Appendix E

Hydraulics Report

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July 29, 2021
Revised August 4, 2021

Lilia Razo
Yolo County Department of Public Works
292 West Beamer Street
Woodland, CA 95834

Re: CR-98 Improvement Project, Phase II, Flood Hydraulics

Dear Ms. Razo:

Pacific Hydrologic Incorporated (PHI) has completed an evaluation of flood hydraulic conditions associated with revising the grade of County Road 98 along with replacing and adding culverts. Background, data, analysis, and conclusions are described in the following paragraphs.

Background:

Yolo County anticipates improvements to County Road 98 from the Solano County Line to Yolo County Road 29 for the purpose of accommodating bicycle traffic and improving corridor safety. The improvements include raising the elevation of County Road 98 at locations where the road is overtopped during infrequent flood events. At and south of County Road 31 overflow during the FEMA Base Flood (FEMA estimate of the most probable 100-year flood) has been mapped by FEMA using approximate study methods without 100-year flood water surface elevations determined. North Davis Drain, an overflow swale of Dry Slough, however has flood risk mapped by FEMA using detailed study methods. As such, new encroachments in the North Davis Drain floodplain are not allowed to increase the water surface elevation or extent of inundation during the FEMA Base Flood (FEMA estimate of the most probable 100-year flood event) unless risks of flood damage are mitigated and a FEMA Conditional Letter of Map Revision (CLOMR) has been issued. The cost and time required for mitigation of flood risk on private properties and for obtaining a FEMA CLOMR are often prohibitive hence the preferred approach to deal with new encroachments is to provide accommodation for conveyance of the FEMA Base Flood without increasing the water surface elevation or the extent of inundation. The current effective FEMA Flood Insurance Rate Map (FIRM) along the County Road 98 corridor is shown in Figure 1.

Study Approach:

This study consists of a flood hydrologic analysis using a rainfall-runoff model to identify runoff approaching the County Road 98 corridor from six subbasins to the west followed by a two dimensional (2D) backwater model identifying existing and proposed condition flood hydraulic characteristics through the study area. The 2D study area consists of a corridor approximately one mile wide extending the full reach of anticipated improvements.

Site Conditions and Basins:

The reach of County Road 98 subject to Phase II improvements is located in an agricultural area with very low gradient land sloping to the east and northeast. A topographic map of the areas directly contributing to County Road 98 cross drainage was developed from CVFED LiDAR terrain data. Topographic data indicates six basins contributing to cross-drainage at County Road 98. The basins are identified in Figure 2. In addition to local drainage, Basin 2 containing North Davis Drain conveys substantial overflow from Dry Slough during the most probable 100-year flood in Dry Slough.

Flood Hydrologic Analysis:

The US Army Corps of Engineers' HEC-HMS v4.2.1 rainfall-runoff program was employed for identifying peak flows of recurrent flood events. The model was run to estimate peak flow during the most probable 100-year normal probability (50% confidence) storm events considering AMC-II conditions. Subbasin areas are summarized in Table 1.

Table 1: Subbasin Areas

Basin	Area (sq mi)
1	0.40
2 (North Davis Drain)	2.89
3	0.98
4a (unnamed channel, upper)	2.36
4b (unnamed channel, lower)	4.48
5	1.24
6	0.63

SCS curve numbers used to estimate losses were from the Yolo County City/County Drainage Manual, Volume 1 (Yolo County Drainage Manual). Initial losses were estimated from curve numbers using TR-55 Table 4-1. Impervious percent within subbasins were estimated to be 1- to 3-percent loosely based on level of development. Curve number computations are included in Appendix A.

Subbasin lag was estimated using the USBR lag equation based on length of main channel to the basin boundary, length across the basin from the point of concentration through the basin centroid (USBR definition), average basin slope, and overland flow roughness coefficient. The first three parameters were scaled and calculated from the topographic map and the overland flow roughness coefficient was estimated to be 0.115 from Table 12 of the Yolo County Drainage Manual for grassland/agricultural, undeveloped conditions. Lag time calculations are included in Appendix A.

Runoff from subbasin 4a was routed to County Road 98 assuming a channel velocity of 4-feet per second and combined with runoff from subbasin 4b to create a hydrograph for Basin 4 at County Road 98.

Subbasin loss and lag data are summarized in Table 2. Peak flows at County Road 98 determined by the rainfall-runoff model during the most probable 100-year storm are identified in Table 3.

Table 2: Summary of Subbasin Loss and Lag Data

Subbasin	Curve Number	Initial Abstraction (inches)	Impervious Area (percent)	Lag (minutes)
1	80	.50	1	104
2	81	.47	1	233
3	82	.44	2	125
4a	71	.82	2	276
4b	81	.47	2	359
5	81	.47	3	217
6	78	.56	3	221

Table 3: Peak Flows at County Road 98 during Most Probable 100-year Storm

Subbasin	100-year Storm Peak Flow (CFS)
1	126
2	613
3	298
4	2019
5	276
6	127

Dry Creek Overflow:

Flood Risk mapped by FEMA along North Davis Drain represents overflow from Dry Slough during the most probable 100-year flood. The FEMA Flood Insurance Study Report (FIS Report) identifies a 100-year flood peak flow of 3359 CFS in Dry Slough upstream of North Davis Drain and of 714 CFS downstream of North Davis Drain. The difference represents overflow to North Davis Drain. The 2D backwater model, however, requires a flood hydrograph rather than a peak flow. Therefore the flood hydrograph for Basin 4 was scaled up to match the peak flow in Dry Creek upstream of North Davis Drain, was delayed to separate it from the local flood peak associated with the direct contributing area, was added to the recession flow from the direct contributing area, and was reduced by the 714 CFS continuing down Dry Slough. Considering overflow from Dry Slough, the peak flow entering Basin 2 is 2705 CFS. The resulting flood hydrograph for Basin 2 at County Road 98 is shown in Figure 3.

Flood Hydraulic Analysis:

The US Army Corps of Engineers' HEC-RAS v6.0 backwater program was employed for identifying flood flow patterns, peak water surface elevations, and the extent of inundation for existing and proposed conditions. The model was based on terrain data collected by the CVFED program in the period 2003 to 2005. The area of interest (2D domain) was defined as a corridor approximately one mile wide extending for the entire reach of proposed project. Overland flow roughness coefficients were based on land cover data from the National Land Cover Database using Manning's overland flow roughness coefficients identified in the HEC-RAS 2D users manual. Hydrographs representing runoff during the most probable 100-year storm for each of the six basins were entered along the west basin boundaries of the 2D domain. Normal depth was specified for the downstream boundaries at locations where flood flow exited the 2D domain. Hydraulic slope at the downstream boundaries was estimated from the topographic map. "2D area breaklines" and internal boundaries were defined to represent existing and proposed fill prisms of significance to the direction of overflow and pattern of flooding. Existing and proposed culverts of potential significance to flood patterns were defined through internal boundaries. The 2D domain is shown in Figure 4 along with upstream and downstream boundary conditions, 2D area breaklines, and internal boundaries.

Flood Risk Evaluation Criteria:

The study area includes watercourses having flood risk mapped by FEMA using detailed study methods and by approximate study methods. In areas having flood risk mapped by FEMA using detailed study methods, FEMA requires mitigation of any increased risk of damage to structures and approval of a Conditional Letter of Map Revision (CLOMR) prior to construction of any new encroachment resulting in an increase in Base Flood (FEMA estimate of the most probable 100-year flood) water surface elevation or extent of inundation. For this reason most new encroachments within the floodplain are designed to avoid any increase in Base Flood water surface elevation. The North Davis Drain has flood risk mapped by FEMA and is subject to this level of compliance.

At and south of CR-31 watercourses have flood risk mapped by approximate study methods. FEMA allows increases in 100-year flood water surface elevations in these areas provided that the increase in water surface elevation does not increase the risk of damage to structures. If the new encroachment results in changes to the extent of inundation during the most probable 100-year flood, a Letter of Map Revision may be required by FEMA.

Of specific concern for this project is potential flood risk impacts to structures located to the west of CR-98 and to structures within the Stonegate Subdivision in the City of Davis. Under existing conditions, considerable flow overtops CR-98 during the most probable 100-year flood. Raising the grade of CR-98 will increase the elevation of approaching flood water prior to and during overtopping events unless provision is made to preserve the overtopping flow or convey the flow through culverts or bridges. Although not identified on the FEMA FIRM, the existing condition 2D backwater model indicates overflow entering the Stonegate subdivision at two locations. Revising the grade of CR-98, CR-31, and CR-32 has the potential to change the pattern of flooding including at Stonegate Subdivision. In addition to avoiding increasing flood water surface elevations west of CR-98 (upstream), grade revisions must be designed in a manner that does not increase overflow entering the Stonegate subdivision.

Existing Flood Hydraulic Conditions:

Flood conditions at CR-98 are straightforward for Basins 1 and 2. Direct runoff from Basin 1 overtops CR-98 and exits the 2D domain substantially separate from flow in other basins. Dry Slough overflow thorough Basin 2 is substantially as identified on the FEMA FIRM as North Davis Drain. Flood conditions at CR-98 related to runoff from the other basins is not straightforward or as identified on the FEMA FIRM. The most significant difference being the fact that considerable flow in the unnamed channel during the 100-year flood peak exits the channel west of CR-98, flows to the north, and crosses CR-98 in the vicinity of CR-31. This overflow path is not identified on the FEMA FIRM. Runoff from Basin 3 combines with overflow from the unnamed channel before overtopping CR-98. Runoff from Basins 5 and 6 combine with additional overflow from the unnamed channel west of CR-98 before being conveyed past CR-98 as overflow and through culverts.

Proposed Condition Flood Hydraulic Analysis:

A proposed condition backwater model run was conducted by replacing existing road crown elevation data in a copy of the existing condition backwater model dataset with initial proposed crown elevation data and replacing or adding culvert data for replaced and added culverts. The backwater program was then run for the initial proposed condition dataset. The initial proposed condition backwater model run indicated significant potential flood risk impacts to structures and increased water surface elevations in North Davis Drain west of CR-98. Road crown grade revisions were recommended and evaluated several times. At such point in time that flood risk impacts were minor requiring only minor adjustments in road crown elevations, road crown elevations and the size of the unnamed channel culvert were adjusted by trial and error until finding a combination of road crown elevations and culvert size that avoided increases in water surface elevation at all structures, along the west side of Stonegate Subdivision, and in North Davis Drain.

Results:

Peak water surface elevations for existing and proposed conditions are identified on Figure 5. The difference in peak water surface elevations is identified on Figure 6. Maximum depths and velocities of flow are shown on Figures 7 and 8 respectively. Existing and proposed road crown elevation data employed in the backwater models for CR-98, CR-31, and CR-32 are identified in Figures 9 through 11 respectively. Tables identifying existing and proposed road crown data employed in the backwater model are presented in Appendix B.

Conclusions:

Revision of road crown grades as indicated in Figures 9 through 11 and replacing the existing culvert conveying the unnamed channel with a new 12’x5’ culvert will avoid any increase in peak water surface elevations at structures and along the west boundary of the Stonegate Subdivision.

Although the water surface elevation within the bounds of the North Davis Drain floodplain is higher for the proposed condition than for the existing condition at one location, given that there is no increase in the water surface elevation at the floodplain limits, no increase in the extent of inundation, and no structures impacted, the evaluation should be considered sufficient to meet

FEMA's "no increase" requirement. The variation in water surface elevation across a cross-section of North Davis Drain is associated with the more precise 2D modeling approach whereas FEMA relied upon a linear backwater model incapable of representing variation in water surface elevation across a cross-section. The use of more detailed backwater models to demonstrate no impact related to public improvements (primarily bridge replacement projects) rather than relying on the FEMA backwater model is a common practice (the FEMA backwater model for North Davis Drain had been requested but not included in the package of North Davis Drain backwater models provided by FEMA).

Shallow flow over road prisms is very efficient and often difficult or impossible to convey in culverts through the road prism especially in areas of low relief. Consequently, flood risk is closely coupled with flow over road prisms and minor differences in the road crown profiles can have significant impacts to flood risk.

The initial and some subsequent proposed condition backwater model runs indicated new areas of inundation east of CR-98 approximately 1400-feet south of CR-32. This new inundation was found to be due to a new culvert proposed at road station 61+00. The culvert was removed from the final proposed condition backwater model.

Recommendations:

Avoid installation of a new culvert in the greater vicinity of road station 61+00 and replace the existing culvert conveying the unnamed channel with a new 12'x5' culvert.

It has been presumed that the proposed project can be constructed to meet the road crown grades in the final proposed condition backwater. If changes to the proposed road crown grades are necessary for the project to be constructed, the changes should be re-evaluated using the backwater model to assure no increase in flood risk.

Sincerely,

Norman S. Braithwaite, P.E., President
Pacific Hydrologic Incorporated

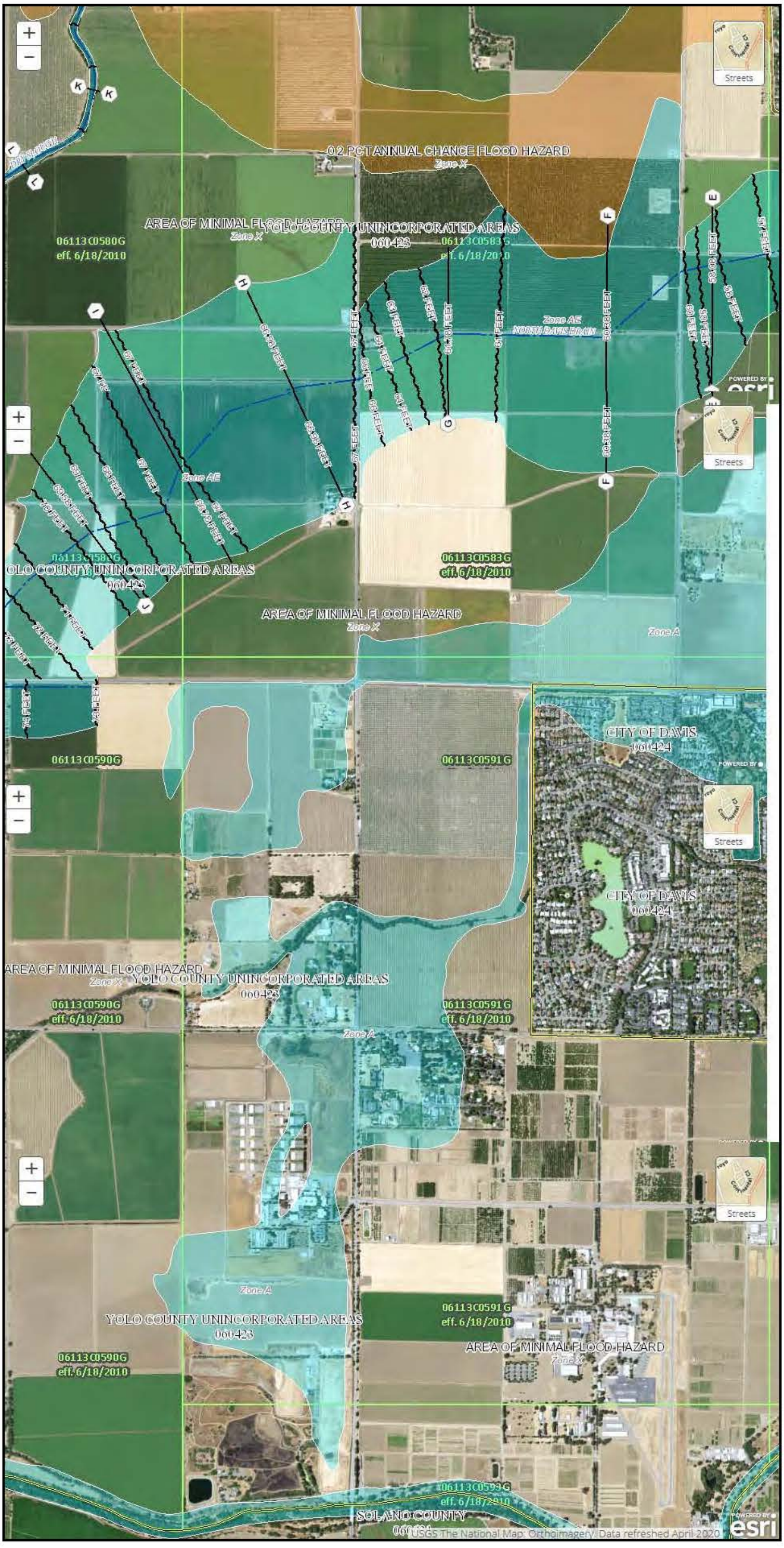

Figure 1: FEMA Flood Insurance Rate Map

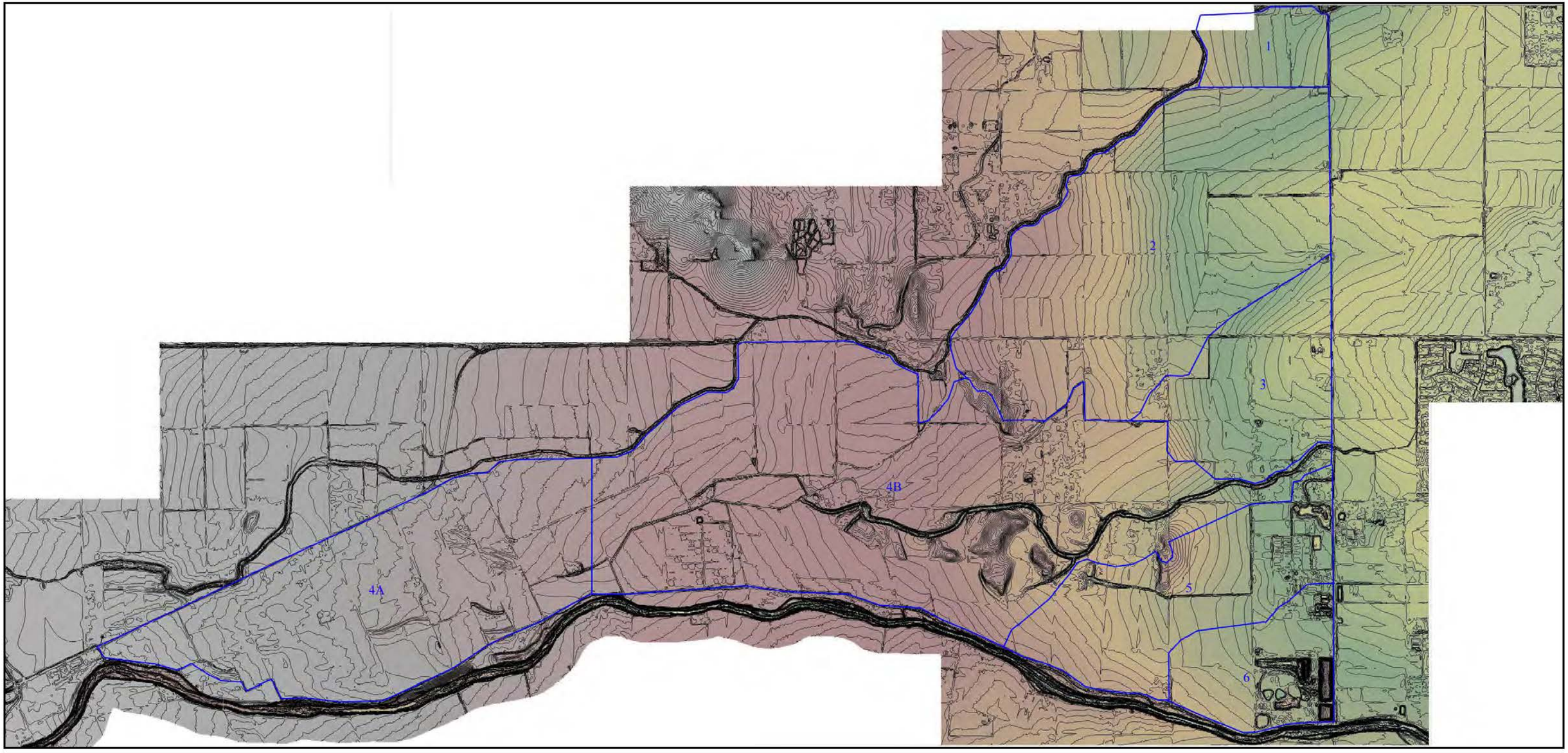

Figure 2: Direct Contributing Basins

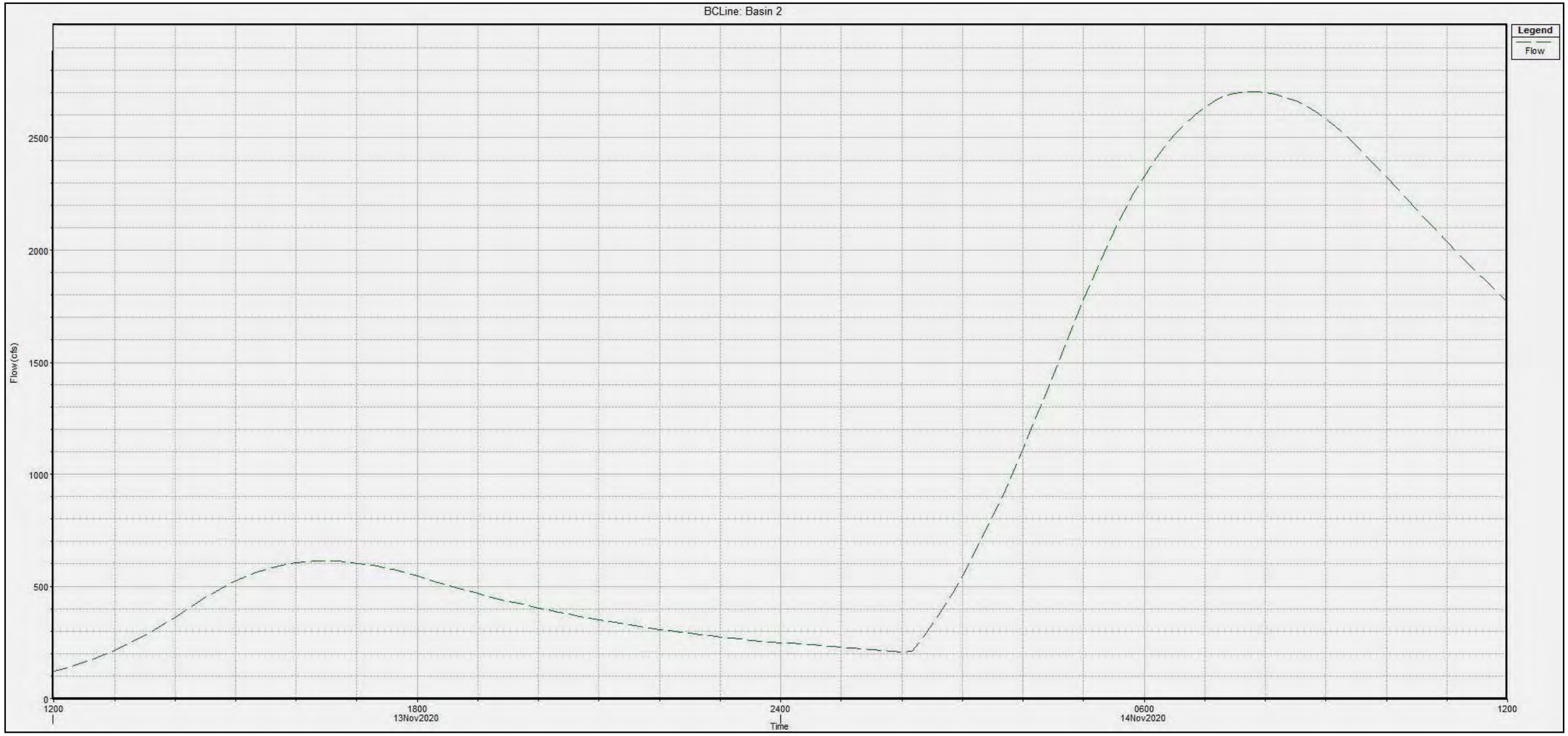

Figure 3: Flood Hydrograph for Basin 2
Peak at 13NOV2020 1630 is from direct contributing basin
Peak at 14NOV2020 0800 is Dry Slough overflow
Delay between peaks is assumed

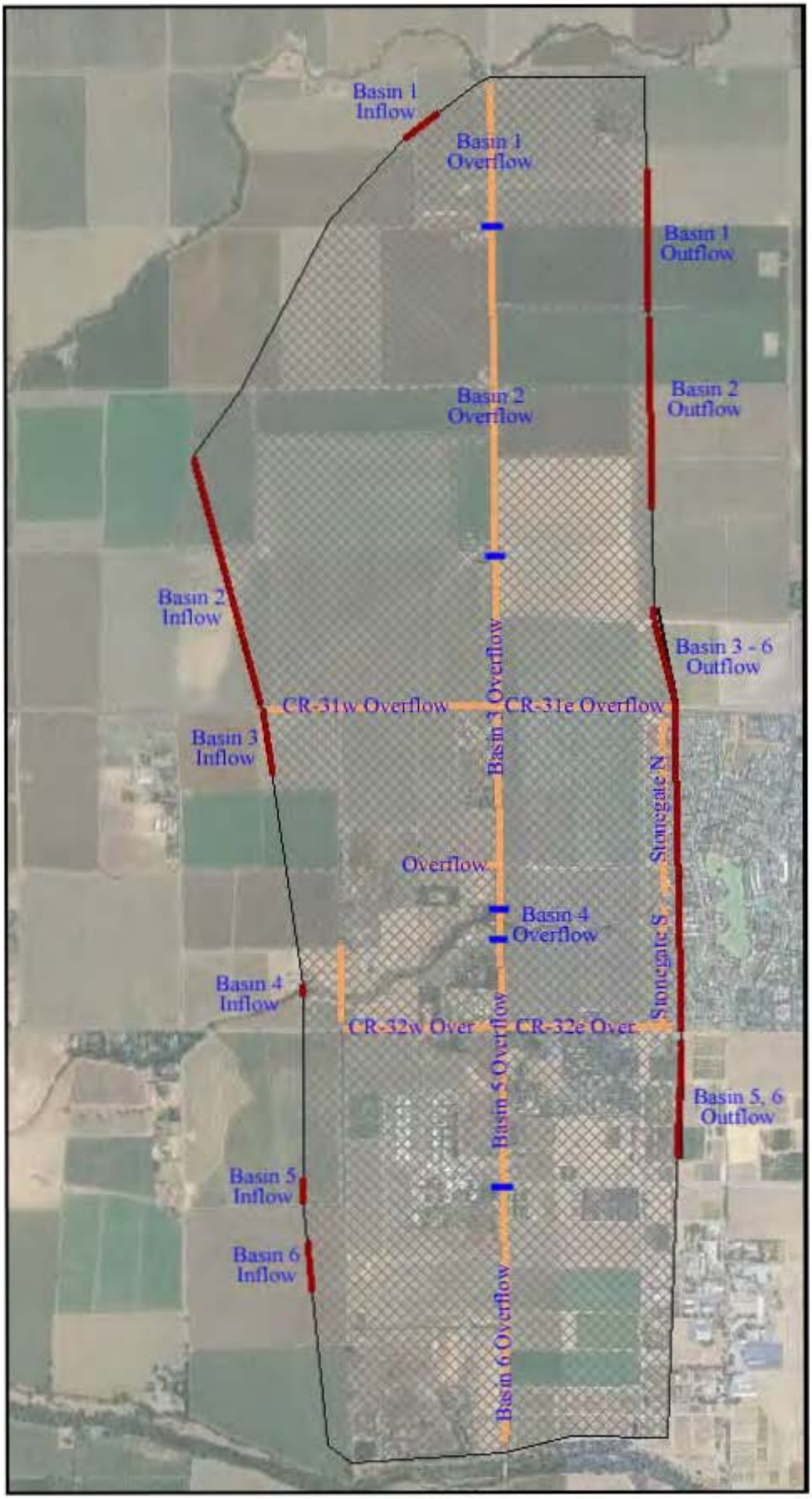

Figure 4: 2D Domain and Boundaries

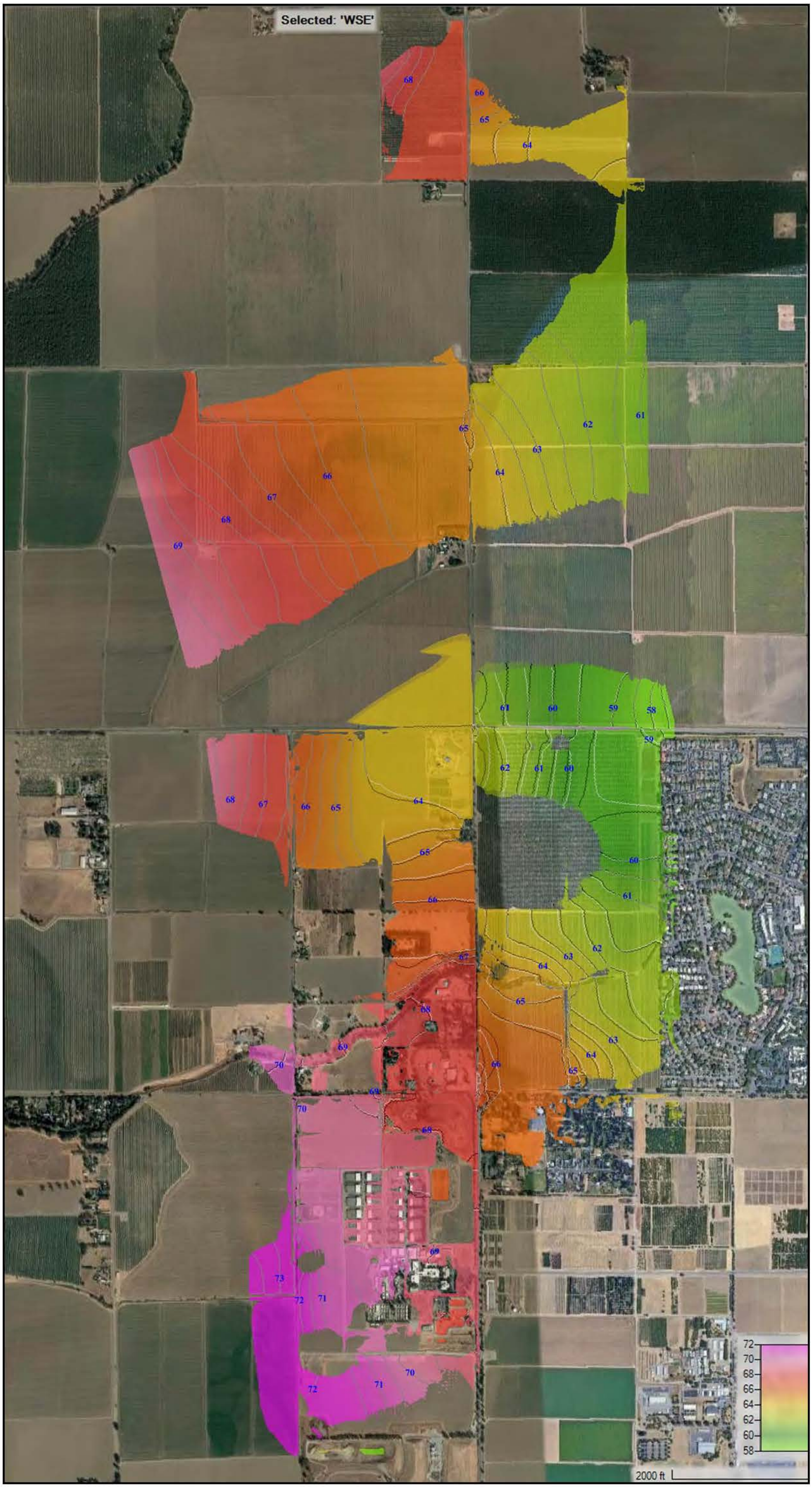

Figure 5: Existing and Proposed Condition Water Surface Elevations, Contour Interval = 0.5-foot
White = Existing, Black = Proposed, Gray = Coincident, Black uphill of White = Lower Water Surface Elevation

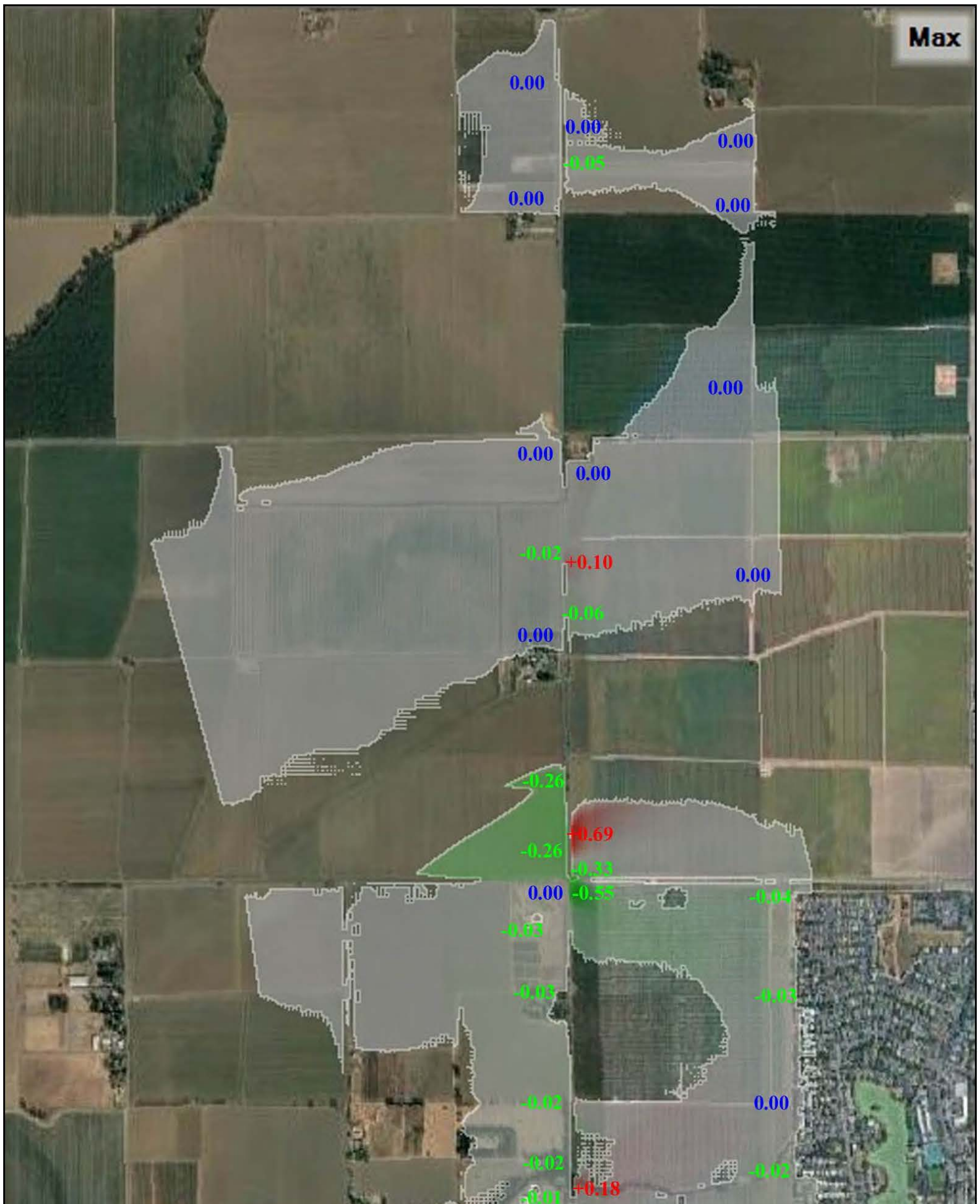

Figure 6: Water Surface Elevation Impact “Heat Map” (Change in Water Surface Elevation) – Feet

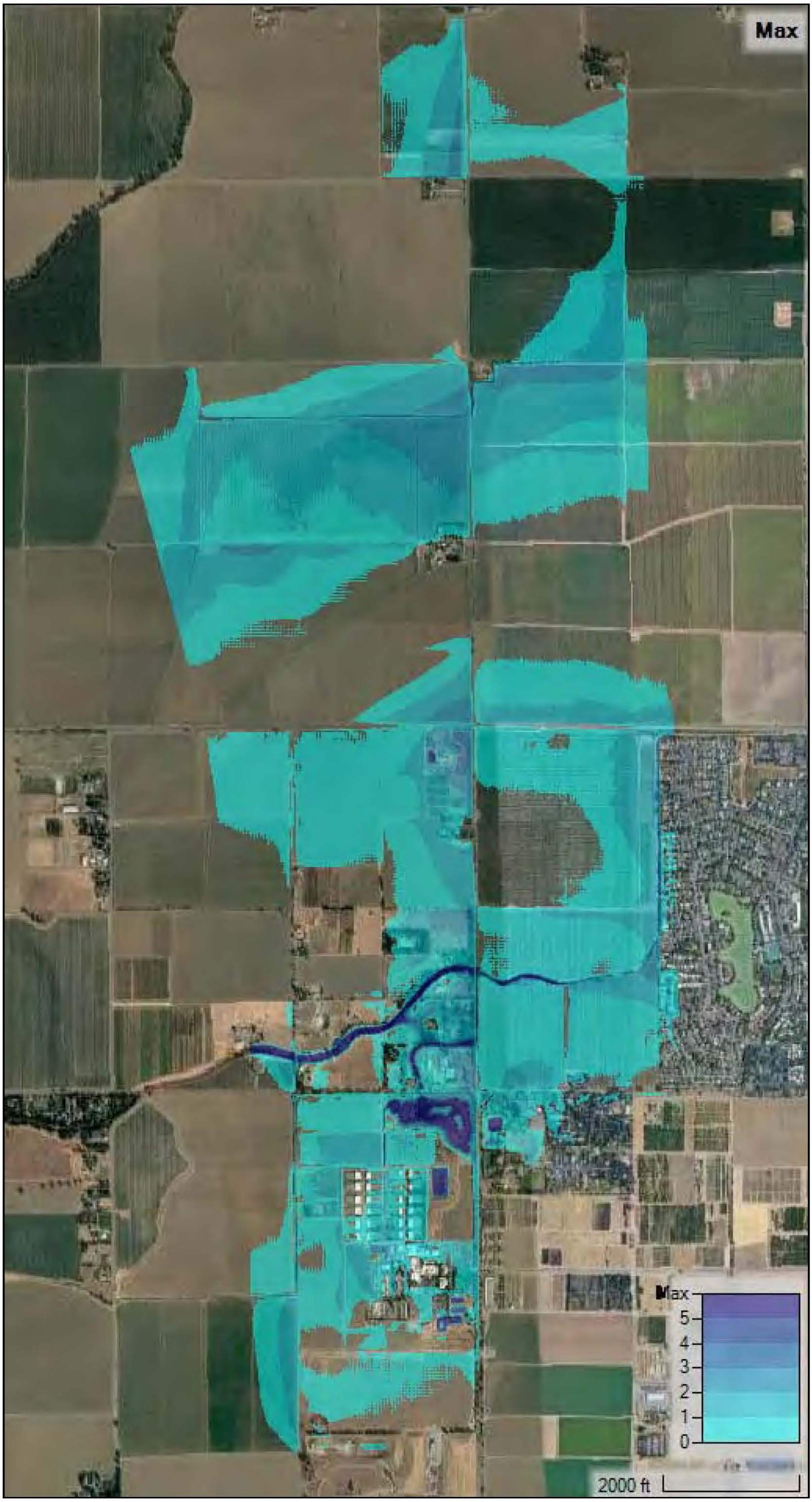

Figure 7: Proposed Condition Maximum Depth – Feet (Existing Condition near Identical)

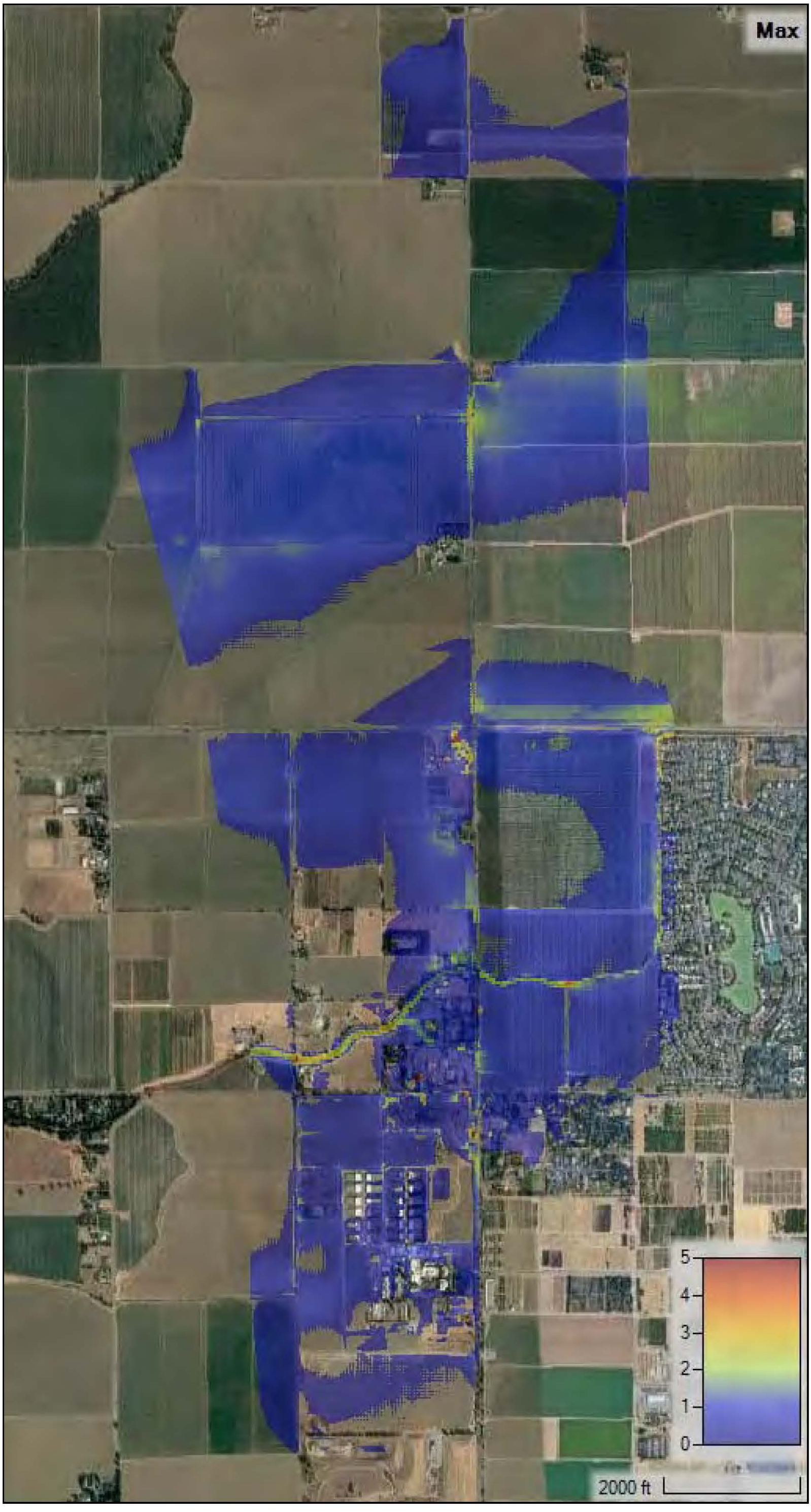

Figure 8: Proposed Condition Maximum Velocity – Feet per Second (Existing Condition near Identical)

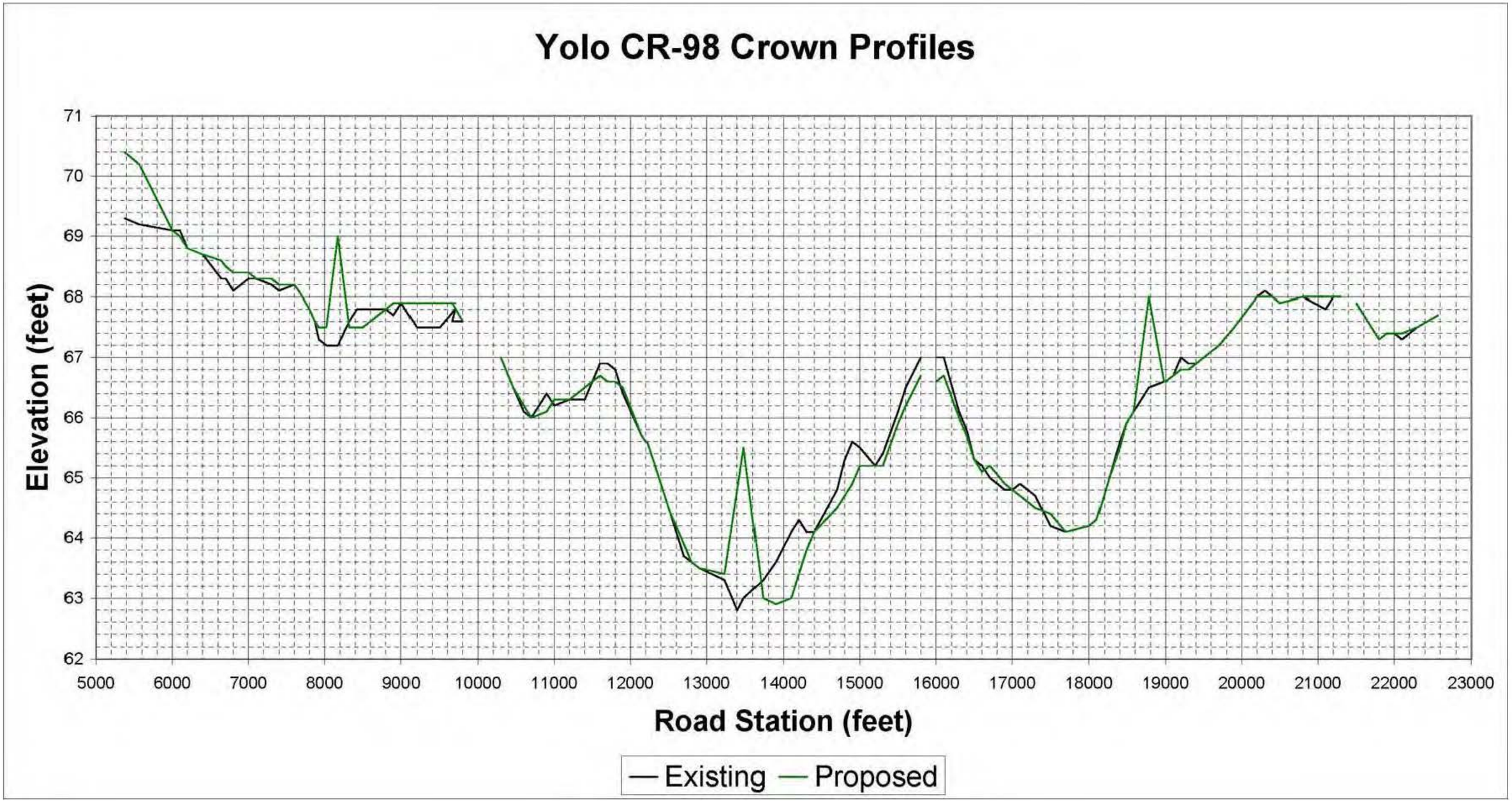

Figure 9: Existing and Proposed Road Crown Profile, County Road 98

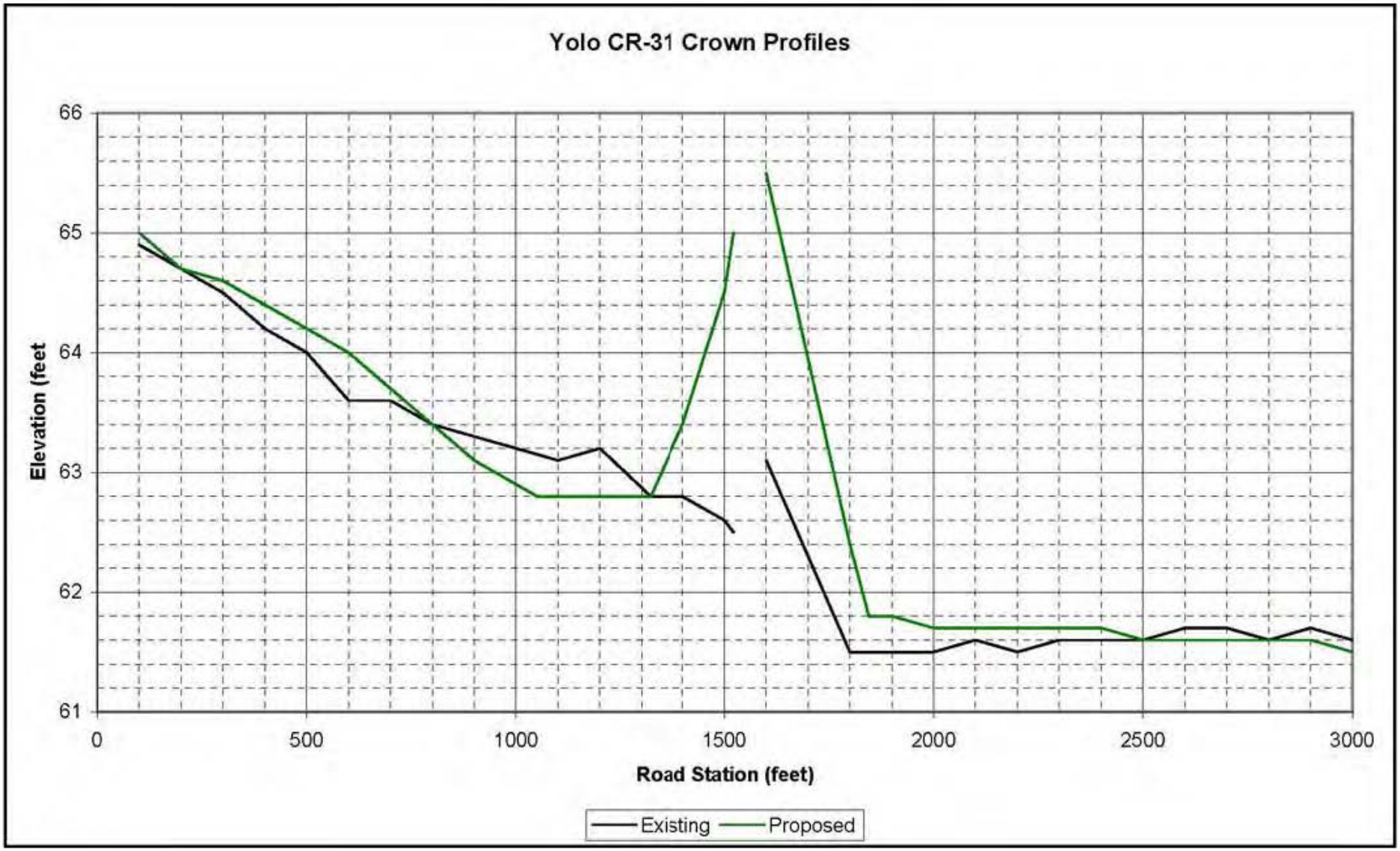

Figure 10: Existing and Proposed Condition Road Crown Profile, County Road 31

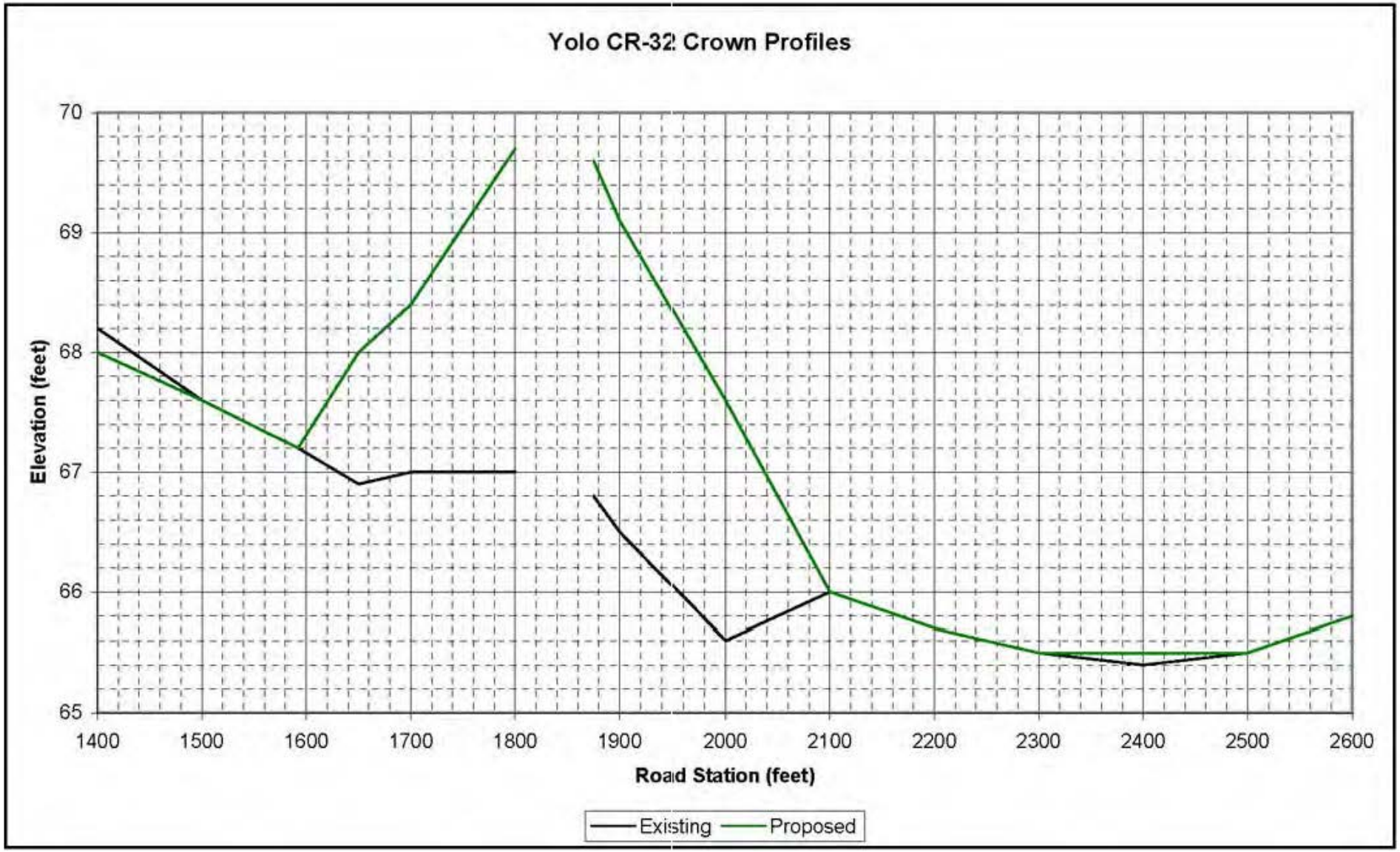

Figure 11: Existing and Proposed Condition Road Crown Profiles, County Road 32

Appendix A

Curve Number and Lag Computations

Yolo County Road 98 culvert study

Curve number calculation

Location	Area (sq mi)	Land Use	Hyd Soil Group	Percent of area	Curve Number		Weighted CN
Basin 1	0.4	Grain	B	12	73	876	
		Grain	C	88	81	7128	80.04
Basin 2	2.89	Grain	B	5	73	365	
		Grain	C	91	81	7371	
		Grain	D	4	84	336	80.72
Basin 3	0.98	Grain	B	2	73	146	
		Grain	C	68	81	5508	
		Grain	D	30	84	2520	81.74
Basin 4A	2.36	Grain	B	15	73	1095	
		Grain	C	30	81	2430	
		Orchard	B	30	58	1740	
		Orchard	C	25	72	1800	70.65
Basin 4B	4.48	Grain	B	5	73	365	
		Grain	C	70	81	5670	
		Grain	D	25	84	2100	81.35
Basin 5	1.24	Grain	B	18	73	1314	
		Grain	C	60	81	4860	
		Grain	D	12	84	1008	
		Industrial	D	10	93	930	81.12
Basin 6	0.63	Grain	B	45	73	3285	
		Grain	C	40	81	3240	
		Grain	D	15	84	1260	77.85

Lag calculation

Location	L (miles)	Lc (miles)	Divide Elev (ft)	Exit Elev (ft)	Slope	n	Lag (m)
Basin 1	0.83	0.83	76	65	13.3	0.115	104
Basin 2	2.8	2.4	89	63	9.3	0.115	233
Basin 3	1	1	70	61	9.0	0.115	125
Basin 4A	3	3	124	106	6.0	0.115	276
Basin 4B	5.3	4.4	106	63	8.1	0.115	359
Basin 5	2.5	2	83	63	8.0	0.115	217
Basin 6	2	2	78	69	4.5	0.115	221

Appendix B

Existing and Proposed Condition Road Crown Profiles

County Road 98

Road Station (feet)	Existing Crown Elev (feet)	Proposed Crown Elev (feet)
5375	69.3	70.4
5565	69.2	70.2
6000	69.1	69.1
6100	69.1	69
6200	68.8	68.8
6400	68.7	68.7
6642	68.3	68.6
6700	68.3	68.5
6800	68.1	68.4
7000	68.3	68.4
7100	68.3	68.3
7300	68.2	68.3
7400	68.1	68.2
7600	68.2	68.2
7658	68.1	68.1
7800	67.8	67.8
7870	67.6	67.6
7922	67.3	67.5
8022	67.2	67.5
8172	67.2	69
8322	67.6	67.5
8422	67.8	67.5
8500	67.8	67.5
8600	67.8	67.6
8800	67.8	67.8
8900	67.7	67.9
9000	67.9	67.9
9100	67.7	67.9
9200	67.5	67.9
9500	67.5	67.9
9663	67.6	67.9
9700	67.8	67.9
9800	67.6	67.6

Road Station (feet)	Existing Crown Elev (feet)	Proposed Crown Elev (feet)
10300	67	67
10462	66.5	66.5
10600	66.1	66.2
10700	66	66
10900	66.4	66.1
11000	66.2	66.3
11200	66.3	66.3
11400	66.3	66.5
11500	66.6	66.6
11600	66.9	66.7
11700	66.9	66.6
11800	66.8	66.6
11900	66.4	66.5
12146	65.7	65.7
12200	65.6	65.6
12220	65.6	65.6
12400	64.9	64.9
12525	64.4	64.4
12600	64.1	64.2
12700	63.7	63.9
12800	63.6	63.6
12900	63.5	63.5
13233	63.3	63.4
13400	62.8	64.8
13483	63	65.5
13733	63.3	63.0
13900	63.6	62.9
14100	64.1	63.0
14200	64.3	63.4
14300	64.1	63.8
14400	64.1	64.1
14700	64.8	64.5
14800	65.3	64.7
14900	65.6	64.9
15000	65.5	65.2
15200	65.2	65.2
15300	65.4	65.2
15500	66.1	65.9
15600	66.5	66.2
15800	67	66.7

Road Station (feet)	Existing Crown Elev (feet)	Proposed Crown Elev (feet)
16000	67	66.6
16100	67	66.7
16300	66.1	66
16400	65.8	65.7
16500	65.3	65.3
16600	65.2	65.1
16705	65	65.2
16900	64.8	64.9
17000	64.8	64.8
17100	64.9	64.7
17300	64.7	64.5
17500	64.2	64.4
17700	64.1	64.1
18000	64.2	64.2
18100	64.3	64.3
18263	65	65
18400	65.6	65.5
18484	65.9	65.9
18580	66.1	66.1
18780	66.5	68
18980	66.6	66.6
19000	66.6	66.6
19100	66.7	66.7
19200	67	66.8
19300	66.9	66.8
19400	66.9	66.9
19600	67.1	67.1
19700	67.2	67.2
19900	67.5	67.5
20200	68	68
20300	68.1	68
20400	68	68
20500	67.9	67.9
20800	68	68
21100	67.8	68
21200	68	68
21300	68	68
21500	67.9	67.9
21600	67.7	67.7
21800	67.3	67.3
21900	67.4	67.4
22000	67.4	67.4
22100	67.3	67.4
22300	67.5	67.5
22575	67.7	67.7

Appendix B (contd)

Existing and Proposed Condition Road Crown Profiles

County Road 31

Road Station (feet)	Existing Crown Elev (feet)	Proposed Crown Elev (feet)
100	64.9	65
200	64.7	64.7
300	64.5	64.6
400	64.2	64.4
500	64	64.2
600	63.6	64
700	63.6	63.7
800	63.4	63.4
900	63.3	63.1
1000	63.2	62.9
1050	63.15	62.8
1100	63.1	62.8
1200	63.2	62.8
1321.6	62.8	62.8
1400	62.8	63.4
1500	62.6	64.5
1522	62.5	65
1600	63.1	65.5
1800	61.5	62.4
1845	61.5	61.8
1900	61.5	61.8
2000	61.5	61.7
2100	61.6	61.7
2200	61.5	61.7
2300	61.6	61.7
2400	61.6	61.7
2500	61.6	61.6
2600	61.7	61.6
2700	61.7	61.6
2800	61.6	61.6
2900	61.7	61.6
3000	61.6	61.5

County Road 32

Road Station (feet)	Existing Crown Elev (feet)	Proposed Crown Elev (feet)
1400	68.2	68
1500	67.6	67.6
1592	67.2	67.2
1650	66.9	68
1700	67	68.4
1800	67	69.7
1875	66.8	69.6
1900	66.5	69.1
2000	65.6	67.6
2100	66	66
2200	65.7	65.7
2300	65.5	65.5
2400	65.4	65.5
2500	65.5	65.5
2600	65.8	65.8