LOWER DEER CREEK FLOOD AND ECOSYSTEM IMPROVEMENT PROJECT – 2D HYDRODYNAMIC MODEL

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PURPOSE

The purpose of this technical memorandum is to document the data and methods used to develop the hydrodynamic model for the Lower Deer Creek Flood and Ecosystem Improvement Project. The model is necessary to simulate existing hydrologic conditions (i.e., velocities, flood extents, and depths) and to quantify Deer Creek aquatic, riparian, and floodplain habitat conditions. This model will also be used to analyze the Proposed Project and Alternatives as part of the environmental planning efforts.

MODEL DOMAIN

The model domain extends along 11 miles of Deer Creek from the Deer Creek Irrigation District (DCID) diversion dam at the upstream end (near USGS stream gage 11383500) to its confluence with the Sacramento River (Figure 1). It also covers a portion of the Sacramento River extending from just upstream of the Champlin Slough confluence to the downstream end at Woodson Bridge (DWR stream gages VIN, A02700, and A02701). The lateral extent of the model boundary was chosen to adequately capture the flooding extent of Deer Creek under different flow conditions while limiting the number of cells to a computationally manageable quantity. Break lines were drawn along linear topographic features (e.g., levees, channel banks, etc.) to enforce mesh cell face alignment and create a more accurate representation of these features by the model. The model mesh has a 25-ft base cell size with smaller cells along some topographic features to provide higher resolution output.

For the purposes of this report, sections of Deer Creek were categorized into the reaches presented in Figure 2. Reach colors have been replicated throughout the graphs presented herein to facilitate model results interpretation and discussion.

FIGURE 1: MODEL DOMAIN AND STREAM GAGES

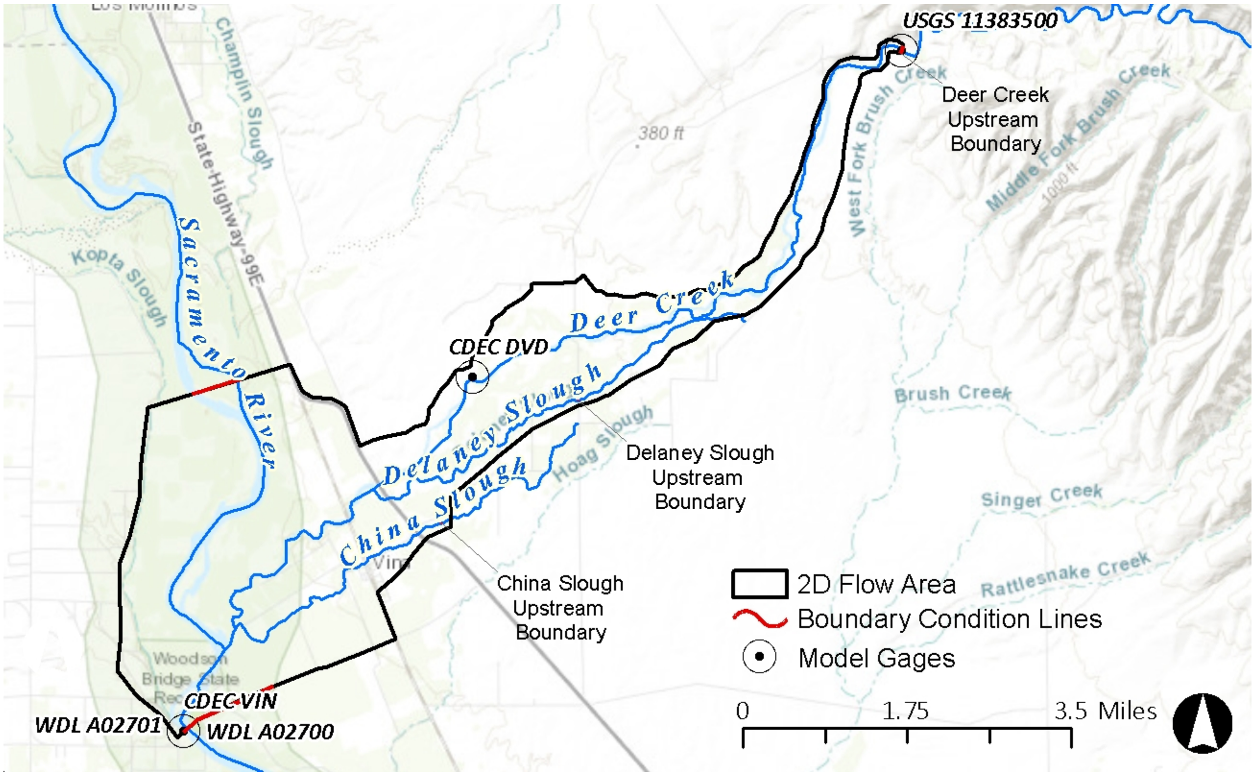
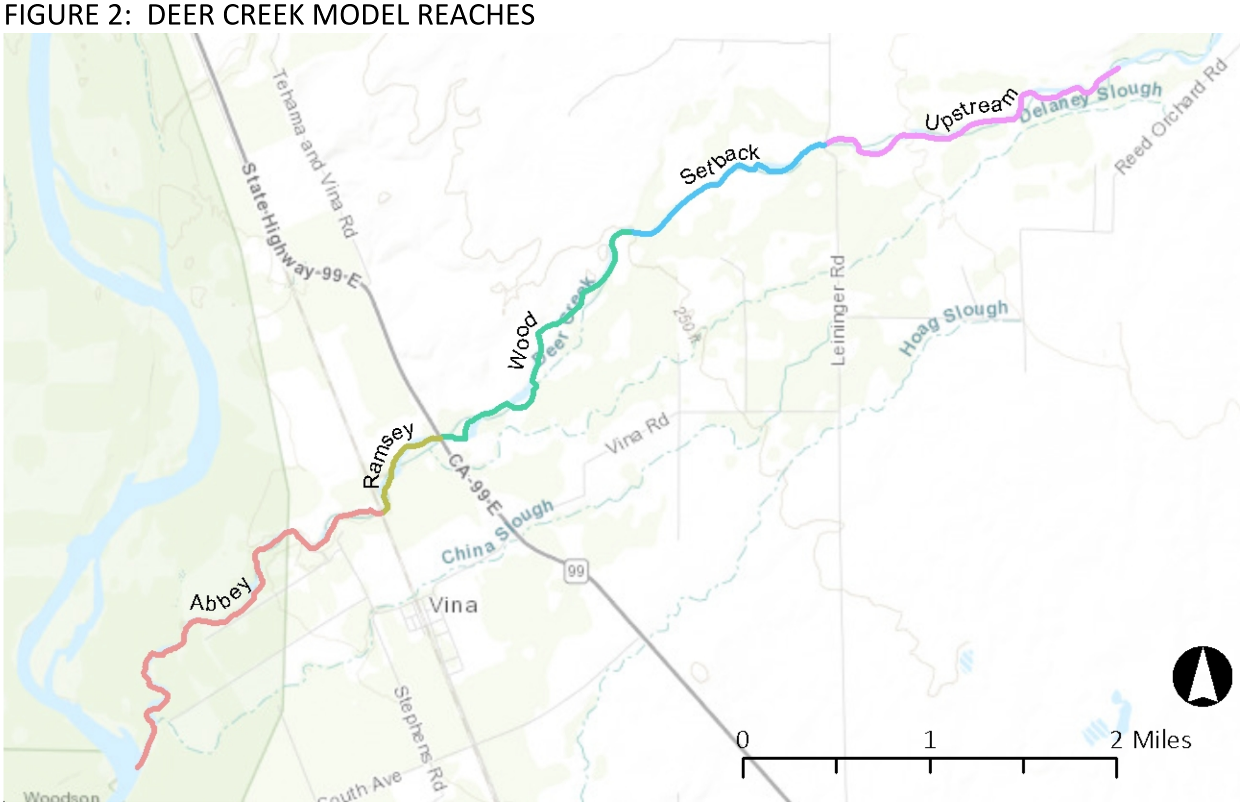


FIGURE 2: DEER CREEK MODEL REACHES



Model Input Data

Data types and sources used in the development of this two-dimensional hydrodynamic model are summarized in Table 1 and described in the sections that follow.

TABLE 1: DEER CREEK 2D MODEL INPUT DATA SUMMARY

Input Data	Data Type	Date	Source
Topography and Channel Bathymetry	LiDAR Survey	2017	Geoterra
Topography and Channel Bathymetry	Deer Creek Bathymetric Survey	2018	FlowWest
Topography and Channel Bathymetry	Sacramento River Bathymetric Survey	2013	DWR Kopta Slough Study
Hydrology and Boundary Conditions	Annual Peak Flows	1912–2017	USGS Deer Creek at Vina (11383500)
Hydrology and Boundary Conditions	15-minute Flow Hydrograph	January 1997	USGS Deer Creek at Vina (11383500)
Hydrology and Boundary Conditions	15-minute Flow Hydrograph	January 1997	DWR WDL Sacramento River at Vina Bridge (A02700-channel only)
Hydrology and Boundary Conditions	15-minute Flow Hydrograph	January 1997	DWR WDL[A] Sacramento River at Vina Bridge (A02701-overflow only)
Hydrology and Boundary Conditions	Mean Daily Flows	1912–2017	USGS Deer Creek at Vina (11383500)
Hydrology and Boundary Conditions	Mean Daily Flows	1945–2015	DWR WDL Sacramento River at Vina Bridge (A02700-channel only)
Hydrology and Boundary Conditions	Stream gage Rating Curve	2017	DWR CDEC[B] Sacramento River at Vina Bridge (VIN)
Hydrology and Boundary Conditions	Stream gage Rating Curve	2017	DWR WDL Sacramento River at Vina Bridge (A02700-channel only)

Input Data	Data Type	Date	Source
Hydrology and Boundary Conditions	Stream gage Rating Curve	2017	DWR WDL Sacramento River at Vina Bridge (A02701-overflow only)
Structures	1D Hydrodynamic Model Geometry	2007/2010	Mussetter Engineering, Inc./ DWR Northern Region Office (NRO)
Structures	Field survey	2018	FlowWest
Land Cover	Aerial Imagery	2017	Geoterra
Land Cover	Special-Status Species Survey	2018	WRA Environmental Consultants

A. California Department of Water Resources Water Data Library (DWR WDL)
B. California Department of Water Resources California Data Exchange Center (DWR CDEC)

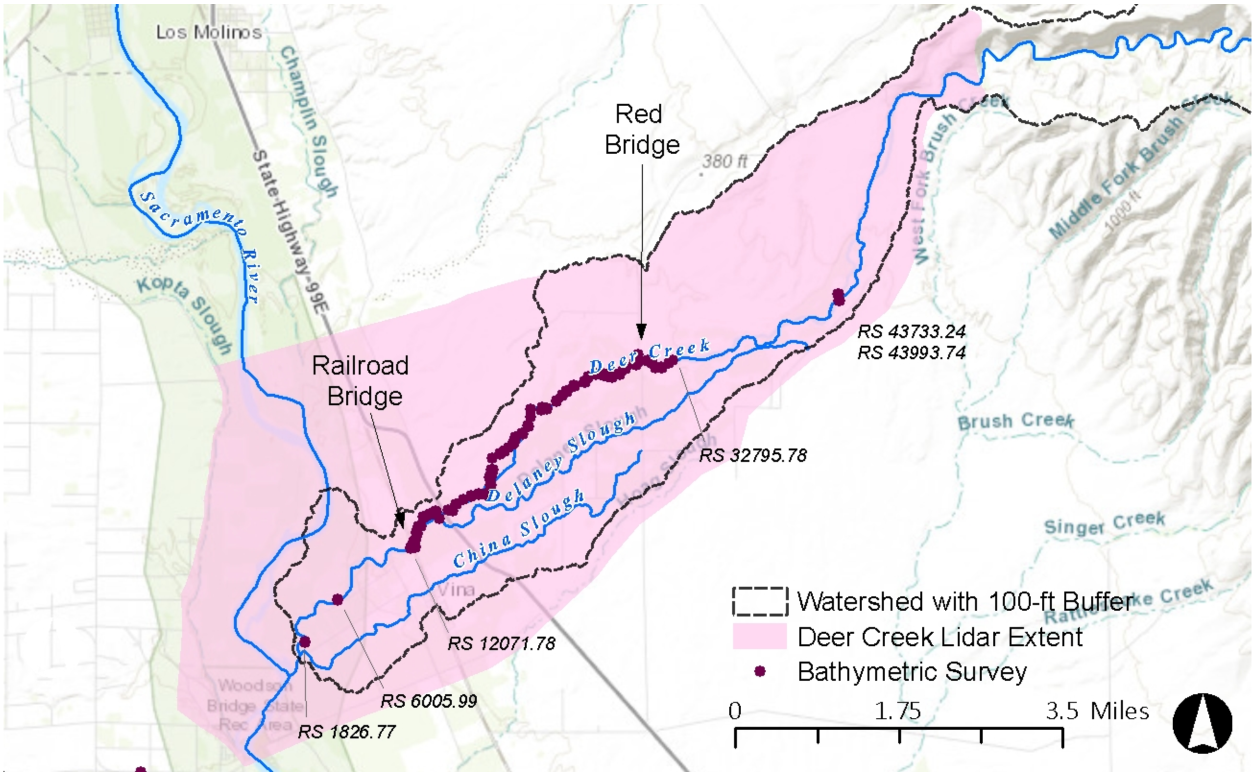
Topography and Channel Bathymetry

Model topography was developed using LiDAR collected throughout the study area on October 31, 2017 (Figure 3). Geoterra collected and processed the LiDAR points into a 2-ft resolution bare earth digital elevation model (DEM) that was used for the model topographic terrain base. The horizontal datum of the data is the North American Datum of 1983 (NAD83), the coordinate system is State Plane Zone 1, and the vertical datum is the North American Vertical Datum of 1988 (NAVD88). All units are in U.S. survey feet.

As LiDAR is unable to penetrate the water surface, channel bathymetries were filled in using other data sources. Sacramento River bathymetry was derived from 2013 Kopta Slough Project cross-sections provided by the DWR NRO on March 6, 2018 by formal request. These data were collected along the Sacramento River every 100 ft throughout the model extent. Deer Creek bathymetry was collected in support of this modeling effort on July 9, 2018 (Figure 3). Cross-sections were collected every 500 ft in the focus area where most of the project elements are proposed—from approximately 2,500 feet upstream of Red Bridge (River Station 32795.78) to just downstream of the Railroad Bridge (River Station 12071.78). Additional cross-sections were collected in the Upstream reach (at River Stations 43993.74 and 43733.24) and in the Abbey reach (at River Stations 6005.99 and 1826.77). See Figure 2 for a map of Deer Creek reaches.

On the day the LiDAR was collected, the flow rate of Deer Creek was 125 cubic feet per second (cfs) near the upstream end of the model boundary (as reported by USGS stream gage 11383500). The Sacramento River stream gage at Woodson Bridge (CDEC station "VIN") was not reporting on that day, so flow was estimated to be approximately 9,550 cfs based on comparisons between the stream gage rating curve and LiDAR-measured water surface elevations. The inundation boundaries provided with the LiDAR dataset were used as the break lines defining the transition between the use of topographic and bathymetric data.

FIGURE 3: TOPOGRAPHIC AND BATHYMETRIC SURVEY EXTENTS



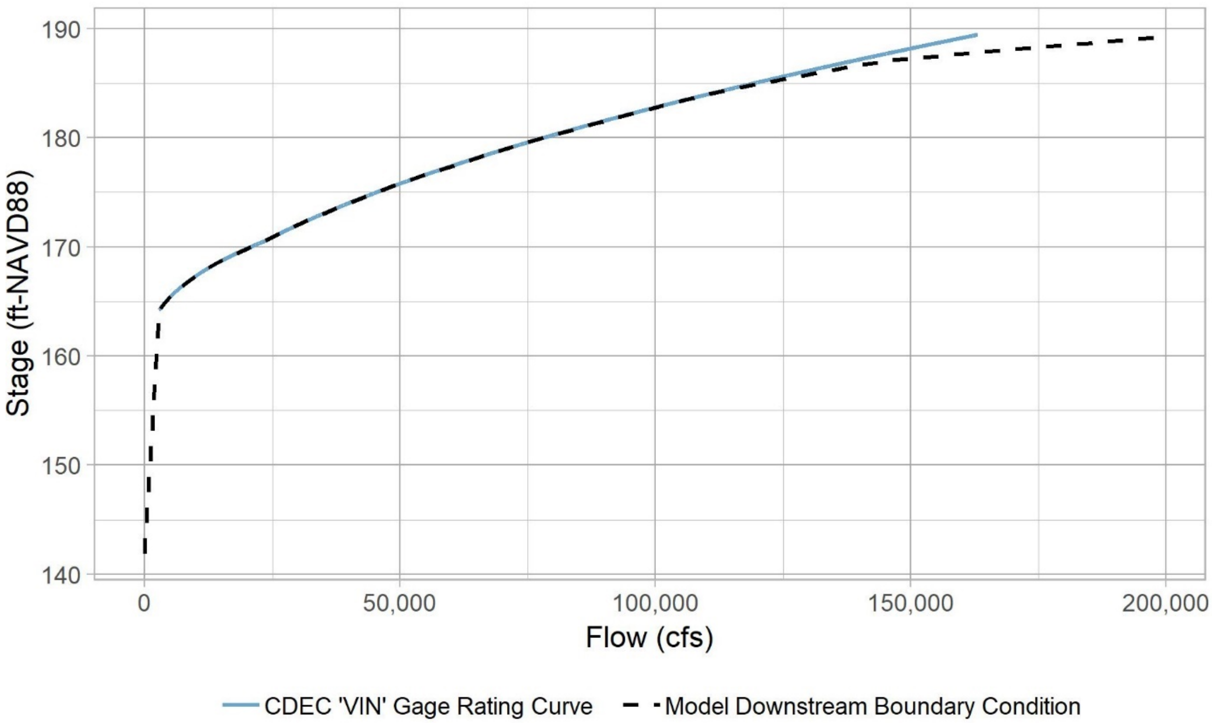
Hydrology and Boundary Conditions

The HEC-RAS software requires user input of upstream and downstream boundary conditions to perform model runs. Typically, the upstream boundary condition is the selected flow rate, and the downstream boundary condition is a known water surface elevation at that flow rate. A total of five boundary conditions (four upstream and one downstream) were used for this study.

Downstream Rating Curve Boundary Condition

The downstream boundary was developed as a modified stream gage rating curve at Woodson Bridge in the Sacramento River (Figure 4, CDEC VIN gage rating table [http://cdec.water.ca.gov/rtables/VIN.html]). Modifications to the published rating curve at this stream gage include defining a river stage at zero flow, paring the table down from 250 to 50 coordinate pairs (HEC-RAS maximum), converting from United States Engineering Datum (USED) to NAVD88, and accounting for overflow that bypasses the stream gage (reported at station WDL A02701 [Sacramento River at Vina Bridge] by the DWR WDL – overflow only). According to the DWR Water Data Library (WDL), the discharge reported by the Sacramento River @ Vina Bridge (station WDL A02700) stream gage does not include the upstream east bank overflow (station WDL A02701) that bypasses the station during high flow events. This led DWR to establish a rating curve for the overflow channel developed from stage-discharge measurements collected in January of 1970. These data were used to adjust the downstream model boundary rating curve by adding estimated overflows to the published rating curve values at stages above the east bank overflow activation stage (184.411 ft-NAV88, Figure 4).

This resulted in flattening and elongation of the rating curve at stages above the east bank overflow activation stage (shown by the dashed line).



Flow Input Boundary Conditions

A total of eight flow input hydrographs were developed for this model (Table 2). For the 2-yr through 100-yr recurrence interval flows, steady state conditions were modeled by linearly increasing the flow rate and holding it constant for a duration adequate to achieve steady state throughout the model extent. Equilibrium was indicated by a sustained constant water surface elevation at the downstream boundary of the model. The January 1997 flow was modeled using the Deer Creek unsteady flow hydrograph recorded at the upstream gage.

TABLE 2: MODEL PEAK FLOW SUMMARY

Modeled Flow Condition	Deer Upstream Boundary	Sacramento Upstream Boundary[A]	Sacramento Channel Only[B]	Woodson Bridge Overflow[C]	Sacramento Downstream Boundary[D]	China Slough[E]	Delaney Slough[E]
Base Flow Calibration	125	9,424	9,549	0	9,549	0	0
2-yr Calibration[F]	5,520	25,962	29,480	0	29,480	17	9
2-yr	5,500	80,500	85,793	0	86,000	17	9
5-yr	9,900	105,100	114,472	180	115,000	51	29
10-yr	13,200	128,800	136,294	5,740	142,000	73	42
25-yr	17,800	125,200	137,000	6,000	143,000	94	55
50-yr (design)	21,000	122,000	137,000	6,000	143,000	106	62
100-yr	25,300	117,700	137,000	6,000	143,000	114	67
January 1997	24,000	170,600	168,000	26,600	194,600	114	67

Grey filled cells indicate Sacramento River median mean daily flow held constant for Deer Creek peak flows > 13,300 cfs

A. Inflow at the upstream Sacramento River model boundary calculated by subtracting Deer Creek flow from Sacramento total flow at Woodson Bridge

B. Flow rates reported for the Sacramento River main channel only at Water Data Library Station A02700

C. Estimated overflow rates that bypass the Sacramento River gage as reported at Water Data Library Station A02701

D. Total flow at Woodson Bridge including estimated overflow

E. Flows derived using USGS Streamstats regional regression tool (https://www.usgs.gov/mission-areas/water-resources/science/streamstats-streamflow-statistics-and-spatial-analysis-tools?qt-science_center_objects=0#qt-science_center_objects)

F. Hydrograph from Deer Creek subtracted from Sacramento River hydrograph at Woodson Bridge. Peak flows are not coincident.

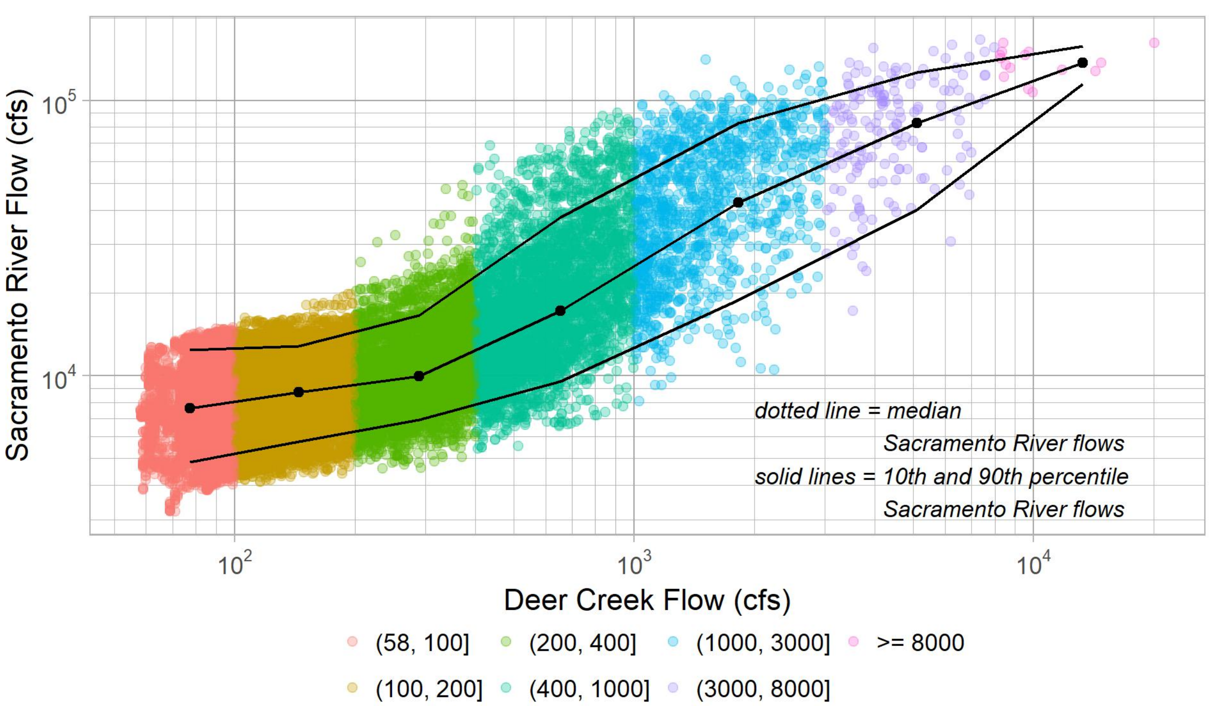
Deer Creek Flows

Deer Creek flow statistics presented in Table 2 are based on analysis of 100 annual peak flows from the USGS stream gage located just upstream of the DCID diversion dam (USGS 11383500). A 1981 USGS Bulletin 17B (*Guidelines for Determining Flood Flow Frequency* - Bulletin #17B of the Hydrology Subcommittee) flow frequency analysis was conducted using the HEC-SPP statistical analysis program to calculate expected flows corresponding to the return periods summarized in Table 2.

Sacramento River Flows

Sacramento River model input flows were developed by updating the analyses performed for the Lower Deer Creek Restoration and Flood Management Feasibility Study (Feasibility Study, DCWC 2011). Mean daily flows were collected from the Sacramento River stream gage at Woodson Bridge (DWR WDL site A02700) and from the Deer Creek stream gage near the DCID diversion dam (USGS 11383500) spanning the years of overlap—1945 to 2015. As in the Feasibility Study, Deer Creek daily flows were sorted into seven bins and the logarithmic mean Deer Creek flow was calculated for each bin. These flows were paired with Sacramento River median, 10th percentile, and 90th percentile mean daily flows for each bin (Figure 5). Since measured peak flows in Deer Creek were not found to be coincident with peak flows in the Sacramento River (DCWC 2011), the dotted line in Figure 5 that defines median Sacramento River flows was used for evaluating hydraulic conditions. For Deer Creek peak flows greater than the calculated logarithmic mean in the last bin (i.e., flows > 13,300 cfs), Sacramento River flow was held constant at the maximum median flow value (137,000 cfs). Using those values, total Sacramento River flow at Woodson Bridge was calculated by adding estimated stream gage bypass overflow values to the median Sacramento River channel flows (Table 2). Since the Sacramento River stream gage at Woodson Bridge is downstream of the Deer Creek confluence, it measures flows for both. The upstream boundary flow input to the Sacramento River was derived by subtracting Deer Creek peak flows from the total Sacramento River flow at Woodson Bridge.

Figure 5: Relationships between measured Coincident Mean Daily Flows in Sacramento River and Deer Creek



China Slough and Delaney Slough Flows

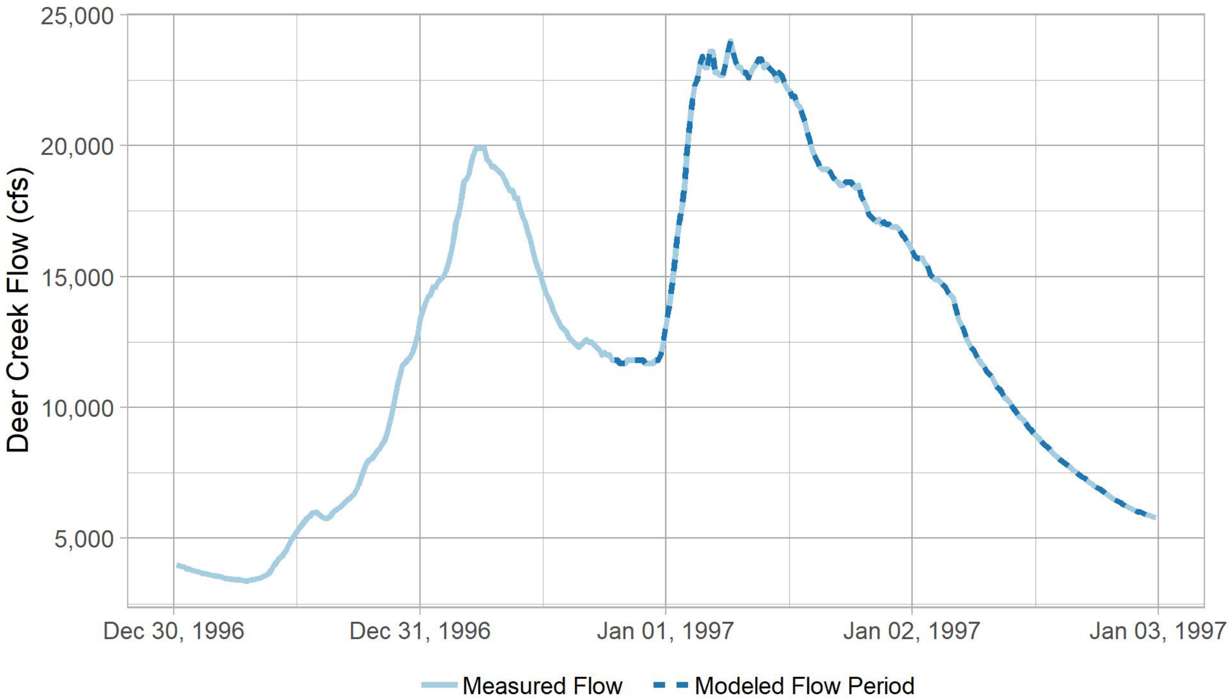
Since China Slough and Delaney Slough are ungaged, the upstream boundary conditions for these drainages were derived using USGS StreamStats regional regressions. Points were selected at the modeled upstream boundary of these drainages from which the StreamStats web application calculated peak flow recurrence intervals. Those flows were used as inputs to the model. Uncertainty related to flow estimates in these two drainages is discussed further in the model limitations and data gaps section.

January 1997 Flow Hydrograph

The January 1, 1997 event in Lower Deer Creek followed a series of storms that occurred during one of the wettest Decembers on record in Northern California (California Nevada River Forecast Center). The most significant of the preceding storms peaked at 20,000 cfs on December 31, 1996 (Figure 6). The following day, peak discharge in Deer Creek reached 24,000 cfs, making it the largest flow event recorded in Deer Creek. The Sacramento River stream gage recorded a maximum total flow of 194,600 cfs (total flow as reported by DWR WDL Sacramento River channel [A02700-channel only] and overflow [A02701-overflow only] gages on that day.

To simulate this event, the model was run with wet antecedent conditions based on maximum water surface elevation results from the 10-yr peak flow steady state simulation. This flow was chosen since it most closely represents the 12,000 cfs base flow reported by the Deer Creek stream gage prior to the start of the January 1, 1997 storm event (Figure 6). Flow in the Sacramento River was held at a steady 170,600 cfs (calculated as 194,600 [Sacramento peak at Woodson Bridge] – 24,000 [Deer Creek peak at upstream gage]) throughout the duration of the simulation. Results of this simulation are summarized in the model results section.

FIGURE 6: JANUARY 1997 FLOW HYDROGRAPH



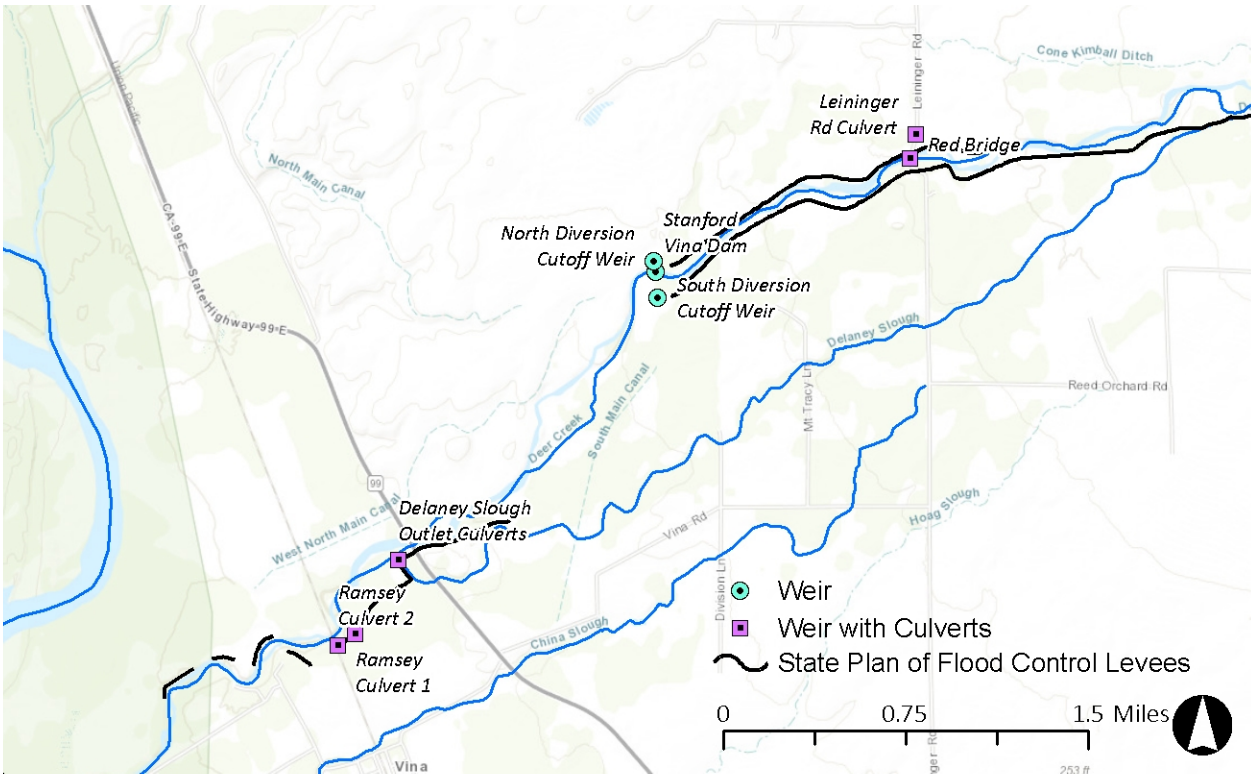
HYDRAULIC STRUCTURES

This HEC-RAS model contains a total of eight hydraulic structures along the Deer Creek corridor (Figure 7). Properties of the structures were established by referencing the Mussetter Engineering, Inc. (MEI) 1D hydrodynamic model (2007), field surveys conducted by FlowWest (2018), and descriptions provided by local stakeholders. All weir and culvert structures were incorporated into the model using HEC-RAS 2D area connection tools. Culvert loss and Manning's coefficients were assigned based on shape, entrance and exit type, and material using the HEC-RAS 5.0 Reference Manual as a guide.

Three Deer Creek bridge crossings exist in the project extent—the railroad bridge, Highway 99E bridge, and Red Bridge at Leininger Road. Since modeled water surface elevations in Deer Creek are much lower than the railroad and Highway 99E bridge decks during even high flow events, it was not necessary to include them as structures in the model domain. Instead, the hydraulic effects of these two downstream bridges on Deer Creek water surface elevations and inundation patterns was captured by including roadway approaches, embankments, and abutments in the model terrain.

Red Bridge stands apart from the other two bridges because water surface elevations have been known to overtop the bridge deck at moderate to high flows. According to model results, water surface elevations reach the bottom of the bridge deck at a peak flow less than the 5-year event and overtop the bridge at a 10-year event. Therefore, Red Bridge was included in the model geometry as a weir with concrete box culverts sized and arranged to approximate the bridge deck, piers, and river bed elevations (Table 1). This method uses culvert equations to model a bridge, which has use limitations described further in the Model Limitations and Data Gaps section. Overall, model results at Red Bridge matched relatively well to local anecdotal accounts of flow dynamics during high flow events.

Figure 7: Model Hydraulic Structure Locations



Land Cover and Roughness

Deer Creek landcover types were mapped using a combination of biological surveys conducted by WRA Environmental Consultants (2018) and high-resolution aerial imagery (2017). Corresponding roughness coefficients were developed and modified based on model calibration (Table 3).

TABLE 3: MODEL LAND COVER TYPES AND ROUGHNESS COEFFICIENTS

Land Cover	Roughness Coefficient
developed/pavement	0.025
bare ground	0.03
canal	0.03
china slough channel	0.03
herbaceous farm	0.03
intermittent stream	0.03

Land Cover	Roughness Coefficient
open waters	0.03
perennial stream	0.03
river	0.03
deer creek bed - abbey reach	0.03
grassland/pasture	0.035
irrigated swale	0.035
seasonal wetland	0.035
seasonal wetland ditch	0.035
vernal pool	0.035
vernal swale	0.035
no landcover data	0.04
residential development	0.045
sparse riparian	0.045
sparse woodland	0.045
deer creek bed - ramsey reach	0.045
deer creek bed - setback reach	0.045
deer creek bed - wood reach	0.045
freshwater marsh	0.05
china slough channel - abbey reach	0.055
orchards	0.055
deer creek bed - upstream reach	0.055
moderate riparian	0.06
moderate seasonal wetland	0.06
moderate woodland	0.06
dense riparian	0.07
dense riparian wetland	0.07
dense seasonal wetland	0.07
dense woodland	0.07
willow scrub wetland	0.07

Note that Manning's N coefficients used in development of 2D models are different (generally lower) than those used in 1D models; and therefore, the coefficients used in this effort may not match those used in previous 1D modeling efforts in Deer Creek.

Model Calibration and Verification

Calibration of a hydraulic model involves comparison of model predictions at a particular flow against corresponding field survey data and adjustments to model parameters (e.g., roughness coefficients) to improve model accuracy. For the purposes of model calibration, water surface elevation data were collected on October 31, 2017 (for base flow conditions) and high-water marks were collected on March 27, 2017 (for a 2-yr event hydrograph). Ultimately, roughness coefficients were increased for the Deer Creek stream bed in the Ramsey, Wood, and setback reaches (from 0.030 to 0.045) and in the Upstream reach (from 0.030 to 0.055). Roughness coefficients were decreased for dense riparian forest, dense riparian wetland, dense seasonal wetland, dense woodland, and willow scrub wetland (from 0.080 to 0.070) and moderate riparian, moderate seasonal wetland, and moderate woodland (from 0.065 to 0.060).

Model verification involves confirming the legitimacy of model results when compared to a conceptual model, or as with this case, to another accepted hydraulic model of the system (i.e., the 2007/2010 DWR NRO 1D model). A model verification process was conducted to investigate model results at the 50-yr project design flow since no survey data were available to perform model calibration at that flow of interest.

Overall, results of the calibration and verification runs show acceptable levels of agreement with survey and the DWR NRO model results. Detailed discussions are provided in the sections that follow. For ease of comparison against the DWR NRO 1D model and orientation within the system, all results are displayed by both river station and reach (Figure 2). Analyses are only provided for those parts of the river within the project footprint (1D river stations 797.46 to 40661.62).

Base Flow Calibration

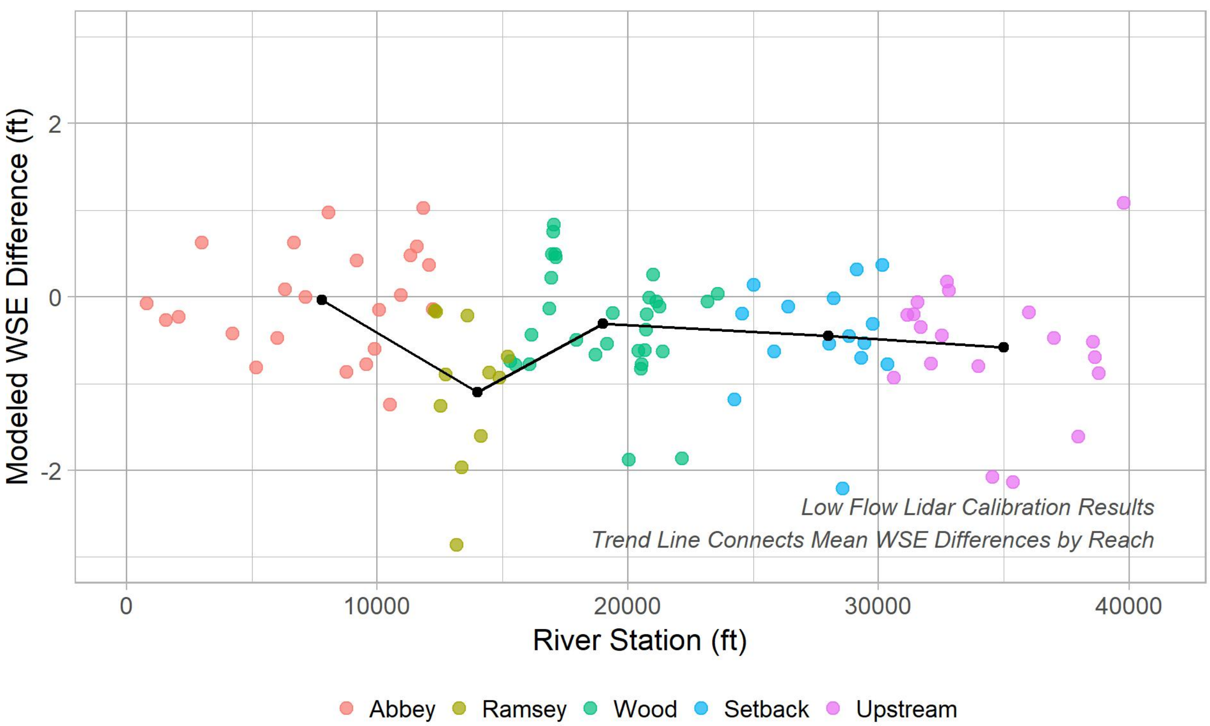
Water surface elevations collected from LiDAR on October 31, 2017 were used to calibrate the model for base flow conditions. On that day, the flow reported at the Deer Creek USGS stream gage (11383500) was a relatively steady 125 cfs, and the flow downstream of the Stanford-Vina Ranch Irrigation Company (SVRIC) Diversion dam (CDEC stream gage DVD - http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=DVD) was reported at 83 cfs. Since flows differed significantly upstream and downstream of the SVRIC dam, and HEC-RAS 2D software does not allow for flow to be removed from the system, two separate simulations representing each of the flows were run. Steady state conditions were modeled by linearly increasing the flowrate and holding it constant for a duration adequate to achieve steady state throughout the model extent—as indicated by a sustained constant water surface elevation at the downstream boundary of the model. Results from the two steady state runs were attributed to their respective region of Deer Creek (i.e., being upstream or downstream of SVRIC dam). Model calibration was achieved by adjusting model roughness coefficients to maximize agreement between model water surface predictions at the calibration flow and surveyed water surface elevations.

At the time this model report was created, no flow data were available from the Sacramento River stream gage at Woodson Bridge (CDEC VIN, WDL A02700 and A02701). However, the flow was approximated using the LiDAR water surface elevation at the downstream boundary and the stream gage rating curve. According to this analysis, the apparent flow in the Sacramento

River during the LiDAR data collection was 9,549 cfs (corresponding to a water surface elevation of 167.188 ft-NAVD88).

Differences between the model results and LiDAR water surface elevations are shown in Figure 8. Values greater than zero indicate the model result was higher than the survey value, and values less than zero indicate model results were lower. Apparent in these low flow calibration results is a downward trend in predicted water surface elevations in the upstream direction punctuated by a dip in values through the Ramsey reach. An explanation for this phenomenon was not found. However, model calibration results from the MEI model (2007) revealed similar difficulties calibrating the model in the Ramsey reach—with calibration data disregarded due to unreasonable results and suspected damage to the staff gages. In general, the results show agreement between the modeled and the surveyed water surface elevations—with mean differences ranging from -0.03 ft to -1.1 ft (represented by the black line in Figure 8). Absolute differences ranged from a minimum of -2.9 ft in the Ramsey reach to a maximum of 1.1 ft in the Upstream reach.

FIGURE 8: LOW FLOW LIDAR SURVEY CALIBRATION RESULTS

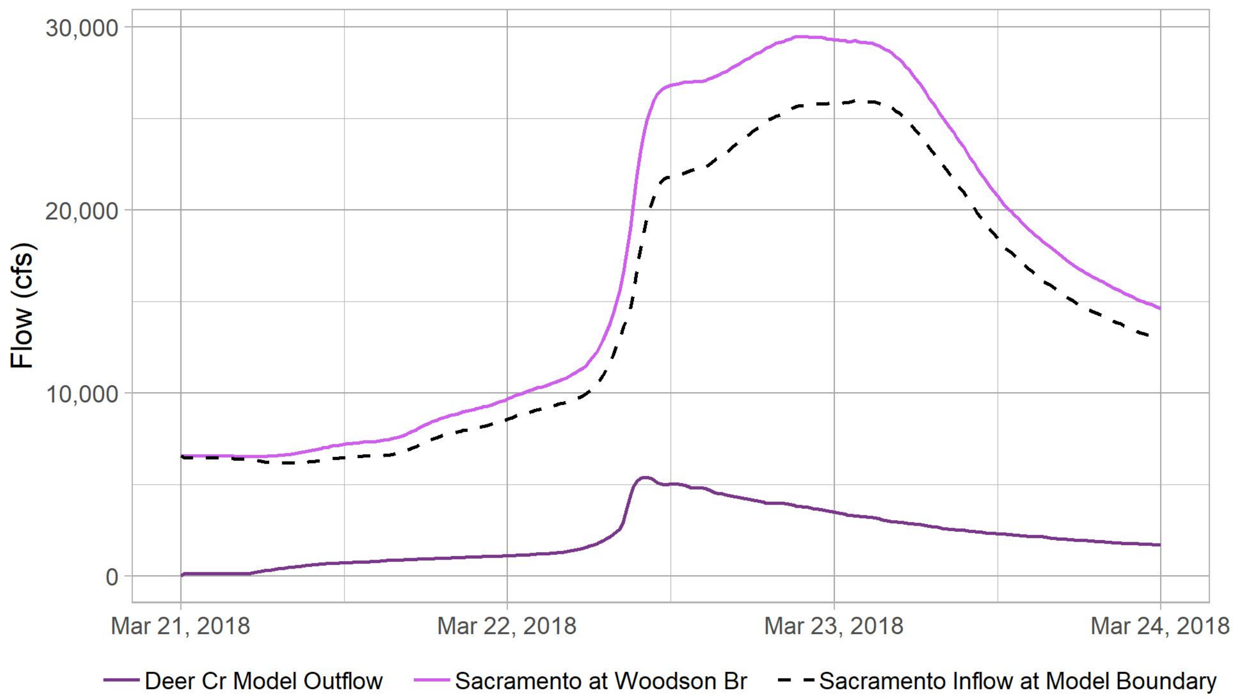


2-YR RECURRENCE INTERVAL CALIBRATION

For this calibration effort, high water marks were identified and surveyed following the March 22, 2018 flow event which corresponded to a 2-year flow in Deer Creek (Figure 9). Deer Creek flow peaked at 5,520 cfs during this event according to the stream gage record (USGS 11383500). The Sacramento River peaked at 29,480 cfs according to the stream gage at Woodson Bridge located downstream of the Deer Creek confluence. The model was run with an unsteady hydrograph flow input, and maximum modeled water surface elevations were compared to high water mark survey elevations. In an iterative fashion, these data were used to refine model calibration—further adjusting roughness coefficients to provide more accurate model results at this higher flow.

To achieve a modeled peak flow approximating that recorded in the Sacramento River at Woodson Bridge, the Sacramento River inflow hydrograph was adjusted by subtracting the modeled Deer Creek hydrograph as output by the model at river station 12285.86—just upstream of the Railroad Bridge and upstream of Sacramento River backwater influence (Figure 9). This method accounts for flow attenuation that occurred as the storm pulse moved downstream.

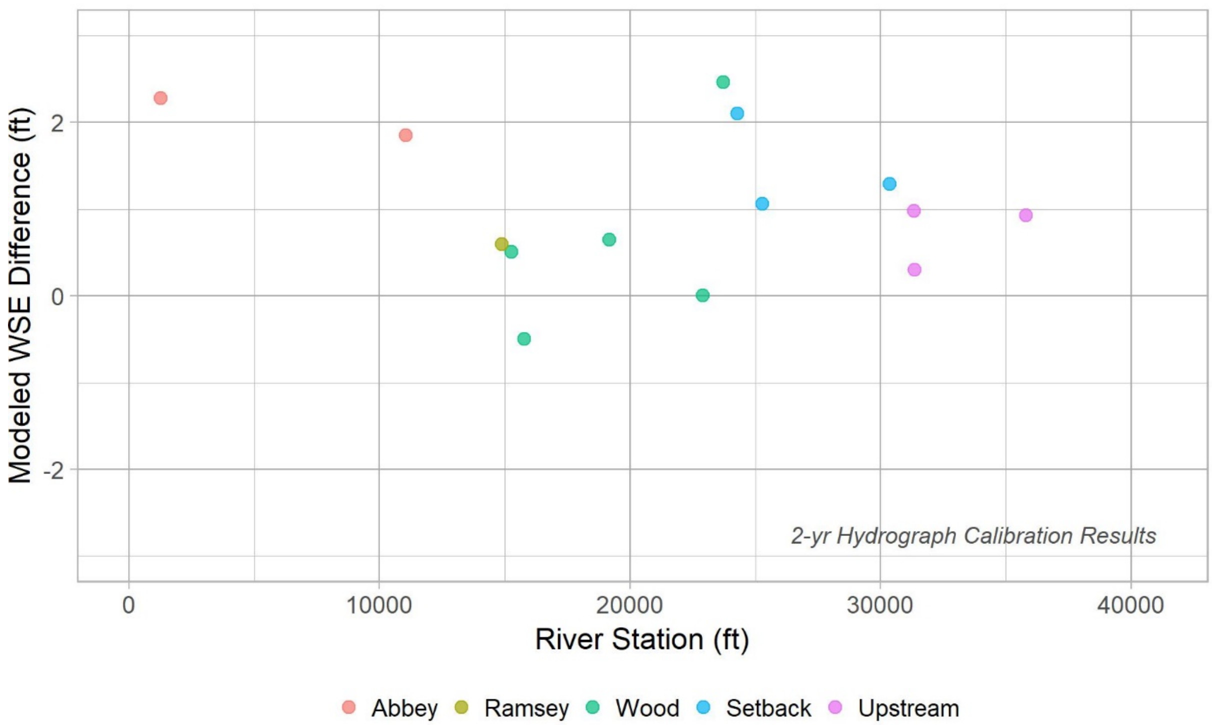
Figure 9: March 22, 2018 Calibration Flow Hydrograph



Field identification of high water marks was determined from discernable debris lines or changes in the orientation of herbaceous vegetation along Deer Creek. The accuracy of this type of survey is generally no more than ± 1 ft due to the uncertainty of pinpointing actual maximum water surface elevations from the various field identifiers. These elevations tend to be more reliable where the river is wider with gently sloping banks (e.g., the Upstream reach), and they are likely less reliable in reaches where the river is narrow, deep, and active with steep banks (e.g., the Abbey reach).

Differences between the model results and 2-yr high water mark elevations are shown in Figure 10. Values greater than zero indicate the model result was higher than the survey value, and values less than zero indicate model results were lower. In general, the results show agreement between the modeled and the surveyed water surface elevations—with absolute differences ranging from a minimum of -0.49 ft to a maximum of +2.46 ft. The most significant differences occur in the Abbey reach, as well as in the Wood and Setback reaches in the vicinity of the SVRIC dam. The fact that most of the points are greater than zero indicates the model is overpredicting water surface elevations as compared to measured values. This is a conservative result.

Figure 10: 2-yr Flow Hydrograph Calibration Results

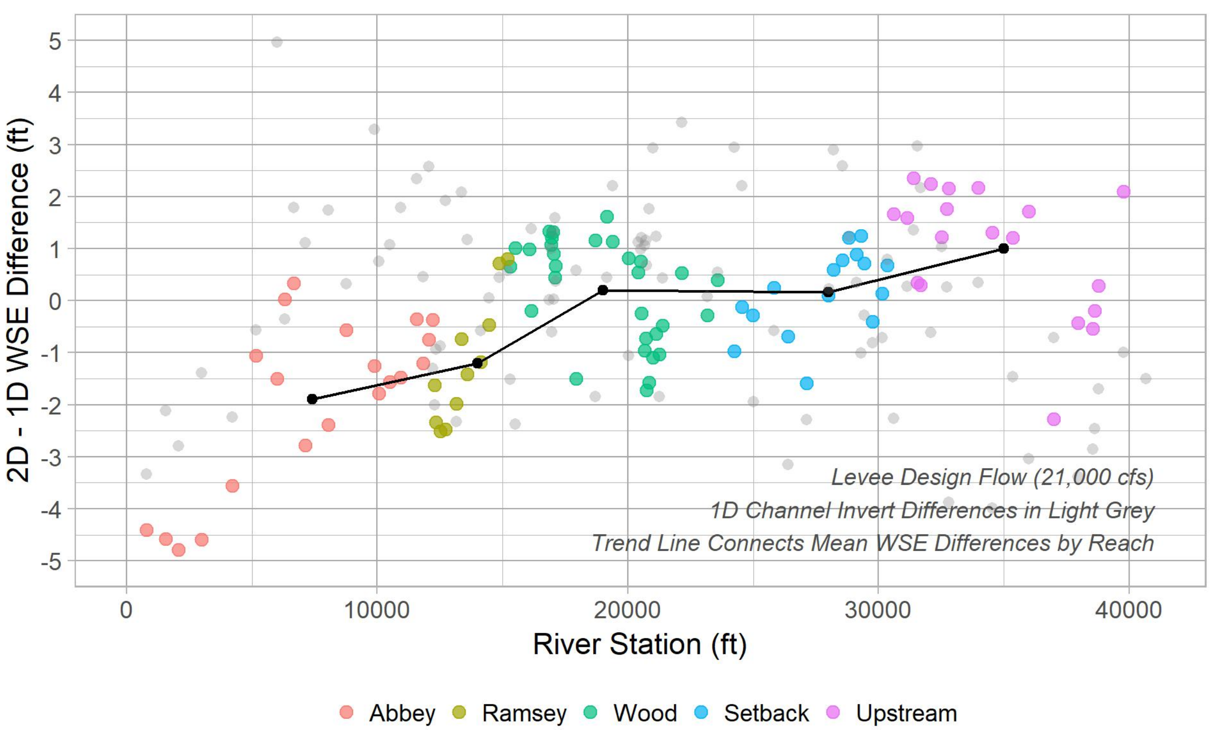


50-yr Recurrence Interval Verification

No survey data were available to calibrate the 2D model at higher flows, so previously accepted results from the DWR NRO 1D model (2007-2010) were used as the basis of comparison. This was done by subtracting the 1D model results at each cross-section within the project footprint from the 2D model water surface elevation results (Figure 11). Therefore, positive values indicate the 2D model is predicting higher water surface elevations and negative values indicate the 2D model is predicting lower water surface elevations relative to the DWR NRO model. In general, the model shows good agreement with the DWR model with mean differences ranging from -1.9 ft (in the Abbey reach) to 1.0 ft (in the Upstream reach). Absolute differences range from -4.8 ft to 2.4 ft. The largest differences are exhibited in the Ramsey reach and the Abbey reach where the 2D model predicts lower water surface elevations.

There are a couple of key differences between the two models which might help explain differences in the downstream results. The first is between the bathymetric data in each model. As can be seen in Figure 11 (grey points), the 2D model has generally lower bathymetric elevations starting from downstream of river station 5157.79. These differences increase in the downstream direction—reaching up to 3.5 ft lower bathymetry in the Abbey reach at the most downstream end. Lower bathymetry in the 2D model would lead to lower water surface elevations in model results. The second difference between the two models is the downstream boundary condition. The downstream boundary in the DWR NRO 1D model was based on known water surface elevation determined from the 1957 profile (189.71 ft-NGVD29, 192.121 ft-NAVD88) at XS 4223.57 in Deer Creek (Deer Creek Flood Control Project Compliance with United States Army Corps of Engineers 1957 Profile, Memorandum, May 18, 2010, DWR Northern Regional Office). This profile—developed by USACE for the Deer Creek Flood Control Project Operation and Maintenance (O&M) Manual—defines the allowable water surface elevation for the project as calculated at the design flow (21,000 cfs) in 1957. In contrast, the downstream boundary of the 2D model is defined as a flow-adjusted rating curve located in the Sacramento River at Woodson Bridge (Figure 4). This boundary was developed with the goal of representing existing conditions in Deer Creek which could then be compared to 1957 conditions, where necessary. A summary of how this boundary influences model results is provided in the model sensitivity section.

FIGURE 11: COMPARISON BETWEEN 2D AND 1D 50-YR LEVEE DESIGN FLOW RESULTS



MODEL SENSITIVITY

Sensitivity analysis is the process of investigating how variation in model input parameters effect model results. These analyses can be used to provide insight into model uncertainty and assist with model calibration. Model sensitivity to the downstream boundary rating curve and Manning's roughness coefficients were performed for the Lower Deer Creek Flood and Ecosystem Improvement model. Results of these analyses are discussed in the sections that follow.

DOWNSTREAM BOUNDARY RATING CURVE

Sensitivity of model results to the downstream boundary condition was investigated by running the 2-yr calibration flow and 50-year design flow with the rating curve stage adjusted by ±10% depth at flow in the Sacramento River (Figure 12). In general, changes to the downstream boundary rating curve did not significantly affect 2-yr results in Deer Creek and effects on 50-yr results were limited to downstream of the railroad bridge (in the Abbey reach, Figure 13). For the 50-year flow, model results fluctuated by a maximum of 3 ft at the Deer Creek confluence with the Sacramento River (River Station 0). Influence of the downstream boundary on model results diminished to zero at River Station 10945.80, just downstream of the railroad bridge.

FIGURE 12: DOWNSTREAM BOUNDARY RATING CURVE ADJUSTMENTS FOR SENSITIVITY ANALYSIS

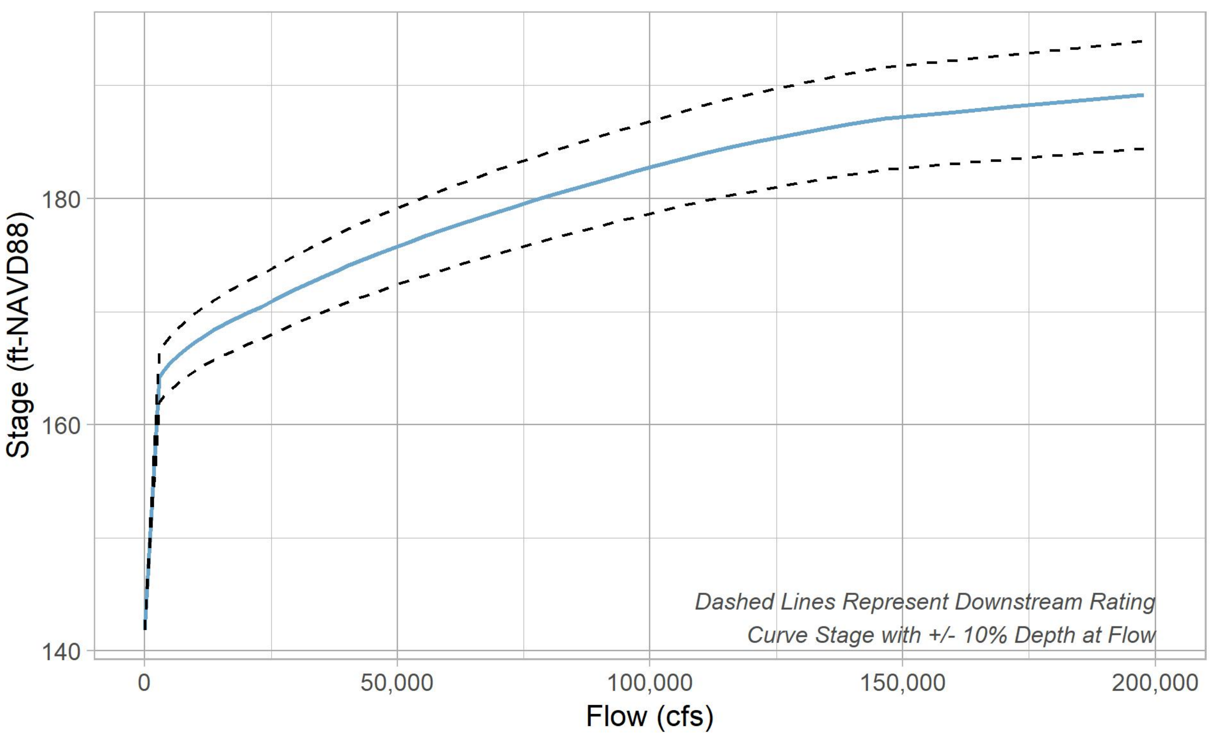
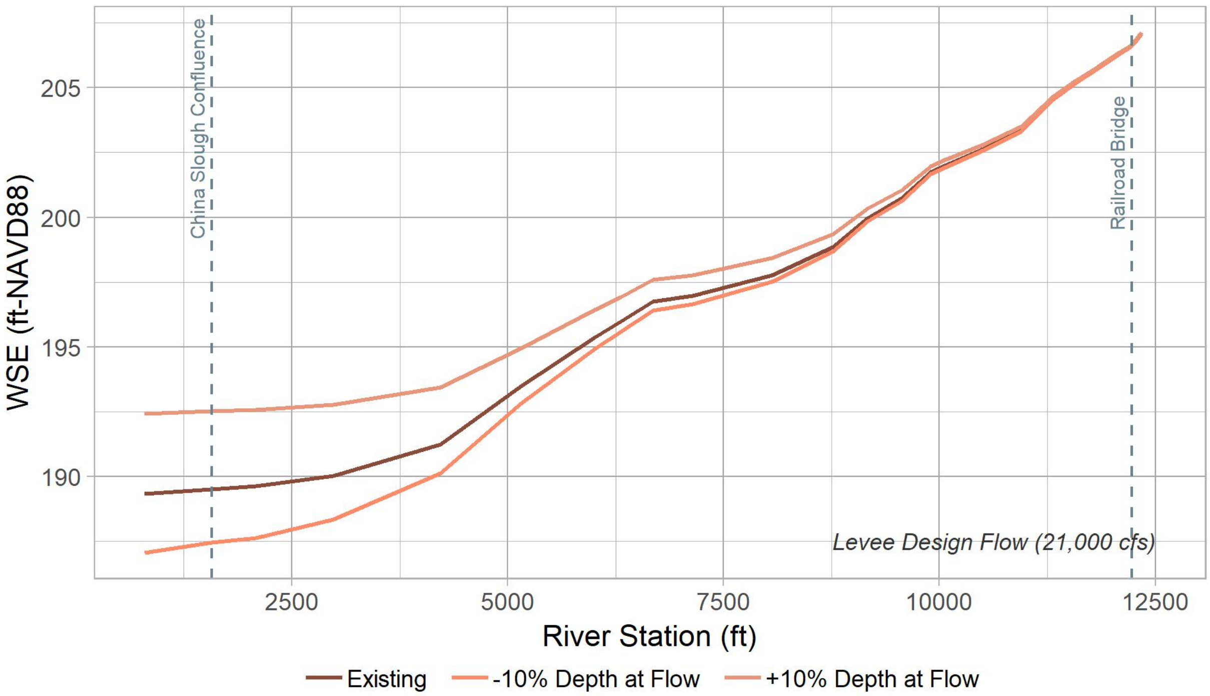


FIGURE 13: DEER CREEK MODEL RESULTS SENSITIVITY TO DOWNSTREAM BOUNDARY, ABBEY REACH, 50-YR FLOW



MANNING'S ROUGHNESS COEFFICIENT

Model sensitivity to Manning's roughness coefficient was tested by running the 50-year event with all Manning's coefficients increased by 25% and comparing model results. Overall, sensitivity to Manning's roughness varied by reach with the Setback reach showing the lowest sensitivity (mean of 0.27 ft) and the Abbey reach showing the greatest sensitivity (mean of 1.5 ft, Table 4).

TABLE 4: ROUGHNESS SENSITIVITY RESULTS BY REACH

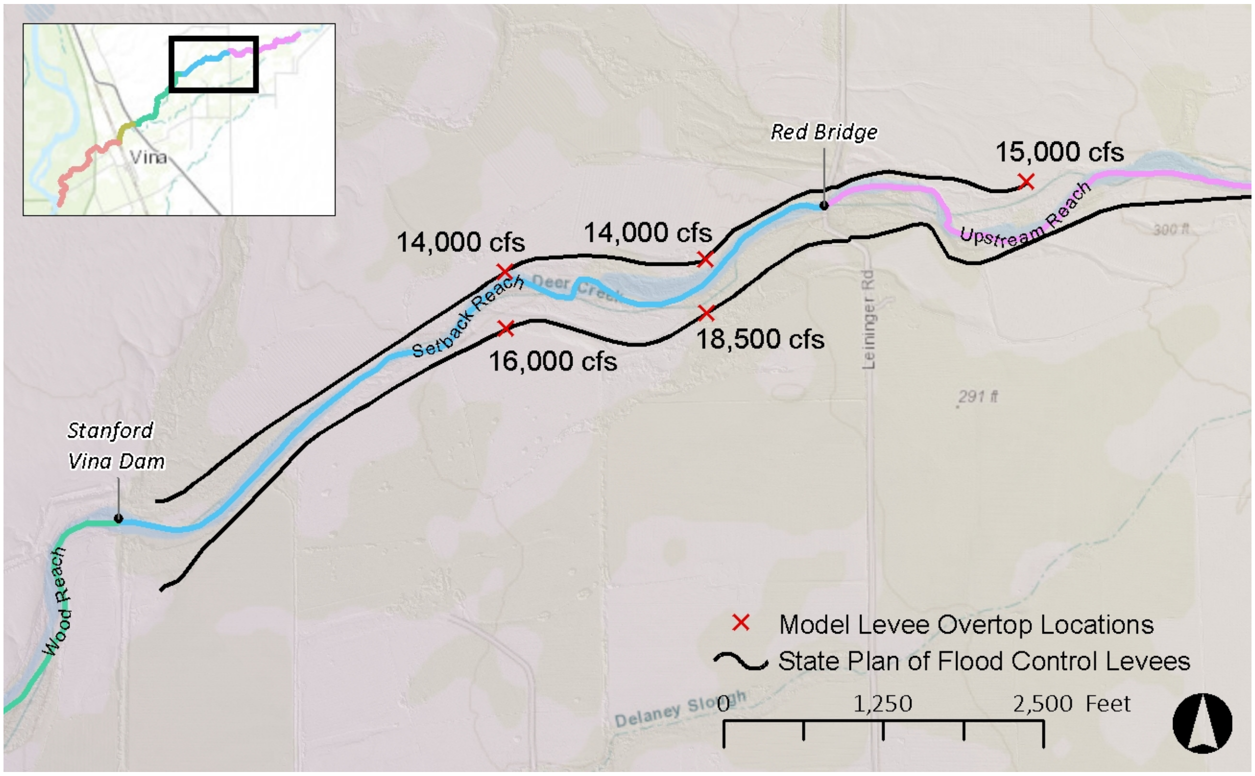
Reach	Minimum Water Surface Elevation Difference (ft)	Maximum Water Surface Elevation Difference (ft)	Mean Water Surface Elevation Difference (ft)
Abbey	0.93	1.9	1.5
Ramsey	0.91	1.5	1.2
Wood	0.71	1.1	0.93
Setback	0.0091	0.72	0.27
Upstream	0.078	1.4	0.77

MODEL RESULTS

This section summarizes 50-yr and 100-yr high flow existing conditions model results. The 50-yr flow corresponds to the original USACE design flow for the Deer Creek Flood Control Project. Output for the 50-yr return interval flows are shown in Appendix A inundation maps (Figure A-1 through Figure A-4). The 1997 event hydrographs were used to represent the 100-year flow results since this event is of interest to local stakeholders. Inundation maps for this event are presented in Appendix B (Figure B-1 through Figure B-4).

In general, model results indicate the Deer Creek Flood Control Project to be out of compliance with documented freeboard requirements as determined from the 50-yr flow water surface elevations. Figure 14 shows locations where the model predicts levee overtopping along with the corresponding overtopping flows below the 50-yr design flow. According to the simulations performed, project levees would begin to overtop under existing conditions at approximately 14,000 cfs with initial overtopping occurring 1,000 ft downstream of Red Bridge along the northern levee in the Setback reach. This corresponds to roughly a 10-yr return interval overtopping the northern levee. The southern levee would begin to overtop when Deer Creek experiences a flow of approximately 16,000 cfs at a location just downstream of the levee repairs that occurred following the January 1997 flood event. This roughly corresponds to a 20-yr return interval on the southern levee. It is important to note that this modeling did not include potential debris jams or other obstructions to flow that have occurred during past high flows on Deer Creek. Overtopping could occur at even lower flows than indicated by this modeling when such obstructions are present.

FIGURE 14: MODEL RESULTS LEVEE OVERTOPPING LOCATIONS AND FLOWS

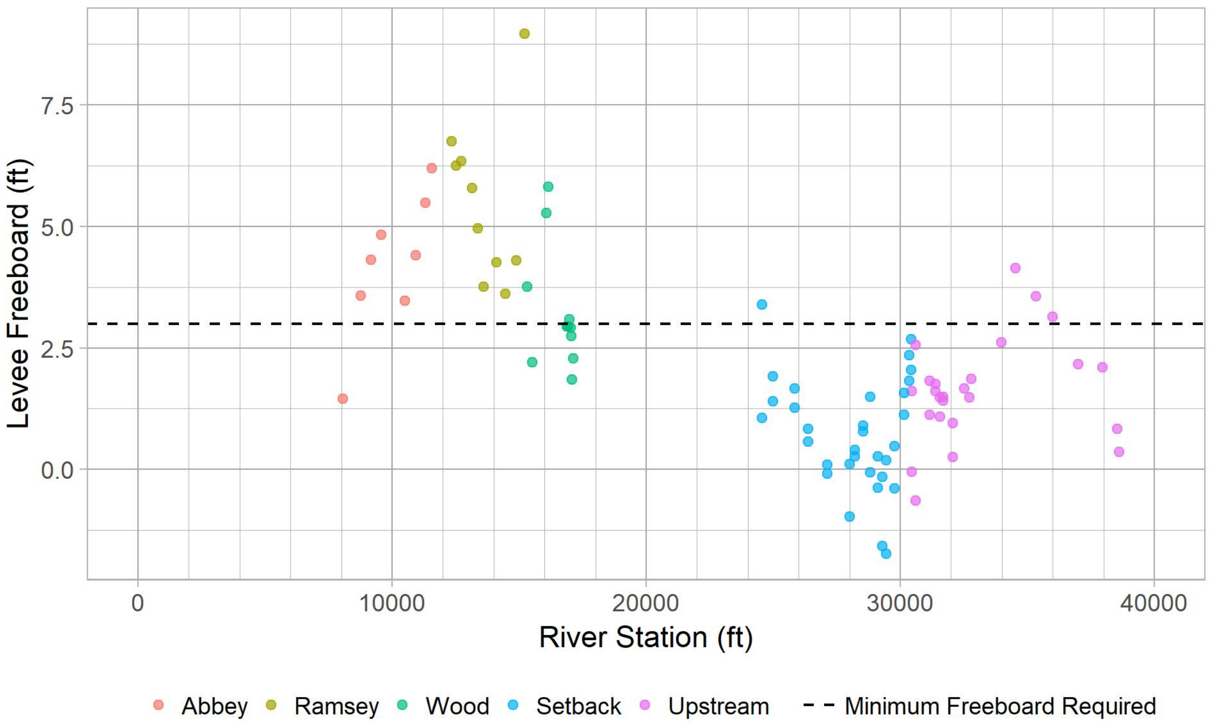


According to the O&M Manual for the Deer Creek Flood Control Project (Sacramento District Army Corps of Engineers, March 1957), the project has a design flow of 21,000 cfs. This corresponds to a near 50-year return interval flow event on Deer Creek. The project levees were designed to provide 3 feet of freeboard above the design flow water surface elevation profile. The O&M Manual requires freeboard be maintained throughout the life of the project.

In 2010, DWR evaluated compliance of the Deer Creek Flood Control Project with the USACE 1957 (Deer Creek Flood Control Project Compliance with United States Army Corps of Engineers 1957 Profile, Technical Memorandum, May 18, 2010) profile and found the project to be out of compliance "for essentially the entire extent." In their evaluation, DWR documented issues with the 1957 data including probable plotting errors, lack of supporting data, and discrepancies between the 1957 Profile, as-built drawings, and existing conditions. DWR's 2010 analysis was based on the DWR NRO 1D model.

As an update to this analysis, existing project freeboard was evaluated using the 2D model. Calculations were performed by subtracting the modeled design flow water surface elevation along Deer Creek from the existing project levee heights (as determined from 2017 LiDAR) at each of the cross-section locations from the DWR NRO 1D model (Figure 15). Points above the dashed line indicate locations where levees pass the 3-ft freeboard requirement relative to the design flow, and points below the line indicate locations where the requirement is not met.

Negative values indicate locations where the levee would be expected to overtop at the design flow.



As with the DWR analysis, the 2D modeling evaluation indicated that a significant proportion of the project is out of compliance with the USACE O&M Manual. The reaches downstream of Highway 99E (Abbey and Ramsey reaches) were mostly found to be in compliance and reaches upstream of Highway 99E (Wood, Setback, and Upstream reaches) were found to be mostly out of compliance. The locations of project levees and freeboard evaluations are also mapped in Appendix A, Figures A-1 through A-4.

Model Limitations and Data Gaps

This model was created to assess existing hydrodynamic conditions in Deer Creek and the surrounding community to support analyses required for environmental documentation. Described below are model limitations and data gaps that should be considered when reviewing model results.

Bridge Modeling

HEC-RAS software does not currently support bridge modeling in a 2-D mesh explicitly. However, it is possible to investigate potential effects of bridges on inundation using either culvert structures in place of bridges (as done with Red Bridge) or adding roadway approaches, embankments, and abutments to the model terrain (as done with the Highway 99E bridge and the railroad bridge). It is important to point out that these methods should not be used to support detailed bridge design or bridge scour analyses. These methods are only meant to investigate effects on overall inundation.

As discussed previously, Red Bridge was modeled as a culvert structure with openings sized and spaced to match the surveyed bridge deck, piers, and river bed elevations. This method uses culvert equations to model a bridge, which could be calibrated to 1D model results with inlet coefficient, n values, and the culvert span as the calibration parameters. Calibration would be obtained by matching either the stage hydrograph or the timing and water surface elevation at maximum inundation between the 1D and 2D versions of the model. However, since model results matched relatively well to local accounts of flow dynamics at the bridge during high flow events, the additional effort required to calibrate this structure was not performed. This was determined to be adequate to support environmental documentation analyses. Future design of a Red Bridge replacement should utilize a detailed and calibrated 1D model.

Stream Flow Gages

One source of uncertainty for this model is the lack of measured flow data in Delaney Slough and China Slough. Flows in these drainages were derived from regional regressions as estimated using the USGS StreamStats web application (https://www.usgs.gov/mission-areas/water-resources/science/streamstats?qt-science_center_objects=0#qt-science_center_objects). StreamStats provides estimates of various streamflow statistics for ungaged sites by solving regional regression equations that relate streamflow statistics of nearby stream gages to basin characteristics for the selected, ungaged stations. The ability of this analysis to provide reasonable estimates of flow statistics depends on the relative size and characteristics of the watersheds that are being compared. However, this uncertainty was deemed insignificant for the purposes of environmental documentation required for this project. Future work related to detailed design of levees and other structures required for project implementation should attempt to resolve this uncertainty.

Culverts

There are also several culverts in Delaney and China Sloughs that have not been surveyed and, as a result, are not included in this model. Reports from landowners and field photos suggest that some of these culverts may be contributing to local flooding problems due to their small size and tendency to be blocked with sediment and debris. The omission of these culverts from the model likely results in more efficient flow conveyance as compared to actual conditions. Future survey efforts have been planned that will collect data for many of the culverts in the system. These data will be used to update the model when available.

Bathymetry

Topographic data used in this model were collected by LiDAR on October 31, 2017, and bathymetric data were collected for Deer Creek in early July 2018. Missing from the model bathymetry are data for the two minor drainages—Delaney Slough and China Slough. Both convey low flows throughout the summer months and are densely vegetated in some locations;

therefore, LiDAR was unable to capture accurate topography and channel bathymetry for these drainages. As a result, the model is likely estimating lower conveyance capacities and higher water surface elevations at a given flow in these drainages as compared to actual conditions. Future survey efforts have been planned to collect bathymetric data for the downstream portion of these drainages. These data will be used to update the model when available.

APPENDIX A

Lower Deer Creek Flood and Ecosystem Improvement Model existing conditions inundation depth maps at 21,000 cfs. This is the design flow for the Deer Creek Flood Control Project (USACE 1957).

Figure A-1. Deer Creek Existing Inundation Depth Map for Abbey Reach

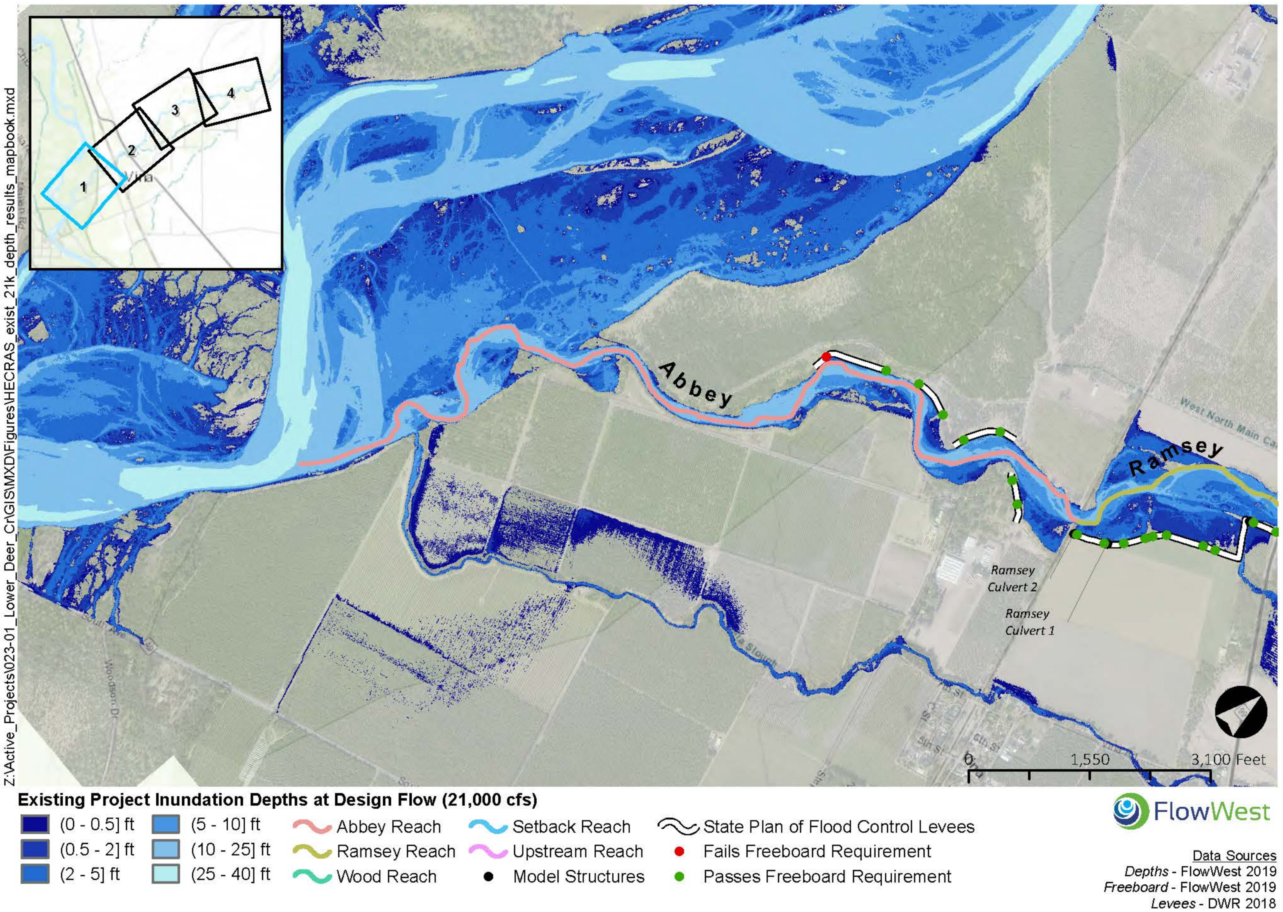


Figure A-1. Deer Creek Existing Inundation Depth Map for Abbey Reach

Figure A-2. Deer Creek Existing Inundation Depth Map for Ramsey and Wood Reach

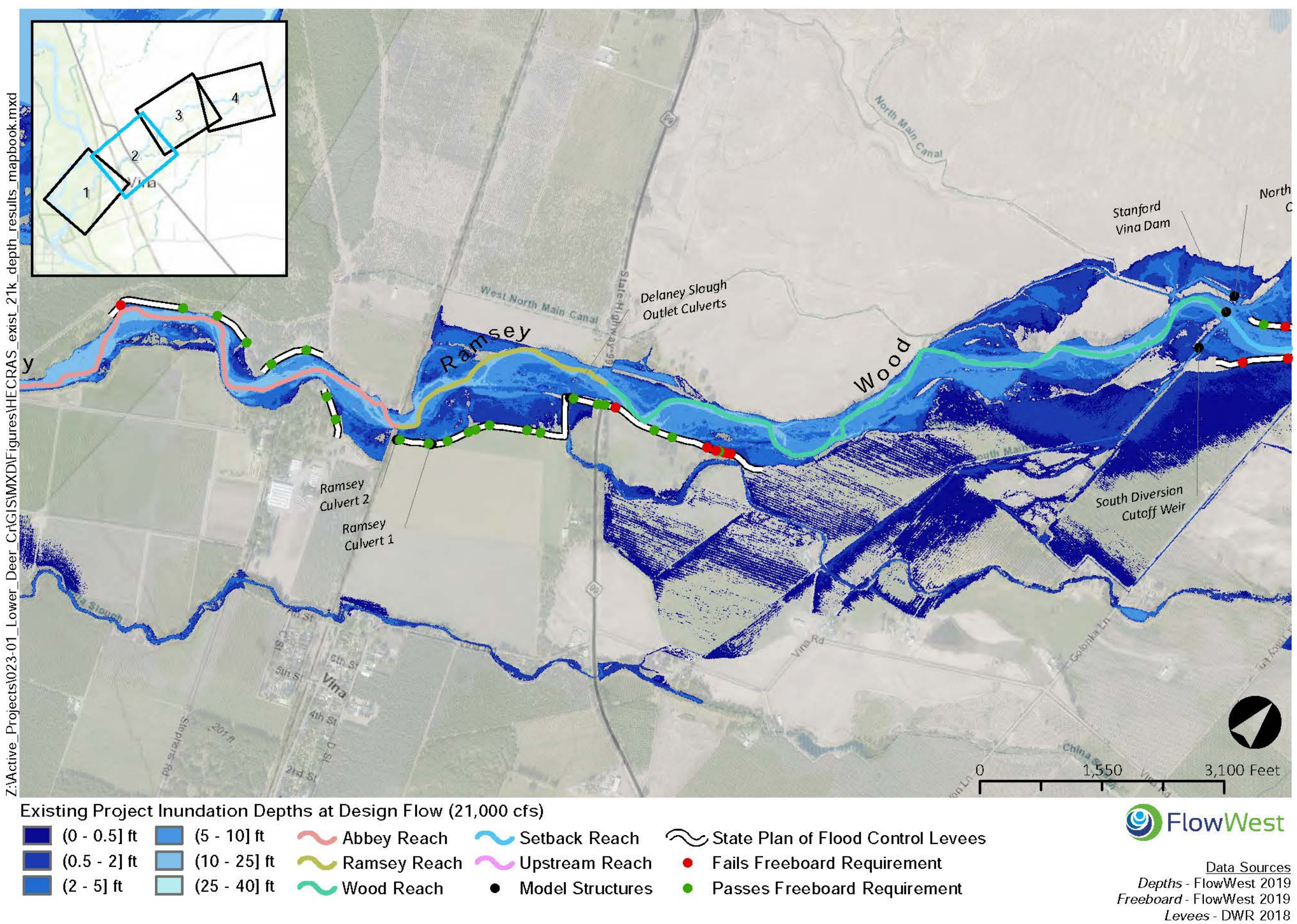


Figure A-2. Deer Creek Existing Inundation Depth Map for Ramsey and Wood Reach

Figure A-3. Deer Creek Existing Inundation Depth Map for Setback Reach

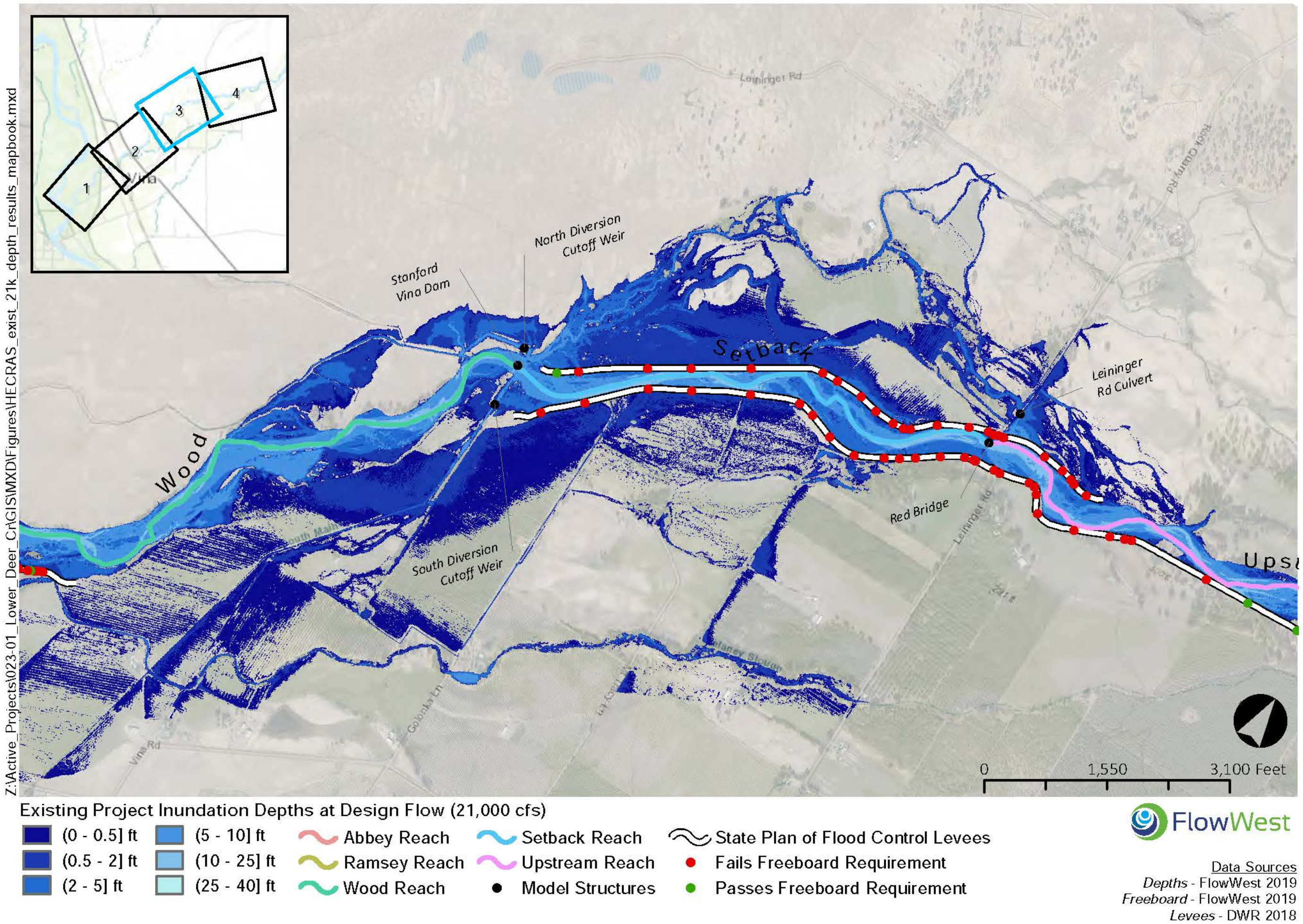


Figure A-3. Deer Creek Existing Inundation Depth Map for Setback Reach

Figure A-4. Deer Creek Existing Inundation Depth Map for Upstream Reach

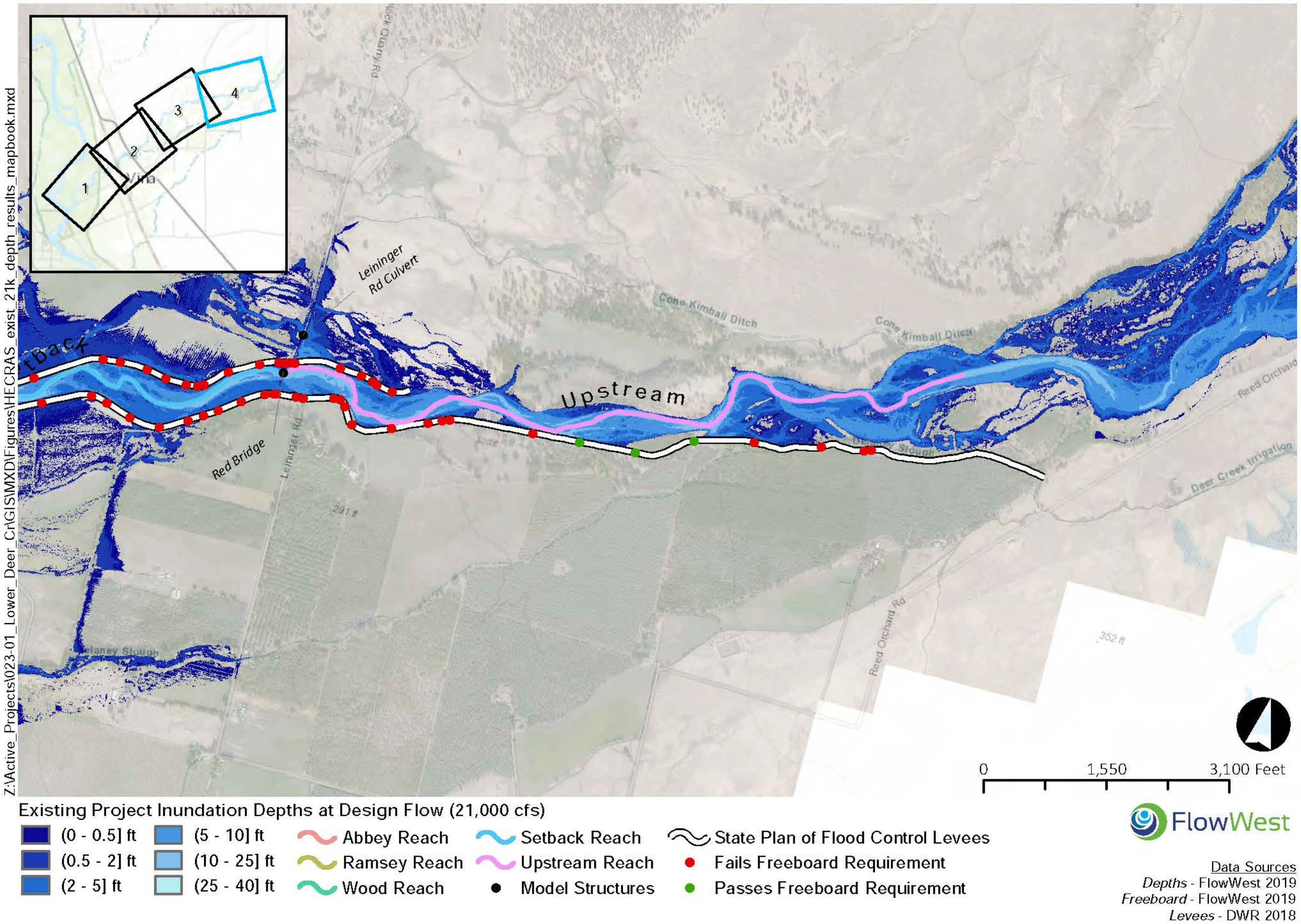


Figure A-4. Deer Creek Existing Inundation Depth Map for Upstream Reach

APPENDIX B

Lower Deer Creek Flood and Ecosystem Improvement Model existing conditions maximum inundation depth maps from January 1997 hydrograph run. Peak Deer Creek flow was 24,000 cfs.

Figure B-1. Deer Creek Inundation Depth Map for Abbey Reach

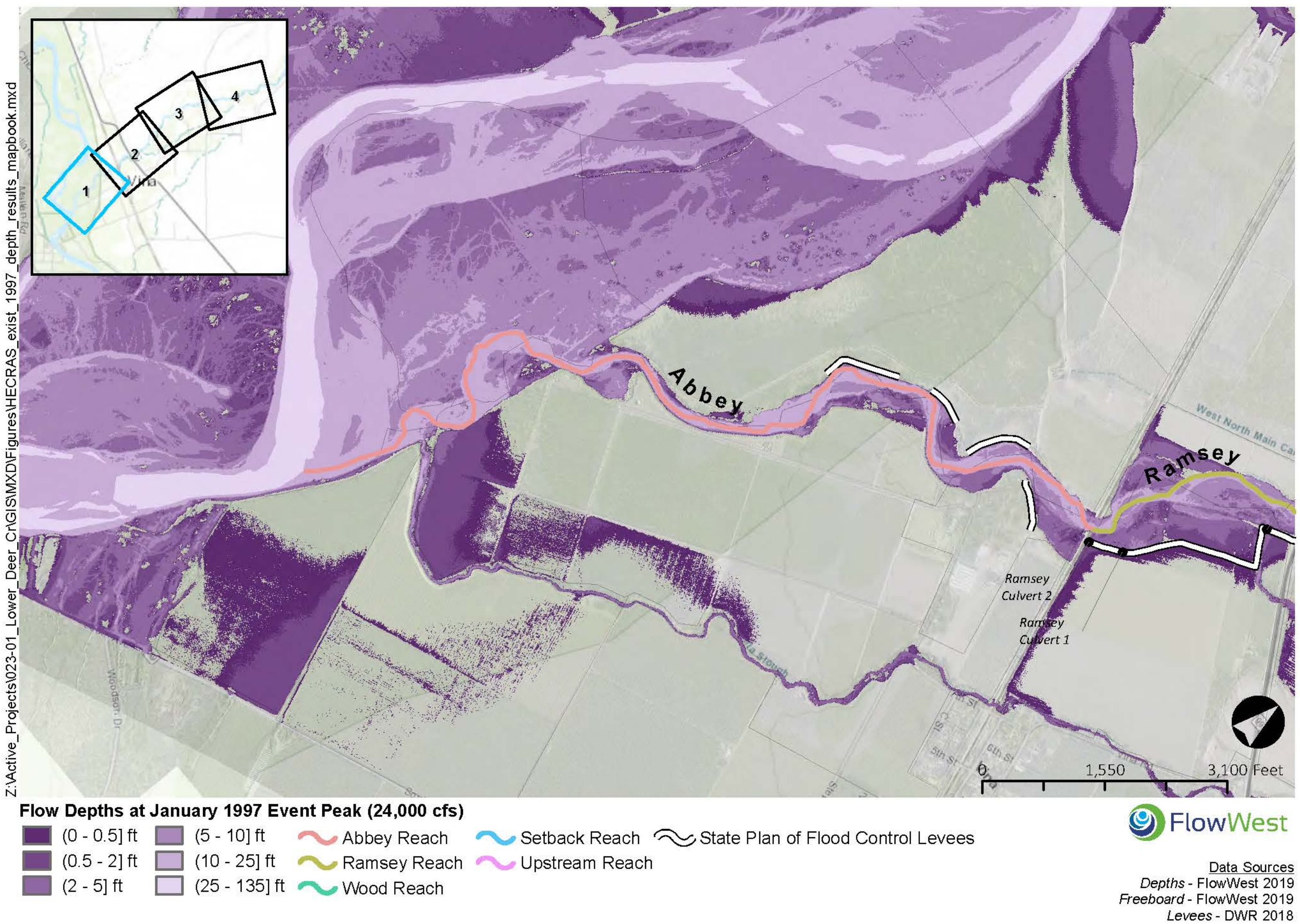


Figure B-1. Deer Creek Inundation Depth Map for Abbey Reach

Figure B-2. Deer Creek Inundation Depth Map for Ramsey and Wood Reach

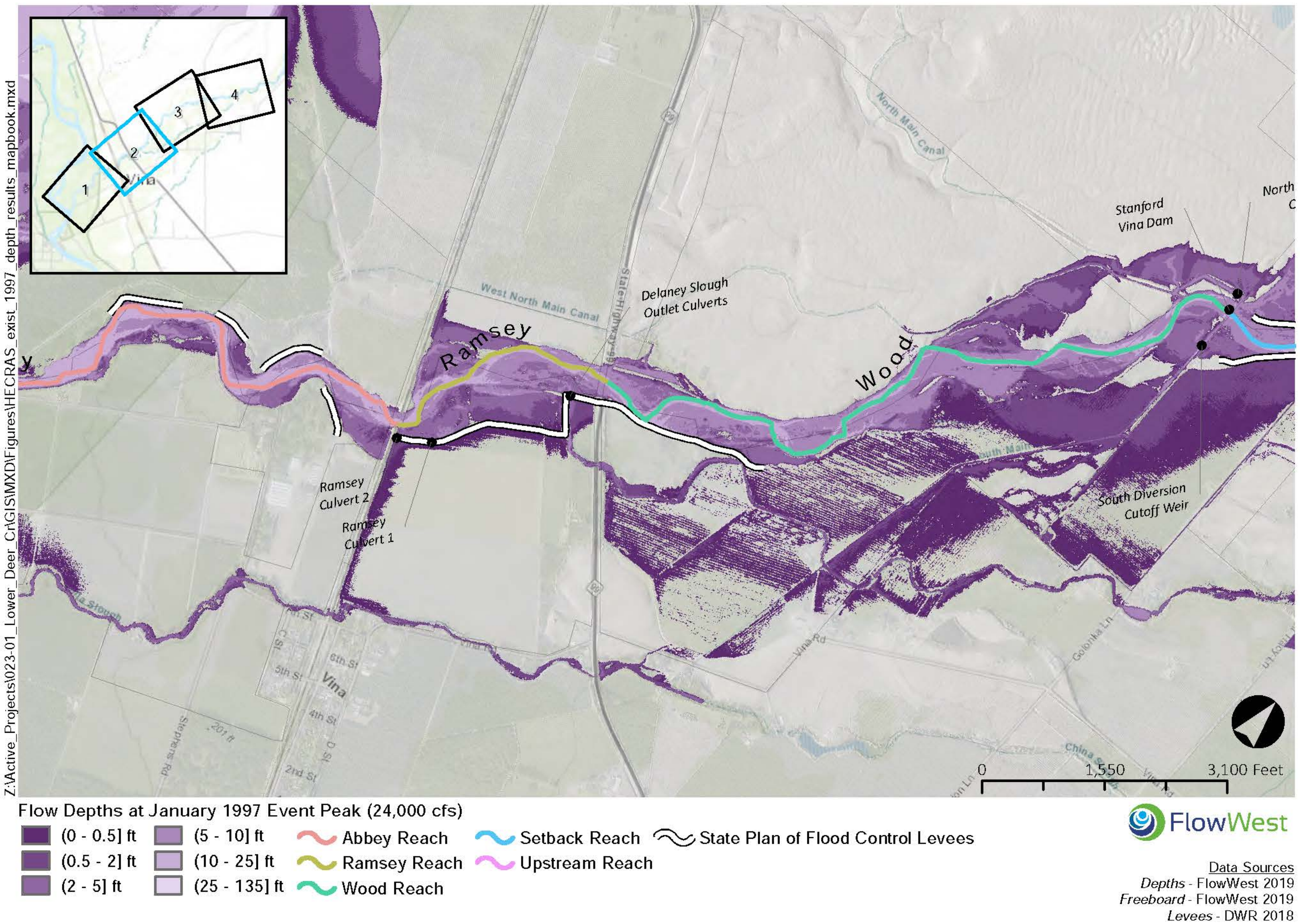


Figure B-2. Deer Creek Inundation Depth Map for Ramsey and Wood Reach

Figure B-3. Deer Creek Inundation Depth Map for Setback Reach

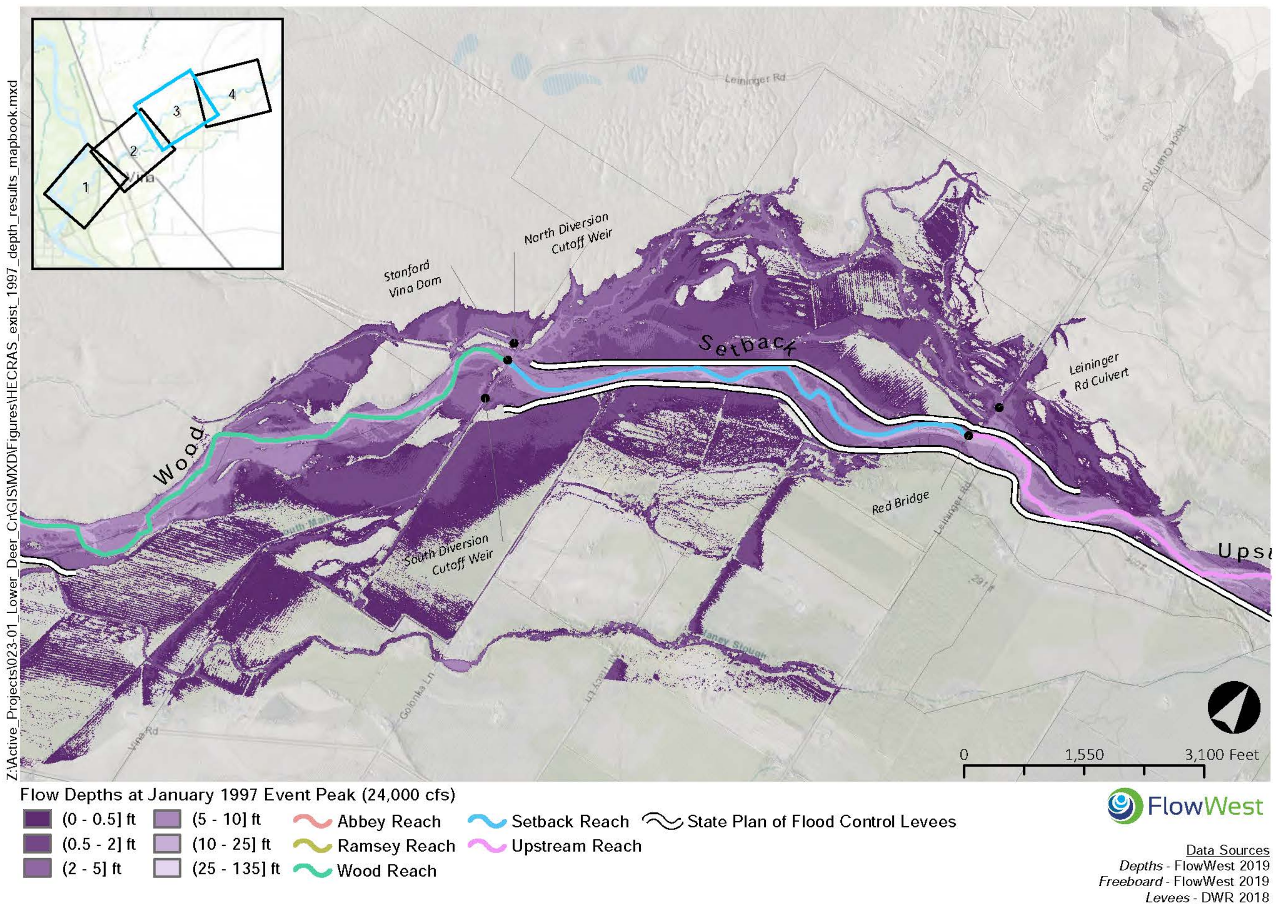


Figure B-3. Deer Creek Inundation Depth Map for Setback Reach

Figure B-4. Deer Creek Inundation Depth Map for Upstream Reach

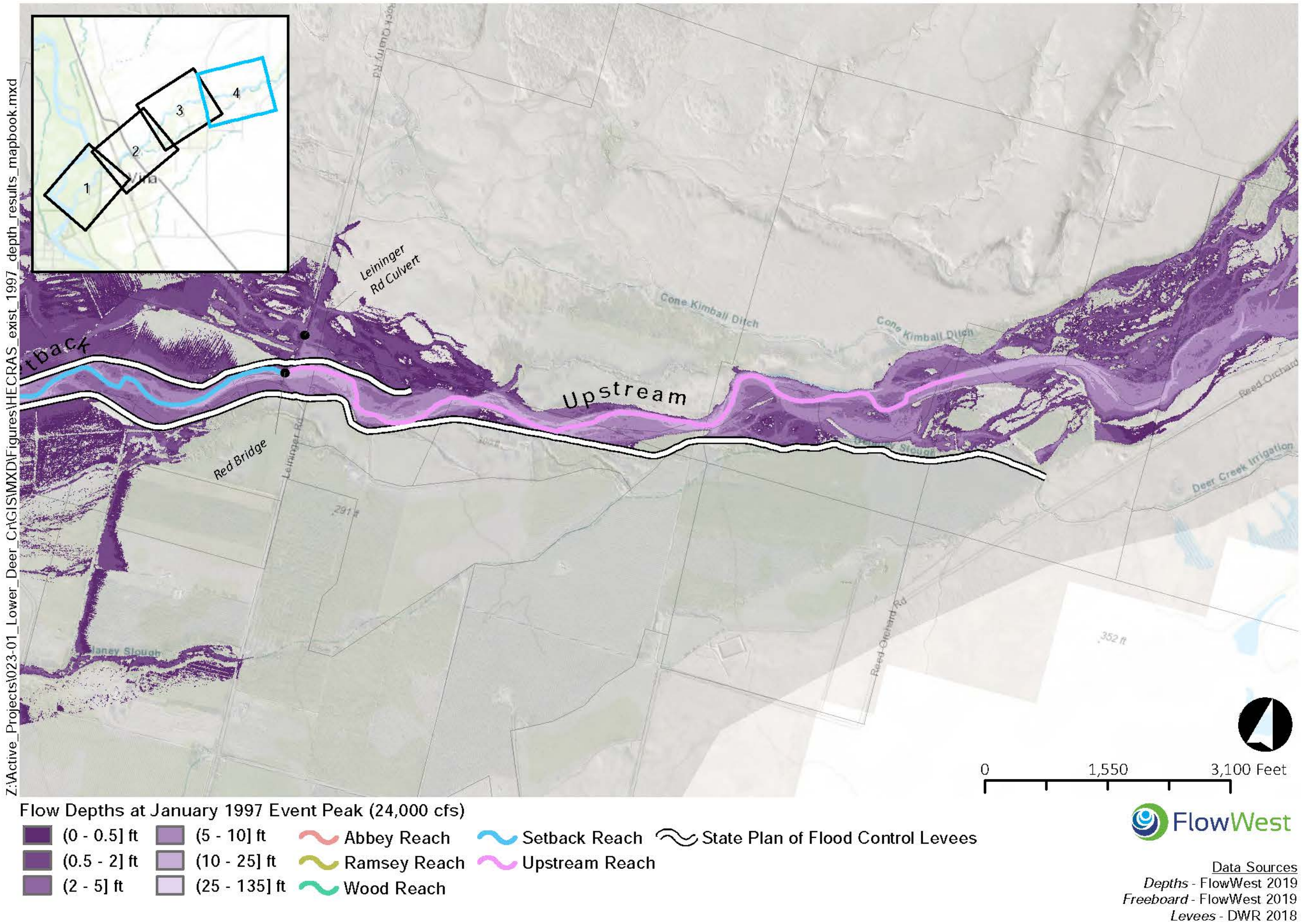


Figure B-4. Deer Creek Inundation Depth Map for Upstream Reach