October 28, 2020
Preliminary Hydrologic &
Hydraulic Assessment
High Top Solar Project, Yakima County
Washington

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Table 1: Table of Data Sources

Data Type	Data Source
Elevation Data	National Map Data Elevation Mapping – 1 arc second
Rainfall	NOAA Atlas 2 Rainfall Data, taken at the centroid of each basin
Soils Data	NRCS/SSURGO Soils Information
Flood Zones	FEMA Firm Panels and Shapefiles
Land Use	USDA Shapefiles

Introduction

On behalf of High Top Solar, LLC Sierra Overhead Analytics, Inc (SOA) has prepared this hydrology report (report) for the High Top Solar Project, located in Yakima County, Washington. This report summarizes the results of the hydrology study which was performed to assess peak flows and flood risk across the project site. A rainfall-runoff model was developed using HEC-HMS to determine the impacts from a 100-year recurrence interval storm event. A two-dimensional (2D) hydraulic model was developed for the 100-year storm using HEC-RAS rain on grid modeling to assess on-site depth and velocity during a large storm. Publicly available rainfall data, United States Department of Agriculture (USDA) SSURGO database soils data, land use mapping, and United States Geological Survey (USGS) digital elevation mapping (DEM) topographic data was used to delineate the watersheds and to approximate runoff volumes across the project area. The methods used in this report generally follow the guidelines of the National Resource Conservation Service (NRCS), and HEC documentation. Relevant excerpts are contained in **Appendix A.**

1. Site Description/Existing Conditions

The site is in Yakima County approximately ten miles southwest of Desert Aire, Washington, is bounded to the south by State Route 24 and surrounded by range land and agricultural land. The approximate center point of the project is located at: 46.549806°N, -120.219261°W. The project site is primarily agricultural/range land that appears to be well kept and is oriented on a generally south-facing hillside. Multiple small channels are evident in satellite imagery and hydraulic modeling results. None of the man-made structures near the site appear to have a great effect on the hydraulics of the project site. The entirety of the project is located within a FEMA Zone X flood zone.

1.1. Pre-Development Drainage

The existing drainages are characterized by primarily agricultural/range land. The site model contains 8 sub-basins (4 on-site basins), which generally drain to the south or southwest. Channelized areas of flow are found on site as evidenced by modeled flow patterns and satellite imagery. The site is generally gradually sloping with some moderate to high velocity flow found

in the channelized portions of the site. Little ponding of water is shown in the models beyond mapped ponding locations.

The site falls entirely in FEMA Zone X – outside of the 100-year floodplain.

1.2. Site Soils

NRCS soils mapping and land use shows on site soils ranging from A to D, representing well-draining to poorly draining soil and low to high runoff potential when saturated. The average curve number for the site is approximately 70, meaning that of the approximate 2.2 inches of water that falls on the site during the 100-year return period storm, 1.5 inches will be excess flow that will impact onsite and downstream structures. Within the site boundaries, erosion potential appears to be low to moderate based on computational modeling. A list of soils types has been included in Table 1. Soil Conservation Service area-weighted curve numbers ranged from 63-74, as shown in Appendix 2.

1.3. Topography

Due to the size of the basins affecting the construction location, SOA utilized National Map Data to create the model domain. The site has general southern exposure, with all basins draining to the south or southwest.

Table 2: Basin Soil Types

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
3	Bakeoven very cobbly silt loam, 0 to 30 percent slopes	19.7	1.10%
36	Finley cobbly fine sandy loam, 0 to 5 percent slopes	13.8	0.80%
55	Harwood-Burke-Wiehl very stony silt loams, 15 to 30 percent slopes	23.3	1.40%
65	Kiona stony silt loam, 15 to 45 percent slopes	185.4	10.80%
68	Lickskillet very stony silt loam, 5 to 45 percent slopes	140.4	8.20%
83	Moxee silt loam, 2 to 15 percent slopes	134.4	7.90%
85	Moxee cobbly silt loam, 0 to 30 percent slopes	363.2	21.20%
102	Ritzville silt loam, 15 to 30 percent slopes	23.6	1.40%
104	Ritzville silt loam, basalt substratum, 0 to 5 percent slopes	38.6	2.30%
105	Ritzville silt loam, basalt substratum, 5 to 15 percent slopes	99.4	5.80%
130	Selah silt loam, 8 to 15 percent slopes	60.5	3.50%
177	Warden silt loam, 2 to 5 percent slopes	7.7	0.40%
187	Willis silt loam, 2 to 5 percent slopes	20.8	1.20%
189	Willis silt loam, 8 to 15 percent slopes	578.5	33.80%
208	Kiona stony silt loam, 15 to 45 percent slopes	0.3	0.00%
209	Lickskillet very stony silt loam, 5 to 45 percent slopes	0.7	0.00%
Totals for Area of Interest		**1710.20**	100%

2. <u>Methods</u>

2.1. Computational Hydrologic Modeling

HEC-1 modeling software was used to calculate the rainfall-runoff hydrographs for the basins. Pre-construction and post-construction HEC-1 models were created and run for 100-year return period storm. It should be noted that upon final design the engineer of record shall establish that the selected BMP and other water quantity and quality measures adhere to the standards set forth by the governing AHJ. No specific requirements could be found for this area of Washington for the purpose of this model.

2.1.1. Basin Delineation

Basins impacting the site were delineated using TOPAZ software, ARCGIS basin delineation mapping, and National Map Data Publicly Available Data. For the purpose of one-dimensional hydrologic routing, six basins were delineated across the site. Locations and boundaries of the basins are shown in Figure 4. Shapefiles of the basin outlines and 1D flow centerlines are available upon request. "No Basin" data was created for one small catchment in order to route

the model accurately at the downstream boundary. This data does not affect any other portions of the model.

2.1.2. Rainfall

Rainfall depth was determined at the centroid of each basin through NOAA ATLAS 2. Given the nature of the mapping, the entire site was modeled to receive 1.5" of rainfall in the 100-year 24-hour event. Rainfall for each basin was temporally distributed through use of the Type-II, 24-hour storm. The basins' main characteristics (e.g. area, curve numbers) are shown in **Table 2**. Full information about each basin is given in **Appendix B.**

Table 3: Basin Drainage Data

Basin	3B	4B	5B	11B	15B	16B	17B
Area (mi^2)	**3.229**	**2.745**	**0.753**	**0.169**	**0.336**	**27.501**	0.734
Pre-CN	71.41	70.90	72.23	64.56	63.39	70.97	74.13

For this site, it is anticipated that the solar arrays will be spaced accordingly for evaluation as a pervious surface and that native vegetation will largely remain or be replanted at the end of construction. Therefore, an estimate for only gravel roads and concrete pads was considered for the post-construction impervious percentage for all basins. Further investigation of the final site layout should be undertaken before a final pervious/non-pervious areal estimate for the system is made.

2.1.3. Curve Numbers

Basin curve numbers for the existing condition were determined using SSURGO soils data and USDA land use data. Composite curve numbers were determined from percent areas of each soil type / land use combination, typical values for which are available in TR-55 **Appendix A**. The soil curve numbers used were estimated according to NRCS method as per TR-55. The pre-construction conditions assumed zero impervious area unless otherwise stated in the detailed curve number calculation, **Appendix B**. Post-construction curve numbers are discussed in the previous section. The current curve numbers are approximations, and will be verified by site geotechnical reports.

2.1.4. Time of Concentration

Lag time was calculated using the SCS Unit Hydrograph method, the equation for which is:

$$T_{lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900\,(\%Slope)^{0.5}}$$

L is the longest drainage path in feet, S = (1000/CN)-10, CN is SCS curve number, and %Slope is the average slope of the watershed, determined through topographic analysis. Time of Concentration is determined by dividing Lag Time by 0.6.

2.1.5. Antecedent Moisture Condition

Antecedent Moisture condition (AMC) is defined by the USDA as the preceding relative moisture of the pervious surfaces prior to the rainfall event. The "average" AMC-II condition was used for the site. This resulted in no modification to the curve numbers calculated in Section 4.1.3.

2.2. 2D Hydraulic Modeling

A 2D hydraulic model was developed for the 100-year storm event to model maximum depths and velocities across the site for the pre-construction scenario. The chosen modeling software was HEC-RAS. Grid cells of 40 feet by 40 feet were used for the model. Topography was interpolated to the grid cells based on the LiDAR data also used to delineate and route the one-dimensional flood waves on Section 4.1. An average Manning's n value of 0.1 was assigned to each open area / cropland grid cell to represent a mix of croplands and light brush. Heavily forested areas and channels were assigned a Manning's n value of 0.085 to represent vegetation-lined channels as was observed on site. The 100-year rainfall return event was temporally distributed using the Type II curve and was used as in input to the rain-on-grid HEC-RAS model.

The two-dimensional set of equations was solved using the diffuse wave method. Stability was maintained through variable timestepping dictated by maximal and minimal Courant numbers (0.25 and 0.95, respectively). The small cell size dictated a small timestep, on average around 3.5 seconds.

Only excess rainfall was modeled as contributing to overland flow. Initial abstraction was calculated by the following equation, where λ is a fixed initial abstraction parameter (0.2) and CN is the average Curve Number of the site, estimated at 70 for this site:

$$I_a = \lambda \left(\frac{1000}{CN} - 10 \right) = 0.7 \; inches \; of \; water$$

3. <u>Discussion of Post Construction BMP</u>

As previously stated, this model and its results generally assume that the site is maintained, post-construction, to pre-construction levels and types of vegetative cover. The model results also assume that only gravel roads and concrete pads will be added to the sub basins as impervious surfaces.

No infiltration basins have been modeled. Given the assumptions listed above, increase to surface runoff is minimal to moderate, and should be able to be remediated using vegetative cover or lined channels therefore maximizing buildable area on site.

Final design and infiltration parameters shall be the responsibility of the Civil EOR chosen for the project.

4. <u>Results</u>

4.1. Computational Hydrologic Modeling

The results of the hydrologic modeling are discussed below. Without knowledge of the post construction site layout, no assumptions were made about pre-construction versus post-construction one-dimensional runoff beyond a small increase to the impervious area percentage for each basin. Final volumetric flowrate difference calculations can be determined once a final layout is chosen and provided for hydraulic modeling purposes.

4.2. 2D Hydraulic Model Results

4.2.1. Pre-Construction (Existing Condition)

The 100-year rainfall return event was temporally distributed using the Type II curve and was used as in input to the rain-on-grid HEC-RAS model to obtain the maximum depths and velocities anticipated in the 100-year event. HEC-RAS output for maximum depth, velocity, and scour is shown on Figures 1-3. Figure 4 shows the impacting drainage basins.

Scour depth was calculated using the methods of Chapter 7 of the HEC 18 Scour Manual. K1, K2, and K3 were calculated to be 1.1, 1.3, and 1.1 respectively, and a box pile of dimensions a=1/2' and L=1/3' were used. For simplicity, the angle of attack was assumed to be zero for all piles. The proper excerpt pages are included in Appendix B.

Channelized flow is apparent on site in natural flow concentration areas. Flow depths within these areas appear to reach just over 7 feet in the deepest part of the channels. Overland flow is negligible as enough channels exist on site to adequately drain most overland flow before it can pool. No ponding areas are visible within the site, nor is evidence of ponding found in the publicly available aerial images. The site is banded along topographic lines with very shallow overland flow, which is an artifact of the elevation data and modeling method. This data was not smoothed as to not artificially affect the results. Tiff surfaces are available upon request

Site flow velocities follow a similar pattern to flow depth onsite. Channelized flow sees velocities as high as 7 feet per second, while overland flow is generally very low velocity. Scour depth does

not exceed 2.0 feet and is limited to the naturally occurring channels. Generally, the soil matrix on site appears to be stable given the aerial images and model results, but further investigation in the form of a Geotechnical Site Investigation would be required before final determinations could be made. Overall, brushing, grading, and slope stabilization within the site may promote increased drainage, while minimizing site soil erosion. Offsite channels should be protected from scour if imperviousness is increased. SOA can run further 2D site models as grading plans are developed. Within the buildable area, flow velocity and erosion potential are not critical items of concern for this site. The site should remain stable under normal flow characteristics. Increased impervious areas can lead to further concentrated flow areas, and therefore a post-construction study should be undertaken before construction begins. Stabilization should be added to the pre-existing drainage structures in order to preserve their integrity.

Table 4 shows the anticipated increase in runoff due to PV installation. Results of the model run show an increase to effected basins, totaling approximately 1.3-acre feet, based on additional impervious area estimates. The methods used to determine this additional runoff volume rely on HEC-1 modeling of impervious area over the entire basin area. Once final grading plans are developed, individual onsite basins should be investigated for additional runoff volume due to additional impervious area. The developer and engineer of the project should account for this additional storage volume in their design.

Table 4: Basin Peak Flows and Volume Increases

Basin	Pre-construction Peak Q (cfs)	Post-construction Peak Q (cfs)	Percent Increase	Runoff Volume Difference (acre-ft)
3B	181.154	181.154	0.00%	0.0034
4B	145.72	145.72	0.00%	0.0035
5B	62.77	62.80	0.05%	0.0460
11B	4.81	4.81	0.17%	0.0098
14B	92.34	92.49	0.16%	0.7820
15B	6.25	6.28	0.41%	0.1440
17B	64.17	64.20	0.04%	0.3220

Assumptions
1. National Map data is adequate for 2D modeling purposes
2. The elevation data has been deemed appropriate for use in pre-construction 2D hydraulic modeling (HEC-RAS)
3. To the greatest extent practical this model represents ponding and flow conditions for excess rainfall occurring on the model surface. This model is an approximation of real-life flow conditions but is limited in its accuracy by the type and accuracy of its inputs. If future calibration data is gathered, the model can be rerun using the calibration data as inputs to check the viability and accuracy of the model.

FIGURES

High Top, LLC.

Sierra Overhead Analytics, Inc.
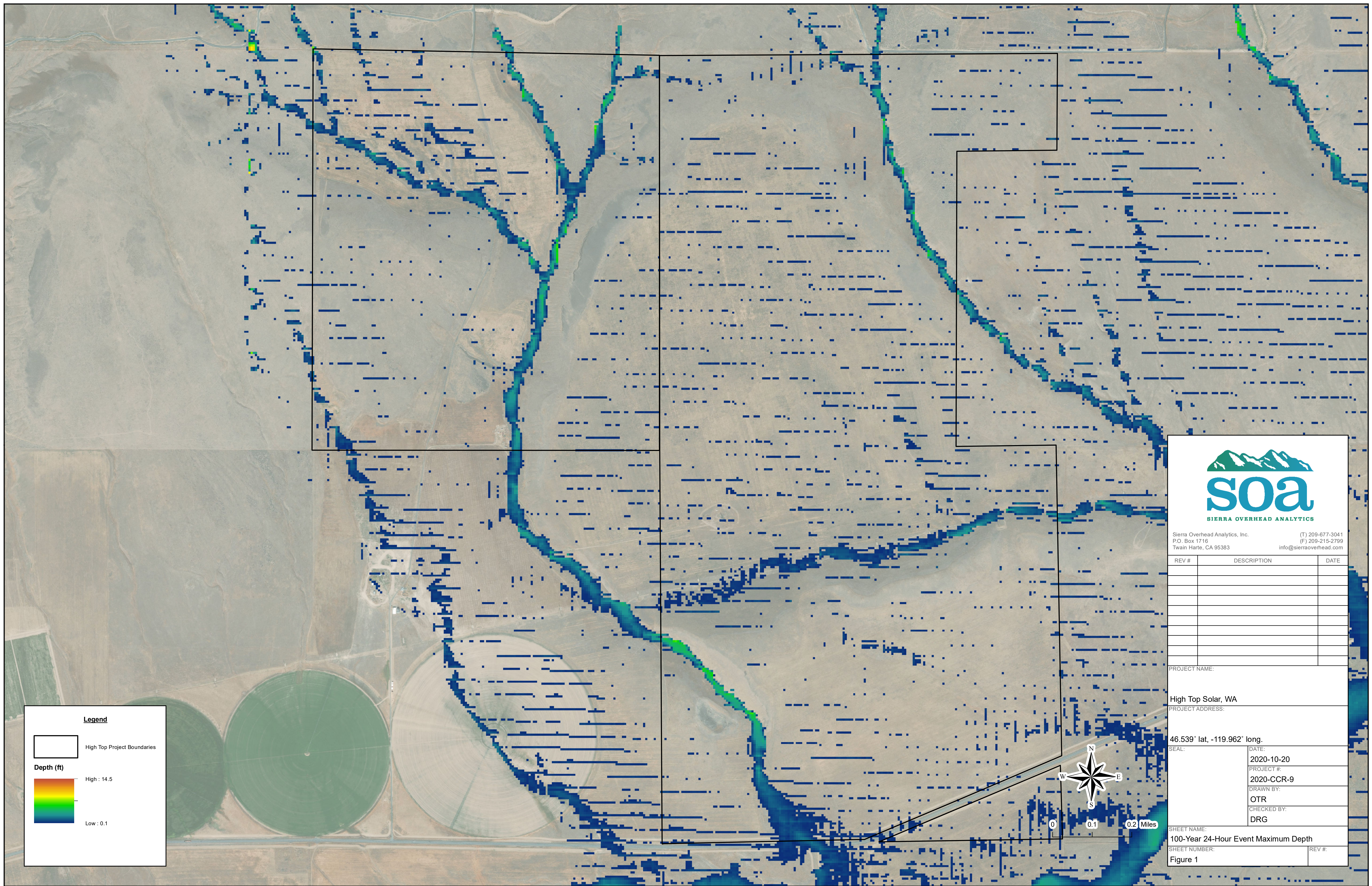
Legend

High Top Project Boundaries

Depth (ft)

High : 14.5

Low : 0.1

N
W E
S

0   0.1   0.2   Miles

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REV #	DESCRIPTION	DATE

PROJECT NAME:

High Top Solar, WA

PROJECT ADDRESS:

46.539˚ lat, -119.962˚ long.

SEAL:	DATE:
	2020-10-20
	PROJECT #:
	2020-CCR-9
	DRAWN BY:
	OTR
	CHECKED BY:
	DRG

SHEET NAME:

100-Year 24-Hour Event Maximum Depth

SHEET NUMBER: REV #:

Figure 1

Coordinate System: NAD 1983 2011 StatePlane Washington South FIPS 4602 Ft US   Basemap Source: ESRI   Land Ownership and PLSS Source: BLM   SEZ Source: Argonne National Laboratory

Legend

High Top Project Boundaries

Velocity (ft/sec)

High : 8.30

Low : 0.01

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PROJECT NAME:

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	DRAWN BY:
	OTR
	CHECKED BY:
	DRG

SHEET NAME:

100-Year 24-Hour Event Maximum Velocity

SHEET NUMBER:

Figure 2

REV #:

0   0.1   0.2 Miles

Legend

High Top Project Boundaries

Scour (ft)

High : 2.13

Low : 0.10

Figure 3

soa
SIERRA OVERHEAD ANALYTICS

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	2020-10-20
	PROJECT #:
	2020-CCR-9
	DRAWN BY:
	OTR
	CHECKED BY:
	DRG

SHEET NAME:

100-Year 24-Hour Event Maximum Scour Depth

SHEET NUMBER:	REV #:
Figure 3	

0　　0.1　　0.2 Miles

W N E S

Figure 4 — Sub-Watershed Basins

Map labels visible on figure: 3B, 4B, 1B, 2B, 7B, 10B, 8B, 5B, 12B, 6B, 9B, NO BASIN 11B, 14B, 13B, 16B, 17B, 15B

Legend

Ostrea Project Boundaries

High Top Project Boundaries

Figure 4

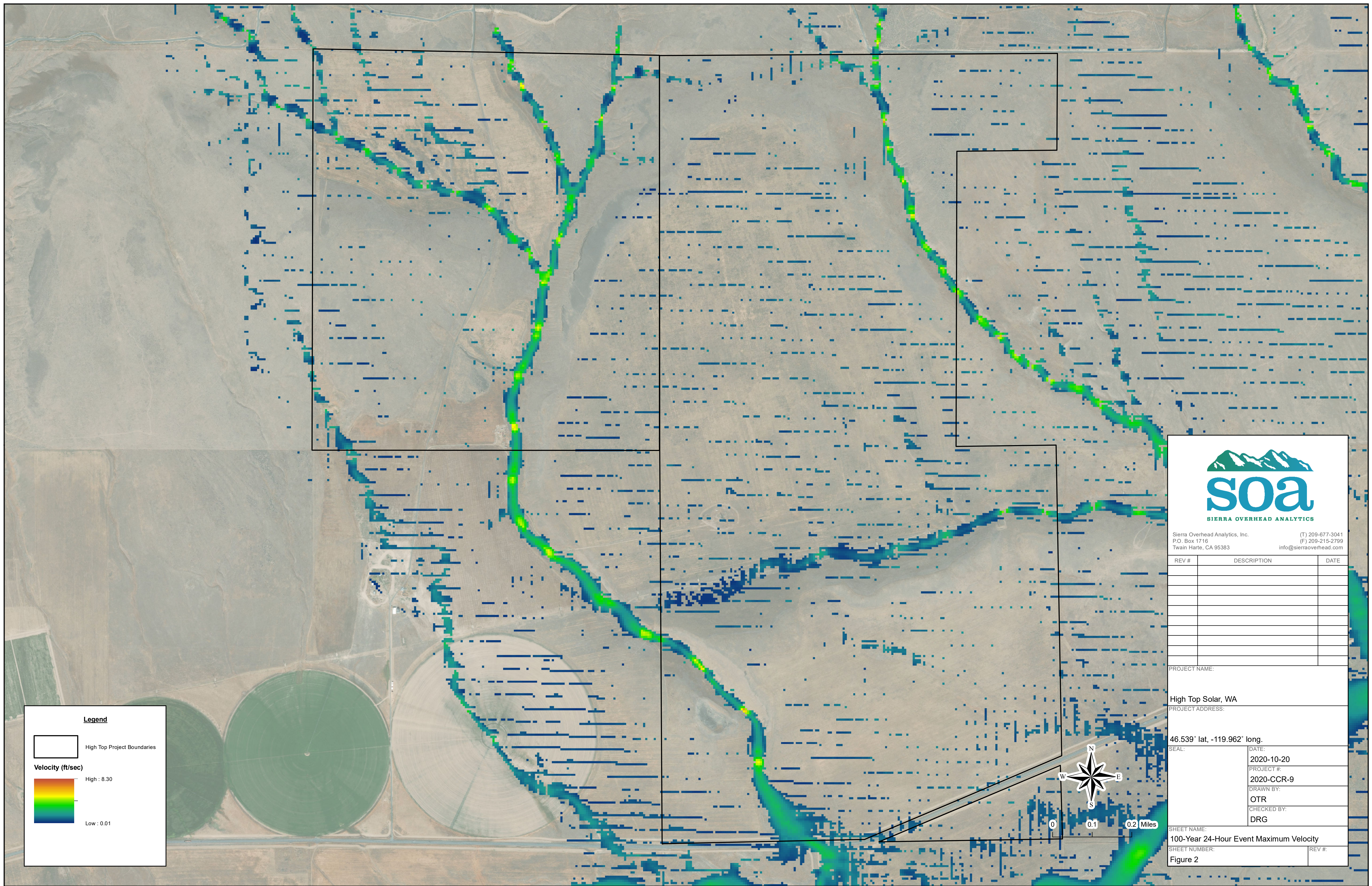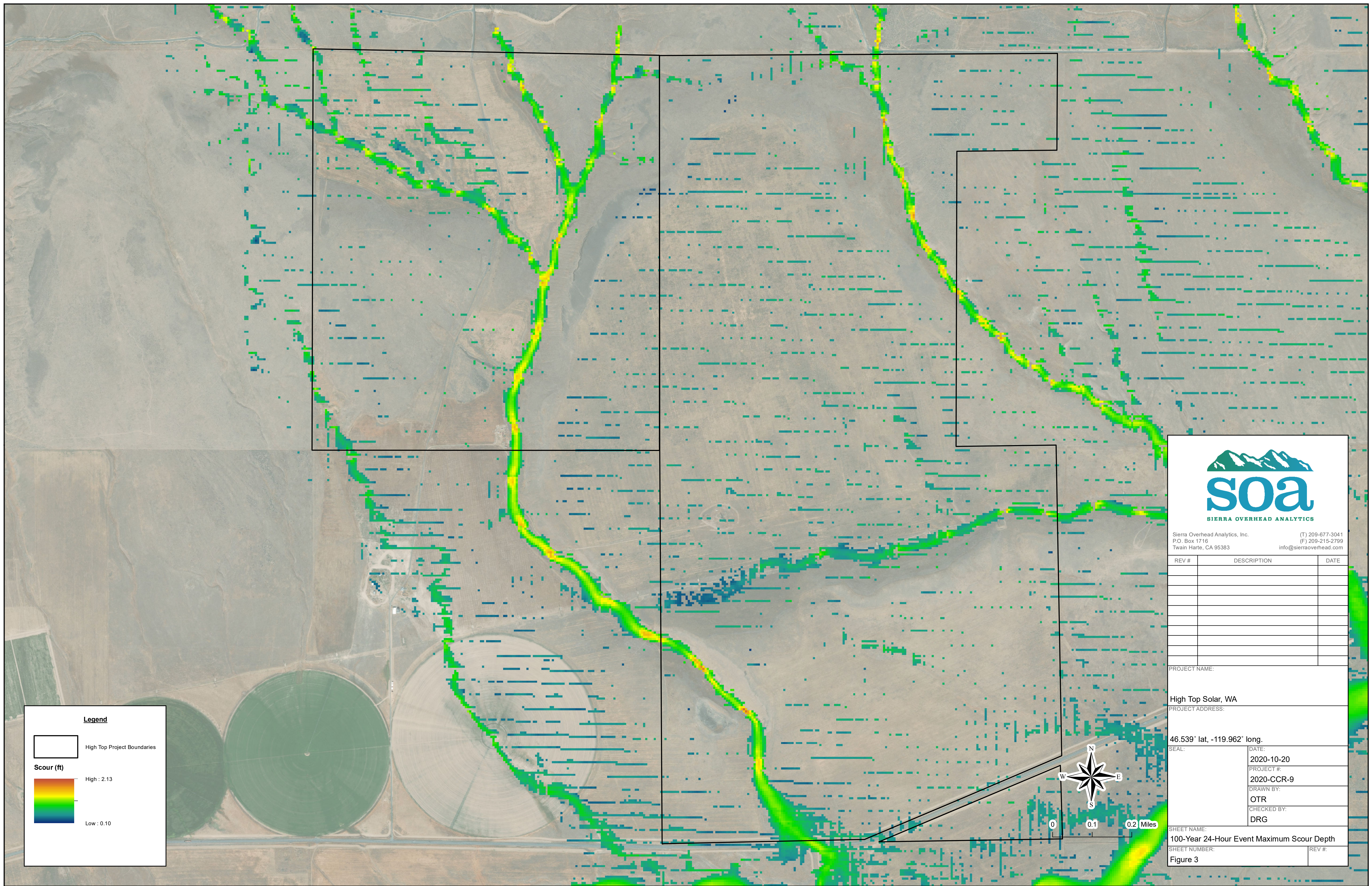| REV #	DESCRIPTION	DATE

PROJECT NAME:

High Top and Ostrea Solar, WA
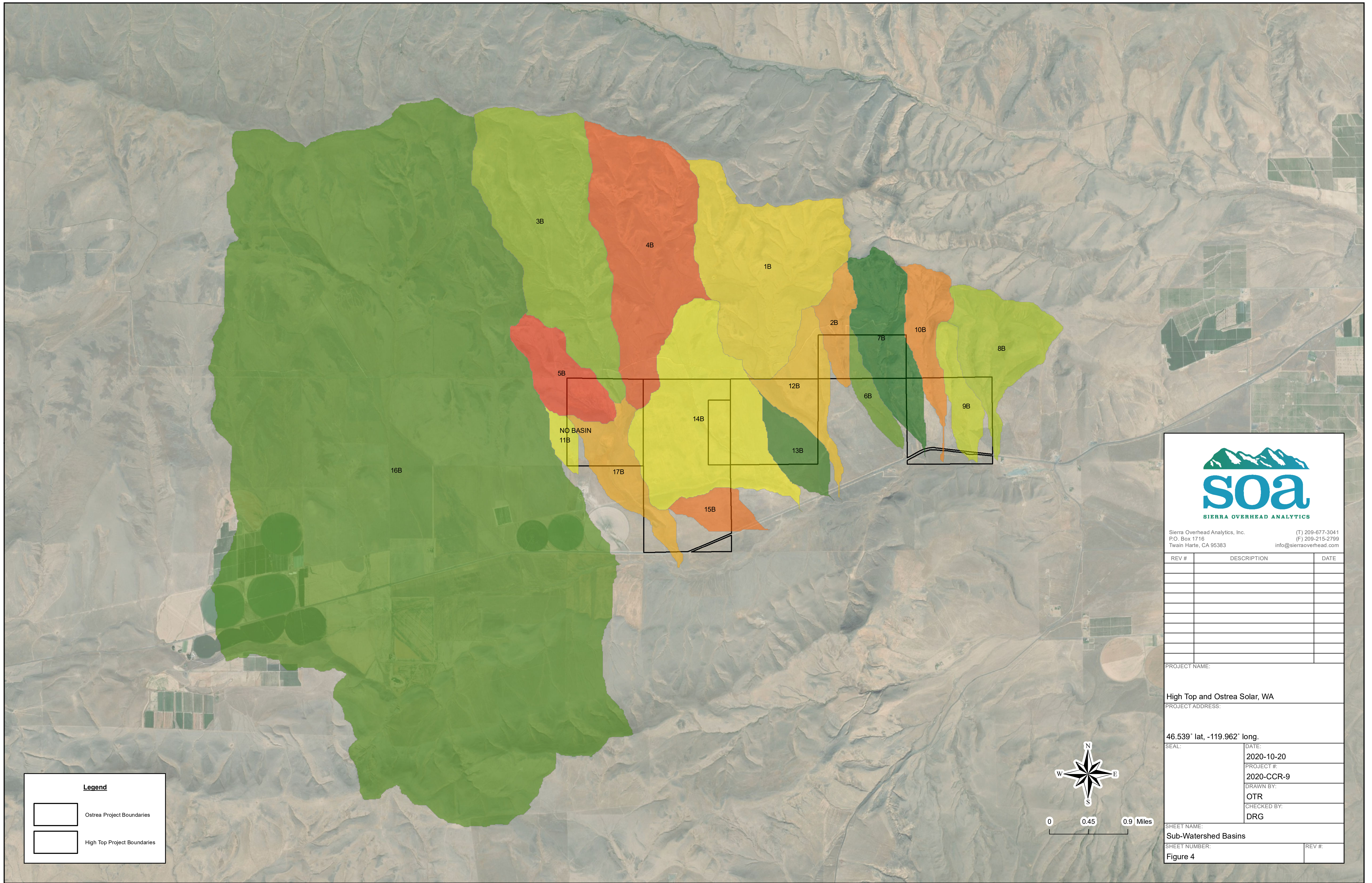
PROJECT ADDRESS:

46.539° lat, -119.962° long.

SEAL:

DATE:
2020-10-20

PROJECT #:
2020-CCR-9

DRAWN BY:
OTR

CHECKED BY:
DRG

SHEET NAME:
Sub-Watershed Basins

SHEET NUMBER:
Figure 4

REV #:

0   0.45   0.9 Miles

APPENDIX A

Supporting Documentation

Soils Mapping

FEMA Panels

Table 2-2a   Runoff curve numbers for urban areas [1]

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc.					
(excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding					
right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier,					
desert shrub with 1- to 2-inch sand or gravel mulch					
and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas					
(pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types					
similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2-2b   Runoff curve numbers for cultivated agricultural lands [1]

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition, and I_a=0.2S

[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

[3] Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

     Poor: Factors impair infiltration and tend to increase runoff.

     Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 2-2c   Runoff curve numbers for other agricultural lands [1]

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1]   Average runoff condition, and $I_a = 0.2S$.

[2]   *Poor:*   <50%) ground cover or heavily grazed with no mulch.
    Fair: 50 to 75% ground cover and not heavily grazed.
    Good: > 75% ground cover and lightly or only occasionally grazed.

[3]   *Poor*:   <50% ground cover.
    Fair: 50 to 75% ground cover.
    Good: >75% ground cover.

[4]   Actual curve number is less than 30; use CN = 30 for runoff computations.

[5]   CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6]   *Poor:*   Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
    Fair: Woods are grazed but not burned, and some forest litter covers the soil.
    Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table 2-2d   Runoff curve numbers for arid and semiarid rangelands [1]

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition [2]	A [3]	B	C	D
Herbaceous—mixture of grass, weeds, and	Poor		80	87	93
low-growing brush, with brush the	Fair		71	81	89
minor element.	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush,	Poor		66	74	79
aspen, mountain mahogany, bitter brush, maple,	Fair		48	57	63
and other brush.	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both;	Poor		75	85	89
grass understory.	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush,	Poor	63	77	85	88
greasewood, creosotebush, blackbrush, bursage,	Fair	55	72	81	86
palo verde, mesquite, and cactus.	Good	49	68	79	84

[1]   Average runoff condition, and I_a, = 0.2S. For range in humid regions, use table 2-2c.

[2]   Poor: <30% ground cover (litter, grass, and brush overstory).
   Fair: 30 to 70% ground cover.
   Good: > 70% ground cover.

[3]   Curve numbers for group A have been developed only for desert shrub.

Figure 2-3   Composite CN with connected impervious area.
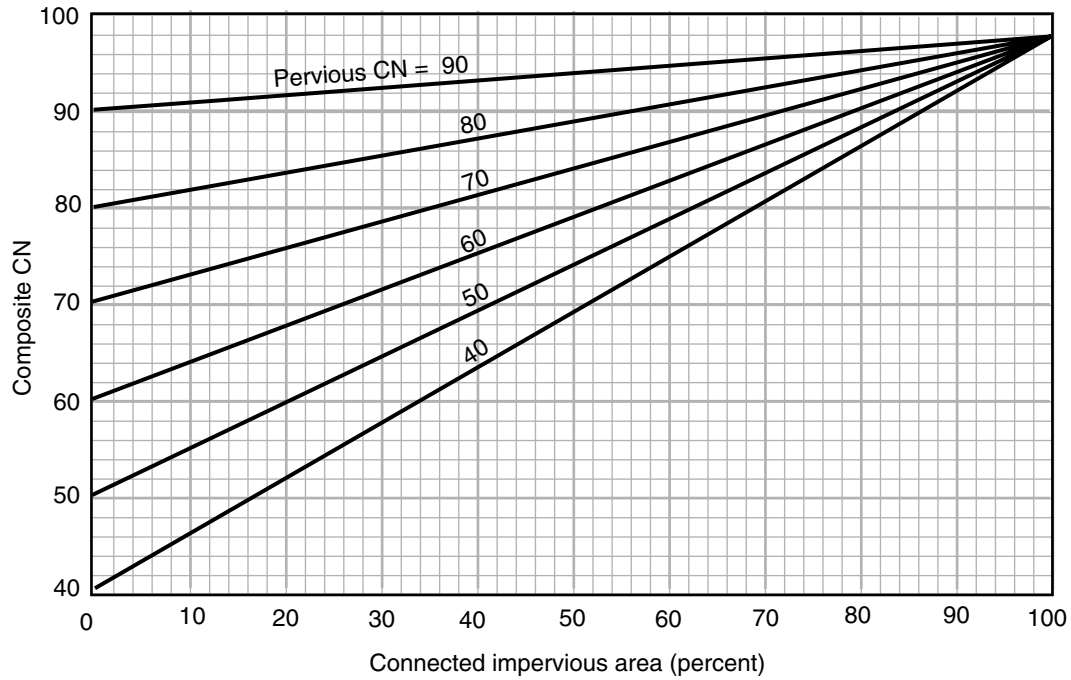
Figure 2-4   Composite CN with unconnected impervious areas and total impervious area less than 30%
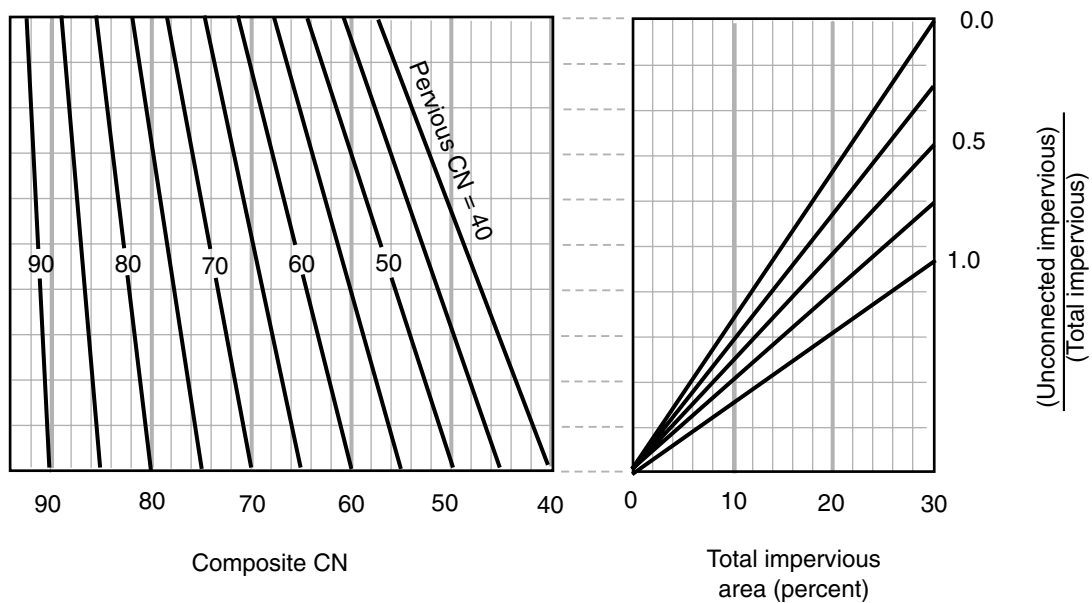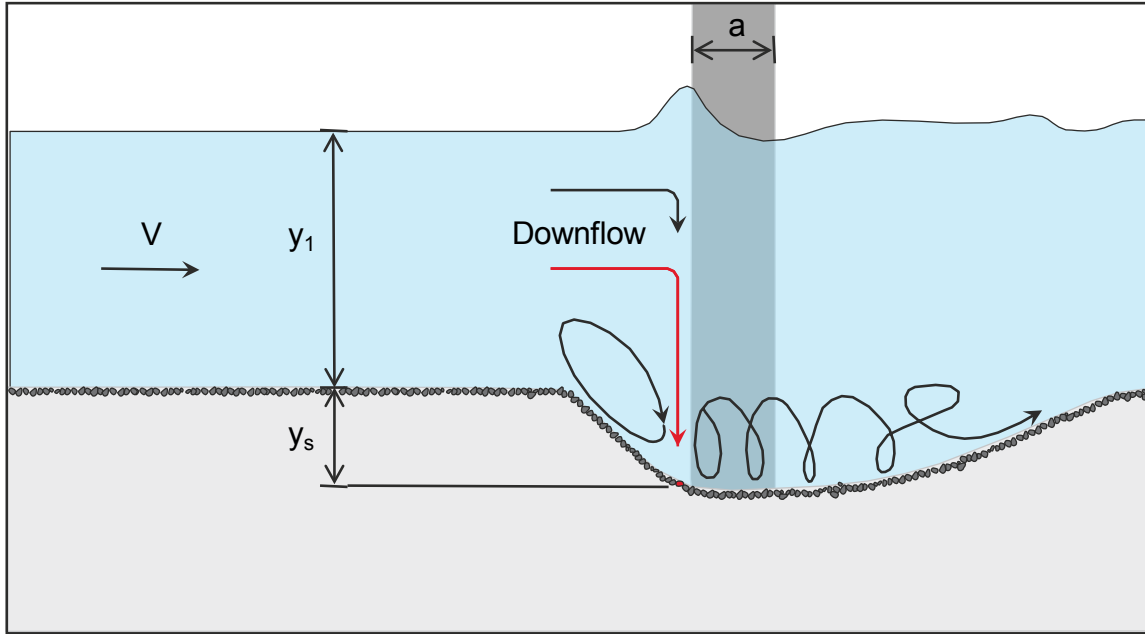
Figure 7.2. Definition sketch for pier scour.

The HEC-18 equation is:

$$\frac{y_s}{y_1} = 2.0\ K_1\ K_2\ K_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} \tag{7.1}$$

As a Rule of Thumb, the maximum scour depth for round nose piers aligned with the flow is:

$y_s \le 2.4$ times the pier width (a) for $Fr \le 0.8$ (7.2)
$y_s \le 3.0$ times the pier width (a) for $Fr > 0.8$

In terms of y_s/a, Equation 7.1 is:

$$\frac{y_s}{a} = 2.0\ K_1\ K_2\ K_3 \left(\frac{y_1}{a}\right)^{0.35} Fr_1^{0.43} \tag{7.3}$$

where:

|		
y_s	=	Scour depth, ft (m)
y_1	=	Flow depth directly upstream of the pier, ft (m)
K_1	=	Correction factor for pier nose shape from Figure 7.3 and Table 7.1
K_2	=	Correction factor for angle of attack of flow from Table 7.2 or Equation 7.4
K_3	=	Correction factor for bed condition from Table 7.3
a	=	Pier width, ft (m)
L	=	Length of pier, ft (m)
Fr_1	=	Froude Number directly upstream of the pier = $V_1/(gy_1)^{1/2}$
V_1	=	Mean velocity of flow directly upstream of the pier, ft/s (m/s)
g	=	Acceleration of gravity (32.2 ft/s²) (9.81 m/s²)
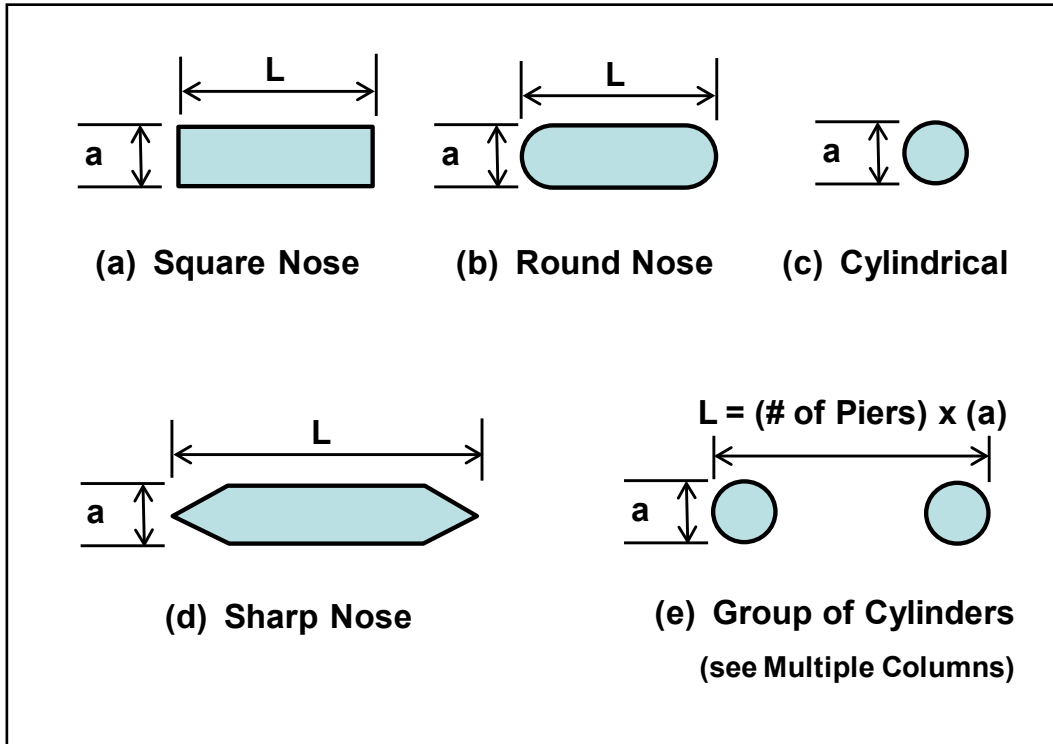
Figure 7.3. Common pier shapes.

The correction factor, K_2, for angle of attack of the flow, θ, is calculated using the following equation:

$$K_2 = (\text{Cos } \theta + \frac{L}{a} \text{ Sin } \theta)^{0.65}$$

(7.4)

If L/a is larger than 12, use L/a = 12 as a maximum in Equation 7.4 and Table 7.2. Table 7.2 illustrates the magnitude of the effect of the angle of attack on local pier scour.

Table 7.1. Correction Factor, K_1, for Pier Nose Shape.	
Shape of Pier Nose	K_1
(a) Square nose	1.1
(b) Round nose	1.0
(c) Circular cylinder	1.0
(d) Group of cylinders	1.0
(e) Sharp nose	0.9

Table 7.2. Correction Factor, K_2, for Angle of Attack, θ, of the Flow.			
Angle	L/a=4	L/a=8	L/a=12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.75	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0
Angle = skew angle of flow L = length of pier			

Table 7.3. Increase in Equilibrium Pier Scour Depths, K_3, for Bed Condition.		
Bed Condition	Dune Height ft	K_3
Clear-Water Scour	N/A	1.1
Plane bed and Antidune flow	N/A	1.1
Small Dunes	$10 > H \geq 2$	1.1
Medium Dunes	$30 > H \geq 10$	1.2 to 1.1
Large Dunes	$H \geq 30$	1.3

Notes:

1. The correction factor K_1 for pier nose shape should be determined using Table 7.1 for angles of attack up to 5 degrees. **For greater angles, K_2 dominates and K_1 should be considered as 1.0**. If L/a is larger than 12, use the values for L/a = 12 as a maximum in Table 7.2 and Equation 7.4.

2. The values of the correction factor K_2 should be applied only when the field conditions are such that the entire length of the pier is subjected to the angle of attack of the flow. Use of this factor will result in a significant over-prediction of scour if (1) a portion of the pier is shielded from the direct impingement of the flow by an abutment or another pier; or (2) an abutment or another pier redirects the flow in a direction parallel to the pier. For such cases, judgment must be exercised to reduce the value of the K_2 factor by selecting the effective length of the pier actually subjected to the angle of attack of the flow. **Equation 7.4 should be used for evaluation and design**. Table 7.2 is intended to illustrate the importance of angle of attack in pier scour computations and to establish a cutoff point for K_2 (i.e., a maximum value of 5.0).

3. The correction factor K_3 results from the fact that for plane-bed conditions, which is typical of most bridge sites for the flood frequencies employed in scour design, the maximum scour may be 10 percent greater than computed with Equation 7.1. In the **unusual** situation where a dune bed configuration **with large dunes** exists at a site during flood flow, the maximum pier scour may be 30 percent greater than the predicted equation value. This may occur on very large rivers, such as the Mississippi. For smaller streams that have a dune bed configuration at flood flow, the dunes will be smaller and the maximum scour may be only 10 to 20 percent larger than equilibrium scour. For antidune bed configuration the maximum scour depth may be 10 percent greater than the computed equilibrium pier scour depth.

4. Piers set close to abutments (for example at the toe of a spill through abutment) must be carefully evaluated for the angle of attack and velocity of the flow coming around the abutment.
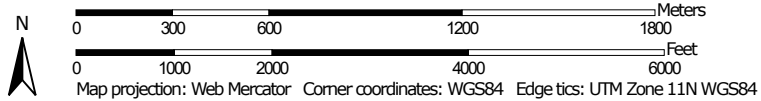
7.3 FLORIDA DOT PIER SCOUR METHODOLOGY

Equation 7.1 has been included in all previous versions of HEC-18 and has been used for bridge scour evaluations and bridge design for countless bridges in the U.S. and worldwide. This equation, which was developed and modified over several decades, could be improved by including bed material size and a more detailed consideration of the bridge pier flow field (see Section 3.6.2). An NCHRP study (NCHRP 2011a) evaluated 22 pier scour equations and found that although the HEC-18 equation did well in comparison to the other equations, the Sheppard and Miller (2006) equation generally performed better for both laboratory and

Map Scale: 1:23,500 if printed on A portrait (8.5" x 11") sheet.

Meters
0   300   600   1200   1800

Feet
0   1000   2000   4000   6000

Map projection: Web Mercator   Corner coordinates: WGS84   Edge tics: UTM Zone 11N WGS84

MAP LEGEND

MAP INFORMATION

Area of Interest (AOI)

☐ Area of Interest (AOI)

Soils

☐ Soil Map Unit Polygons

〜 Soil Map Unit Lines

■ Soil Map Unit Points

Special Point Features

(ω) Blowout

⊠ Borrow Pit

✻ Clay Spot

◇ Closed Depression

✕ Gravel Pit

∴ Gravelly Spot

◉ Landfill

⋀ Lava Flow

⚒ Marsh or swamp

⚒ Mine or Quarry

◎ Miscellaneous Water

○ Perennial Water

⌄ Rock Outcrop

+ Saline Spot

∴ Sandy Spot

⊜ Severely Eroded Spot

◇ Sinkhole

⟫ Slide or Slip

⌀ Sodic Spot

⊜ Spoil Area

⚬ Stony Spot

⚬ Very Stony Spot

⟁ Wet Spot

△ Other

〜 Special Line Features

Water Features

〜 Streams and Canals

Transportation

╫ Rails

〜 Interstate Highways

〜 US Routes

〜 Major Roads

〜 Local Roads

Background

▨ Aerial Photography

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Yakima County Area, Washington
Survey Area Data: Version 20, Jun 4, 2020

Soil Survey Area: Yakima Training Center, Parts of Kittitas and Yakima Counties, Washington
Survey Area Data: Version 17, Jun 4, 2020

Your area of interest (AOI) includes more than one soil survey area. These survey areas may have been mapped at different scales, with a different land use in mind, at different times, or at different levels of detail. This may result in map unit symbols, soil properties, and interpretations that do not completely agree across soil survey area boundaries.

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jun 29, 2015—Mar 5, 2017

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
3	Bakeoven very cobbly silt loam, 0 to 30 percent slopes	19.7	1.1%
36	Finley cobbly fine sandy loam, 0 to 5 percent slopes	13.8	0.8%
55	Harwood-Burke-Wiehl very stony silt loams, 15 to 30 percent slopes	23.3	1.4%
65	Kiona stony silt loam, 15 to 45 percent slopes	185.4	10.8%
68	Lickskillet very stony silt loam, 5 to 45 percent slopes	140.4	8.2%
83	Moxee silt loam, 2 to 15 percent slopes	134.4	7.9%
85	Moxee cobbly silt loam, 0 to 30 percent slopes	363.2	21.2%
102	Ritzville silt loam, 15 to 30 percent slopes	23.6	1.4%
104	Ritzville silt loam, basalt substratum, 0 to 5 percent slopes	38.6	2.3%
105	Ritzville silt loam, basalt substratum, 5 to 15 percent slopes	99.4	5.8%
130	Selah silt loam, 8 to 15 percent slopes	60.5	3.5%
177	Warden silt loam, 2 to 5 percent slopes	7.7	0.4%
187	Willis silt loam, 2 to 5 percent slopes	20.8	1.2%
189	Willis silt loam, 8 to 15 percent slopes	578.5	33.8%
Subtotals for Soil Survey Area		**1,709.2**	**99.9%**
Totals for Area of Interest		**1,710.2**	**100.0%**

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
208	Kiona stony silt loam, 15 to 45 percent slopes	0.3	0.0%
209	Lickskillet very stony silt loam, 5 to 45 percent slopes	0.7	0.0%
Subtotals for Soil Survey Area		**1.0**	**0.1%**
Totals for Area of Interest		**1,710.2**	**100.0%**

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A No Base Flood Elevations determined.

ZONE AE Base Flood Elevations determined.

ZONE AH Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.

ZONE AO Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.

ZONE AR Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.

ZONE A99 Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.

ZONE V Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.

ZONE VE Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X Areas determined to be outside the 0.2% annual chance floodplain.

ZONE D Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

- - - - - - Floodplain boundary
- - - - - - Floodway boundary
- - - - - - Zone D boundary
- - - - - - CBRS and OPA boundary

Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

~~~~~ 513 ~~~~~ Base Flood Elevation line and value; elevation in feet*

(EL 987) Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988 (NAVD 88)

Ⓐ——Ⓐ Cross section line

(23)———(23) Transect line

97°07'30", 32°22'30" Geographic coordinates referenced to the North American Datum of 1983 (NAD 83)

4275000m N 1000-meter Universal Transverse Mercator grid ticks, zone 10

6000000 M 5000-foot grid ticks: Washington State Plane coordinate system, south zone (FIPSZONE 4602), Lambert Conformal Conic

DX5510 Bench mark (see explanation in Notes to Users section of this FIRM panel)

M1.5 River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
November 18, 2009

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 2000'

1000 0 2000 4000 FEET
600 0 600 1200 METERS

Map area labels

JOINS PANEL 0850

U.S. BUREAU OF LAND MANAGEMENT

YAKIMA FIRING CENTER MILITARY RESERVATION
(AREA NOT INCLUDED)

ZONE X

YAKIMA COUNTY
UNINCORPORATED AREAS
530217

WASHINGTON DEPARTMENT OF NATURAL RESOURCES

Cold Creek

Dry Creek

ZONE A

WAUTOMA ROAD

JOINS PANEL 1150
JOINS PANEL 1200
JOINS PANEL 1550

APPENDIX B

Basin Curve Number Estimation

```
Runoff Curve Number Report for Basin 1B

HSG  Land Use Description                      CN  Area      Product
                                                  mi^2      CN x A

C    Mixed Rangeland                          70  1.197     83.766
B    Mixed Rangeland                          56  0.489     27.360
D    Mixed Rangeland                          77  1.041     80.148
A    Mixed Rangeland                          35  0.014      0.496


CN (Weighted) = Total Product \ Total Area
==========================================
                                 69.9819


Runoff Curve Number Report for Basin 2B

HSG  Land Use Description                      CN  Area      Product
                                                  mi^2      CN x A

C    Mixed Rangeland                          70  0.089      6.230
D    Mixed Rangeland                          77  0.260     19.986
B    Mixed Rangeland                          56  0.037      2.077


CN (Weighted) = Total Product \ Total Area
==========================================
                                 73.3654


Runoff Curve Number Report for Basin 3B

HSG  Land Use Description                      CN  Area      Product
                                                  mi^2      CN x A

B    Shrub and Brush Rangeland                56  0.255     14.306
C    Shrub and Brush Rangeland                70  0.234     16.392
B    Mixed Rangeland                          56  0.135      7.550
C    Mixed Rangeland                          70  1.228     85.936
D    Mixed Rangeland                          77  0.866     66.663
D    Shrub and Brush Rangeland                77  0.433     33.331
D    Cropland and Pasture                     84  0.043      3.577
C    Cropland and Pasture                     79  0.035      2.803


CN (Weighted) = Total Product \ Total Area
==========================================
                                 71.4066


Runoff Curve Number Report for Basin 4B

HSG  Land Use Description                      CN  Area      Product
                                                  mi^2      CN x A

C    Shrub and Brush Rangeland                70  0.021      1.486
D    Shrub and Brush Rangeland                77  0.191     14.709
C    Mixed Rangeland                          70  0.913     63.890
D    Mixed Rangeland                          77  1.111     85.533
B    Mixed Rangeland                          56  0.488     27.339
C    Cropland and Pasture                     79  0.021      1.677


CN (Weighted) = Total Product \ Total Area
==========================================
                                 70.8995
```

```
Runoff Curve Number Report for Basin 5B

HSG  Land Use Description                          CN  Area     Product
                                                      mi^2     CN x A

D     Mixed Rangeland                             77   0.340   26.210
C     Mixed Rangeland                             70   0.206   14.396
B     Mixed Rangeland                             56   0.121    6.751
C     Cropland and Pasture                        79   0.043    3.361
D     Cropland and Pasture                        84   0.043    3.574


CN (Weighted) = Total Product \ Total Area
==========================================
                              72.2264


Runoff Curve Number Report for Basin 6B

HSG  Land Use Description                          CN  Area     Product
                                                      mi^2     CN x A

D     Mixed Rangeland                             77   0.158   12.184
C     Mixed Rangeland                             70   0.014    0.963
B     Mixed Rangeland                             56   0.007    0.385
D     Cropland and Pasture                        84   0.062    5.201
A     Cropland and Pasture                        49   0.007    0.337
C     Cropland and Pasture                        79   0.021    1.630


CN (Weighted) = Total Product \ Total Area
==========================================
                              77.1538


Runoff Curve Number Report for Basin 7B

HSG  Land Use Description                          CN  Area     Product
                                                      mi^2     CN x A

C     Mixed Rangeland                             70   0.139    9.717
D     Mixed Rangeland                             77   0.753   57.943
B     Mixed Rangeland                             56   0.117    6.546
D     Cropland and Pasture                        84   0.088    7.364
A     Mixed Rangeland                             35   0.022    0.767
B     Cropland and Pasture                        69   0.007    0.504


CN (Weighted) = Total Product \ Total Area
==========================================
                              73.6299


Runoff Curve Number Report for Basin 8B

HSG  Land Use Description                          CN  Area     Product
                                                      mi^2     CN x A

C     Mixed Rangeland                             70   0.362   25.350
D     Mixed Rangeland                             77   0.085    6.561
B     Mixed Rangeland                             56   0.575   32.210
C     Cropland and Pasture                        79   0.014    1.122
D     Cropland and Pasture                        84   0.007    0.596
B     Cropland and Pasture                        69   0.007    0.490
A     Cropland and Pasture                        49   0.014    0.696
A     Mixed Rangeland                             35   0.121    4.225
```

```
CN (Weighted) = Total Product \ Total Area
==========================================
                          60.0838


Runoff Curve Number Report for Basin 9B

HSG  Land Use Description                   CN  Area      Product
                                                mi^2      CN x A

B    Mixed Rangeland                        56  0.136      7.594
A    Mixed Rangeland                        35  0.043      1.499
D    Mixed Rangeland                        77  0.029      2.198
C    Mixed Rangeland                        70  0.114      7.994
C    Cropland and Pasture                   79  0.071      5.638
B    Cropland and Pasture                   69  0.029      1.970
A    Cropland and Pasture                   49  0.014      0.699


CN (Weighted) = Total Product \ Total Area
==========================================
                          63.377


Runoff Curve Number Report for Basin 10B

HSG  Land Use Description                   CN  Area      Product
                                                mi^2      CN x A

A    Mixed Rangeland                        35  0.015      0.516
D    Mixed Rangeland                        77  0.384     29.538
B    Mixed Rangeland                        56  0.133      7.436
C    Mixed Rangeland                        70  0.052      3.615
D    Cropland and Pasture                   84  0.030      2.479
B    Cropland and Pasture                   69  0.015      1.018


CN (Weighted) = Total Product \ Total Area
==========================================
                          71.1294


Runoff Curve Number Report for Basin 11B

HSG  Land Use Description                   CN  Area      Product
                                                mi^2      CN x A

B    Mixed Rangeland                        56  0.075      4.223
C    Mixed Rangeland                        70  0.075      5.279
D    Mixed Rangeland                        77  0.019      1.452


CN (Weighted) = Total Product \ Total Area
==========================================
                          64.5556


Runoff Curve Number Report for Basin 12B

HSG  Land Use Description                   CN  Area      Product
                                                mi^2      CN x A

B    Mixed Rangeland                        56  0.233     13.036
D    Mixed Rangeland                        77  0.113      8.691
C    Mixed Rangeland                        70  0.219     15.308
D    Cropland and Pasture                   84  0.071      5.926
C    Cropland and Pasture                   79  0.099      7.802
```

```
CN (Weighted) = Total Product \ Total Area
==========================================
                          69.1923


Runoff Curve Number Report for Basin 13B

HSG  Land Use Description                    CN  Area      Product
                                                 mi^2      CN x A

D    Mixed Rangeland                         77  0.074      5.727
D    Cropland and Pasture                    84  0.335     28.113
C    Mixed Rangeland                         70  0.030      2.082
C    Cropland and Pasture                    79  0.052      4.113


CN (Weighted) = Total Product \ Total Area
==========================================
                          81.5606


Runoff Curve Number Report for Basin 14B

HSG  Land Use Description                    CN  Area      Product
                                                 mi^2      CN x A

D    Cropland and Pasture                    84  0.219     18.397
A    Cropland and Pasture                    49  0.007      0.346
B    Cropland and Pasture                    69  0.791     54.597
C    Mixed Rangeland                         70  0.572     40.058
D    Mixed Rangeland                         77  0.374     28.832
C    Cropland and Pasture                    79  0.064      5.023
B    Mixed Rangeland                         56  0.593     33.233


CN (Weighted) = Total Product \ Total Area
==========================================
                          68.8598


Runoff Curve Number Report for Basin 15B

HSG  Land Use Description                    CN  Area      Product
                                                 mi^2      CN x A

D    Cropland and Pasture                    84  0.026      2.210
B    Cropland and Pasture                    69  0.099      6.806
B    Mixed Rangeland                         56  0.178      9.943
C    Mixed Rangeland                         70  0.033      2.302


CN (Weighted) = Total Product \ Total Area
==========================================
                          63.3922


Runoff Curve Number Report for Basin 16B

HSG  Land Use Description                    CN  Area      Product
                                                 mi^2      CN x A

C    Mixed Rangeland                         70  6.747    472.261
B    Mixed Rangeland                         56  2.751    154.039
D    Mixed Rangeland                         77  3.447    265.431
C    Cropland and Pasture                    79  4.137    326.791
B    Cropland and Pasture                    69  4.917    339.306
D    Shrub and Brush Rangeland               77  1.984    152.758
B    Shrub and Brush Rangeland               56  0.331     18.516
C    Shrub and Brush Rangeland               70  0.915     64.019
```

```
D    Cropland and Pasture                          84    1.421    119.370
A    Cropland and Pasture                          49    0.661     32.403
A    Mixed Rangeland                               35    0.190      6.648


CN (Weighted) = Total Product \ Total Area
==========================================
                     70.9655


Runoff Curve Number Report for Basin 17B

HSG  Land Use Description                          CN   Area      Product
                                                        mi^2      CN x A

B    Mixed Rangeland                               56    0.064      3.595
B    Cropland and Pasture                          69    0.171     11.813
C    Cropland and Pasture                          79    0.257     20.287
D    Mixed Rangeland                               77    0.007      0.549
D    Cropland and Pasture                          84    0.178     14.980
C    Mixed Rangeland                               70    0.021      1.498
A    Cropland and Pasture                          49    0.036      1.748


CN (Weighted) = Total Product \ Total Area
==========================================
                     74.1359
```