15
By:	SCA
Chkd:	CCS
Apprvd:	TJS

			Channel Configuration							Hydraulic Calculations						
Reach Designation	**Q100 from HEC-HMS (cfs)**	**HEC HMS Element ID for Q**	**Bed Slope (ft/ft)**	**Left Side Slope (H:1V)**	**Right Side Slope (H:1V)**	**Bottom Width (ft)**	**Maximum Channel Depth (ft)**	**Mannings 'n' for Capacity (Depth Calculation)**	**Mannings 'n' for Stability (Velocity Calculation)**	**Maximum Velocity (ft/sec)**	**Maximum Normal Flow Depth (ft)**	**Normal Depth with Velocity 'n' (ft)**	**Froude Number**	**Conjugate Depth (ft)**	**L/d2 Ratio**	**Minimum Length of Jump (ft)**
NC OUT	109.2	J-N5C5J4	0.36	4	4	12	2	0.026	0.026	18.2	0.44	0.44	5.15	2.79	6.07	16.9
TD OUT	93.7	J-T5D5J4	0.40	4	4	12	2	0.026	0.026	17.8	0.39	0.39	5.33	2.58	6.09	15.7
OP OUT	85	S-OP	0.32	4	4	12	2	0.026	0.026	16.0	0.39	0.39	4.78	2.31	6.00	13.9
RS OUT	71.9	J-R4S5	0.31	4	4	12	2	0.026	0.026	15.0	0.36	0.36	4.64	2.06	5.97	12.3

Note: Side slopes for downchutes measured in line with flow.

FIGURES



LEGEND

1910	EXISTING GROUND TOPOGRAPHY (SEE REFERENCE 2)
2000	DESIGN TOP OF FINAL COVER GRADES (ASH POND 92 AND SW SECTION 16 UPSTREAM RAISE)
1960	PROPOSED TOP OF FINAL COVER GRADES (ASH POND 91 UPSTREAM RAISE)
	PICKUP TRUCK ACCESS ROAD
	HYDRAULIC JUMP BASIN
	BASIN DELINEATION
	TERRACE CHANNELS
	DOWNCHUTE CHANNELS
	OUTLET CHANNELS
	EXISTING OFF-SITE DRAINAGE

Ash Pond 91 is now referred to as Upstream Raise 91,
Ash Pond 92 is now referred to as Upstream Raise 92 (10/13/2021).

N

0 300 600 Feet

GREAT RIVER ENERGY
COAL CREEK STATION
UNDERWOOD, NORTH DAKOTA

SURFACE WATER BASIN LAYOUT

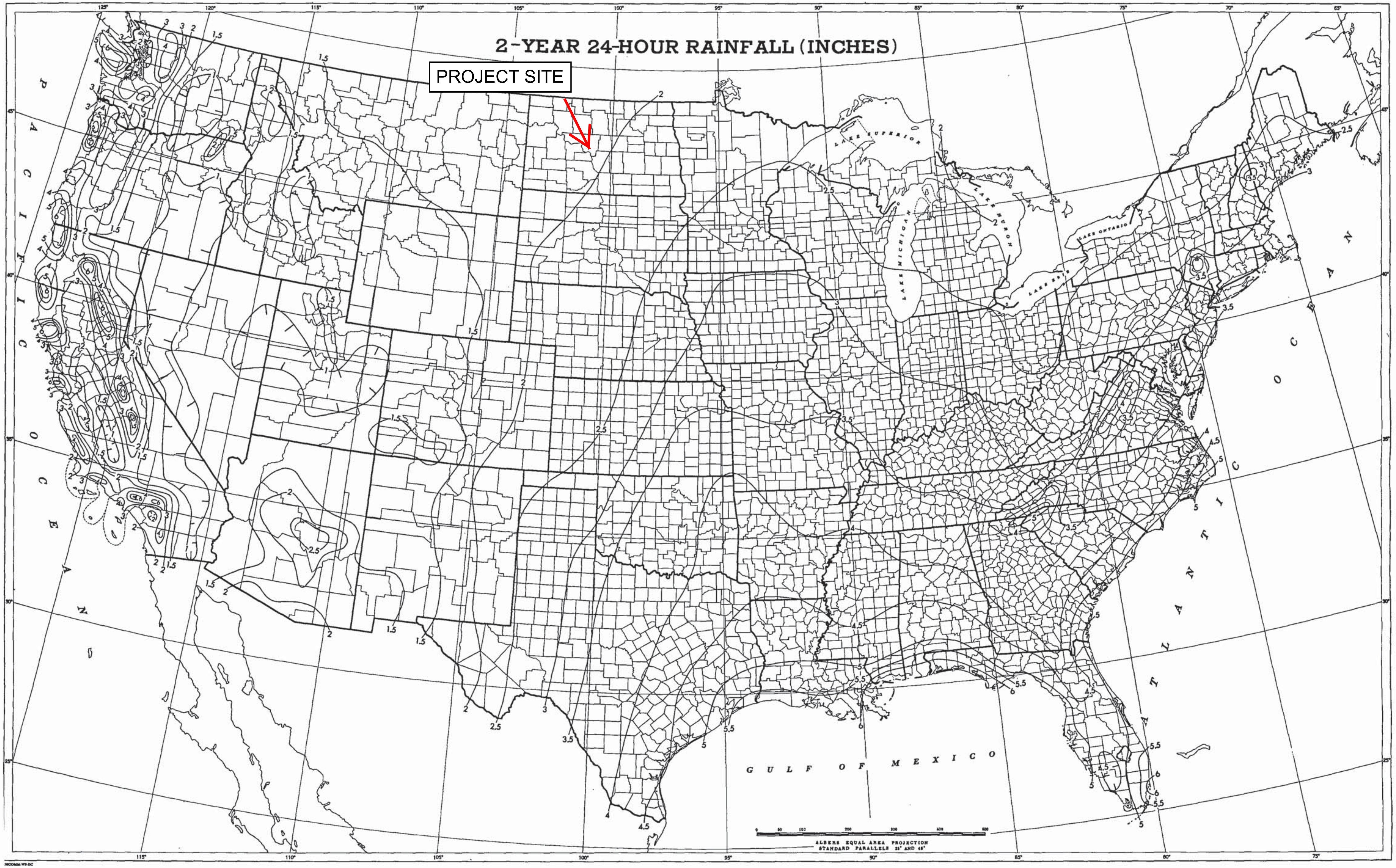
FIGURE 1

Golder Associates

Path: \\Denver.golder.gds\gal\projects\14JOBS\1400644 - GRE\Ash Pond 91_Appendix C\C-7 Surface Water\ | File Name: AP91 H&H june2014.dwg

ATTACHMENT A

RAINFALL FREQUENCY ATLAS (TP-40) –
100-YEAR, 24-HOUR RAINFALL AND
2-YEAR, 24-HOUR RAINFALL


2-YEAR 24-HOUR RAINFALL (INCHES)
PROJECT SITE
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


100-YEAR 24-HOUR RAINFALL (INCHES)
PROJECT SITE
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

ATTACHMENT B

TIME OF CONCENTRATION CALCULATION EQUATIONS AND COEFFICIENTS

ATTACHMENT B
TIME OF CONCENTRATION AND MANNING'S FLOW COEFFICIENTS

TR-55 (1986)

Sheet Flow Travel time (SCS Upland Method)

$$T_t = \frac{0.007 \, (n' \, L)^{0.8}}{(P_2)^{0.5} \, s^{0.4}}$$

Where: T_t = travel time (hr); n' = roughness coefficient; L = flow length (ft);

P_2 = 2-yr storm depth (inches); s = slope (ft/ft)

flow velocity = L/(60T_t)

Flow Type	Surface Type	roughness n	Surface Description	Short Description
Sheet/Overland Flow	A	0.011	Fly Ash	Fly Ash
	B	0.05	Fallow (no residue)	Fallow
	C	0.06	Cultivated soils: Residue cover <= 20%	Cover<20%
	D	0.17	Cultivated soils: Residue cover > 20%	Cover>20%
	E	0.15	Grass: Short grass prairie	Short Grass
	F	0.24	Grass: Dense grasses	Dense Grass
	G	0.41	Grass: Bermuda grass	Bermuda Grass
	H	0.13	Range (natural)	Range
	I	0.40	Woods: Light underbrush	Light woods
	J	0.80	Woods: Heavy underbrush	Heavy Woods

Shallow Concentrated Flow Velocity (SCS Upland Method)

$v = mS^{0.5}$

Where: v = velocity (fps); m = roughness coeffient; S = slope (ft/ft)

Flow Type	Surface Type	Roughness m	Surface Description	Short Description
Shallow Conc. Flow	P	20.3282	Paved Surfaces	Paved
	U	16.1345	Unpaved Surfaces	Unpaved

Channel Flow Velocity (Mannings Velocity)

$v = 1.49/n \, Rh^{2/3} S^{1/2}$

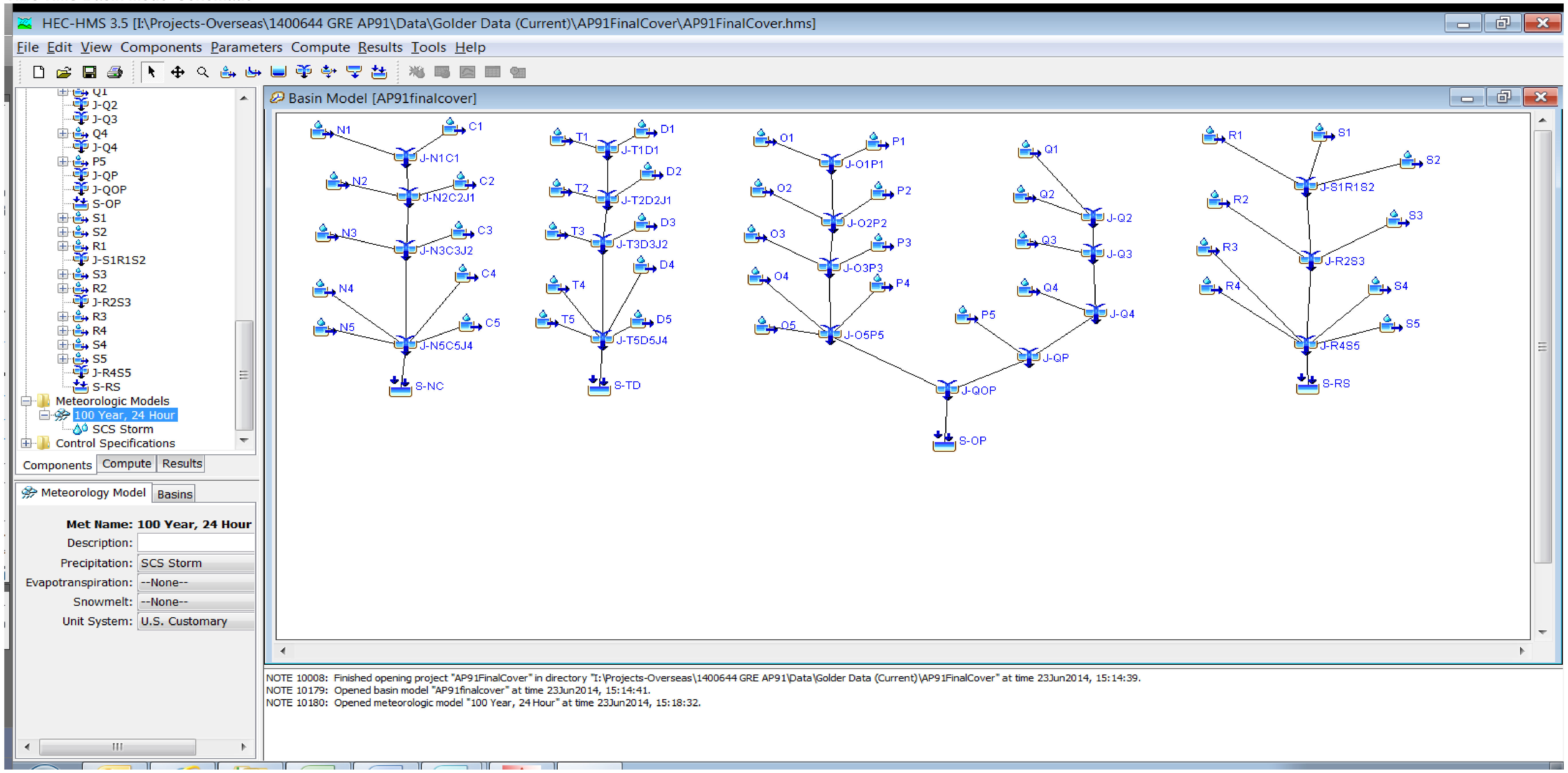
Where: v = velocity (fps); n = roughness coeffient; Rh = Hydraulic Radius (ft), S = slope (ft/ft)

Lining Type	Mannings n for Depth	Mannings n for Velocity	Material	Maximum Velocity	Maximum Shear Stress
A	0.026	0.026	ACB	25	
C	0.024	0.022	CSP	50	
E	0.025	0.022	Earth-lined	3	
G	0.035	0.030	Grass-lined	5	
I	0.017	0.013	Ductile Iron	50	
P	0.012	0.009	Plastic	25	
R	0.040	0.035	Riprap	16	
T	0.035	0.030	Turf Reinf.	10	1.5
Z	0.058	0.026	Flexamat	19	24

ATTACHMENT C

HEC-HMS SCREEN CAPTURES AND INPUTS

HEC-HMS Basin Model Schematic



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