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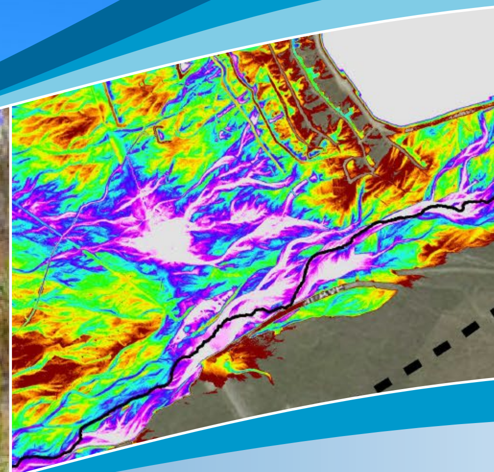

Phase 1 High-Flow Study for Seven Oaks Dam

March 2019

HIGH-FLOW STUDY OF SEVEN OAKS DAM: PHASE 1 FINAL REPORT

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Acronyms and Abbreviations

BA	Biological Assessment
BO	Biological Opinion
CBD	Center for Biological Diversity
cfs	cubic feet per second
DEM	digital elevation model
DTM	digital terrain model
EHL	Endangered Habitats League
FVA	Fundamental Vertical Accuracy
GIS	geographic information system
HEC-RAS	Hydrologic Engineering Center River Analysis System
LiDAR	light detection and ranging
mi^2	square miles
MSHMP	Multi Species Habitat Management Plan
NAVD88	North American Vertical Datum of 1988
NGVD	National Geodetic Vertical Datum
NGVD29	National Geodetic Vertical Datum of 1929
NNG	nonnative grasses
RAFSS	Riversidian alluvial fan sage scrub
RMSE	root-mean-square-error
SAR	Santa Ana River
SARC	Santa Ana River Crossing
SBKR	San Bernardino kangaroo rat
SBVMWD	San Bernardino Valley Municipal Water District
SBVWCD	San Bernardino Valley Water Conservation District
SOD	Seven Oaks Dam
SPF	Standard Project Flood
spineflower	slender-horned spineflower
TIN	triangulated irregular network
Upper SAR HCP	Upper Santa Ana River Habitat Conservation Plan
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
Wash Plan HCP	Upper Santa Ana Wash Land Management and Habitat Conservation Plan
WCM	Water Control Manual
woollystar	Santa Ana River woollystar
WSPA	Woollystar Preserve Area

Executive Summary

The purpose of the High Flow Study (HFS) is to evaluate the feasibility of using high-flow releases from Seven Oaks Dam (SOD) to achieve the mitigation requirements identified in the 2000 Biological Assessment (BA), 2002 Biological Opinion (BO), and 2013 Multi-species Habitat Management Plan (MSHMP). The BO anticipated that high-flow water releases from SOD would be used to maintain and enhance habitat for listed species under the MSHMP, as outlined in the BA. The primary objective of the high-flow release conservation measures were to compensate for potential changes in floodplain characteristics and listed species' habitat caused by construction and operation of SOD.

The steps implemented in Phase 1 of the HFS approach are outlined below:

- A science advisory committee was appointed to review objectives, methods, and results from investigations, and provide guidance on future work.
- Target species distributions were compiled and contrasted with existing information about Riversidian alluvial fan sage scrub seral stage and geomorphic position (height above and distance from thalweg).
- An assessment of changes in channel morphology across the time period from 1964 to 2015 was conducted.
- Operations of SOD, including Water Control Manual (WCM) operating guidelines and constraints, and past high-flow events were reviewed.
- The extent of overbank effects from modeled releases from SOD under the current WCM in the study area and in combination with high-flows from tributaries (e.g., Mill, City, and Plunge creeks) was evaluated, including the degree to which modeled flood extents overlap known species distributions.

In pursuing the study objectives, the following observations were made.

Habitat Distribution Relative to Disturbance

Seral stage elevation profiles and species distributions broadly support the scientific consensus that appropriate habitat is linked to past flood disturbance. However, purposeful flooding of areas with mature vegetation, which present the greatest opportunity for habitat succession, could result in short-term impacts to populations of the species of interest (expected to be offset by long-term benefits to these species).

Morphological Changes to the Alluvial Fan

The 1969 flood events resulted in significant changes in the morphology of the Santa Ana River (SAR) and appeared to be the last major hydrogeomorphic change in the study area. Channel confinement from bridges and levee construction likely have contributed to channel downcutting observed between 1964 and 1998, but the area appears to have stabilized since 1998. This downcutting resulted in increased bank heights downstream of the Orange Street Bridge that may impede future efforts to produce overbank flows for habitat renewal purposes in the lower sections of the river. The thalweg elevation trend between 1998 and 2015 is net sediment deposition. Construction of grade control structures for the Mentone Pipeline crossing and SARC Pipeline have

increased bed elevations that may increase opportunities for flooding and habitat renewal in the upper sections of the river.

Peak Flows and Constraints of Seven Oaks Dam

There is additional capacity within the WCM guidelines to create or contribute to high-flow events up to approximately 5,000 cfs within the study area, but no flow releases for the purpose of habitat renewal appear to have taken place in the two decades since start of operations at SOD. Flow contributions from SOD are likely to be limited to 5,000 cfs or less, in spite of the dam's rated gate outflow capacity of 7,000 cfs. The most important limit on instigating or contributing to ecologically meaningful flow events from SOD is the WCM limit to 50 cfs during rising conditions, which effectively prevents timing releases with high-flow contributions from tributaries.

Mill Creek will continue to contribute substantial flood flows to the SAR. However, SOD has not been making high-flow releases that contribute to Mill Creek flows in a manner predicted in the Technical Report for the BA. Releases have not been synchronized with Mill Creek peak flows to date during the operation of SOD.

Fluvial Disturbance Extents

Flood extents, particularly those extents simulating releases from SOD with 100-year contributions from tributaries (Scenario 6), ultimately still inundate less than 25% of the recorded species observation locations in the study area. Maximum releases from SOD (7,000 cfs) without tributary contributions could still inundate some portion of species occurrence locations – woollystar (16%) and SBKR (15%), but not spineflower (1%). The 1969 breakout area stands out as the most likely place for drainage manipulation to produce overbank flows outside the main channel of the SAR.

The infiltration loss analysis performed for this study shows that appreciable losses will occur depending upon soil saturation conditions, the magnitude and duration of flood flows, and the distance downstream from SOD. Infiltration losses should be accounted for when planning for future SOD releases.

The following topics are proposed for investigation in Phase 2 of the High-Flow Study:

Hydrology – Explore changes in operation of the dam, particularly the feasibility of combining high-flow releases from SOD with natural high flows from tributary flows, primarily Mill Creek. Evaluate alternative flow release regimes (not included in the current SOD WCM) that could be effective in providing overbank flow in the WSPA.

Structural – Present key locations where structures (e.g., channel obstructions) and/or pilot channels could be constructed to force a portion of the flood flow out onto floodplain/terrace areas, possibly into remnant channels. Evaluate the extent of overbank effects from releases under the current SOD WCM with implementation of diversion dikes within the WSPA as described in the BA.

1969 Breakout Area – Evaluate the feasibility of removing the rock plug constructed at the inlet of the 1969 breakout channel that separates the breakout channel from the active SAR. Determine how much flow could be routed into the breakout channel and the fate of the flow as it travels downstream.

Modeling – Demonstrate that enhancement measures would perform as described through use of 2D modeling. The work would include incipient motion analysis to model the particle sizes predicted to be mobilized for a given flood magnitude; analysis of particle size and sediment concentration variation in the water column; and evaluation of sediment supply from the SAR and Mill Creek.

Evaluate physical manipulation and mechanical disturbance of the floodplain to mimic flood disturbance. Prioritize the species of interest and set up framework for evaluation of different disturbance regimes.

Chapter 1
General Introduction

The U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion (BO) in December 2002 for Seven Oaks Dam (SOD) calling for intermittent high-flow release events from SOD. The BO anticipated that water releases would be made to maintain and enhance habitat for listed species under a finalized Santa Ana River Woollystar Preserve Area (WSPA) Multi-species Habitat Management Plan (MSHMP) for listed species, as outlined in the Biological Assessment (BA) for the Seven Oaks Dam Project (USACE 2000a). Among the species listed are the slender-horned spineflower (spineflower), San Bernardino kangaroo rat (SBKR), and Santa Ana River woollystar (woollystar).

The 2002 BO issued by USFWS addressed compensation, conservation measures, and recommendations associated with the species of interest (spineflower, SBKR, woollystar). One conservation recommendation specified in the BO was acquisition of floodplain habitat along the upper Santa Ana River (SAR) and below SOD for species conservation purposes. To this end, approximately 760 acres of land were purchased and used to form the WSPA. The 2002 BO called for additional conservation measures to sustain the species of interest within the WSPA. A multi-species adaptive management plan was prepared to guide management of the preserve area, resulting in the MSHMP. This document was intended to guide management of WSPA lands to sustain the three species of interest. Management recommendations issued in prior documents were incorporated or referenced in the MSHMP.

The primary objective of the high-flow release conservation measures outlined in both the BA and the MSHMP is to compensate for potential negative changes in floodplain characteristics and listed species' habitat brought about by construction and operation of SOD. The BA and MSHMP describe these releases, coupled with diversion dikes, as being intended to create directed overbank flows for the benefit of listed species. There is concern that the measures identified in the 2002 BO may not have the ability to create the intended mitigation result if implemented as proposed in the MSHMP. This study analyzes the potential of those measures to achieve the desired biological mitigation result described in the 2002 BO and 2012 MSHMP both within the WSPA and in other areas of the SAR watershed outside of the WSPA.

Study Area

The area covered by the High-Flow Study includes those areas considered in the SOD BA (USACE 2000a), BO (USFWS 2002), the WSPA and adjacent properties, and the SAR corridor from SOD to the San Bernardino Airport (Figure 1 in Chapter 10, *Figures*). While the study area is bound by the geographic limits of the BO, the potential for mitigation or other conservation solutions in other areas of the watershed should also be considered if needed. All lands containing known records of woollystar, spineflower, and SBKR downstream of the dam that may fall within or outside the WSPA were considered.

Study Approach and Objectives

The following outlines the approach to evaluate the feasibility of high-flow releases from SOD for the purpose of achieving the mitigation outcomes identified in the BA/BO and MSHMP.

- Appointment of a science advisory committee to review objectives, methods, and results from investigations, and provide guidance on future work.
- Compilation of the known distributions of the species of interest, contrasting them with existing information about Riversidian alluvial fan sage scrub (RAFSS) seral stage and geomorphic position (height above and distance from thalweg).
- Assessment of changes in channel morphology across the time period from 1964 to the present, including assessment of changes in the SAR channel thalweg height through the period.
- Review of historic operations of SOD, including Water Control Manual (WCM) (USACE 2003) operating guidelines and constraints, and past high-flow events.
- Evaluation of the extent of overbank effects from releases from SOD under the current SOD WCM in the study area and in combination with high-flows from tributaries (e.g., Mill, City, and Plunge creeks). This includes summaries of the degree to which modeled flood extents overlap the known species distributions.

Input on the information presented in this document will be used to develop a work plan for the next steps in the study. Next steps may include impact analysis of proposed flood/non-flood disturbance to regenerate habitat for the species of interest.

Chapter 2

Establishment of the Science Advisory Committee

The science advisory committee was composed of the science experts from Stillwater Science, Blue Octal Solutions, and the San Diego Zoo. Representing Stillwater Science were Christian Braudrick, Bruce Orr, and Wendy Katagi. Representing Blue Octal Solutions were Mike Lamb and J. Toby Minear. Representing the San Diego Zoo were Debra Shier and Thea Wang.

The High-Flow Study investigators responsible for preparing this report were composed of the ICF technical team, including Manna Warburton, Brendan Belby, Greg Nichols, and Scott Fleury.

The litigants in the lawsuit against the U.S. Army Corps of Engineers (USACE) regarding failure to assess harm to federally protected species from the operations of SOD were observers to the science advisory committee meetings and webinars. The litigants include Endangered Habitats League (EHL), Center for Biological Diversity (CBD), San Bernardino Valley Municipal Water District (SBVMWD), and San Bernardino Valley Water Conservation District (SBVWCD). Representing EHL were Dan Silver, Gerald Braden, and Chris Campbell. Representing CBD were Eileen Anderson and Tiffany Yap. Representing SBVMWD was Heather Dyer, and representing SBVWCD was Jeff Beehler.

Meeting and Presentation Formats

An initial kickoff meeting and site visit were held prior to start of work for the High-Flow Study to finalize study objectives. During the initial meeting, various tasks were identified and methods were proposed. Following the kickoff meeting, there was a site visit by a subset of the committee to review in person the conditions within the study area.

Investigator results were compiled into three presentations and hosted in webinar format on three dates (August, October, and November 2018) during the execution of the High-Flow Study. In December of 2018, a workshop was hosted by SBVWCD, and state and federal agency staff were invited to engage with the science advisory committee and litigants to discuss the results of the HFS.

Results

Committee feedback was initially received in verbal format in a question and answer session immediately following presentations. Additional coordination with individual science advisors took place via email and phone communication. Summary feedback for meetings and workshops was generally submitted as a series of written questions to which the investigators responded, also in writing. Following the December workshop, feedback was submitted as technical memos. These feedback and response documents are included as Appendix 1, *Science Advisor Feedback and Response Logs*.

Chapter 3
Distribution of Habitat Relative to Hydrologic Disturbance Regimes

There is a relationship between succession in the RAFSS plant community and habitat quality for the three species under consideration in the 2000 BA, but that relationship is not well understood (USACE 2000a). The final BA states that woollystar were found in post-1938 overbank surfaces, channels, and margins, and in one case in a 1969 channel. Based on the range of ages for the various overbank surfaces, woollystar habitat in this area has generally persisted from between 75 and 150 years before being disturbed by flood events or being eliminated by succession into mature RAFSS. Additional studies indicate that SBKR reach their highest densities in early and intermediate successional alluvial scrub, but that density may not be a good indicator of population fitness. Timing of succession and its effects on SBKR habitat quality is not well understood. Citations conflict on age of surfaces (time since last major disturbance) within the study area. A single study (Barbour and Wirka 1997) indicates succession from Riversidian alluvial fan sage scrub to climax phases of chaparral or Riversidian sage scrub would probably not occur during the planned lifetime of the SOD project (100 years). There is evidence that degradation and/or reduced suitability is associated with increasing age of the alluvial fan surfaces downstream of the dam (Lucas et al. 2016), indicating that succession is taking place.

We defined woollystar, spineflower, and SBKR spatial extent by examining a variety of data sources previously compiled for other documents including the Upper Santa Ana River Habitat Conservation Plan (Upper SAR HCP) and Upper Santa Ana Wash Land Management and Habitat Conservation Plan (Wash Plan HCP). Compiling all historical records of presence allowed for a conservative estimate of the extents of occupied habitat within the study area. The goal was to identify all areas that contained habitat capable of supporting the species of interest. Habitat for woollystar, spineflower, and SBKR appears to be dependent on flood disturbance to promote or maintain conditions that are favorable to the species. The frequency of flood disturbance regimes associated with habitat creation and maintenance are currently disputed, but estimates range from 75 to 2,000 years. The types of disturbance thought to promote habitat renewal for the species of interest include flushing of fine sediment, replenishment of coarse sediment including coarse sand and cobble, and vegetation removal.

Data Sources

Data sources for this portion of the study included existing geographic information system (GIS) data from the Upper SAR HCP, Wash Plan HCP, USFWS, and San Diego Zoo detailing observations for the species of interest. We also reviewed existing published scientific literature and technical reports examining flood processes and biological communities in the study area. Species distribution data were contrasted against elevation data from the 2015 digital elevation model (DEM) for the study area as well as successional vegetation layers for the study area. Overlaying of habitat data with elevation profiles allowed for assessment of different habitat types' and species distributions' likelihood of being influenced by high flows.

Methods

For the current study, only records based on positive trapping results were utilized for SBKR occurrences. Positive records are assumed to be a more reliable account of distribution than negative records because of the possibility of failure to observe the species when it is present (i.e., potentially present in the habitat but not detected in the trap). For the three species of interest, all available data sources indicating presence were compiled into a single file and treated equally, regardless of source or age of record. Compilation of all available presence data results in a conservative map of the distribution of species records within the study area. The species records document all known locations confirmed to support the species of interest.

For SBKR, data from multiple sources were compiled to indicate point locations where the species had been identified as present within the boundaries of the study area (Figure 2). In addition, estimates for SBKR habitat quality associated with previous work were available (Figure 3). The majority of species records had been previously compiled for mapping efforts as part of the Upper SAR HCP and Wash Plan HCP. New species records, including recent USFWS efforts and Dr. Shier's surveys, were also included. For spineflower and woollystar, all available data had been previously compiled for mapping efforts as part of the Upper SAR HCP and Wash Plan HCP (Figure 4, Figure 5).

A potential pitfall associated with the use of positive observations to portray distributions for the species of interest is the lack of data on negative observations. In spite of the depth and span of records, there are no compiled data on species absences within the study area. To compound this issue, absence data rapidly become less valuable over time, as conditions on the ground may change to favor species presence through natural or other factors, particularly with mobile species such as SBKR. The species distributions presented in this document should be viewed with these issues in mind.

Vegetative cover data produced in conjunction with USFWS survey efforts and previously compiled for the Wash Plan HCP were available in GIS format. These data classify the majority of the study area into different vegetative cover groups based on the successional or seral stage of vegetation in the area (Figure 6). Work focused on vegetative successional patterns on the floodplains of the SAR indicate that seral stage is correlated with time since last flood disturbance (Lucas et al. 2016). Burk et al.'s (2007) assessment of vegetative stage and soil type in the SAR alluvial fan below SOD indicates that early successional vegetation is associated with the 1969 flood, and intermediate successional vegetation is associated with the 1938 flood. In general, they found that vegetation type was strongly associated with changes in soil texture, with older flood surfaces containing a higher percentage of fines and organic matter, and younger flood surfaces containing more sand.

Estimated discharges for historic flood events were taken from the 2000 BA and Burk et al. 2007. In their journal article examining vegetative succession and soil texture in the study area, Burk et al. report flood discharges that were consistently higher than those reported in the 2000 BA, but cites USACE as the source of their numbers. No additional explanation is offered by Burk et al. for the differences in discharge between the two documents. For the 1969 event, Burk et al. estimate 32,460 cubic feet per second (cfs) and USACE estimates 25,700 cfs. The reported U.S. Geological Survey (USGS) gage values for 1/25/1969 are 15,300 cfs for SAR Mentone gage and 20,000 cfs for Mill Creek Yucaipa gage (note USGS qualifies the Mill Creek flow as an estimate). If the SAR and Mill Creek reached their peak flow simultaneously at the confluence (which is unknown), then the combined peak discharge is 35,300 cfs. All sets of estimated historic flood discharge as reported by USACE and Burk et al. are presented in Table 1.

Results

A height above thalweg elevation DEM was created using the following process to aid in the seral stage analysis. The main channel of the SAR below SOD was demarcated using GIS software and flow accumulation analysis of the 2015 light detection and ranging (LiDAR) DEM to identify the thalweg (lowest continuous channel bottom). Cross-sections were designated manually across the flood terrace and channels, oriented perpendicular to the active SAR channel and flood terrace. The elevation of the thalweg where it is intersected by a given cross-section was identified and assigned as the elevation of the cross-section. A new DEM was created based on interpolation of thalweg elevations between cross-sections. Then, the thalweg elevation DEM was subtracted from the DEM of ground elevations to create a third DEM of the height above thalweg elevation. The height above thalweg DEM (Figure 7) represents the height above nearest perpendicular SAR thalweg position.

Seral stage was contrasted against presence records for the species of interest to produce estimates of the percentage composition by seral stage for species within the study area (Figure 8). Using seral stage as a proxy for time since last flood disturbance allowed for an assessment of previous work indicating positive correlations between flood disturbance and presence of the species of interest.

Seral stage vegetation cover and map points for the species of interest within the study area were then queried against the height above 2015 thalweg model to calculate the vegetation type or species location's height and distance from thalweg. These measures taken together summarize the relative ease with which specific points, occupied by different seral stages and the species of interest within the study area, could be flooded by water releases from SOD and tributaries. These figures are presented as Figure 9 to Figure 15 indicating the seral stage elevation profiles, and Figure 16 and Figure 17 indicating the species record elevation profiles.

Discussion

For the purposes of this study, height above thalweg was used as an approximate measure of the relative floodability of points within the study area. Examining height above thalweg for the various successional stages of the RAFSS plant community indicated differences based on succession stage. Earlier seral stages have lower elevation profiles relative to later seral stages, with as much as an 8-foot difference between mean height above thalweg of pioneer and mature RAFSS communities within the study area. This fits with previous work indicating that time since last flood disturbance and RAFSS seral stage are related (Burk et al. 2007), as probability of flood disturbance is expected to be strongly influenced by the topography of the river channel and surrounding terraces.

There is evidence for a relationship between seral stage and observations of the species of interest within the study area, with the vast majority of species observations occurring within pioneer, intermediate, and intermediate/mature RAFSS communities. However, these earlier seral stages also occupy the majority of land within the study area, containing 84% of the total surface area (Table 2). The proportion of species observations occurring within mature and mature/nonnative grasses (NNG) is low (woollystar 13%, spineflower 1%, SBKR 12%), highlighting potential opportunities for flood disturbance–based habitat renewal. Low occupancy by the species of interest makes these surfaces attractive for restoration purposes, as it potentially reduces impacts on the species from any proposed environmental flow releases.

These later seral stages may provide better restoration opportunities, but their floodability potential is low. Mature seral stage RAFSS surfaces within the study area are on average 8 to 10 feet above the thalweg of the mainstem SAR, and delivering environmental flow releases to these surfaces may be technically challenging. Mature/NNG surfaces stand out as being the most appropriate as candidates for flood disturbance because of their low occupancy by the species of interest and lower average height above thalweg (0 to 2 feet). Within the study area, these surfaces are restricted to the northern perimeter of the study area boundaries (Figure 6) along the banks of Plunge Creek. Their position within the larger watershed and distance from the main channel of the SAR make it difficult to conceive of methods that would deliver SOD water releases to these areas without first flooding the majority of other available habitat.

Summary

- Seral stage elevation profiles and species distributions reported here broadly support the scientific consensus that appropriate habitat is linked to past flood disturbance, with younger seral stages holding the majority of species records.
- Pioneer, intermediate, and intermediate/mature surfaces have more favorable elevation profiles for purposeful flooding in comparison with mature surfaces, but flooding of these surfaces would likely result in short-term impacts on populations of the species of interest (expected to be offset by long-term benefits to these species).
- Mature and mature/NNG surfaces present the greatest opportunity for avoiding or reducing impacts on populations of the species of interest when introducing flood disturbance, but have elevation profiles or spatial distributions within the study area that make delivery of environmental flows from SOD difficult or impossible.

Chapter 4
Analysis of Morphological Changes to the Alluvial Fan

Over the operational lifetime of SOD, it is expected to prevent the downstream movement of some 32,000 acre-feet of sediment (USACE 2003). The effect of sediment trapping behind dams on downstream river morphology is well described (Kondolf 1997; Collier et al. 2000). Sediment-free (clear) water released from dams has high potential to recruit new sediment supply from the downstream channel bed and banks. This can result in initial channel downcutting and subsequent channel armoring downstream of dams generally. However, because SOD also substantially reduces peak flows, the increased sediment transport potential created by the release of clear water may be more than offset by the reduction in flood flows capable of transporting sediment. The trend could be toward aggradation or degradation, particularly given the uncertainty of the role Mill Creek plays in supplying sediment to the main channel. Potential downcutting of the channel thalweg is particularly relevant to the current study because significant downcutting may reduce future opportunities for overbank flooding by incising the channel and changing the bank profile.

Large-scale erosion and deposition comparable to what occurred during the 1969 flood event are not expected to take place within the study area following the start of operations at SOD. Sediment transport studies conducted by USACE have concluded that in association with sediment trapping by the dam, downstream water shear stresses will be such that bed and bank armoring will occur (USACE 2000b). Armoring takes place when smaller particles are winnowed from coarser substrates and transported downstream, leaving in place larger substrates sometimes referred to as a lag deposit. These substrates then form an armor layer preventing further erosion. The combination of armoring and reduced flood discharges associated with operation of the dam is expected to reduce fluvial processes and stabilize the SAR streambed (USACE 2000b).

Morphological changes to the study area were assessed by digitizing historic topographic maps from 1964 and 1987 and photogrammetry contours from 1998, and comparing them with an existing DEM collected via LiDAR in 2015. Examination and comparison of the four elevation sources allowed for an assessment of the channel profile through the period leading up to the start of operations at SOD and through the majority of the period of operation. This allowed for an assessment of morphologic change that occurred in the study area as a result of flooding, including effects of the 1969 events (see Table 1) and changes in the longitudinal SAR thalweg elevation profiles. Changes in elevation between the 1998 and 2015 profiles are expected to reflect erosional/depositional trends associated with operation of SOD. Examining differences in channel morphology between those years may provide some evidence of the reduced fluvial processes and bed stabilization predicted by USACE.

Data Sources

Historic Aerial Composites

Aerial photo-imagery was downloaded from the Aerial Photography Collections curated by University of California, Santa Barbara (accessed 2018) and California State University San Bernardino's Historic Aerial Photo Archives (2017). An attempt was made to use images from a single aerial survey, but in the case of the 1930, 1950, and 1970s series, multiple aerial survey images from different time periods within a decade were used to compose tiled mosaics of historic imagery of the study area.

Digital Elevation Models

Paper copies of 1964 and 1987 4-foot contour topographic maps of the study area were obtained from SBVMWD staff. The 1964 4-foot contour map cited as its method of collection the following: "Prepared under the direction of the Chief Engineer, San Bernardino County Flood Control District. Map prepared by photogrammetric methods utilizing Kelsh stereoplotting instrument and 20 convergent, distortion free, photographs dated Dec 12, 1964." The 1987 4-foot contour cited as its method of collection the following: "Prepared by Airborn Systems, Inc. of Anaheim, California, for the San Bernardino County Flood Control District from aerial photography at an approximate scale of 1 inch=1,200 feet, exposed June 1 1987, under ASI Project No. 87-894, using semi-automated Kern PG-2/AT/DC2B stereoscopic plotting instruments." The 2015 DEM was based on a LiDAR survey of the study area conducted by USACE.

Contours from 1998 Photogrammetry

For the USACE study to predict how SOD operations would affect habitat, aerial photos were flown on November 20, 1998, at a scale of photography of 1 inch = 600 feet. Based on a scale of mapping of 1 inch = 100 feet, the photogrammetry was used to create a digital terrain model (DTM) at a 2-foot contour interval (USACE 2000b). This topography was used by USACE for the hydraulic modeling discussed in Chapter 6. The actual DTM is not available for this study; however, ICF does have the topography derived from the DTM for 181 cross-sections along the SAR from Greenspot Road to the grade control structure at Interstate 10 just upstream of the Lytle Creek confluence.

Methods

Historic Aerial Composites

Individual images were georeferenced by assigning control points to linking landmarks that have not changed location on the image with the same landmarks on current orthoimagery. Aerial composite dates are reported in Table 1 and allow reference to various ecologically significant flow events and the imagery bracketing those events in time.

1964 and 1987 Digital Elevation Models

Paper copies of the 1964 and 1987 4-foot contour maps were obtained and scanned to produce digital images. Digital images of the scanned maps were geo-referenced using local landmarks and tiled using ArcGIS software. Contour lines were extracted from scanned images manually, and then assigned a height value based on the original designation. Vectorized contours were used to produce DEMs for portions of the study area based on the 1964 and 1987 4-foot contours. The resulting DEMs were produced at 10-foot horizontal resolution.

Error for the 2015 DEM is reported in the LiDAR metadata as 0.57 foot Fundamental Vertical Accuracy (FVA) at a 95% confidence level, derived according to National Standards for Spatial Data

Accuracy, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy, assessed and reported using National Digital Elevation Program/American Society for Photogrammetry and Remote Sensing Guidelines and tested against the triangulated irregular network (TIN) using ground points. Error for the historic contour maps was estimated by comparing control points outside the main course of the river and accessory floodways, in locations believed to be stable through the time period of interest (1964 to 2015). Each DEM was compared to 2,727 control point elevations derived from the LiDAR-based 2015 DEM. Based on this comparison, the 1964 DEM is 3.31 feet FVA at a 95% confidence level, using (RMSEz) x 1.96000. The 1987 DEM is 4.38 feet FVA at a 95% confidence level, using (RMSEz) x 1.96000.

Elevation difference mapping was performed by using raster analysis to subtract the more recent DEM from the older DEM.

Contours from 1998 Photogrammetry

The vertical error of the 2-foot contours is not reported in USACE 2000b, but based on American Society for Photogrammetry and Remote Sensing accuracy standards, the limiting root-mean-square-error (RMSE) is set at one-third the contour interval. For this study, the vertical error of the 1998 contours is set at ±0.67 foot. The cross-sections in the USACE (2000b) Hydrologic Engineering Center River Analysis System (HEC-RAS) model with 1998 elevations were exported into GIS software as 3D polylines.

Vertical Datum Conversion

The 1964, 1987, and 1998 topographic sources are originally in the National Geodetic Vertical Datum of 1929 (NGVD29) vertical datum while the 2015 LiDAR is in the North American Vertical Datum of 1988 (NAVD88) vertical datum. The USACE software Corpscon (USACE 2009) was used to aid the conversion process of the NGVD29 sources into NAVD88 to match the 2015 LiDAR datum. Elevations in NAVD88 are 2.72 feet higher than NGVD29 at the Greenspot Road crossing of the SAR, 2.66 feet higher at the Orange Street crossing, and 2.50 feet higher near South Waterman Avenue.

Thalweg Change Analysis

Thalweg elevations (i.e., minimum channel bed elevations) were determined for all 4 years of topography and used to assess changes in thalweg elevations that have occurred between 1964 and 2015. For the 1964 and 1987 topographic sources, channel alignments were digitized in GIS through the georeferenced contours and the elevation and station distance along the alignment where the alignment intersected a contour were recorded. Note that this analysis only uses the original contours as depicted on the scanned and georeferenced historic contour maps and does not use elevations interpolated between the contours used to made the DEMs. A similar process was used for the 2015 LiDAR. Longitudinal profiles showing how thalweg elevations change along the alignment were created.

The locations for which thalweg elevations were compared against other years were standardized by using 97 cross-section alignments (1998 topography is only available at cross-sections). The station distance of where the cross-sections intersected each year's thalweg alignment was recorded. The elevation of the thalweg at the intersection was determined by linear interpolation using the elevations of the adjacent upstream and downstream contour.

Thalweg elevation change was determined by subtracting the older topographic source from the more recent source (e.g., 1987 values from the 1964 values). Elevation changes greater than zero (positive change) indicate the bed was higher in 1987 than 1964, and elevations less than zero (negative change) indicate the opposite. The vertical error estimates were added to the thalweg change graphs to account for error in the topographic sources when interpreting morphologic change. For example, the estimated 1964 elevation error is ±3.31 feet and the 1987 error is ±4.38 feet. When comparing the change that occurred between 1964 and 1987, emphasis is placed on change that exceeds ±7.69 feet (the estimated aggregate potential error). Blocks were added to the thalweg change graphs to indicate where the upper and lower error estimates are either both above, or both below, the zero change line. Red blocks indicate where erosion occurred and yellow blocks indicate where deposition occurred. This process adds confidence in identifying locations where real erosion or deposition occurred, although in this example, the magnitude of the change may vary by ±7.69 feet.

Results

Historic Imagery

The historic aerial imagery illustrates the degree and duration of various disturbance types within the study area, including human manipulation of the study area (Figure 18 to Figure 25 in Chapter 10, *Figures*). Of interest to the present study is the degree of vegetation removal associated with storm flows (Table 1). Specifically, areas where scouring of vegetation took place during the 1969 flood events are discernible on Figure 21, depicting 1970 aerial imagery of the study area. Contrasting this with Figure 3 and Figure 6 (SBKR Habitat Survey Results and RAFSS Seral Stage) gives indications about relationships between vegetation type, habitat quality, and flood disturbance. Examination of the 1970 image indicates that overbank and scouring flows during the 1969 events re-contoured large portions of the main channel, particularly downstream of the Orange Street road bridge. Re-contoured areas are evident from vegetation removal and sand deposition visible in the images. These re-contoured areas correlate with present day mapped stands of pioneer, intermediate, intermediate/mature RAFSS, and high-quality habitat for SBKR.

Change in Elevation from DEMs

Although the 1964 and 1987 contour maps do not cover the entire study area, they do capture the majority of the SAR thalweg (Figure 26 and Figure 27). The 2015 DEM does cover the entire study area (Figure 28). Erosional/depositional differences between the DEMs are illustrated on Figure 29, Figure 30, and Figure 31. These figures depict erosion as red areas, and deposition as blue areas. Significant erosional changes were observed in some areas when comparing the elevational profile of the thalweg for 1964 and 1987 DEMs against the 2015 model. This erosional change appears to be associated with the 1969 flood events, as the erosional features appear between the 1964 and 1987 DEMs, then remain relatively stable from 1987 to 2015. Additional anecdotal evidence for the 1969 events being the major driver of this include landmarks within the 1970 aerial imagery that appear flood related and persist through to the current-day imagery. These features indicate that the majority of the channel surface downstream of Orange Street was re-worked during the 1969 events.

Thalweg Change

Comparison of bed thalweg elevations changes that occurred between 1964 and 1987 are shown on Figure 32. Overall, more of the channel exhibited erosion by 1987 compared to deposition, indicated by the channel distance within red boxes (erosion) versus yellow boxes (deposition). The most severe erosion occurred near State Route 210. Accounting for potential vertical error, the channel bed was between 7 feet and 22 feet lower in 1987 compared to 1964. A similar pattern is observed between 1987 and 1998 (Figure 33). The most severe erosion between 7 feet and 18 feet occurred between State Route 210 and Alabama Street. A trend of net deposition is observed between 1998 and 2015 along the majority of the study area (Figure 34). The thalweg in the reach that includes the Santa Ana River Crossing (SARC) Pipeline located just below the new Greenspot Road Bridge (constructed in 2014) was between 5 feet and 7 feet higher in 2015 than it was in 1998. Farther downstream, where the grade control structure was constructed across the SAR in 2013 as part of the East Branch Extension of the Mentone Pipeline, the 2015 thalweg elevation is approximately 9 feet to 12 feet higher than in 1998. The erosional trend observed from 1964 to 1998 near State Route 210 does not continue to 2015, as net deposition is observed in this reach. When averaged over the entire reach, the bed elevations in 2015 were between 0.4 foot and 2.9 feet higher than in 1998.

The 1964 to 2015 thalweg analysis spans the entire historic period included in this study (Figure 35). The overall trend in the study area is more erosion than deposition. This is particularly apparent for an over 7,000-foot reach between Orange Street and Alabama Street, which includes State Route 210. Maximum bed erosion in this reach ranges from 13 feet to 21 feet when accounting for vertical error estimates. Bed elevations in the vicinity of the 1969 breakout area do not indicate a strong trend of either erosion or deposition. The most pronounced area of increased bed elevations occurs between the Mill Creek confluence and the SARC Pipeline, where elevations were between 9 feet and 16 feet higher in 2015 than they were in 1964.

Discussion

The majority of erosional change that took place from 1964 to 1987 (Figure 29 and Figure 32) occurred in the downstream portions of the river, from the Orange Street Bridge west. The Orange and Alabama Street bridges, both present during the 1969 event, may have played a role in promoting erosion in this area by constricting the channel and increasing water shear stresses downstream. Although this erosional downcutting of the main channel thalweg took place prior to start of operations for SOD, it has implications for the current study because such features may result in reduced opportunities for promoting overbank flooding within the study area. Levees and dikes appear to have been installed along the south bank of the channel in the downstream section following the 1969 events, resulting in the SAR thalweg shifting north and being further constrained by the addition of State Route 210 road berm.

The SAR thalweg and channel experienced continued downcutting near Alabama Street from 1987 to 1998 (Figure 33). This trend of downcutting near Alabama Street did not continue from 1998 to 2015 (Figure 34). Although some deposition over this period is observed in the area near the Orange Street and Alabama Street bridges, in 2015 the channel bed is still at least 13 feet lower downstream of State Route 210 compared to 1964. On a study reach average, between 0.4 foot and 2.9 feet of net deposition occurred between 1998 and 2015, with the most deposition occurring at the Mentone

Pipeline constructed in 2013. The 10-foot bed elevation increase at the Mentone Pipeline crossing and 6-foot increase at the SARC Pipeline likely increase 2015 water surface elevations compared to 1998 conditions, thereby increasing opportunities for promoting overbank flooding upstream of these locations. The comparison of 1998 and 2015 thalweg elevations indicates that SOD has not resulted in overall downcutting of the channel bed. Channel armoring of the SAR upstream of Mill Creek likely occurred, but the input of sediment from Mill Creek and City Creek, and reductions in peak flows created by SOD, has likely contributed to the net increase in thalweg elevations of 0.82 foot in the study area.

Summary

- The 1969 flood events resulted in significant changes in the channel thalweg profile of the SAR within the study area.
- Construction of the Orange Street Bridge and Alabama Street Bridge, as well as channel confinement downstream, likely contributed to channel downcutting observed between 1964 and 1987. This area has stabilized since 1998. These flood-driven changes have resulted in a channel morphology in the river profile downstream of the Orange Street Bridge that may impede future efforts to produce overbank flows for habitat renewal purposes in the lower sections of the river.
- There are seemingly only small topographic changes to the study area since start of operations for SOD. This is in contrast to other studied dams where sediment supply is reduced disproportionally to water supply, leading to dramatic erosional changes. The thalweg elevation trend between 1998 and 2015 is net sediment deposition. Construction of grade control structures for the Mentone Pipeline crossing and SARC Pipeline have increased bed elevations that may increase opportunities for flooding and habitat renewal.

Chapter 5
Peak Flows and Constraints Analysis of Historic Operations of Seven Oaks Dam

This chapter begins with presentation of peak flood flow analysis on the SAR for both pre and post-SOD conditions. This is followed by presentation of the constraints analysis of the historic operations of SOD.

Annual Peak Flow Frequency Analysis

The USGS gage 11051500 Santa Ana River near Mentone is just downstream of SOD and is the source for peak flows in the SAR between SOD and the confluence with Mill Creek. The gage has peak flow values for 121 years dating back to 1891, with continuous records from the 1897–2017 water years (with the exception of missing year 1930). The USGS gage 11054000 Mill Creek near Yucaipa is 5.6 miles upstream of Mill Creek's confluence with the SAR, has a drainage area of 42.4 square miles (mi^2), and is the best source for peak flows on Mill Creek. The gage has peak flow values for years 1920–1938 (1929 missing) and then again from years 1948–1986 (1976 missing). Because about 10.3 mi^2 (19.5%) of the total 52.7 mi^2 watershed area is downstream of the gage location, flood frequency values for Mill Creek at the confluence with the SAR will be somewhat higher than reported below because of the additional watershed runoff.

Annual peak streamflows reported by USGS for both the SAR and Mill Creek gages are listed in Table 3. In addition to listing the date and magnitude of the peak flow, the table lists USGS qualifiers about the flow, such as whether the peak flow is an estimate, an instantaneous peak, or maximum daily average, and if it is affected by regulation or diversion upstream. For the SAR peak flows, the qualifier "6" begins in water year 1999 to denote the completion of SOD construction and beginning of discharge affected by regulation. ICF performed Bulletin 17B flood frequency analysis (Flynn et al. 2006) on the peak flows to develop annual peak flow frequency curves (also known as annual exceedance probabilities). The curve on Figure 36 is for the SAR pre-dam regulation and the curve on Figure 37 is post-dam regulation. The flood frequency curve for Mill Creek is shown on Figure 38. The flow magnitudes of the 1.25-year through 100-year recurrence interval are listed in Table 4.

Table 4 also lists the flood frequency values reported by USACE during the planning of SOD construction. The pre-SOD values were determined by USACE using the plotting position method and they are consistently higher than the pre-SOD values determined by ICF from Bulletin 17B methods. Table 4 also lists the USACE-predicted dam outflow release frequencies based on modeling of dam operations. The 2-year event is reported as 400 cfs, the 5- and 10-year events as 500 cfs, the 20-year event as 2,500 cfs, and the 100-year event as 5,000 cfs. The Bulletin 17B analysis ICF performed on the 1999–2017 peak flow record produced larger values for the 5-, 10-, and 20-year events (847 cfs, 1,750 cfs, and 3,260 cfs, respectively) than what USACE predicted. One explanation for this is that there have been four SOD test releases over the period of record that resulted in higher flows than what would otherwise have been released based on the reservoir operations guidelines discussed below in this chapter.

The Mill Creek flood frequency values listed in Table 4 are quite similar between the USACE (1988b) analysis and the analysis ICF performed for this study. This is expected because the gage data and Bulletin 17B method of analysis was the same for both assessments.

USACE reported expected flood frequency values for the SAR downstream of the Mill Creek confluence (Table 5). Page 22 in USACE (2000b) states the discharges were:

> "…determined by adding the n-year peak outflow from Seven Oaks Dam to the contemporaneous n-year discharges for Mill Creek. These values were plotted and a smooth curve was fit through the data."

More description on this curve-fitting method is described in USACE 1988b, and included in Table 5. It is not clear how the USACE method accounted for the fact that peak flows on the SAR did not necessarily occur at the same time as peak flows on Mill Creek prior to SOD construction (nor do they with SOD in place). The far-right column in Table 3 shows the difference in days between peak flows on the SAR and Mill Creek. Of the 54 annual peak flows available for the Mill Creek near Yucaipa gage, 30 of them (56%) occurred with one day of the SAR peak flow. For 44% of the historic record peak flows on the SAR and Mill Creek did not occur at the same time.

A different approach for estimating flood frequency values for the SAR downstream of Mill Creek is to sum the Mill Creek n-value recurrences with different SOD release magnitudes (Table 6). For illustration purposes, releases of 3,000 cfs, 5,000 cfs, and 7,000 cfs are evaluated in Table 6. A crucial assumption to this analysis is that SOD is released to strategically occur in conjunction with when Mill Creek flood flow is peaking. As described below in this chapter in the *Discussion* section, this is not the case, and the flood recurrence values presented by USACE (2000b) downstream of Mill Creek present a best-case scenario of SOD releases synchronized to take advantage of Mill Creek peak flood flows.

Constraints Analysis of Historic Operations of Seven Oaks Dam

Operating records for flow input and output from SOD were examined and contrasted with operating parameters detailed in the WCM (USACE 2003). Specific topics of interest included the following.

- Magnitude: how much flow is the dam currently capable of releasing from its outlet?
- Frequency: How often were reservoir pool conditions (e.g., head) met in order to make a release?
- Duration: how long (e.g., hours, days) did releases occur for?

Data Sources

SOD Contributions

- Curated 1-hour interval digital staff gage readings from 9/2010 to 6/2018, supplied by SBVWCD
- Scanned paper dam operators' field notes at haphazard interval manual and digital staff gage readings from 2/2000 to 6/2018, supplied by Orange County Flood Control District

- Peak Annual Flow, publicly available via the web, hosted by USGS
- 15-minute discharge data for Mentone gages 11051499 and 11051502, publicly available via the web, hosted by USGS

Methods

SOD Contributions

Dam operators' paper field notes were manually entered and collated into a spreadsheet. An initial quality control step was performed to remove entry error by checking and removing out-of-range values. All out-of-range values were checked against paper copies prior to being modified.

Dam operator entries were coerced to the nearest 15-minute interval using the *zoo* package in the R statistical computing environment (Zeileis and Grothendieck 2005; R Core Team 2017). Missing data entries were interpolated via bracketed mean values using the *dplyr* package in R (Wickham et al. 2015). This resulted in straight-line interpolations of staff gage values between gaps in dam operator entries at a continuous 15-minute timestep interval.

A second quality control step was performed to correct additional sources of error. These sources included dam operator data entry errors and digital staff gage measurement errors. Dam operator entry errors generally presented as switched number values for single entries. Digital staff gage measurement errors generally presented as a series of entries that departed significantly from manual staff gage entries. Both error types were visible as irregularities within an otherwise extremely regular range of readings. Errors of both types were always checked against bracketing data values believed to be accurate. Both errors represented less than 1% of the total dam operator values used to construct the data series.

The 15-minute discharge data publicly available for flows downstream of the dam are located at two gaging stations. These are the Mentone gages 11051499 and 11051502. In combination, they compose the outflow of the dam. Gage data were aligned along the start data of 02/2000 and then added together to derive a combined outflow, which is referred to as the combined Mentone gage 11051500. USGS gage data were treated in the same fashion as dam operator entries to ensure all data were in 15-minute interval time series from start of operations (02/2000) to present (06/2018).

Dam Operator's Guidance (Interpreting the Water Control Manual)

Guidance within the WCM (USACE 2003) consisted of a series of conditions and gate settings related to staff gage elevations at SOD. Language taken from the WCM pertaining to the release schedule is presented below. Bolded texts below are edits for clarity with updated protocol language from the 2014 WCM water quality guidance.

Debris Pool

> **"The debris pool elevation is up to 2200 feet, NGVD.**[1] …releases from the dam are reduced to a maximum of 3 cfs in order to form the debris pool starting 1 October of each year. The debris pool is held until the end of the **storm event (updated water quality guidance** [USACE 2014]**),** when it is

[1] National Geodetic Vertical Datum

drained on a schedule established in cooperation with the downstream water agencies during the development of the Phase II GDM (USACE 1988a). During the month of June, releases will equal inflow plus 10 cfs, and during the months of July and August, releases will equal inflow plus 20 cfs" (USACE 2003:7-5).

Intermediate Pool

"The Intermediate Pool is that portion of the flood control pool that lies below the sill of the main intake. The releases within this range should match inflow up to the maximum release capability of the project. The combined release capability of the low flow gate and the MDL in this range is approximately 400 to 500 cfs" (USACE 2003:7-5).

Trash Rack Pool

"The trash rack **pool is** between elevations 2265 and 2292.5 feet, NGVD. Within this range, releases are based only on the rising and falling pool elevations at SOD. During the pool rising stages, releases, if required, will be cut back to a release that is considered to be the maximum safe rate through the MDL when the water surface elevation is between elevations 2265 and 2299 feet, NGVD. The reason for this is to avoid drawing floating debris into the trash racks and possibly rendering the main outlets inoperative. The 2299 elevation allows for sufficient submergence of the trash rack to avoid vortex formation. The maximum safe release rate, when the pool is rising, will be determined by project operating experience but is theoretically on the order of 50 cfs. During falling stages, releases will be made in accordance with the project design schedule as shown on Plate 7-01. These are theoretical maximum safe rates ranging up to 2000 cfs" (USACE 2003:7-6).

Flood Control Pool

"This is the pool between elevations 2299 feet, NGVD and the spillway crest at elevation 2580 feet, NGVD. Within the flood control pool, release rates from SOD are based on concurrent conditions at Prado Dam. During flood events, SOD will store water destined for Prado Dam as long as the reservoir pool at Prado reservoir is rising, and the pool at SOD is not approaching the spillway. Once the reservoir water surface elevation at Prado Dam reaches its peak and starts to recede, SOD releases will be made based upon the SOD pool elevation, ranging from a minimum of 2,000 cfs at elevation 2299 feet, NGVD up to the maximum rate of 7,000 cfs at elevation 2580 feet, NGVD" (USACE 2003:7-6).

Calculating the Rising/Falling Condition for Seven Oaks Dam

Included in the WCM release schedule language are several references to a rising or falling condition for SOD and Prado Dam. Because SOD levels never reached 2,299 feet NGVD during the 18-year period under review (start of operations to 06/2018), the rising/falling condition for Prado Dam was not examined. In order to calculate the rising/falling condition for SOD, the current staff gage reading representing water surface elevation needs to be compared against previous values. In the comparison with previous values, a range or time window must be specified. This time window is not specified in the text of the WCM, but plates 8-01 and 8-01A illustrating the Standard Project Flood (SPF) and Reservoir Design Flood indicate a 24-hour period separating cessation of flood input into the dam and output (dam discharge) greater than 50 cfs. This 24-hour period was confirmed by SBVWCD staff to be an appropriate estimate for the time window (Cozad pers. comm.).

Using 24 hours as the time window for rising/falling condition at SOD, the current staff gage reading was compared against the rolling maximum staff gage reading for the previous 24-hour period. If the current staff gage value was found to be greater than the maximum value in the previous 24 hours, then a rising condition was inferred, and flow guidance was imputed to be 50 cfs. If less than or equal to the value, then a falling condition was inferred, and flow guidance was imputed based on reservoir height following the guidance listed in the WCM language detailed above. Based on this, all water level entries in the completed time series were assigned a maximum flow guidance (referred to as *guidance* on figures).

Results

SOD Contributions

A file containing a continuous record of SOD water level in feet NGVD, outflow in cfs (combined USGS gage 11051500), and WCM guidance in cfs at 15-minute intervals from start of operations (2/2000) to present (6/2018) was compiled from the data sources. Figure 39 in Chapter 10, *Figures*, depicts water level as taken from the digital staff reading for SOD operations for the period from start of operations for the dam (02/2000) to present (06/2018). The red line demarks the water level for which programmed flows as taken from the WCM (Plate A-01) may exceed 500 cfs. Examining this plot, three water years (2005, 2010, and 2011) stand out as being the only periods during the 18-year period of record where programmed flows were greater than 500 cfs.

Figure 40 depicts the subset of recorded data points when SOD was in the falling state. This portrays the contrast between the WCM guidance at a specific water elevation and the peak, mean daily, and average outflows at that elevation. The plot highlights potential opportunities to increase flows within the WCM guidance by potentially increasing outflows up to the designated maximum when the dam water level is at higher elevations.

Figures A2.01–A2.18 in Appendix 2, *SOD Operating Parameters for the Period of Record*, are a series of two-part figures depicting the 18 years the dam has been in operation. The bottom plot is water level in feet, the top plot is the WCM guidance for the concordant water level (blue line), combined outflow for the Mentone gages (orange line), and the peak annual flow as reported for the USGS gages (red dot). The entire series is justified by water year (October 1 to September 30). The water year displayed in each figure is the abbreviated calendar year.

Special Events

Three time periods stand out as significantly different from the remaining annual cycles. These periods are 2005, 2010, and 2011 and correspond to SOD gate test events (Figure 41, Figure 42, and Figure 43). Peak flows for these release events are 4,179 cfs on March 9, 2005; 3,159 cfs on July 15, 2010; 4,648 cfs on February 15, 2011; and 5,003 cfs on March 1, 2011. During these periods, operations at the dam appeared to deviate from the WCM flow guidance. It is assumed that this deviation was conducted for the sole purpose of testing the gate apparatus. No description of which guidance was followed during these periods is available. Telephone communication with SBVWCD indicates that gate test operations in 2005 resulted in damage to the main control gate. This damage was repaired and the gate apparatus was retested in 2010 and 2011. Again, no description of operating procedure or explanation of apparent deviation from the WCM guidance during these periods is available.

These special event periods are characterized by water levels greater than 2,200 feet NGVD. It is unclear if water elevations greater than 2,200 feet resulted from deviation from the WCM or were the result of increased precipitation during those periods. It may be that gate test events were coordinated around higher-than-average precipitation events in the upper watershed. In spite of uncertainties surrounding SOD gate testing operating parameters, outflows during these events are useful for characterizing the conditions of future high-flow events.

Discussion

Constraints

The main element constraining outflows as prescribed by the WCM is the SOD rising/falling condition. As interpreted by the investigators, when input into the reservoir exceeds evaporative loss plus infiltration loss, the reservoir will be in a rising condition, and outflow will be limited to 50 cfs. During any significant rainfall event, SOD is likely to be in a rising condition for the duration of the event and likely for some period of time following the event. This effectively prevents timing high-flow releases from SOD to coincide with peak flows from tributary systems.

A secondary element constraining outflows is the WCM schedule for discharge based on water level (Plate A-01 [USACE 2003]). SOD water levels above 2,200 feet NGVD were rare, occurring three times during the 18-year period of record. During average rainfall years, this limits contributions from SOD to 500 cfs or less.

Other potential constraints on outflows include issues not detailed in the WCM. These include public safety issues associated with high-flow releases both within and outside of typical seasonal periods. During the gate test events, local municipal and law enforcement personnel participated in warning the public and keeping the floodway free of people. In addition, potential flood damage to downstream habitat for other listed species, specifically Santa Ana sucker, may need to be considered when proposing a high-flow event. Finally, various elements of public transport and water conservation infrastructure may be at risk for flood damage during a high-flow event. No specific flow values are available for constraints external to the WCM.

During the period of record, dam levels were never recorded at elevations past 2,400 feet NGVD. Based on operating parameters in the WCM, this effectively limits the maximum contribution to downstream high-flow events to 4,000 cfs or less. It is possible that through an agreement with the dam operator and other stakeholders, streamflow input into the dam could be retained to a point where the 2,400-foot limit was exceeded, thereby allowing for greater outflows.

None of the SOD releases higher than 3,000 cfs have been coordinated with high flows occurring on tributaries to the SAR, including Mill Creek. Although Mill Creek no longer has an active gage, the SAR near E Street gage (11059300) records flow inputs from Mill Creek and other major tributaries, including City Creek, Plunge Creek, San Timoteo Creek, and East Twin Creek.

Since 1999, and the beginning of flow regulation in SOD, two notable flood events have happened on the upper SAR. The SAR E Street gage recorded a flow of 35,700 cfs (59-year recurrence interval) on January 11, 2005, and a flood of 27,800 cfs (30-year recurrence interval) on December 22, 2010. The flow magnitudes, dates, and recurrence intervals of the contributing tributaries for which gage data is available, including the SOD release contribution, are also listed in Table 7. The total drainage area of the gaged tributaries and SAR upstream of the SOD release is 380.3 mi^2, which is 70.3% of the drainage area at the SAR E Street gage (541 mi^2). The Mill Creek near Yucaipa gage's drainage area is 42.4 mi^2, which accounts for 26% of the drainage area that is not accounted as a gaged input to the SAR E Street gage (Table 7).

From this information estimates of the Mill Creek flow contribution were made. Upper and lower Mill Creek estimates are provided based on the minimum and maximum recurrence intervals of the tributaries. The difference between the peak flow at the SAR E Street gage and the total of the contributing tributaries' peak flows is also listed. This total is between the upper and lower Mill Creek estimates for both events. For the January 2005 event, Mill Creek is estimated to have peaked between 8,200 cfs and 20,000 cfs. For the December 2010 event, Mill Creek is estimated to have peaked between 8,300 cfs and 16,000 cfs.

The maximum SOD flow releases made during these two flood events are also listed in Table 7. SOD released 670 cfs on January 9, 2005, which has a recurrence interval of 14 years based on the USACE (2003) outflow frequency curve. The corresponding recurrence interval on Mill Creek is estimated between 26 years and 83 years. SOD released 50.1 cfs on December 22, 2010, which has a recurrence interval of less than 1 year and is a typical low-flow condition release. The corresponding recurrence interval on Mill Creek is estimated between 28 years and 63 years.

A key conclusion of this analysis is that Mill Creek will continue to contribute substantial flood flows to the SAR. However, SOD has not been making high-flow releases that contribute to Mill Creek flows in a manner that matches the flood recurrence intervals for the SAR downstream of Mill Creek predicted by USACE (2000b) and listed in Table 5. The values in this table assumes that a n-value recurrence flood on Mill Creek will be matched with an equal n-value recurrence event from SOD releases. These types of synchronized releases have not occurred to date during the operation of SOD.

Opportunities

Figure 40 indicates outflows from SOD during the falling condition. At lower reservoir levels, outflows often approached or exceeded WCM guidance. As reservoir level increased, outflows tended to stay near 750 cfs. Based on this, there may be opportunities to increase flow contributions from SOD at elevated reservoir levels while remaining within WCM guidelines for outflow. Based on conditions during the 18-year period of record, these flow contributions would be in the range from 500 to 4,000 cfs.

Summary

- There appears to be additional capacity within the WCM guidelines to create or contribute to high-flow events up to approximately 5,000 cfs within the study area.
- Flow contributions from SOD are likely to be limited to 5,000 cfs or less, based on the period of record, in spite of the dam's rated gate outflow capacity of 7,000 cfs. This assumes similar inflow and climatic conditions in the future as those observed for the period of record and may not match future contributions based on long-term climate projections for the region.
- There may be other operational constraints in addition to the WCM (e.g. inter-agency agreements regarding flood releases, public safety, infrastructure risks) that ICF is unaware of that may ultimately limit releases. ICF does not currently have any documentation of such constraints.
- USACE (2000b) reports flood recurrence intervals for the SAR downstream of Mill Creek that combine SOD releases with n-value recurrence events on Mill Creek (Table 5). This assumes SOD releases are timed to closely match the peak flow on Mill Creek as it enters the SAR. However,

synchronized release with peak tributary flows does not appear to be provided for based on review of WCM guidance. The most important limit on instigating or contributing to ecologically meaningful flow events from SOD is the rising condition limit to 50 cfs, which effectively prevents timing releases with high-flow contributions from tributaries.

Chapter 6
Determine Fluvial Disturbance Extents in the Study Area

The extent of flooding associated with various discharge scenarios for SOD was estimated using hydraulic modeling tools and available historical records for the system. Flood extents were then contrasted with species distribution records to provide some estimation of the degree to which flood disturbance from the dam could be expected to interact with the species of interest.

Data Sources

- 2015 LiDAR DEM. This digital elevation model represents the most recent topographic survey of the study area available.
- 1999 USACE HEC-RAS Model. This was the original hydraulic model used by USACE to assess impacts of SOD altered flood regime to the study area.
- USGS gage data. All available USGS gage data for the study area and significant tributaries was compiled and analyzed.

Methods

HEC-RAS 1D Model

A 1D HEC-RAS hydraulic model was run to obtain a coarse evaluation of the flow magnitudes necessary for floodplain inundation of identified habitat areas. The USACE Hydrologic Engineering Center in Davis, California, created a HEC-RAS model for an initial assessment of SOD on SBKR habitat (Appendix D, HEC Initial Overflow Study and Sediment Transport Analysis, in USACE 2000b). The model includes the SAR from just upstream of Greenspot Road downstream to the Interstate 10 crossing, and reaches on Mill Creek, Plunge Creek, and City Creek (Figure 44 in Chapter 10, *Figures*). The geometry used for the model's cross-sections is based on 2-foot contours developed from a DTM created from photogrammetry of aerial photos flown in 1998 (USACE 2000b). The model includes 151 cross-sections on the SAR spaced about 150 feet apart. Because the report for the HEC-RAS model was prepared in 1999 (Appendix D in USACE 2000b), this original model is hereafter referred to as the 1999 model.

- ICF obtained the 1999 model and made the following updates:
- Updated elevations on the cross-sections using the 2015 LiDAR
- Edited channel and overbank flow lengths based on 2015 channel morphology
- Adjusted levee and ineffective flow elevations based on changes in topography that occurred since 1998 and different assumptions about flow confinement on the cross-sections. This is an important point, particularly in braided channels with multiple channel braids that are engaged at different flow levels, as assumptions about flow confinement are particularly important in a 1D model. Unless specified to not do so, HEC-RAS will place water across the entire cross-section

at a single water surface elevation. This often is not realistic because high ground prevents flood water in the channel from accessing certain areas of the cross-section (e.g., a secondary flood channel). ICF assigned ineffective flow areas on cross-sections to limit the portions of the cross-section allowed to convey water. For example, ineffective flow areas were set on the tops of berms or high banks that separate the main channel from secondary flood channels or floodplain areas. This told the model to not allow conveyance in these areas until the water surface reached a high enough elevation that flow could engage these areas.

- Added new bridge crossings not included in the original model

ICF used the same Manning's n values as the original model. The original model based n values on field inspection and photograph inspection. A channel n value of 0.08 was used for the SAR upstream of Mill Creek, 0.07 for SAR between Mill Creek and City Creek, and 0.06 for downstream of City Creek. A Manning's n value of 0.1 was used for overbank areas consisting of rough terrain, with sand, rock, bushes, and small trees (USACE 2000b). A sensitivity analysis of channel Manning's n values is presented later in this chapter.

The model includes seven flood events (2-, 5-, 10-, 20-, 50-, 100-, and 200-year recurrence intervals) for three different conditions (pre-dam, March 1998, and post-dam). The downstream boundary condition is based on the normal depth at channel energy slope of 0.00625 foot/foot. The downstream boundary is several miles away from the study area and determined far enough away to not affect results in the study area (USACE 2000b).

Modeled Flood Scenarios

Flow scenarios were composed of contributions from SOD and tributaries, regardless of whether they could occur based on current operational constraints. Tributary flow contributions from Mill Creek and City Creek are important to the total flow of the mainstem SAR flows in the study area. ICF performed new Bulletin 17B flood frequency analysis (Flynn et al. 2006) using gage peak flow records available through the 2017 water year to compare the new flood frequency values with the 1999 HEC-RAS model values (Table 8). The flood frequency values used in the 1999 model for Mill Creek and City Creek are listed in Table 9. The Bulletin 17B values calculated for Mill Creek are fairly similar whereas the calculated values for City Creek are higher than the 1999 model's values. In order to be consistent with the 1999 model, the same Mill Creek and City Creek tributary contribution flood frequency values were used for the new model. Two flood scenarios for water releases from SOD were modeled: (1) 3,000 cfs and (2) 7,000 cfs maximum release. These are based on constraints listed in the WCM and parameters obtained from previous operations during the period of record and discussions with individuals familiar with SOD operations, as previously discussed in the section covering dam operations. The 7,000 cfs maximum release scenario was then paired with calculated recurrence values for 5-, 10-, 50-, and 100-year events from nearby tributaries. As previously stated in Chapter 5, this scenario makes a major assumption that the SOD releases are timed to match the peak flows of the tributaries. Like the 1999 model, the new model was run in steady-state conditions (i.e., constant flow rate).

The following flow scenarios were chosen for the HEC-RAS modeling outflows to evaluate overbank flooding conditions within the study area.

Scenario 1: SOD by Itself at 3,000 cfs

Assumes the SOD release is not coordinated with simultaneous flow contributions from other tributary systems (Mill Creek and City Creek). The 3,000 cfs value is the estimated highest flow release obtainable without significant multi-agency coordination.

Scenario 2: SOD by Itself at 7,000 cfs

Assumes the SOD release is not coordinated with simultaneous flow contributions from other tributary systems (Mill Creek and City Creek). The 7,000 cfs value is the estimated highest flow release that the dam outlet works are capable of producing. Any releases from SOD approaching 7,000 cfs would require significant multi-agency coordination for public safety and damage control of public infrastructure within the flood limits.

Scenarios 3–6: 7,000 cfs and 5-, 10-, 50-, 100-Year Event

These scenarios model releases from the dam coordinated with simultaneous flow contributions from other tributary systems (Mill Creek and City Creek). Timing release events from SOD to coincide with peak flow contributions from the tributaries could promote overbank flooding within the study area. The scenarios model a range of likely peak flow contributions from tributaries, coupled with the maximum flow contribution from SOD.

The modeled water surface elevations at the cross-sections for each flow scenario were imported into GIS. A TIN layer of continuous water surface elevations for the study area was created by interpolating between the cross-sections. The 2015 LiDAR surface was subtracted from the interpolated water surface layer to create an inundation layer that shows areas of inundation where the water surface is higher than the ground. The inundation layer was clipped to the boundaries of the flow confinement limits on the cross-sections described above in the *Methods* section. This relates to the previous discussion of ineffective flows and not allowing water to be conveyed on areas of the cross-section separated from the main channel until water surface elevations are high enough to engage them. For example, an area on the floodplain separated from the flow in the main channel by an artificial berm was clipped out of the inundation layer and not shown as area that would be flooded.

Key Differences between ICF and USACE HEC-RAS Modeling Inundation Areas in the Study Area

The inundation maps generated from the 1999 HEC-RAS model (e.g., Figure 4a in USACE 2000b) show numerous areas of inundation disconnected from the inundation of the main channel.

Appendix D of the USACE (2000b) report states:

> "The inundated areas shown in the map are a visualization of the HEC-RAS results. The mapping process is a set of geometric calculations interpolating surfaces from results on lines and comparing one surface to another. It is not a hydraulic computation following the flow of water from one cross section to another. For this reason, the inundation map includes a number of ponds-isolated areas where the water surface is higher than the ground surface-that may not represent the hydraulics in the field. Because of the complexity of the terrain and the limitations of the survey data used to construct the terrain model, it is nearly impossible to say that an isolated patch of water in the model result would or would not be present in an actual flood. In order to make the visualization as

conservative as possible, no ponds were removed from the maps generated from the model results" (USACE 2000b, Appendix D, page 14).

This is a critical distinction between the 1999 model's inundation maps (USACE 2000b) and inundation maps generated for this study. Much of the inundation shown for the 1999 model would not occur in reality because high ground separates the isolated inundation areas from the channel's active flow and flow would have no way to access these isolated areas. As previously described, ICF clipped the inundation results based on where it seemed likely water could and could not access on the land surface. This leads to much smaller inundation areas mapped for this study than are presented by USACE (2000b).

SRH-2D Model

The 1D HEC-RAS model has limitations when modeling hydraulics and flood extents in channel morphologies common in the SAR and tributaries (e.g., braided/split flow) because:

- The 1D model calculates water surface elevations only at cross-sections, thus requiring interpolation between the cross-sections when mapping inundation areas.
- The 1D model assumes all the flow vectors are oriented downstream perpendicular to the cross-section.
- Only one water surface elevation can be calculated for a cross-section, when in reality in braided channels the water surface elevations can vary appreciable from bank to bank.
- In cases of split flows, the user has to specify the distribution of flows into the channel splits.
- The user also has to make assumptions about how to confine water along a cross-section by specifying accessible and inaccessible flow areas.

The advantage of the 1D model is that a large area can be modeled quickly with model runs only requiring a few minutes or less. This enables an initial assessment of which areas are inundated, or close to being inundated, by the modeled flow scenarios. In turn, this initial assessment aids in identifying priority areas that warrant further analysis using a 2D model, which better simulates the channel and floodplain hydraulics but requires longer time durations to complete model runs.

Two-dimensional hydraulic modeling was performed using the SRH-2D numerical model (Lai 2008). The initial 2D modeling effort is focused on the SAR and Mill Creek confluence area that includes the 1969 breakout location on the north bank downstream of the confluence. This area was selected for the initial analysis because it is the location where several historic flood events have inundated the flood terrace to the north and has been the discussion among stakeholders as an area to investigate further for feasibility of flooding again with SOD in place. This is also the same area of focus as the 1999 HEC-RAS model and BA (USACE 2000b) and provides an opportunity to compare the results from a 2D model with a 1D model. ICF will look to perform similar 2D modeling at other locations once the stakeholders provide feedback on other priority areas that require further analysis.

The SRH-2D numerical model was created by the U.S. Bureau of Reclamation at its Technical Service Center in Denver, Colorado. The model is a 2D depth-averaged velocity, finite element model well suited for simulating hydraulics in braided channel morphologies and lateral flow onto overbank areas. SRH-2D uses a flexible hybrid mesh of structured quadrilateral and/or triangular cells that provides a good balance of modeling accuracy and time to complete model runs. The model was run using a steady-state flow condition for two of the scenarios analyzed and an unsteady condition for the third scenario of routing a hydrograph through the model. All model setup, including mesh generation and boundary condition establishment, was performed in the Surface-water Modeling System software published by Aquaveo (Aquaveo 2009).

Elevations in the model are based on LiDAR flown in 2015. The resolution of the modeling mesh is 3-foot spacing between model nodes in channel areas, which is the same resolution of the raster cell size in the LiDAR elevation surface.

Roughness values for the modeling mesh were not calibrated because no nearby gages are available for aiding calibration and no known aerial photographs showing the extent of high water circa 2015 are available. A Manning's n roughness value of 0.04 was used for the channel. The specified roughness value was determined based on consideration of grain roughness (Limerinos 1970) related to particle size and surface irregularities that also provide roughness and are not already accounted for in the density of the node spacing in the mesh surface or grain size (Tonina and Jorde 2013). These 2D roughness values are lower than what was used in the 1D hydraulic model because much of the bedform roughness and other flow resistance factors (e.g., channel geometry) are accounted for in the 2D mesh. Manning's n values in vegetated areas range from 0.06 to 0.1 depending on the vegetation density. A 2D model sensitivity test to roughness values can be performed for the next phase of the study.

The upstream boundary conditions on the SAR and Mill Creek were set at locations where the flow is concentrated into one channel braid. The water surface elevation assigned to the models' downstream boundary condition at the East Branch Extension of the Mentone Pipeline crossing was determined from the HEC-RAS 1D model. The parabolic turbulence coefficient was set to 0.6 in the model (Pasternack 2011). Monitoring lines and points were established on the model to monitor water surface elevations and continuity calculations during the model run. Each modeled flow was run at a time step of 0.1 second until an acceptable level of convergence was obtained in continuity, water surface elevations, and velocities.

Three flow scenarios were evaluated for the initial 2D analysis:

- 7,000 cfs SOD release with no tributary input from Mill Creek
- 7,000 cfs SOD release with 19,500 cfs tributary input from Mill Creek (26,500 cfs total flow). The 19,500 cfs value is the Mill Creek 100-year event value used in the 1999 HEC-RAS model (USACE 2000b).
- A hydrograph based on the March 1, 2011, SOD release that includes infiltration losses

Modeled Hydrograph with Infiltration Losses

The volume of water released from SOD will decrease as it flows downstream due to infiltration losses in the channel substrate. ICF evaluated infiltration losses by running a flood hydrograph in an unsteady condition SRH-2D model with infiltration losses.

Hydrograph Development

Three flood events with peak flows over 4,000 cfs as have been released from SOD. The magnitudes and durations of these flood hydrographs are listed in Table 10. The March 1, 2011, release had the highest peak flow (5,003 cfs) but the duration and total volume of the February 15 and March 1, 2011, events were greater. The February 2011 hydrograph has a long ramp-up time in which it took nearly 12 days for flows to increase from 50 cfs to 500 cfs. It only took 11 hours for the March 2011 flood to achieve the same flow increase (see Figure 45 for comparison of the winter 2011 hydrographs). The March 2005 flood release (Figure 46) had a duration of only 5 hours with an abrupt shutdown of flow. This event is associated with the first gate test and problems that occurred with the gate operation during this test likely curtailed the duration.

The March 1, 2011, flood release was used as the basis for the hydrograph modeled in SRH-2D because it has the highest peak flow and a shorter ramp-up time. A comparison of the hydrograph used in the model against the measured hydrograph is shown on Figure 46. The ramp-up time on the rising limb of the model hydrograph was condensed to shorten the duration of the modeled flood event. The unsteady SRH-2D hydrograph that simulates the March 2011 SOD release has a duration of 33 hours and a peak flow of 5,003 cfs.

Modeled Infiltration Losses

The SRH-2D model has the option to calculate infiltration losses using the Green-Ampt method. The Green-Ampt model is derived by applying Darcy's law to account for soil infiltration when there is excess water at the ground surface (Mein and Larson 1973). A sharp wetting front separates a saturated soil zone at the top from a lower "dry" zone with an initial water content (Figure 47). The depth of the wetting front increases as infiltration progresses deeper into the ground. The equation for the Green-Ampt model is expressed as (Mein and Larson 1973; Lai 2006):

$$f_p = K_s\left(1 + \frac{S(\theta_s - \theta_i)}{F}\right)$$

where f_p is infiltration capacity [inches per hour], K_s is saturated hydraulic conductivity [inches per hour], S is capillary suction at the wetting front [inches], θ_s is the saturated moisture content [proportion], θ_i is initial moisture content [proportion] present in the "dry" zone, and F is cumulative infiltrated depth [inches]. The SRH-2D model continuously calculates the Green-Ampt infiltration losses for every element in the model mesh.

ICF used the soil surface texture properties available in GIS format from the Natural Resources Conservation Service Soil Survey Geographic database (NRCS 2018) to map soil texture at the site. Gravelly sand composes 62% of the site's area, followed by stony loamy sand (33%) and sandy loam (5%). The Green-Ampt parameters for soil texture reported in Table B-2 of Appendix B, Rainfall Loss Parameters, in the Arizona Department of Transportation's Hydrology Manual (2014) were used. The SRH-2D model allows the user to apply unique Green-Ampt parameters to every material zone (i.e., Manning's n roughness zone). The weighted average Green-Ampt parameters were calculated for each material zone (Table 11). The Green-Ampt parameters vary little throughout the site because of the similarity in the surface soil texture. Note the initial moisture content used in the model is low to simulate initially relatively dry soil conditions. Use of higher initial moisture content values would result in less infiltration loss occurring in the time between initial soil infiltration and when the soil becomes saturated.

Results

HEC-RAS 1D Model

The results of the 1D flood inundation mapping for the six flow scenarios are shown on Figure 48 through Figure 53. Each map lists the flow magnitudes in each reach of the SAR based on the modeled flow scenario. Maps depicting the six flood scenarios and their interactions with map records for the species of interest are shown on Figure 54, Figure 55, and Figure 56. Estimates of the extent of inundation of species occurrence records by the six flood scenarios are presented in Table 12.

HEC-RAS Manning's n Sensitivity Analysis

Analysis was performed to test how sensitive the HEC-RAS results are to variations in Manning's n roughness values. As previously stated, the original 1999 USACE HEC-RAS model used a channel n value of 0.08 for the SAR upstream of Mill Creek, 0.07 for SAR between Mill Creek and City Creek, and 0.06 downstream of City Creek. The sensitivity test consisted of adjusting the channel n values to three different variations: (1) 0.03; (2) 0.045; and (3) 0.06. The model was rerun for each of these different n value scenarios. Results are presented for three different flow scenarios: Scenario 1, 3,000 cfs SOD release with no tributary inflows; Scenario 2, 7,000 cfs SOD release with no tributary inflows; and Scenario 6, 7,000 cfs SOD release with 100-year recurrence interval events on the tributaries. These three scenarios were selected for the analysis because they span the range of flow magnitudes assessed in the modeling and will show how the sensitivity of the model to roughness values varies with flow depths.

A graph was created for each variation in n value and flow magnitude scenario that shows the changes in both water surface elevation and mean channel depth. Results for flow Scenario 1 are presented on Figure 57–Figure 59, flow Scenario 2 on Figure 60–Figure 62, and flow Scenario 6 on Figure 63–Figure 65. The results are summarized by model reach in Table 13. The n values used in the sensitivity analysis are all lower than what is in the original model. The lower roughness values mean less channel flow resistance, and therefore lower water surface elevations and mean channel depths compared to the original model. Key results from the analysis include:

- Scenario 1, the lowest flow magnitude analyzed, is most sensitive to n value. Using a n value of 0.03 results in average reductions in water surface elevation of -0.9 foot in the Upper Reach and -0.8 foot in the Middle Reach. Corresponding reductions in mean channel depth are -34% and -45%.
- For Scenario 1, using a n value of 0.06 results in average reductions in water surface elevation of -0.5 foot in the Upper Reach and -0.2 foot in the Middle Reach. Corresponding reductions in mean channel depth are -21% and -11%.
- Higher flow levels and resultant larger channel flow depths mute the effect of variation in n value. For Scenario 3, using a n value of 0.03 results in average reductions in mean channel depth of -26% in the Upper Reach and -27% in the Middle Reach. The values for a n value of 0.06 are reductions in mean channel depth of -17% in the Upper Reach and -8% in the Middle Reach.

As previously mentioned, ICF used the same Manning's n values as the original 1999 model created by Gary Brunner and his team at the Hydraulic Engineering Center, who are the lead developers of

HEC-RAS software. Use of the same n values enabled a better comparison of changes in water surface elevation that are attributed to changed ground elevations between 1998 and 2015 rather than variation in n values. Use of lower n values in the model creates lower water surface elevations and reduced flow depths. This would lead to less flood inundation than is shown in the mapping results presented for this study.

SRH-2D Model

Steady Condition Model

The 2D modeled flow depths and flow velocities for the flow scenario of 7,000 cfs SOD release and no Mill Creek tributary input are shown on Figure 66 and Figure 67, respectively. The 2D modeled flow depths and flow velocities for the flow scenario of 7,000 cfs SOD release and 19,500 cfs Mill Creek tributary input are shown on Figure 68 and Figure 69, respectively. Each map has a layer of "Discharge Calculation XS." These cross-section lines show the total flow conveyed through different parts of the channel in order to see how flow is routed through different channel braids.

No flow is overbanking into the larger breakout area under either flow scenario. For the 7,000 cfs scenario, only 37 cfs is conveyed through the braid channel nearest the breakout area. The upper end of this braid channel is elevated high relative to the main channel, thereby limiting how much flow can enter the channel braid. At the 26,500 cfs scenario, 2,253 cfs is conveyed through the same braid channel with the great majority of the flow (20,295 cfs) conveyed through the main braid to the south.

Also of interest is the flow pattern along Mill Creek. As flow levels increase on Mill Creek, a secondary flood channel to the west of the main channel and along the toe of the levee becomes active. The model shows that 2,446 cfs (13% of the total flow) is conveyed down this channel's upper reach when the total flow in Mill Creek is 19,500 cfs. The same secondary channel has 6,204 cfs when it mixes with SAR flow. The flow from this secondary channel joins the SAR well downstream of where Mill Creek's main channel flow enters, and also downstream of the 1969 breakout location. This has implications for the ability of Mill Creek flow contributions to aid in inundating the breakout area because: (1) not all of Mill Creek's flow is aligned to enter the breakout area, and (2) if the morphology of Mill Creek changes in the future (e.g., channel shift to the west and into the secondary flood channel) and more of Mill Creek's flow is routed down the westerly channel alignment, then even less Mill Creek flow would be available for inundation of the breakout area.

Figure 70 is a close-up, detailed map of the channel near the 1969 breakout area downstream of the Mill Creek confluence. It shows the 2D modeled flood inundation areas for both flow scenarios and 5-foot contours in white based on the 2015 LiDAR. This map also has a yellow "1969 Breakout Profile Alignment" layer. The profile line begins atop the levee on the south bank and extends northwest into the lowest elevation of the 1969 breakout area. Based on examination of the LiDAR and field assessment, this is the lowest elevation and likely first area to be inundated by a flood flow. It provides a flow path connection between the river channel and the broader breakout area on the flood terrace. Figure 71 is a graph showing profiles of ground elevations and modeled water surface elevations for both flow scenarios along the profile line mapped on Figure 70. The graph shows at station 1,300 feet on the profile alignment there is a 5-foot-tall, human constructed, rock plug at the channel inlet that separates the river and the flood terrace breakout area. The rock plug is preventing flow from spreading into the breakout area at the 7,000 cfs flow scenario, and especially at the 26,500 cfs scenario.

Modeled Hydrograph with Infiltration Losses

The modeled inflow and outflow hydrographs are shown on Figure 72. The inflow peak of 5,003 cfs occurs at the 15-hour timestep in the model. It takes 14 minutes for the peak to travel 2.07 miles to the downstream end of the model reach (travel velocity of 12.9 feet per second). The peak flow is reduced to 4,841 cfs at the downstream boundary due to 162 cfs infiltration loss (-3.2%). The model inflow volume of water for the entire hydrograph is 4,491 acre-feet (Figure 72). The outflow volume is reduced to 4,320 acre-feet due to 171 acre-feet infiltration loss (-3.8%). A tabular summary comparison of the model's inflow hydrograph and outflow hydrograph characteristics is presented in Table 14.

The modeled inflow, outflow, infiltration, and surface storage volumes were used to calculate percent error in mass balance as a measure of model error by (Kallio et al. 2015):

$$Percent\ Error = \frac{v_{inflow} - \left(v_{outflow} + v_{infiltration} + v_{surface}\right)}{v_{inflow}} \times 100$$

The result is a calculated -1.3% error in mass balance between flows entering and leaving the model. This low value indicates the unsteady condition model is satisfactorily conserving mass as it accounts for infiltration losses over the course of the hydrograph.

Infiltration rates for each model timestep were calculated as the infiltration volume divided by the corresponding inundated surface area. The rate of infiltration loss varies over the course of the hydrograph (Figure 73). The initial infiltration loss is highest, near 3 inches per hour, on the rising limb of the hydrograph when the rate of change in flow magnitude and wetted inundation area increases rapidly. Water spilling out into previously un-wet areas contributes to relatively high losses. At the peak of the hydrograph the infiltration loss is 1.8 inches per hour. On the falling limb of the hydrograph the rate of infiltration loss decays because sustained wetting and saturation of the inundated area's substrate causes infiltration to approach its capacity rate (Figure 73). At the end of the hydrograph (33 hour timestep at 50 cfs) the infiltration rate reaches the average saturated hydraulic conductivity (*Ksat*) for the site (0.97 inch per hour). This trend of reduced infiltration loss rates is evident in comparison of the inflow and outflow hydrographs (Figure 72). The differences in flow between the inflow and outflow are greater on the rising limb than on the falling limb.

Comparison with Measured Infiltration Losses

Scheevel Engineering (2016) reported infiltration rates for Mill Creek recharge basins with an initial rate of 3.4 feet per day decaying to 1.4 feet per day. Geoscience reviewed historic measured rates in the region and conducted new infiltrometer testing and reported infiltration rates at eight locations on upper SAR tributaries ranging from 3.0 feet per day to 7.0 feet per day (Geoscience 2012:23). The modeled infiltration rates (Figure 73) using the Green-Ampt method for this study reach a high of 6.0 feet per day and decay to 2.0 feet per day when infiltration potential equals *Ksat*. The results are in agreement with the reported rates used for other hydrological studies in the study area vicinity.

Comparison with Measured Streamflow Losses

Comparison of the 15-minute USGS gaging records of SAR flows provides another means to evaluate flow losses that occurred during dam test releases. Combined gages 11051499 and 11051502 measure flows released at the dam (see schematic on Figure 74 [SBVMWD 2004]). Note that the

11051499 gage is located upstream of the Cuttle Weir and the Conservation District Canal that diverts water to the spreading grounds and elsewhere. The USGS E Street gage (11059300) on the SAR is 13.2 miles downstream of the dam (just downstream of the Lytle Creek Channel).

March 9, 2005 Flood

The hydrographs for the two locations during the March 9, 2005, release are shown on Figure 75. Mean daily precipitation records from three regional gages are also graphed for the same period to show if runoff from precipitation could have contributed to the SAR flow measured at the E Street gage. No precipitation occurred for 5 days prior to or during this test release. Several tributaries enter the SAR between the gages. Streamflow gage records show tributary flows on March 9 of estimated 45 cfs on Plunge Creek, 57 cfs on City Creek, and estimated 7 cfs on Lytle Creek at Colton. The flows had been decreasing for several days prior to March 9 on the tributaries and continued to decrease after March 9, indicating that storm runoff from the tributaries was not an appreciable contributing factor to the peak flow measured at the E Street gage. The lack of precipitation and trends in the tributary gage records indicate that the differences in streamflow between SOD and the E Street gage can be attributed largely to infiltration losses and possible diversions into the Cuttle Weir.

A tabular summary comparison of the SOD and E Street Gage hydrograph characteristics is presented in Table 14. The peak flow of 4,179 cfs at the dam traveled downstream at an average velocity of 10.3 feet per second and was reduced by 2,559 cfs (-61%) to a peak of 1,620 cfs at the E Street gage. The peak flow rate of loss was 194 cfs per mile. The flood volume of 678 acre-feet at the dam was reduced by 384 acre-feet (-57%) to a volume of 294 acre-feet at the E Street gage. Unlike the hydrograph just downstream of the dam, the shape of the flood hydrograph at the E Street gage does not have a well-defined peak followed by a progressively decreasing falling limb (Figure 75). The reason for the plateauing of peak flow, including a sharp decrease before peaking again, is not certain. Possible reasons include instrumentation error at the gage's stage recorder, or flood water diversions were made at the Cuttle Weir that decreased the flow downstream. It is notable that the USGS 15-minute interval data changes to 8 minutes for one interval at the peak then resumes to 15 minutes. If the actual peak was higher than what the E Street gage records indicate, then the infiltration losses would be less than calculated.

February 15 and March 1, 2011 Floods

Two separate SOD releases were made in the winter of 2011, the first on February 15 and another on March 1, 2011 (Figure 76). For the first event, releases from the dam started ramping up from 3 cfs on February 1, 2011. Streamflow measured at SOD progressively increased for 2 weeks and reached 563 cfs by 7:00 a.m. on February 15. At this time release rates increased substantially until reaching a peak of 4,648 cfs at 1:45 p.m. on the same day (see Figure 77 for detail of this event). No precipitation occurred for 2 weeks covering the period from the beginning of the release on February 1 to the peak on February 15. The mean daily precipitation hyetograph does show up to 0.5 inch of rain occurred after the peak on February 16. A review of hourly precipitation records at the University of California, Riverside gage shows the first traces of precipitation did not begin until 4:00 a.m. on February 16, also after the peak and the recession of the falling limb.

Streamflow gage records show tributary flows on February 15 of 10 cfs on Plunge Creek, 15 cfs on City Creek, and 0 cfs on Lytle Creek at Colton. The flows had been fairly stable at these levels for several days prior to February 15, indicating that storm runoff from the tributaries was not an appreciable contributing factor to the peak flow measured at the E Street gage. The lack of precipitation and trends in the tributary gage records indicate that the differences in streamflow between SOD and the E Street gage can be attributed largely to infiltration losses and possible diversions into the spreading grounds.

Although precipitation and tributary runoff do not appear to have influenced the February 15 release, they do appear to have influenced the March 1 release (Figure 76). At the Plunge Creek Canyon gage, 2.4 inches of rain were measured for the period February 16–27. The streamflow gage records show a response to this rainfall. By February 26, tributary flows increased up to 90 cfs on Plunge Creek, estimated 100 cfs on City Creek, and estimated 78 cfs on Lytle Creek at Colton. The flows on Plunge Creek and City Creek decreased to 36 cfs and 46 cfs, respectively, by March 1. Unlike the previous two dam releases on March 9, 2005, and February 15, 2011, the measured streamflow at the E Street gage (6,470 cfs) was higher than at the dam (5,003 cfs) for the March 1 event. Because the streamflow measured at the E Street gage during the March 1 dam release was likely influenced by tributary runoff, this event is not used in the infiltration analysis nor discussed further.

A tabular summary comparison of the SOD and E Street Gage hydrograph characteristics for the February 15, 2011, event is presented in Table 14. The peak flow of 4,648 cfs at the dam traveled downstream at an average velocity of 11.1 feet per second and was reduced by 608 cfs (-13%) to a peak of 4,040 cfs at the E Street gage. The peak flow rate of loss was 46 cfs per mile. The flood volume[2] of 2,923 acre-feet at the dam was reduced by 1,060 acre-feet (-36%) to a volume of 1,863 acre-feet at the E Street gage.

Compare 1D and 2D Model Results

The flood inundation mapping results from the 1D HEC-RAS and 2D SRH-2D hydraulic models are compared for two flow scenarios.

1. 7,000 cfs SOD release with no tributary input from Mill Creek (Figure 78)

The 1D and 2D flooding extents generally match fairly well. The best match occurs where the flow is confined to areas with simpler channel planform (fewer channel braids). Not unexpectedly, the 1D model does a poorer job of distributing flow through locations of split channel flow. The 2D model shows a small amount of flow (37 cfs) in the channel braid nearest the 1969 breakout area whereas the 1D model does not have flow in this area. The differences between the models are limited to inundation extent within the active channel. It is not the case that one model predicts overbanking onto the floodplain terrace and the other model does not.

2. 7,000 cfs SOD release with 19,500 cfs tributary input from Mill Creek (Figure 79)

Comparative results for this flow scenario are similar to the first scenario. Note that 1D flood inundation mapping was not performed along Mill Creek. The channel braids predicted to have flow are the same between both models, but the flooding extent within the channel braids varies. Neither model predicts appreciable overbanking onto the floodplain terrace.

[2] Flood volumes were calculated for the portion of the flood hydrographs between the inflection points on the rising and falling limbs. For the February 15, 2011, flood, the 2-week ramp-up from 3 cfs to 563 cfs on the Seven Oaks Dam hydrograph was excluded from the volume calculation. Similarly, for the E Street gage, the volume calculation began at the abrupt increase in flow on the rising limb at 500 cfs.

In conclusion, the 2D model provides enhanced detail of flow patterns in the complex flow environment. The differences between the models are small enough to validate the approach of this study to use the 1D model as the model that covers the entire study area reach and provides an initial coarse assessment of flood inundation extents. The initial 1D model results are then used to aid in identifying sub-reaches that would benefit from more finely detailed 2D modeling.

Discussion

1D scenarios demonstrate the likely extents of inundation under a range of flow contributions. The 3,000 and 7,000 cfs flows from SOD with no contributions from tributaries are the most likely scenarios, given the constraints of the WCM. 1D model results from these indicate some small fraction of total species records are inundated. This gives some indication as to the degree to which high flows from SOD have the potential to affect the species of interest and their habitats. The majority of species points remain outside the extent of inundation for these scenarios, and it is likely that ecologically significant flows cannot be produced by SOD in isolation.

At 7,000 cfs, SOD contributes some small fraction of total flows for simulations modeling tributary contributions. However, the total fraction of species records inundated remains low until 100-year event contributions from tributaries are considered. For the 100-year event scenario (#6), SOD's contribution is estimated to be one-third that of Mill Creek (7,000 versus 21,000 cfs). An event of this nature would likely have meaningful effects on the species even without SOD contribution.

Infiltration Losses

Analysis of modeled and measured infiltration losses was performed to better understand infiltration losses that may occur in the upper SAR from future SOD releases. The modeled infiltration capacity rates of 2–6 feet per day using the Green-Ampt method (Figure 73) compare well with reported values of 3–7 feet per day (Scheevel Engineering 2016; Geoscience 2012). The modeled reductions in both peak flow and total flood volume also compare fairly well with the USGS gage measurements from the February 15, 2011, flood (Table 14). The modeled peak flow loss rate (78 cfs per mile of channel) and measured February 15 peak flow loss rate (45 cfs per mile) are within 52% of each other. The modeled total flood volume loss rate (83 acre-feet per mile of channel) and measured February 15 peak flow loss (80 acre-feet per mile of channel) are within 4% of each other. The modeled results compare less favorably with the measured March 9, 2005, flood hydrographs. As previously mentioned, the shape of the March 9 flood hydrograph at the E Street gage does not have a well-defined peak (Figure 75). In 15 minutes the reported streamflow decreased from 1,320 cfs to 862 cfs, then increased up to 1,620 cfs 15 minutes later. Because of the uncertainty with this flood's E Street gaging record, the February 15, 2011, dam release is considered better for comparing with the modeled results.

Estimates for both peak flow losses and total flood volume losses for nine locations downstream of SOD are listed in Table 15. The hypothetical 5,000 cfs flood release is the same as modeled and shown on Figure 72. For the estimates of peak flow loss, two scenarios are given: (1) Scenario 1a uses the Green-Ampt modeled peak flow loss rate of 78 cfs per mile of channel, and (2) Scenario 1b uses the peak flow loss rate of 46 cfs per mile based on analysis of the USGS gage measurements. For the total flood volume losses, only one loss rate scenario is used because the modeled and measured rates are so similar. By the time a 5,000 cfs flood release reaches the Mill Creek confluence, between

2% to 4% of the peak flow and 4% of the total flood volume have been lost to infiltration. At State Route 210, 7% to 11% of the peak flow and 13% of the total flood volume have been lost. At the final location assessed, the E Street gage 13.7 miles downstream of the dam, infiltration causes between 13% to 21% of the peak flow and 25% of the total flood volume to be lost.

Summary

- Flood extents, particularly those extents simulating releases from SOD with 100-year contributions from tributaries (Scenario 6), ultimately still inundate less than 25% of species records in the study area.
- Maximum releases from SOD without tributary contributions can still inundate some amount of woollystar (16%) and SBKR (15%), but not spineflower (1%). Spineflower distributions are restricted, density is low, and getting flow to these populations will be challenging.
- The 1969 breakout area stands out as the most likely place for drainage manipulation to produce overbank flows outside the main channel of the SAR.
- The infiltration loss analysis performed for this study shows that appreciable infiltration losses will occur depending upon antecedent soil saturation conditions, the magnitude and duration of flood flows, and the distance of a location downstream from SOD. Infiltration losses should be accounted for when planning for future SOD releases.

Chapter 7
High-Flow Study Synopsis and General Discussion

This progress report is a summary of work completed to date (February 2019) under the objectives of the High-Flow Study. The overall objective of the High-Flow Study is to evaluate the feasibility of high-flow releases from SOD for the purpose of achieving the mitigation outcomes identified in the 2000 BA/2002 BO and 2012 MSHMP.

Establishment of the Science Advisory Committee

A science advisory committee was appointed to review objectives, methods, and results from investigations, and provide guidance on future work. Advisory feedback and investigator responses received through October 15, 2018, are compiled in Appendix 1, *Science Advisor Feedback and Response Logs*.

Distribution of Habitat Relative to Hydrologic Disturbance Regimes

The known distributions of the species of interest were compiled and contrasted with existing information about RAFSS seral stage and relative geomorphology (height above and distance from thalweg).

- Seral stage elevation profiles and species distributions reported here broadly support the scientific consensus that appropriate habitat is linked to past flood disturbance, with younger seral stages generally correlated with locations of the majority of species occurrence records.
- Elevation profiles for surfaces within the study area indicate that locations with optimal habitat conditions and greater numbers of species observations coincide with lower elevations and greater floodability (lower height above thalweg) in comparison with less optimal habitat.
- Pioneer, intermediate, and intermediate/mature seral stage surfaces have more favorable elevation profiles for purposeful flooding in comparison with mature and mature/NNG surfaces. Mature and mature/NNG surfaces present the greatest opportunity for avoiding or reducing impacts on populations of the species of interest when introducing flood disturbance, but have elevation profiles or spatial distributions within the study area that make delivery of environmental flows from SOD difficult or impossible.

Analysis of Morphological Changes to the Alluvial Fan

Changes in channel morphology from 1964 to 2015 were assessed using historical topographic maps and modern LiDAR surveys. This included assessment of changes in the SAR channel thalweg height through the period of record.

- The 1969 flood events resulted in significant erosional changes in the channel thalweg profile of the SAR within the study area.
- Flood-driven changes have resulted in a channel morphology in the river profile downstream of the Orange Street Bridge that may impede future efforts to produce overbank flows for habitat renewal purposes.
- The thalweg elevation trend between 1998 and 2015 is net sediment deposition in the study area. Construction of grade control structures for the Mentone Pipeline crossing and SARC Pipeline have increased bed elevations that may increase opportunities for flooding and habitat renewal.

Constraints Analysis of Historic Operations of Seven Oaks Dam

Historic operations of SOD for the period of record were reviewed. This included review of WCM operating guidelines and examination of past high-flow releases from the dam.

- There appears to be additional capacity within the WCM guidelines to create or contribute to high-flow events up to approximately 5,000 cfs within the study area based on the record of releases.
- Flow contributions from SOD are likely to be limited to 5,000 cfs or less, based on the period of record and in spite of the dam's rated outflow capacity of 7,000 cfs. This assumes similar inflow and climatic conditions in the future as those observed for the period of record and may not match future contributions based on long-term climate projections for the region.
- There may be other operational constraints in addition to the WCM (e.g. inter-agency agreements regarding flood releases, public safety, infrastructure risks) that ICF is unaware of that may ultimately limit releases. ICF does not currently have any documentation of such constraints.
- The most restrictive limit on instigating or contributing to ecologically meaningful flow events from SOD is the rising condition limit to 50 cfs, which effectively prevents timing releases with high-flow contributions from tributaries.
- Mill Creek will continue to contribute substantial flood flows to the SAR. However, SOD has not been making high-flow releases that contribute to Mill Creek flows in a manner predicted by USACE (2000b).

Determine Fluvial Disturbance Extents in the Study Area

The extent of overbank effects from releases from SOD was evaluated under the current WCM guidance, and in combination with high flows from tributaries (i.e., Mill, City, and Plunge creeks). This includes summaries of the degree to which modeled flood extents overlap species distributions.

- Flood extents, particularly those extents simulating releases from SOD with 100-year contributions from tributaries (Scenario 6), ultimately still inundate less than 25% of species records in the study area.

- Maximum releases from SOD without tributary contributions can still inundate some portion of woollystar (16%) and SBKR (15%) habitat areas, but not spineflower (1%) habitat areas. Spineflower distributions are restricted, density is low, and getting flow to these populations will be challenging.
- The 1969 breakout area stands out as the most likely to produce overbank flows outside the main channel of the SAR using drainage manipulation.

Discussion

The inundation limits for all scenarios without additional drainage manipulation are restricted to the main channel, and no overbank flows or breakout events into historic breakout areas on the flood terrace are predicted. Without breaching of berms that isolate low-lying floodplain areas from the active channel, and within existing WCM guidance, high flows emanating from SOD are unlikely to produce flood disturbance on a scale large enough to alter successional trends within the study area and therefor satisfy the requirements of the BA/BO and MSHMP. 1D and 2D flood simulations indicate that releases from SOD in isolation will have reduced inundation areas compared with scenarios that include contributions from tributaries. This highlights the effect of the WCM guidance, which prevents synchronized release with peak tributary flows, thus constraining the ecological usefulness of high-volume discharges from the dam.

Modeled flooding of the study area would disturb pioneer and intermediate seral stages almost exclusively. Mature and mature/NNG surfaces are the most beneficial areas for introducing disturbance intended to return the surface to earlier seral stages. This is because existing habitat within these surfaces is less optimal for the species of interest, and species observations within these areas are low or absent. Without human manipulation of the land surface, in particular artificial berms constructed to confine flood flows, mature and mature/NNG surfaces cannot be flooded.

Flooding of mature surfaces would likely result in impacts on populations of the species of interest through incidental flooding of surrounding lower-elevation habitats, particularly in downstream reaches. This has broad implications for any future proposals to flood the study area for purposes of habitat renewal because of the likelihood of short-term impacts on populations of the species of interest associated with flood disturbance (however, note that short-term impacts are expected to be offset by long-term benefits to these species).

Phase 2 of the High-Flow Study

Input and feedback on the information presented in this document will be used to develop a work plan for the next steps and Phase 2 of this study. Next steps may include impact analysis of proposed flood and non-flood disturbance alternatives to regenerate habitat for the species of interest in the study area.

Alternative Measures for Consideration to Enhance Habitat Creation and Maintenance

- **Hydrology** – Explore changes in operation of the dam, particularly the feasibility of combining high-flow releases from SOD with natural high flows from tributary flows, primarily Mill Creek. Evaluate alternative flow release regimes (not included in the current SOD WCM) that could be effective in providing overbank flow in the WSPA. This would require entering into discussions with USACE and Orange County Flood Control District representatives to determine the likelihood of a change in operation as well as exploration of other constraints not detailed in the WCM.

- **Structural** – Present key locations where structures (e.g., channel obstructions) and/or pilot channels could be constructed to force a portion of the flood flow out onto floodplain/terrace areas, possibly into remnant channels. The assessment would evaluate the need for diversion dikes or other structures required to achieve objectives. Evaluate the extent of overbank effects from releases under the current SOD WCM with implementation of diversion dikes within the WSPA as described in the BA.

- **1969 Breakout Area** – Evaluate the feasibility of removing the rock plug constructed at the inlet of the 1969 breakout channel that separates the breakout channel from the active SAR. Determine how much flow could be routed into the breakout channel and the fate of the flow as it travels downstream.

- **Modeling** – Demonstrate that enhancement measures would perform as described through use of 2D modeling. ICF has conducted initial sediment transport work that would be expanded upon and presented as part of the next phase. The work would include incipient motion analysis to model the particle sizes predicted to be mobilized for a given flood magnitude; analysis of particle size and sediment concentration variation in the water column; and evaluation of sediment supply from the SAR and Mill Creek. The extent and location of 2D modeling will be expanded to include additional reaches based on stakeholder feedback.

- Evaluate physical manipulation and mechanical disturbance of the floodplain to mimic flood disturbance. Using habitat parameters taken from the San Diego Zoo habitat model for SBKR, ICF would estimate the types and extents of disturbance needed to promote regeneration of younger seral stages of RAFSS habitat.

- Prioritize the species of interest and set up framework for evaluation of different disturbance regimes. This would include entering into discussions with USFWS to receive guidance on priority setting, estimation of take due to short-term impacts on populations of listed species, and feasibility of alternative disturbance regimes.

Chapter 8
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Chapter 9
Tables

Table 1. Compilation of Ecologically Significant Flow Events with Estimated Flow Values Based on Literature Sources

Flood Event Date	Historic Aerial Imagery Date	Historic Topographic Date	USACE (2000a) Reported Peak Flow Downstream of Mill Creek (cfs) [1]	Burk et al. (2007) Reported Peak Flow (cfs) [2]	USGS SAR Mentone Gage Peak Flow (cfs)	USGS Mill Creek Yucaipa Gage Peak Flow (cfs)
1/22/1862	--	--	96,700	320,000	--	--
2/23/1891	--	--	58,100	100,000	53,700	--
1/27/1916	--	--	31,500	--	29,100	--
2/16/1927	--	--	25,700	--	24,000	4,500
	1930–1937[4]	--	N/A	--	--	--
3/2/1938	--	--	58,600	100,000	52,300	18,100
	1952–1959[4]	--	N/A	--	--	--
	--	1964[3]	N/A	--	--	--
11/22/1965	--	--	12,900	--	8,000	10,000
12/6/1966	--	--	18,500	--	15,300	10,000
	1968[4]	--	N/A	--	--	--
1/25/1969	--	--	25,700	32,460	15,300	20,000
2/25/1969	--	--	12,000	40,495	--	--

[1] USACE 2000a
[2] Burk et al. 2007 *reports different discharges for events listed in the 2000 BA but does not detail whether Mill Creek contributions are included.
[3] SBVWCD Archive
[4] University of California, Santa Barbara Library Historic Aerial Photography Archive 2018
-- No gage record available
Also included are time periods for historic aerial and topographic data in relation to flood events.

Table 2. Seral Stage Surface Areas within the Study Area

Seral Stage	Surface Area (sq. ft.)	Surface Area (sq. mi.)	Proportion
Pioneer	20,510,791	0.74	15%
Intermediate	49,209,745	1.77	35%
Intermediate/Mature	46,075,731	1.65	33%
Mature	18,669,149	0.67	13%
Mature/NNG	4,757,774	0.17	3%
Total	139,223,192	4.99	100%

Table 3. USGS Reported Annual Peak Streamflow for the Santa Ana River near Mentone and Mill Creek near Yucaipa

Water Year	USGS 11051500 Santa Ana River near Mentone			USGS 11054000 Mill Creek near Yucaipa			SAR Peak Date minus Mill Creek Peak Date (days)
	Date	cfs	Qualifier	Date	cfs	Qualifier	
1891	2/23/1891	53,700	2,7	--	--	--	--
1897	2/18/1897	620	1	--	--	--	--
1898	10/14/1897	250	1	--	--	--	--
1899	3/20/1899	73	1	--	--	--	--
1900	5/6/1900	225	1,2	--	--	--	--
1901	11/21/1900	1,564	1,2	--	--	--	--
1902	3/2/1902	485	1	--	--	--	--
1903	4/1/1903	4,910	1	--	--	--	--
1904	3/23/1904	280	1	--	--	--	--
1905	3/13/1905	321	1	--	--	--	--
1906	3/12/1906	2,400	1	--	--	--	--
1907	3/21/1907	1,900	1	--	--	--	--
1908	2/4/1908	240	1	--	--	--	--
1909	1/22/1909	1,335	1	--	--	--	--
1910	1/1/1910	8,500	1,2	--	--	--	--
1911	3/10/1911	1,840	1	--	--	--	--
1912	3/6/1912	280	1	--	--	--	--

Water Year	USGS 11051500 Santa Ana River near Mentone			USGS 11054000 Mill Creek near Yucaipa			SAR Peak Date minus Mill Creek Peak Date (days)
	Date	cfs	Qualifier	Date	cfs	Qualifier	
1913	7/18/1913	89	1	--	--	--	--
1914	2/21/1914	2,190	1	--	--	--	--
1915	2/10/1915	870	1	--	--	--	--
1916	1/27/1916	29,100	5	--	--	--	--
1917	2/25/1917	164	5	--	--	--	--
1918	3/7/1918	3,780	5	--	--	--	--
1919	9/29/1919	145	5	--	--	--	--
1920	2/22/1920	2,700	5	2/22/1920	650	5	0
1921	3/14/1921	1,100	5	3/14/1921	280	5	0
1922	12/20/1921	3,600	5	12/20/1921	896	5	0
1923	12/13/1922	1,800	5	12/13/1922	440	5	0
1924	3/27/1924	194	5	--	--	--	--
1925	7/23/1925	67	5	12/16/1924	3	2,5	219
1926	4/6/1926	1,850	5	4/5/1926	900	5	1
1927	2/16/1927	24,000	2,5	2/16/1927	4,500	2,5	0
1928	2/4/1928	354	5	2/4/1928	105	5	0
1929	4/4/1929	520	5	--	--	--	--
1930	5/3/1930		5	5/13/1930	55	5	-10
1931	8/29/1931	1,500	5	7/27/1931			
1932	2/9/1932	1,740	1,5	2/9/1932	400	5	0
1933	1/29/1933	73	5	1/29/1933	12	5	0
1934	12/31/1933	1,880	5	1/1/1934	328	5	-1
1935	4/8/1935	780	5	8/23/1935	246	5	-137
1936	2/11/1936	820	5	2/11/1936	620	5	0
1937	2/6/1937	8,000	5	2/6/1937	23,90	2,5	0
1938	3/2/1938	52,300	5	3/2/1938	18,100	2,5	0
1939	9/25/1939	772	5	--	--	--	--
1940	1/8/1940	1,390	5	--	--	--	--
1941	12/24/1940	3,080	5	--	--	--	--

Water Year	USGS 11051500 Santa Ana River near Mentone			USGS 11054000 Mill Creek near Yucaipa			SAR Peak Date minus Mill Creek Peak Date (days)
	Date	cfs	Qualifier	Date	cfs	Qualifier	
1942	4/4/1942	134	5	--	--	--	--
1943	1/23/1943	5,200	5	--	--	--	--
1944	2/22/1944	890	5	--	--	--	--
1945	2/2/1945	2,500	5	--	--	--	--
1946	12/23/1945	4,000	5	--	--	--	--
1947	11/23/1946	1,450	5	--	--	--	--
1948	4/3/1948	157	5	2/5/1948	4.5	5	58
1949	1/20/1949	108	5	4/19/1949	14	1	-89
1950	2/7/1950	350	5	2/6/1950	170	5	1
1951	5/14/1951	38	5	4/29/1951	46	5	15
1952	12/30/1951	1,020	5	12/30/1951	738	5	0
1953	1/7/1953	244	5	4/27/1953	178	5	-110
1954	1/25/1954	2,050	5	6/25/1954	410	5	-151
1955	11/11/1954	278	5	11/11/1954	139	5	0
1956	1/26/1956	1,200	5	1/27/1956	193	5	-1
1957	1/13/1957	1,710	5	1/13/1957	256	5	0
1958	4/3/1958	2,170	5	7/29/1958	990	5	-117
1959	2/16/1959	652	5	2/16/1959	415	5	0
1960	4/27/1960	82	5	7/22/1960	167	5	-86
1961	11/6/1960	41	5	8/23/1961	1,060	2,5	-290
1962	2/11/1962	848	5	12/2/1961	208	5	71
1963	2/10/1963	880	5	9/18/1963	150	5	-220
1964	4/2/1964	92	5	10/18/1963	135	5	167
1965	4/9/1965	688	5	8/14/1965	235	5	-127
1966	11/22/1965	8,000	5	11/22/1965	10,000	2,5	0
1967	12/6/1966	15,300	5	12/6/1966	10,000	2,5	0
1968	3/8/1968	288	5	11/19/1967	324	5	110
1969	1/25/1969	15,300	5	1/25/1969	20,000	2,5	0
1970	2/28/1970	1,380	5	3/1/1970	136	5	-1

Water Year	USGS 11051500 Santa Ana River near Mentone			USGS 11054000 Mill Creek near Yucaipa			SAR Peak Date minus Mill Creek Peak Date (days)
	Date	cfs	Qualifier	Date	cfs	Qualifier	
1971	11/29/1970	6,600	5	11/29/1970	1,200	2,5	0
1972	12/24/1971	1,970	5	6/6/1972	266	5	-165
1973	2/11/1973	778	5	2/11/1973	92	5	0
1974	1/8/1974	208	5	7/19/1974	140	5	-192
1975	12/4/1974	453	5	3/8/1975	120	5	-94
1976	9/11/1976	1,380	5	9/11/1976	--	--	--
1977	5/8/1977	504	5	1/3/1977	111	5	125
1978	2/10/1978	2,170	5	2/10/1978	5,400	2,5	0
1979	3/27/1979	1,680	5	8/6/1979	290	5	-132
1980	2/21/1980	5,930	5	1/29/1980	5,540	2,5	23
1981	1/29/1981	230	5	1/29/1981	111	5	0
1982	3/17/1982	2,300	5	3/17/1982	238	5	0
1983	2/27/1983	3,280	5	11/30/1982	587	5	89
1984	12/25/1983	947	5	12/25/1983	564	5	0
1985	12/19/1984	1,190	5	7/19/1985	741	5	-212
1986	2/15/1986	1,320	5	2/15/1986	715	5	0
1987	11/18/1986	168	5	--	--	--	--
1988	1/17/1988	148	5	--	--	--	--
1989	2/4/1989	350	5	--	--	--	--
1990	2/17/1990	142	5	--	--	--	--
1991	3/1/1991	810	5	--	--	--	--
1992	2/12/1992	1,040	5	--	--	--	--
1993	1/7/1993	7,010	5	--	--	--	--
1994	2/8/1994	439	5	--	--	--	--
1995	3/5/1995	9,000	5	--	--	--	--
1996	2/21/1996	1,350	5	--	--	--	--
1997	1/26/1997	1,870	5	--	--	--	--
1998	2/24/1998	3,010	5	--	--	--	--
1999	2/18/1999	149	6	--	--	--	--

Water Year	USGS 11051500 Santa Ana River near Mentone			USGS 11054000 Mill Creek near Yucaipa			SAR Peak Date minus Mill Creek Peak Date (days)
	Date	cfs	Qualifier	Date	cfs	Qualifier	
2000	2/21/2000	246	6	--	--	--	--
2001	2/5/2001	49	6	--	--	--	--
2002	11/7/2001	16	6	--	--	--	--
2003	3/20/2003	612	6	--	--	--	--
2004	3/31/2004	73	5	--	--	--	--
2005	3/9/2005	2,960	6	--	--	--	--
2006	3/8/2006	639	6	--	--	--	--
2007	4/25/2007	335	6	--	--	--	--
2008	3/27/2008	426	6	--	--	--	--
2009	5/18/2009	65	6	--	--	--	--
2010	7/15/2010	3,160	6	--	--	--	--
2011	3/1/2011	5,000	6	--	--	--	--
2012	4/18/2012	156	1,6	--	--	--	--
2013	6/2/2013	104	6	--	--	--	--
2014	4/15/2014	148	6	--	--	--	--
2015	4/16/2015	171	6	--	--	--	--
2016	4/24/2016	98	1,6	--	--	--	--
2017	1/17/2017	247	6	--	--	--	--

USGS Qualification Codes
1 Discharge is a Maximum Daily Average
2 Discharge is an Estimate
5 Discharge affected to unknown degree by Regulation or Diversion
6 Discharge affected by Regulation or Diversion
7 Discharge is an Historic Peak

Table 4. Annual Peak Flow Frequency Analysis of the Santa Ana River near Mentone and Mill Creek near Yucaipa USGS Gages

Water Years	No. Years Used in Analysis	Source	Method	Recurrence Interval in Years									
				1.25	1.5	2	2.33	5	10	20	25	50	100
USGS 11051500 Santa Ana River near Mentone													
Pre-Seven Oaks Dam Regulation													
Pre-1975[1]	77	USACE 1988b; 2003	Median Plotting Position	--	--	1,100	--	4,300	8,800	17,000	20,500	34,000	58,000
1897–1998	101	ICF	Bulletin 17B	263	480	910	1,190	3,280	6,510	11,500	13,700	22,300	34,700
Post-Seven Oaks Dam Regulation													
--	--	USACE 1988b; 2003	Modeled Estimate	--	--	400	--	500	500	2,500	2,900	3,800	5,000
1999–2017[2]	19	ICF	Bulletin 17B	70.3	124	231	301	847	1,750	3,260	--	--	--
USGS 11054000 Mill Creek near Yucaipa													
1920–1938; 1948–1986	67	USACE 1988b	Bulletin 17B	31	--	200	--	1,210	3,080	6,000	6,640	15,800	28,100
1920–1938; 1948–1986	54	ICF	Bulletin 17B	76	159	346	478	1,590	3,510	6,796	8,220	14,200	23,300
1948–1986	38	ICF	Bulletin 17B	82	157	320	434	1,390	3,140	6,320	7,680	14,000	24,200

[1] Per pg. V-1 in USACE 1988b: "The discharge-frequency relationships for Seven Oaks Dam (pl. 7-22) were derived from data collected at the stream gauge "Santa Ana River near Mentone", which is located about 1 mile downstream of the dam site. No changes were made to the 1975 Review Report discharge-frequency curve which was presented without the expected probability adjustment."

[2] Flood frequency curve not extrapolated beyond the period of record since peak flows restricted by maximum dam release. Flood frequency affected by four SOD test flow releases of magnitudes higher than what would have been released otherwise based on the USACE WCM (2003).

Table 5. U.S. Army Corps of Engineers Annual Peak Flow Frequency Analysis of the Santa Ana River Downstream of Mill Creek

	Recurrence Interval in Years					
Method	**2**	**5**	**10**	**25**	**50**	**100**
Pre-Seven Oaks Dam Regulation						
Curve Fitting[1,2]	1,400	5,600	11,700	22,000	45,000	75,000
Post-Seven Oaks Dam Regulation						
Curve Fitting[1,2]	760	2,050	4,300	8,000	15,500	25,000

[1] Per pg. V-9 in USACE 1988b: "The present and future, 'without project' discharge-frequency curves for points downstream of City Creek and Mill Creek (pls. 7-50, 7-51, 7-52, and 7-53, respectively) were derived by adjusting the Santa Ana River near Mentone discharge-frequency curves for each location. The Santa Ana River near Mentone curves were used in lieu of the Mill Creek curve since the peak discharges for the locations downstream of City Creek and Mill Creek are a direct result of runoff from the upper Santa Ana River watershed. Hence, the discharge-frequency curves for locations downstream of City Creek and Mill Creek adopt the same general curve slope as the Santa Ana River near Mentone curves (pl. 7-22). SPF peak discharges for each location were computed using the Santa Ana River basin model. The resulting SPF discharges of 115,000 and 112,000 ft3 /s, for downstream of City Creek and Mill Creek, respectively, were plotted at the 180-year frequency, identical to the frequency of SPF at the Mentone gauge site. Using the SPF as anchor points, curves were drawn for each location parallel to the Mentone gauge curves. Present and future, 'without project,' discharge frequency curves for these two locations are determined to be unchanged since increases in urbanization will be negligible."

[2] Per pg. 22 in USACE 2000b: "Discharges determined by adding the n-year peak outflow from SOD to the contemporaneous n-year discharges for Mill Creek. These values were plotted and a smooth curve was fit through the data."

Table 6. Annual Peak Flow Frequency Analysis of the Santa Ana River Downstream of Mill Creek for Seven Oaks Dam Release Scenarios

	Recurrence Interval in Years[1]								
Seven Oaks Dam Release	**1.25**	**1.5**	**2**	**2.33**	**5**	**10**	**25**	**50**	**100**
3,000	3,082	3,157	3,320	3,434	4,390	6,140	10,680	17,000	27,200
5,000	5,082	5,157	5,320	5,434	6,390	8,140	12,680	19,000	29,200
7,000	7,082	7,157	7,320	7,434	8,390	10,140	14,680	21,000	31,200

[1] Values determined by summing the SOD release with the n-year flood recurrences determined with Bulletin 17B analysis for water years 1948–1986 at the Mill Creek near Yucaipa gage 11054000.

Table 7. Analysis of Seven Oaks Dam Release Flows in Relation to Tributary Flood Events

		January 2005 Event			December 2010 Event		
Location	**Drainage Area (mi²)**	**Peak Flow (cfs)**	**Date of Peak Flow**	**Recurrence Interval (years)**	**Peak Flow (cfs)**	**Date of Peak Flow**	**Recurrence Interval (years)**
Santa Ana River near E Street (11059300)	541	35,700	1/11/2005	59	27,800	12/22/2010	30
Gaged Inputs to Santa Ana River E Street Gage							
City Creek (11055800)	19.6	9,900	1/10/2005	83	7,250	12/22/2010	50
Plunge Creek (11055500)	16.9	3,920	1/10/2005	30	5,740	12/22/2010	63
San Timoteo Creek (11057500)	125	3,950	1/9/2005	26	4,150	12/22/2010	28
East Twin Creek (11058500)	8.8	>600[1]	1/9/2005	--	2,120	12/22/2010	28
Seven Oaks Dam Release[2]	210	670	1/9/2005	14[3]	50.1	12/22/2010	<1
Total for Gaged Inputs	*380.3*	*19,040*	--	--	*19,310*	--	--
Difference Between SAR E St. and Total Inputs	**160.7**	**16,660**			**8,490**		
Estimated Mill Creek Flow							
Lower Estimate	42.4	8,200	1/9/2005 or 1/10/2005	26	8,300	12/22/2010	28
Upper Estimate	42.4	20,000	1/9/2005 or 1/10/2005	83	16,000	12/22/2010	63

[1] The 2005 water year peak flow occurred on 10/20/2004. No 15-minute data available online for January 2005. Mean daily flow reached maximum of 600 cfs on 1/9/2005.

[2] Combined 15-minute records of USGS gages 11051499 and 11051502 represent SOD release.

[3] Per SOD outflow frequency curve in Plate 8-03 in USACE 2003.

Table 8. Bulletin 17B Flood Recurrence Values for Regional Gages in the Study Area

Period of Record	Station Name	Drainage Area (sq. mi.)	Recurrence Interval in Years 1.25	1.5	2	2.33	5	10	25	50	100
1972–2017	Cajon Creek below Lone Pine Creek near Keenbrook	56.5	186	377	768	1,020	2,840	5,390	10,400	15,500	22,100
1948–1986	Mill Creek near Yucaipa	42.4	825	157	320	434	1,390	3,140	7,680	14,000	24,200
1920–2017	City Creek near Highland	19.6	132	227	403	514	1,280	2,390	4,690	7,310	10,900
1920–2017	Devil Canyon Creek near San Bernardino	5.49	27	44.6	77.4	98.1	248	480	1,010	1,660	2,650
1921–2017	East Twin Creek near Arrowhead Springs	8.8	64.7	113	205	264	681	1,300	2,610	4,130	6,270
1991–2017	Lytle+Bryne+Cond+Inf-W27	46.6	168	326	640	842	2,270	4,270	8,200	12,300	17,700
1919–2017	Plunge Creek near East Highlands	16.9	106	190	347	443	1,080	1,940	3,540	5,200	7,310
1897–1998	SAR near Mentone	210	263	480	910	1,190	3,280	6,510	13,700	22,300	34,700
1912–2017	Waterman Canyon Creek near Arrowhead Springs	4.82	42.2	65	104	128	278	478	872	1,300	1,890

Table 9. Flood Frequency Values from the Original 1999 HEC-RAS Model (USACE 2000b)

River	Reach	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
City Cr.	Main Stem	190	700	1,300	2,000	5,000	6,000
City Cr.	lower	190	700	1,300	2,000	5,000	6,000
Mill Cr.	Main Stem	180	1,100	2,600	5,100	11,000	19,500
Plunge Cr.	Main Stem	160	900	2,300	3,600	6,800	10,500
Santa Ana	Upper	400	500	500	2,500	3,800	5,000
Santa Ana	Middle	610	2,000	4200	8,000	15,000	25,000
Santa Ana	Lower	800	2,700	5500	10,000	20,000	31,000

Table 10. Seven Oaks Dam flood Releases with Peak Discharges over 4,000 cfs

Date of Peak	Peak Flow[1] (cfs)	Flood Duration[2] (hours)	Flood Volume (acre-feet)
3/9/2005	4,179	5	675
2/15/2011	4,648	16.3	2,923
3/1/2011	5,003	54	5,161

[1] From combined 15-minute records of USGS gages 11051499 and 11051502.

[2] Determined from inflection points on rising and falling limbs of the hydrograph. The 2/15/11 flood has a duration is 330 hours and volume of 10,822 acre-feet if the 2-week ramp-up from 3 cfs to 563 cfs is included in the calculations.

Table 11. Weighted Average Green-Ampt Parameters Used for the SRH-2D Infiltration Calculations

SRH-2D Material Zone	Saturated Hydraulic Conductivity K_s (in/hr)	Capillary Suction at Wetting Front S (in)	Initial Moisture Content θ_i (proportion)	Saturated Moisture Content θ_s (proportion)
Active Channel	1.16	2.72	0.04	0.40
Mill Creek Side Channel	0.81	3.78	0.05	0.39
Light Vegetation	1.11	2.71	0.04	0.39
Medium Vegetation	1.16	2.74	0.04	0.40
Dense Vegetation	0.84	3.62	0.05	0.39
Weighted Average	0.97	3.25	0.05	0.39

Table 12. Percentage of Species Records Inundated by the Six Flood Scenarios

Species	Flood Scenario	Inundated	Total	Percentage Inundated
Woollystar	1	167	2,141	7.80%
Woollystar	2	344	2,141	16.07%
Woollystar	3	346	2,141	16.16%
Woollystar	4	346	2,141	16.16%
Woollystar	5	426	2,141	19.90%
Woollystar	6	530	2,141	24.75%

Species	Flood Scenario	Inundated	Total	Percentage Inundated
SBKR	1	96	818	11.74%
SBKR	2	121	818	14.79%
SBKR	3	121	818	14.79%
SBKR	4	121	818	14.79%
SBKR	5	158	818	19.32%
SBKR	6	175	818	21.39%
Spineflower	1	1	186	0.54%
Spineflower	2	2	186	1.08%
Spineflower	3	2	186	1.08%
Spineflower	4	2	186	1.08%
Spineflower	5	3	186	1.61%
Spineflower	6	5	186	2.69%

Table 13. Summary Results of HEC-RAS Model Channel Manning's n Sensitivity Test

		Seven Oaks Dam 3,000 cfs Tributaries 0 cfs		Seven Oaks Dam 7,000 cfs Tributaries 0 cfs		Seven Oaks Dam 7,000 cfs Tributaries 100-yr	
Model Reach[2]	**Model Sensitivity Test n Values[1]**	**Average Reduction in Water Surface Elevation (ft)**	**Average Reduction in Mean Channel Depth (%)**	**Average Change in Water Surface Elevation (ft)**	**Average Reduction in Mean Channel Depth (%)**	**Average Change in Water Surface Elevation (ft)**	**Average Reduction in Mean Channel Depth (%)**
SAR Upper Reach	0.03	-0.9	-34%	-0.9	-26%	-0.9	-26%
SAR Middle Reach	0.03	-0.8	-45%	-1.0	-39%	-1.4	-27%
SAR Upper Reach	0.045	-0.8	-33%	-0.9	-25%	-0.9	-25%
SAR Middle Reach	0.045	-0.5	-29%	-0.7	-27%	-1.0	-21%
SAR Upper Reach	0.06	-0.5	-21%	-0.6	-17%	-0.6	-17%
SAR Middle Reach	0.06	-0.2	-11%	-0.3	-10%	-0.4	-8%

[1] The original model's channel Manning's n values are 0.08 for the Upper Reach and 0.07 for the Middle Reach

[2] SAR Upper Reach is from SOD to Mill Creek. SAR Middle Reach is from Mill Creek to confluence with City Creek.

Table 14. Comparison of Flood Characteristics from Modeling and at the Seven Oaks Dam and E Street Gaging Locations

Location	Reach Distance (mi)	Flood Duration (hr)	Time of Peak Flow	Peak Flow (cfs)	Reduction in Peak Flow (cfs)	Rate of Peak Flow Loss (cfs/mi)	Peak Flow Velocity (ft/s)	Flood Volume (ac-ft)	Flood Volume Loss (ac-ft)	Rate of Flood Volume Loss (ac-ft/mi)
SRH-2D Modeled Flood										
Greenspot Road	--	--	15.00 hr	5,003	--	--		4,491	--	--
Mentone Pipeline	2.1	33	15.24 hr	4,841	162	78	12.3	4,320	171	83
March 9, 2005 Flood										
USGS 11051499 & 11051502	--	4.8	3/9/2005 12:15 PM	4,179	--	--	--	675	--	--
USGS 11059300	13.2	5.8	3/9/2005 2:08 PM	1,620	2,559	194	10.3	294	382	29
February 15, 2011 Flood										
USGS 11051499 & 11051502	--	16.3	2/15/2011 1:45 PM	4,648	--	--	--	2,923	--	--
USGS 11059300	13.2	16.8	2/15/2011 3:30 PM	4,040	608	46	11.1	1,863	1,060	80

Table 15. Estimates for Peak Flow Losses and Total Flood Volume Losses for Nine Locations Downstream of Seven Oaks Dam

		Reductions in Peak Flow								
		Scenario 1a			Scenario 1b			Reductions in Flood Volume		
Seven Oaks Dam Peak Release (cfs)		5,000			5,000			Seven Oaks Dam Hydrograph Volume (ac-ft)	4,491	
Peak Flow Loss Rate (cfs/mi)		78			46			Flood Volume Loss Rate (ac-ft/mi)	83	
Location	Distance from Seven Oaks Dam (mi)	Peak Flow Loss (cfs)	Peak Flow (cfs)	Percent Reduction (%)	Flow Loss (cfs)	Total Flow (cfs)	Percent Reduction (%)	Flood Volume Loss (ac-ft)	Flood Volume (ac-ft)	Percent Reduction (%)
Seven Oaks Dam Release	0.0	0	5,000	0%	0	5,000	0%	0	4,491	0%
Greenspot Road	1.3	-98	4,902	-2%	-58	4,942	-1%	-105	4,386	-2%
Mill Creek Confluence	2.4	-188	4,812	-4%	-111	4,889	-2%	-200	4,291	-4%
Mentone Pipeline/Opal Avenue	3.4	-262	4,738	-5%	-154	4,846	-3%	-278	4,213	-6%
Orange Street	6.0	-472	4,528	-9%	-278	4,722	-6%	-502	3,989	-11%
210 Highway	7.2	-559	4,441	-11%	-330	4,670	-7%	-595	3,896	-13%
Alabama Street	7.7	-597	4,403	-12%	-352	4,648	-7%	-636	3,855	-14%
City Creek Confluence	8.5	-663	4,337	-13%	-391	4,609	-8%	-706	3,785	-16%
11059300 E Street Gage	13.7	-1,069	3,931	-21%	-630	4,370	-13%	-1,137	3,354	-25%

Chapter 10
Figures

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Legend

- Area Of Interest
- SA River Wash Plan Area

0 0.25 0.5 0.75 1 Kilometers

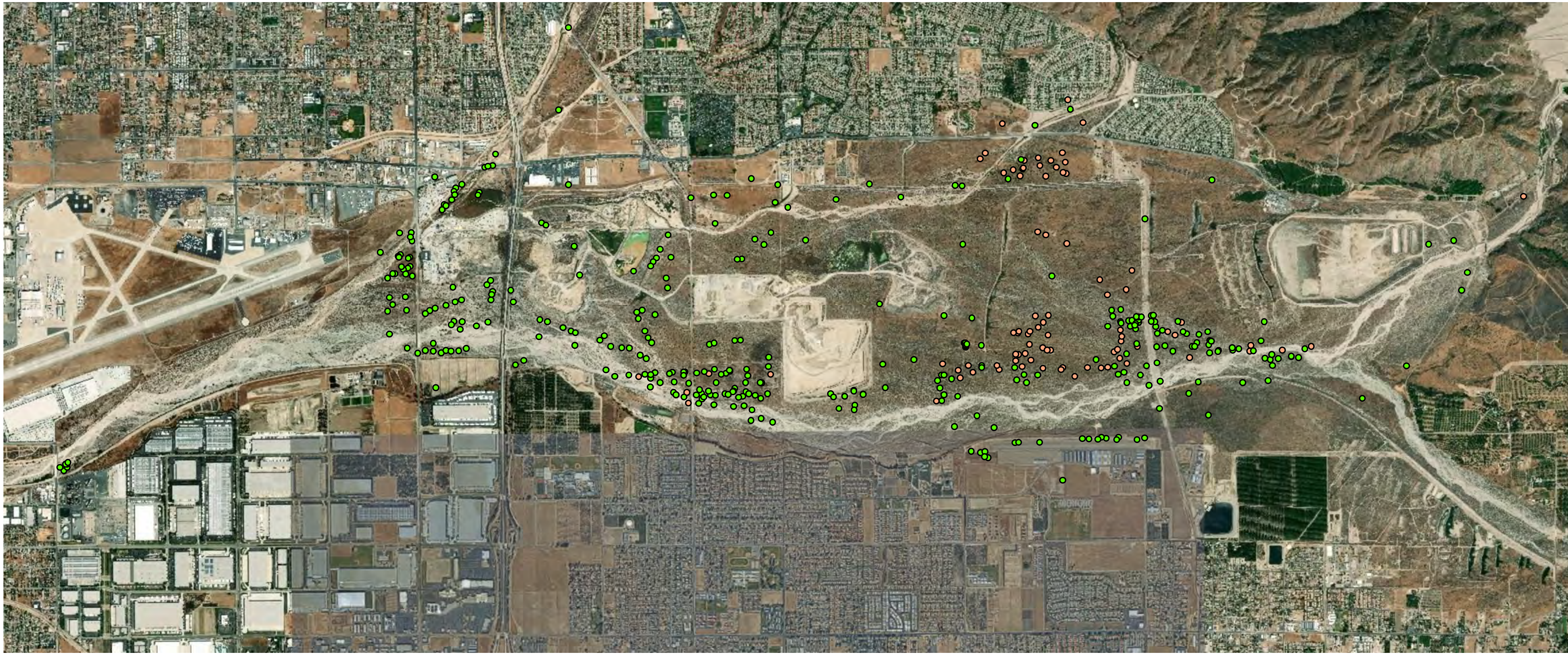
0 0.25 0.5 0.75 1 Miles

1:35,500

N

ICF

Figure 1
Study Area



Legend

- Absent
- Present

0 0.25 0.5 0.75 1 Kilometers

0 0.25 0.5 0.75 1 Miles

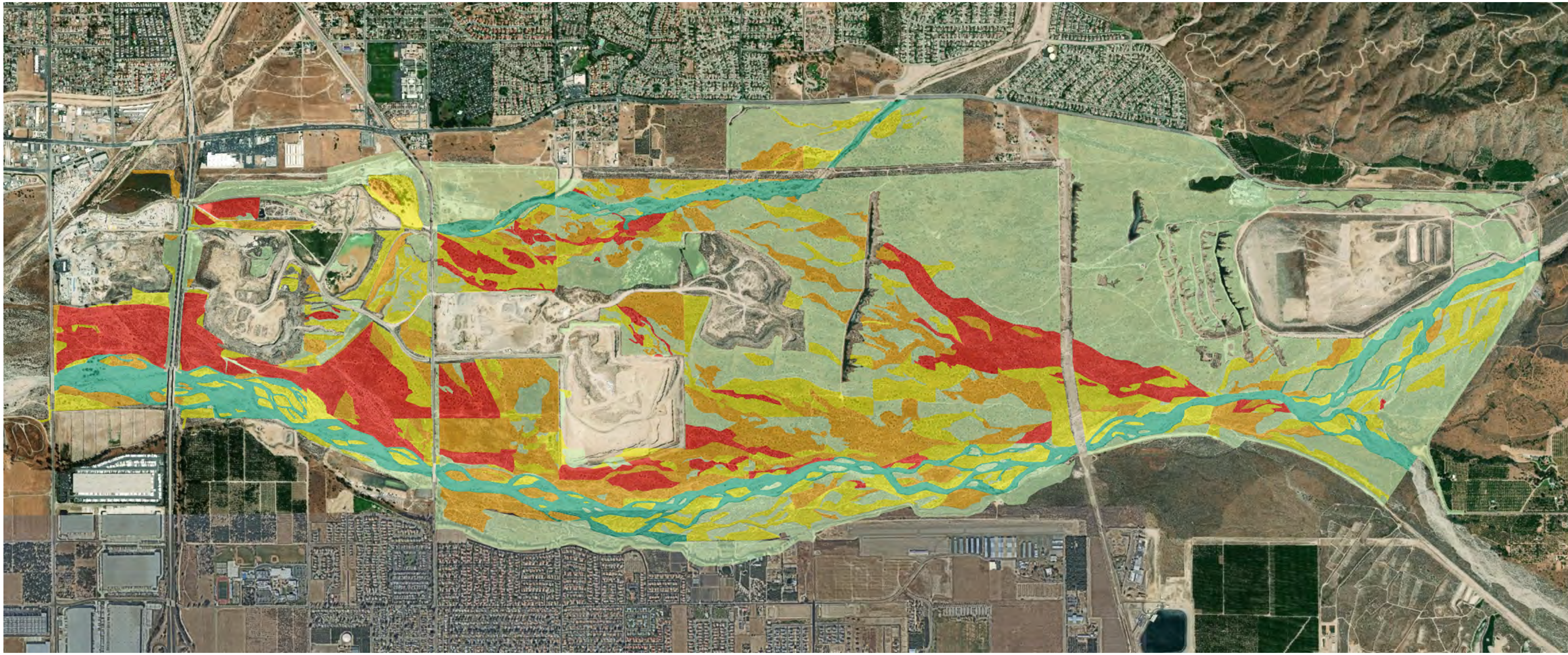
1:35,500

N

ICF

Figure 2

SBKR Distribution Within The Study Area



Legend

- High Suitability
- Medium Suitability
- Low Suitability
- Very Low Suitability
- Ecological Process Area

0 0.25 0.5 0.75 1 Kilometers

0 0.25 0.5 0.75 1 Miles

1:25,500

N

ICF

Figure 3

SBKR Habitat Quality

ICF

Figure 4

Santa Ana Wollystar Distribution Within The Study Area

Legend

Present

0 0.25 0.5 0.75 1 Kilometers

0 0.25 0.5 0.75 1 Miles

1:35,500

N

Figure 5

Slender-horned Spineflowe Distribution Within The Study Area

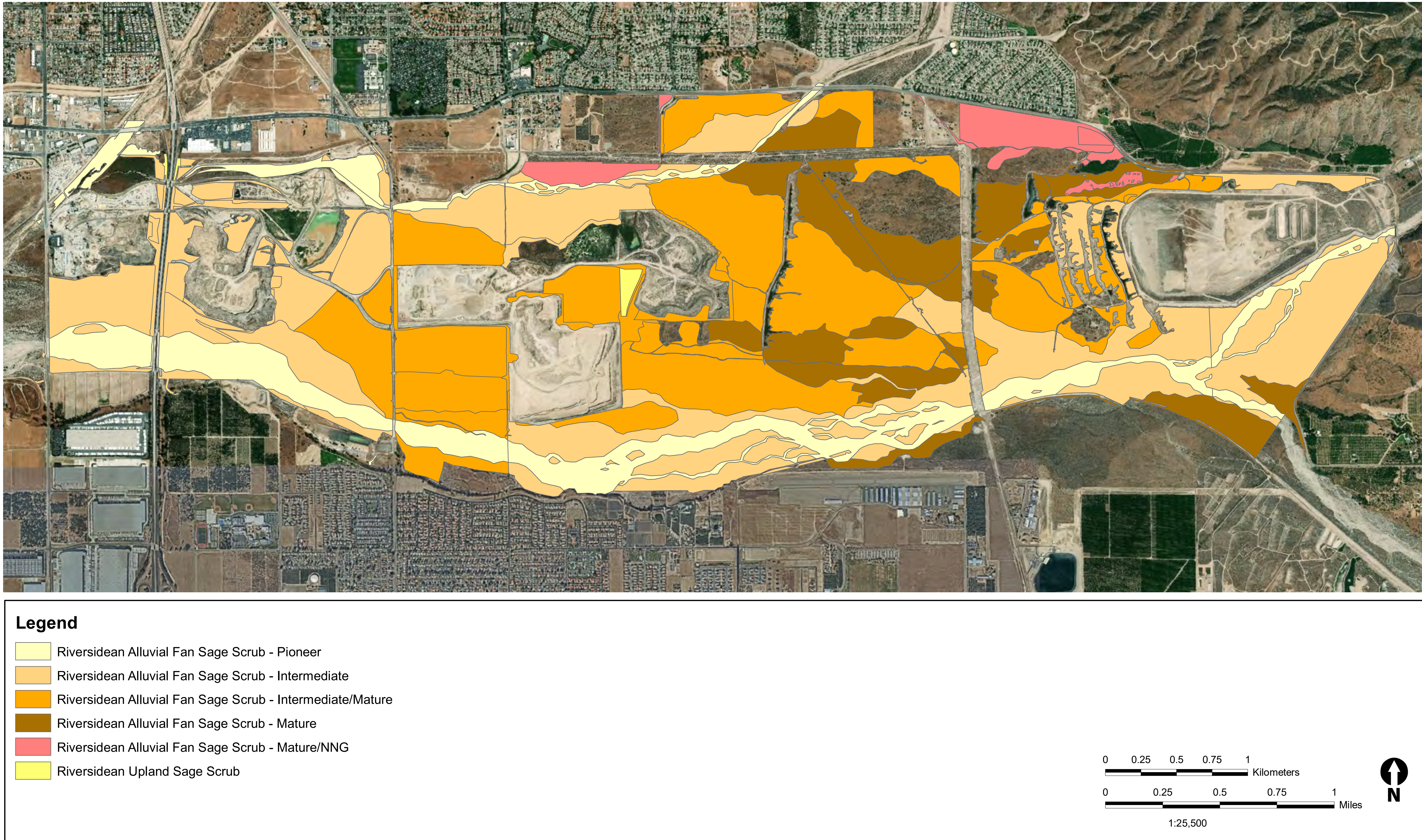


Figure 6

Vegetation withSeral Stage Within The Study Area

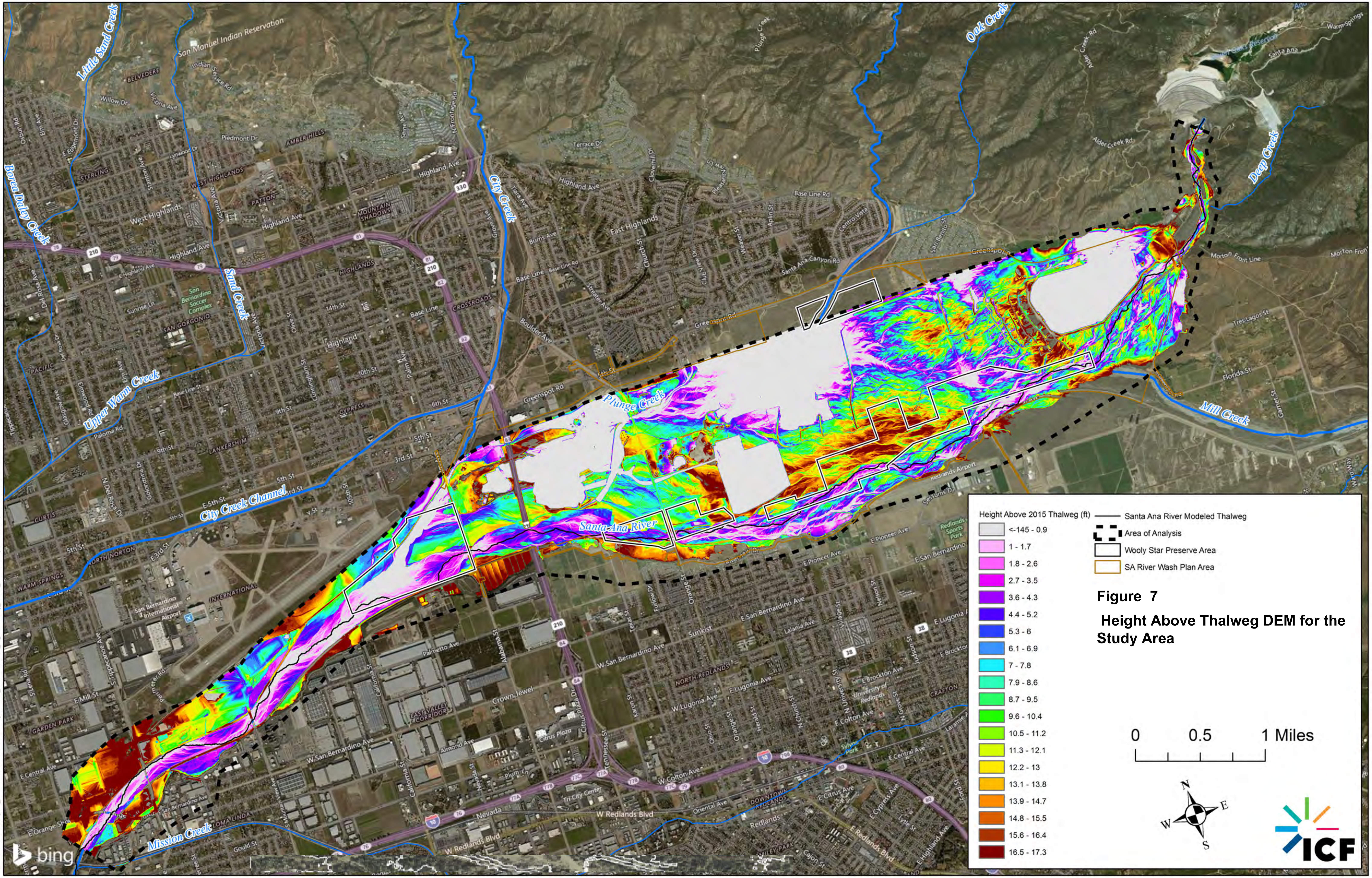


Figure 7

Height Above Thalweg DEM for the Study Area

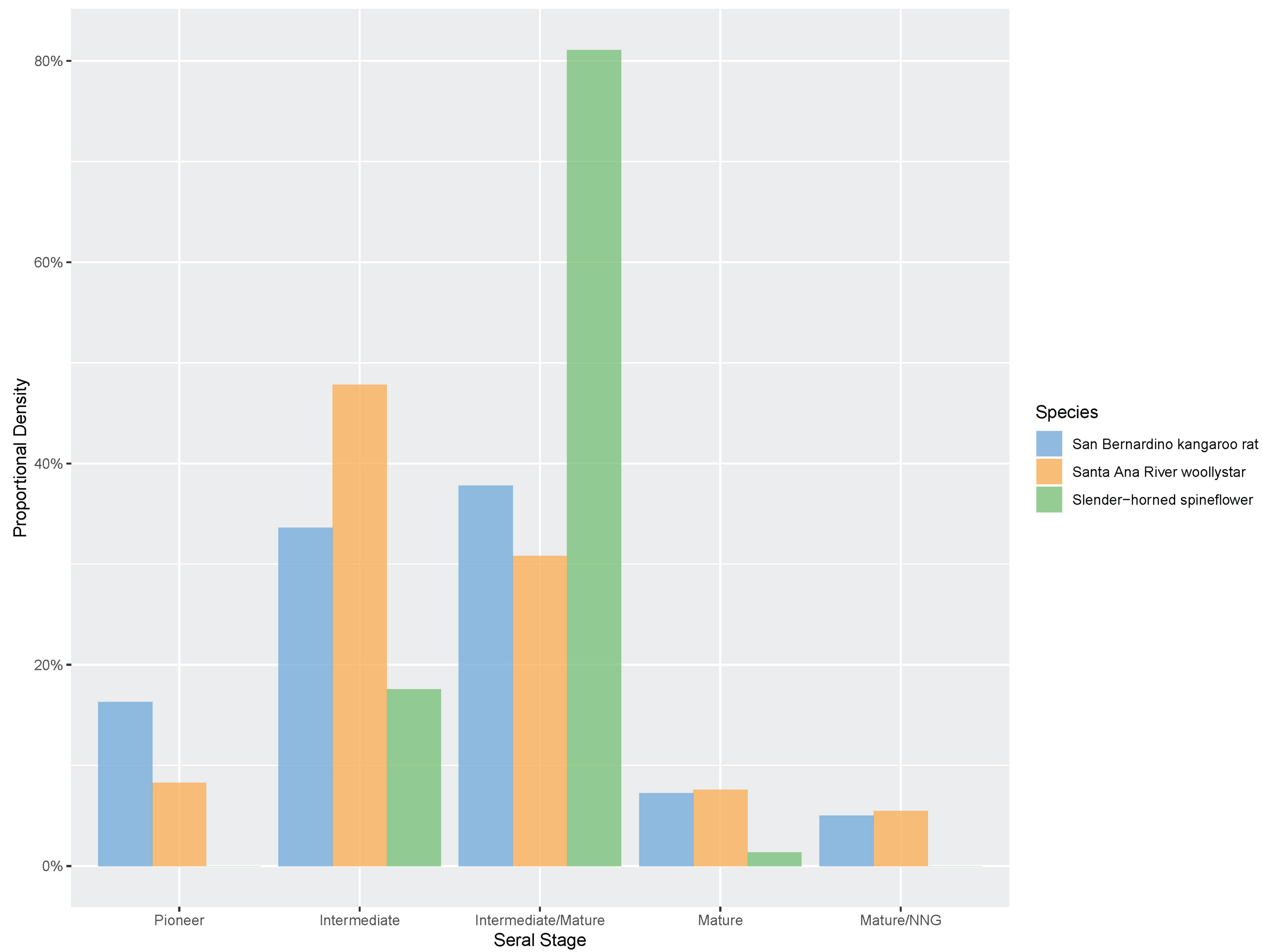


Figure 8
Histogram of Density of Species by Seral Stage Adjusted for Surface Area

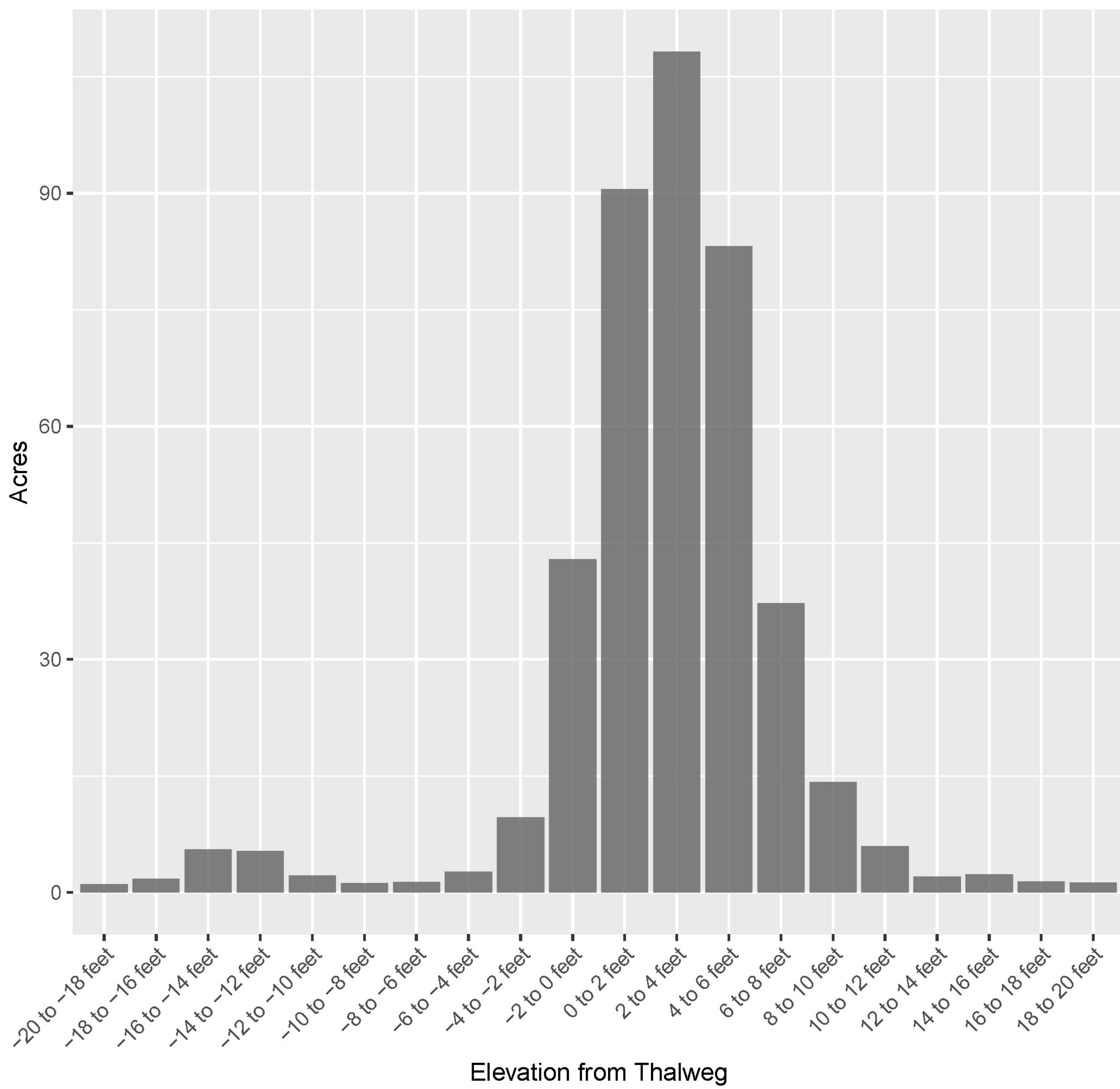


Figure 9
Pioneer Seral Stage Elevation Above Thalweg

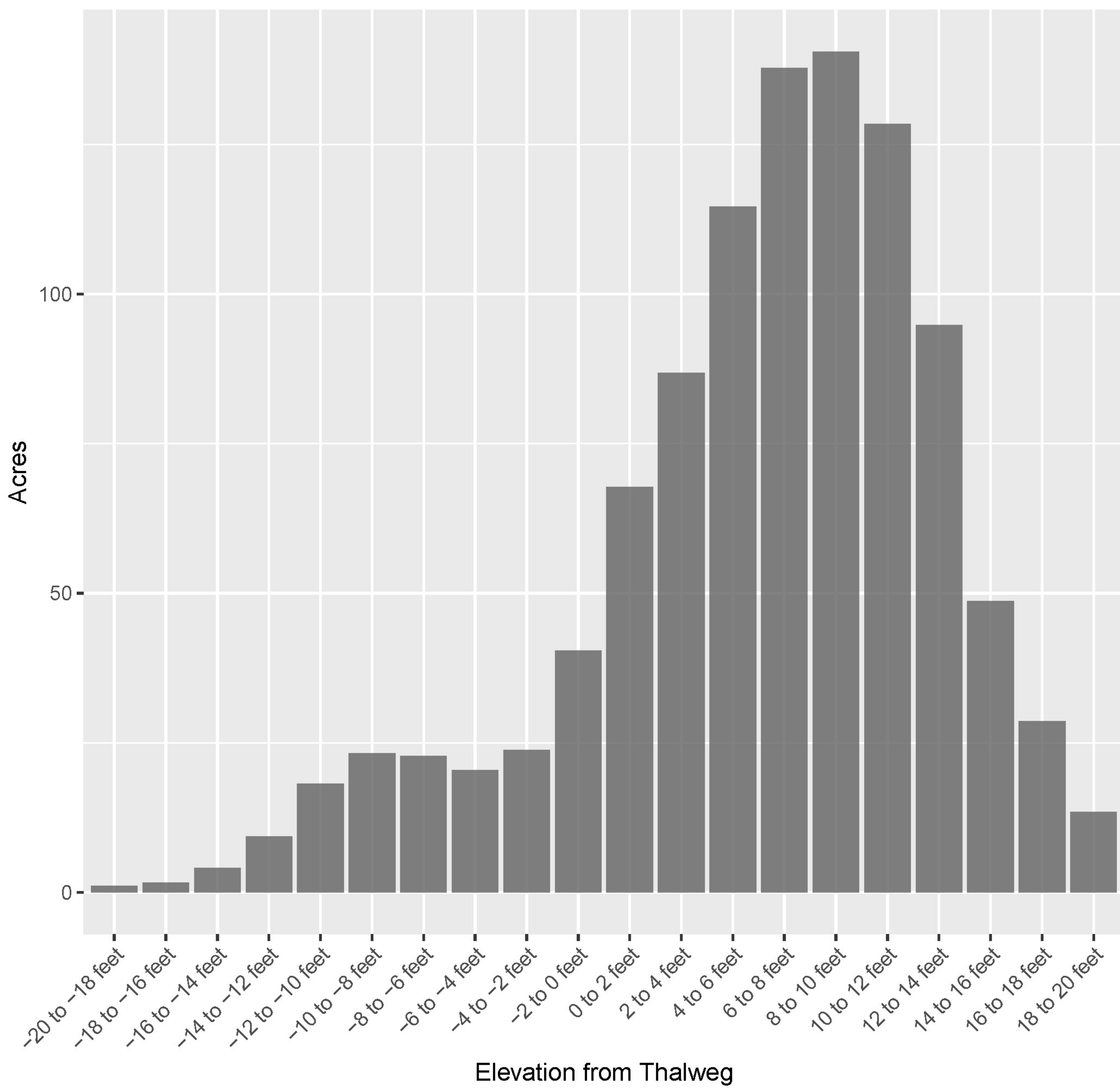


Figure 10
Intermediate Seral Stage Elevation Above Thalweg

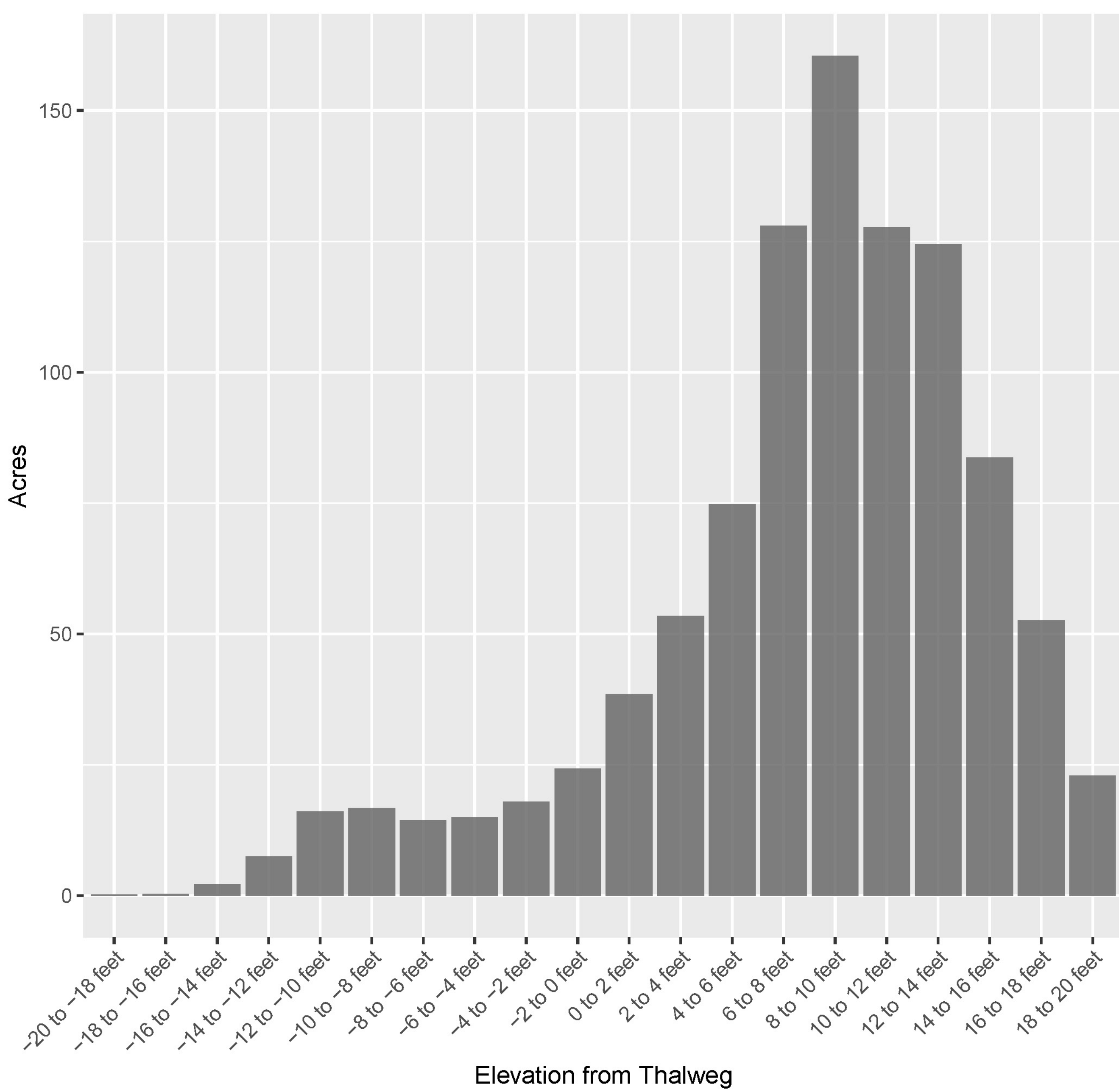


Figure 11
Intermediate/Mature Seral Stage Elevation Above Thalweg

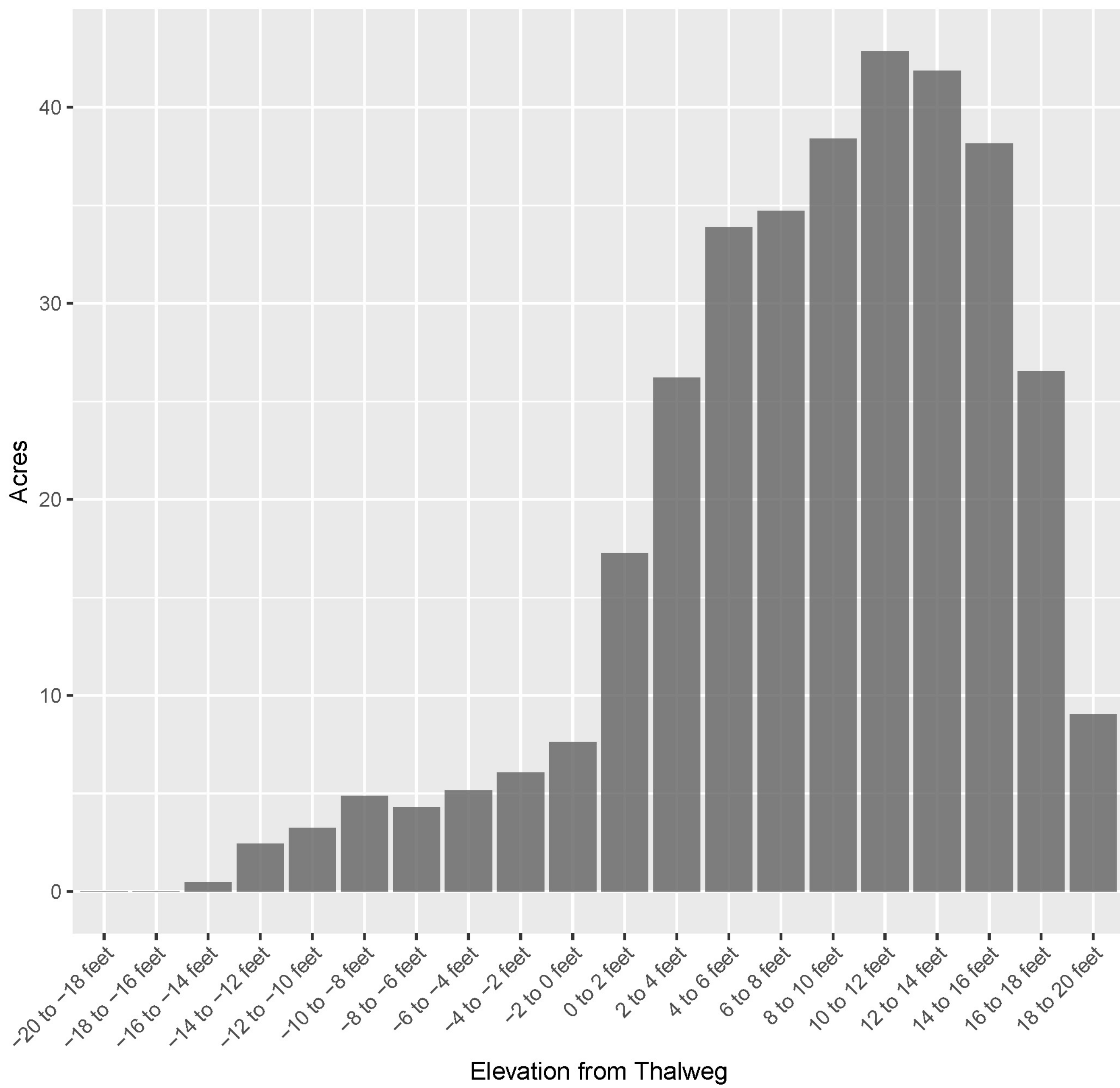


Figure 12
Mature Seral Stage Elevation Above Thalweg

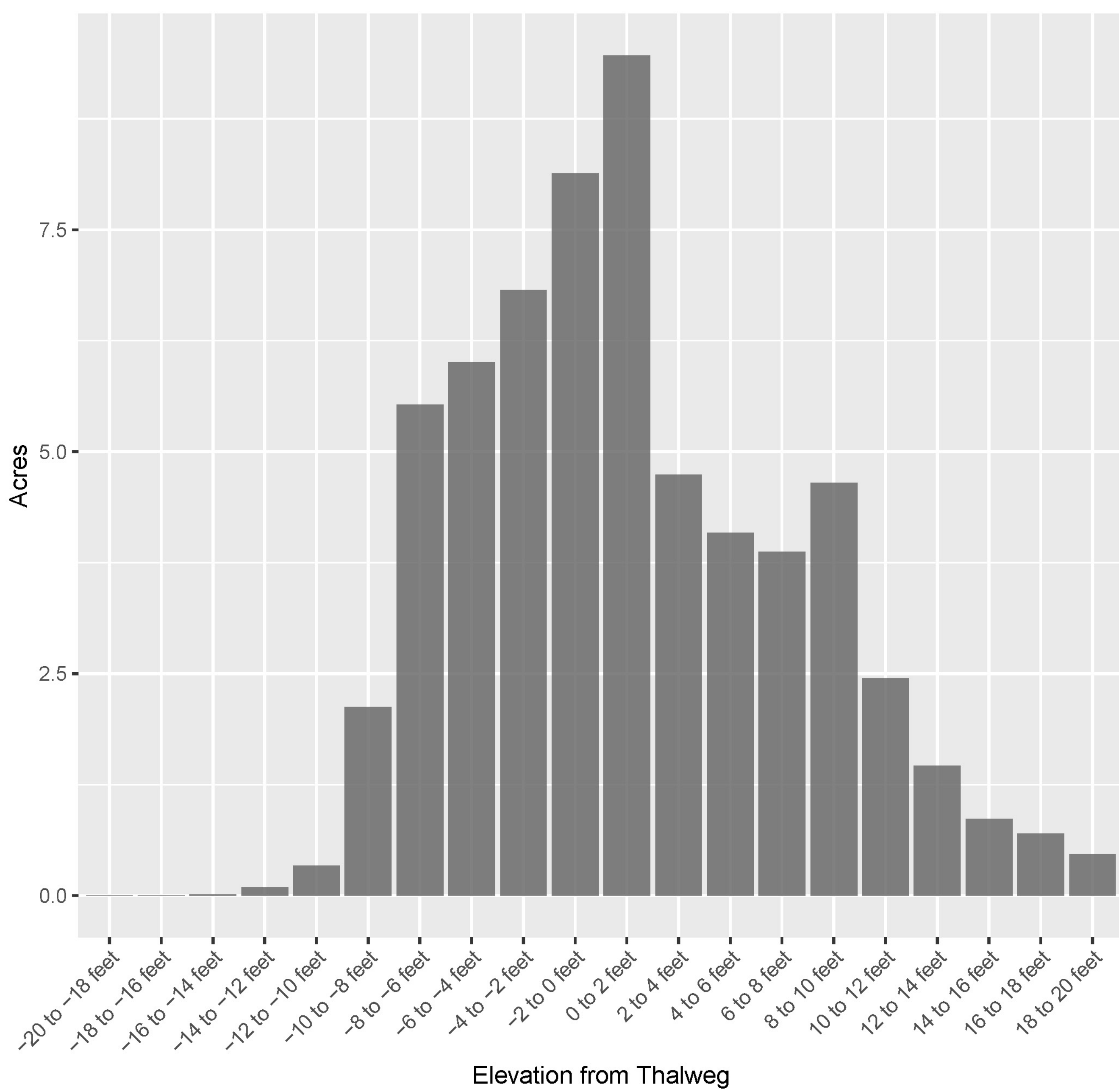


Figure 13
Mature/Non-Native Grassland Seral Stage Elevation Above Thalweg

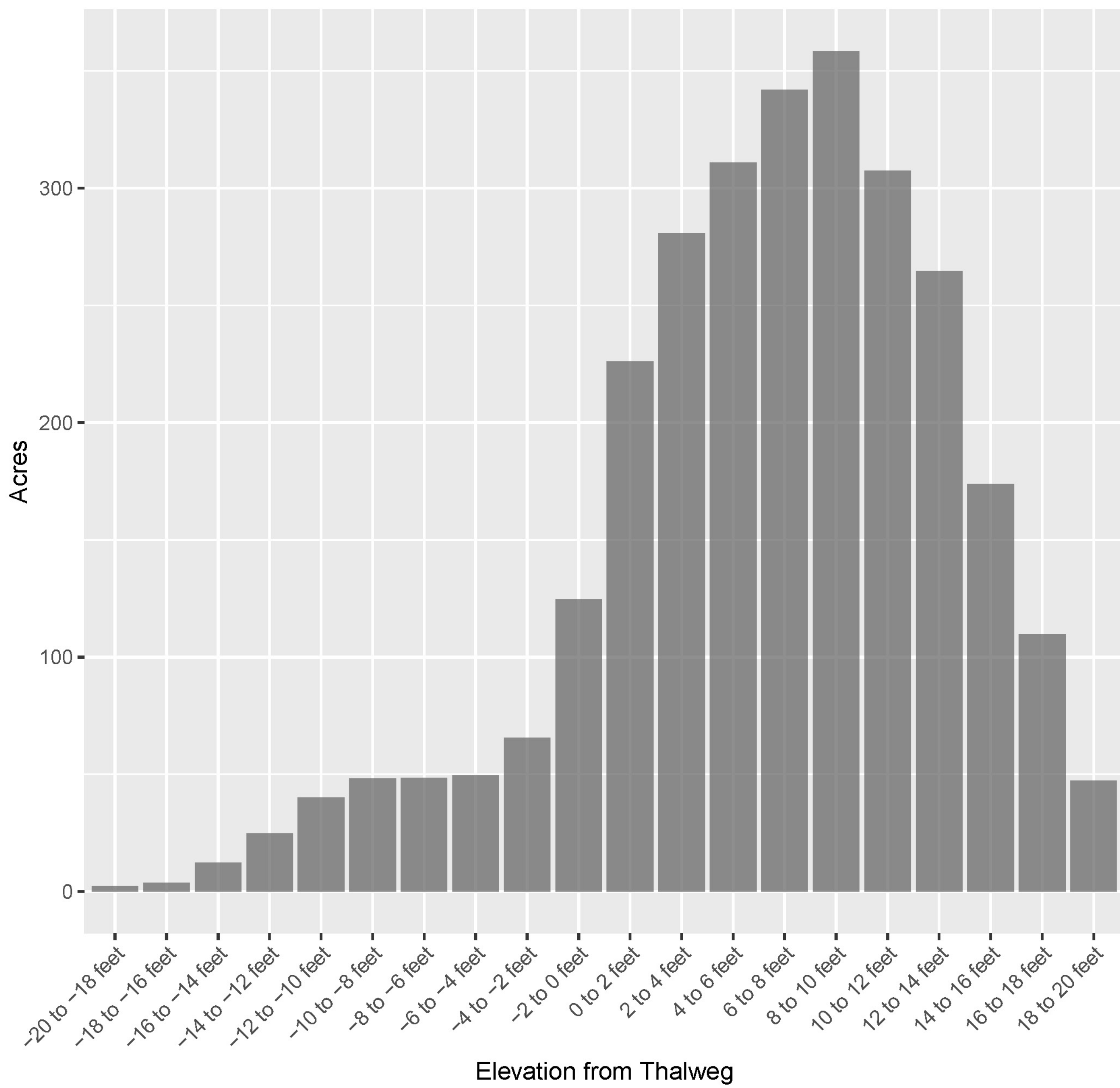


Figure 14
Study Area Elevation Above Thalweg

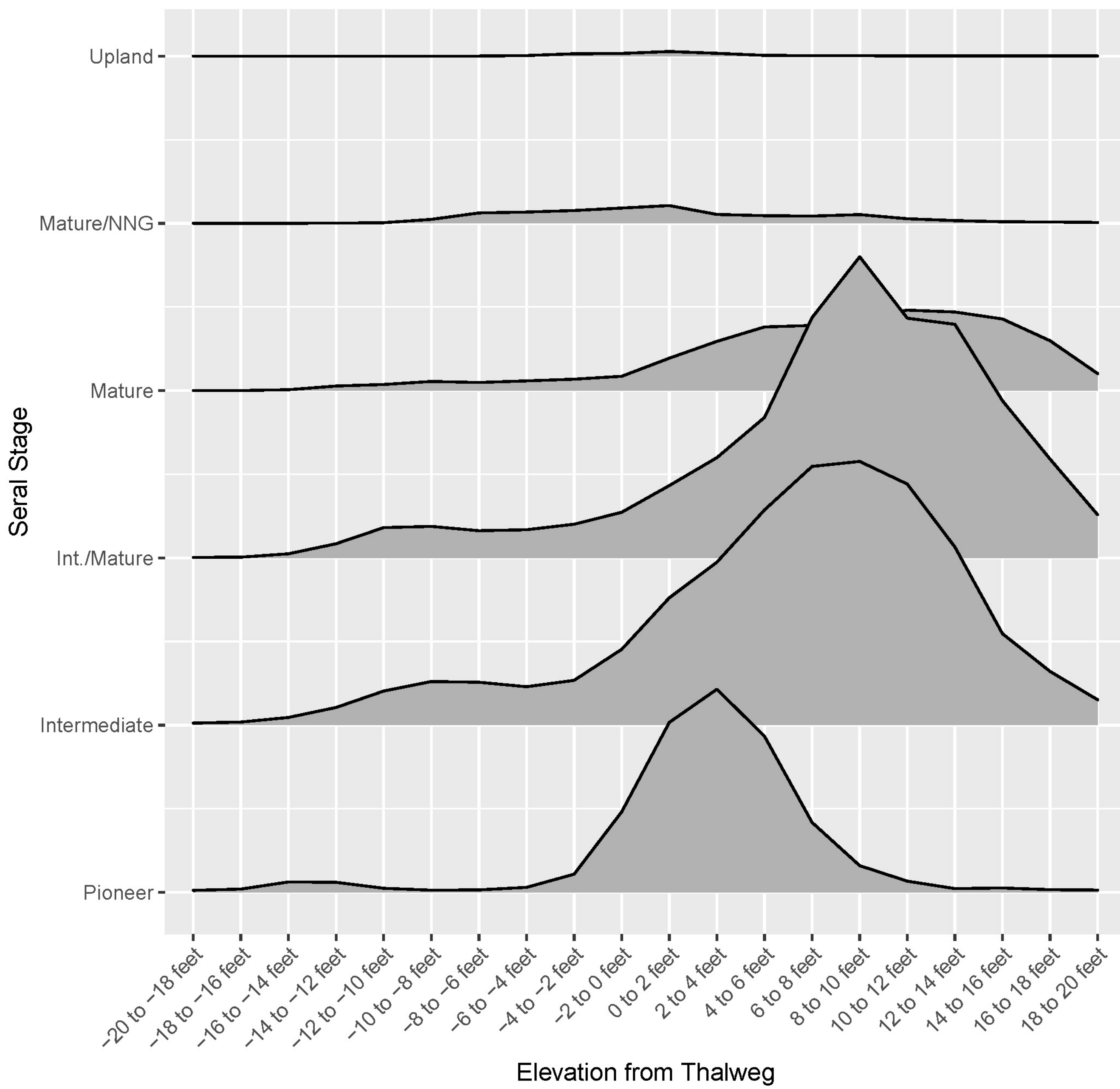


Figure 15
Ridgeline Plot of Elevation Above Thalweg for all Seral Stages

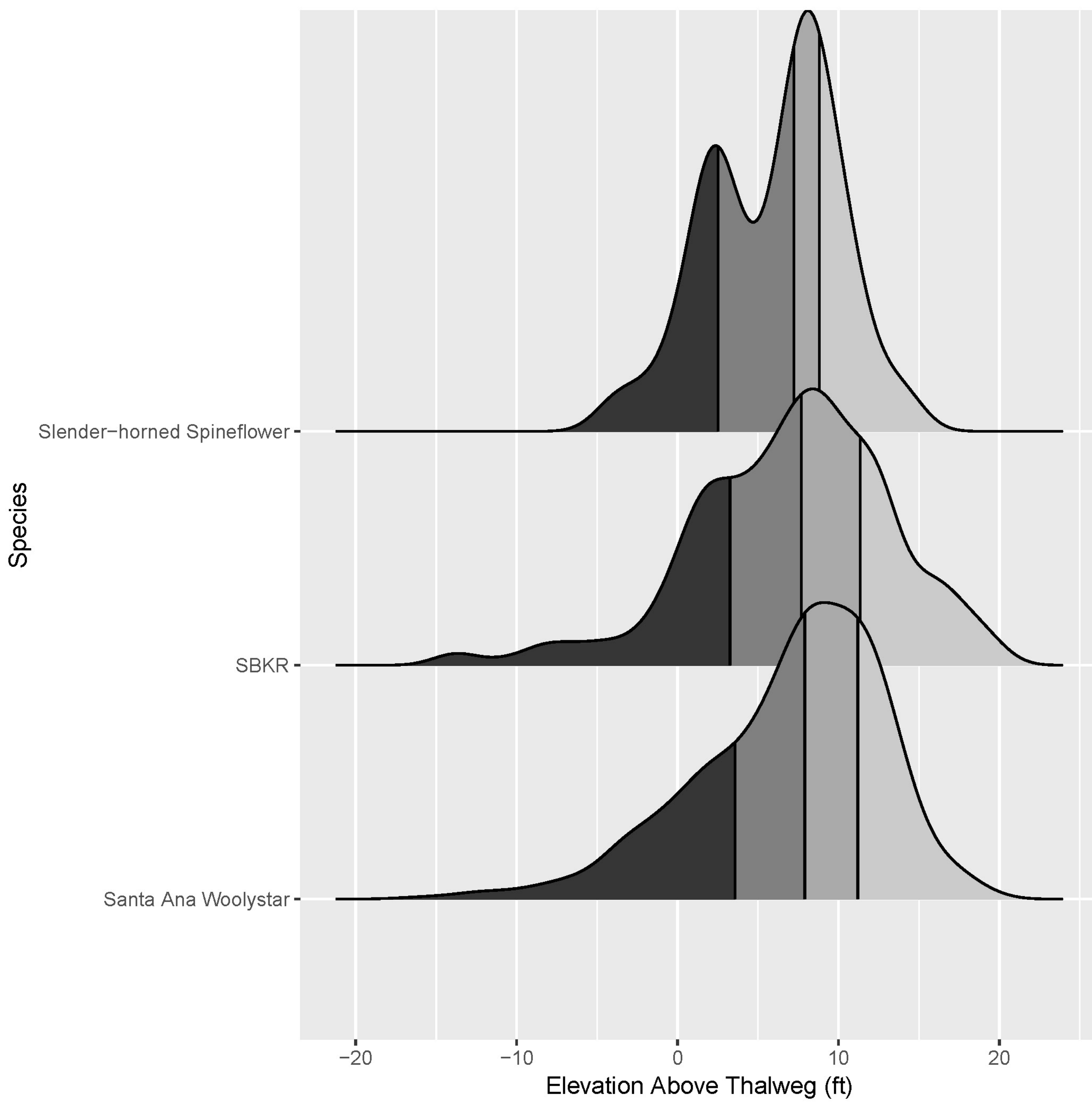


Figure 16
Ridgeline Plot of Elevation Above Thalweg for the Species of Interest

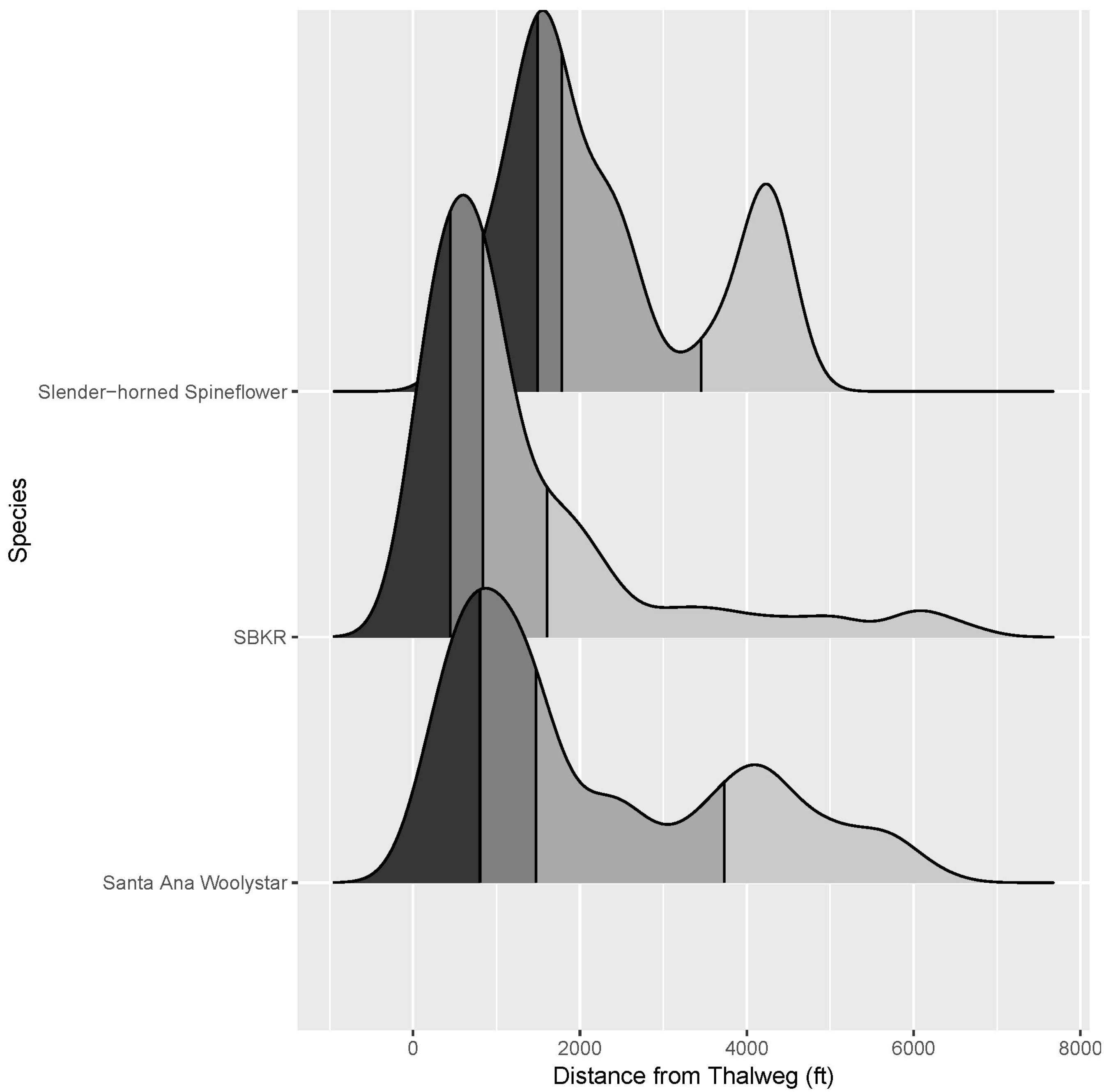
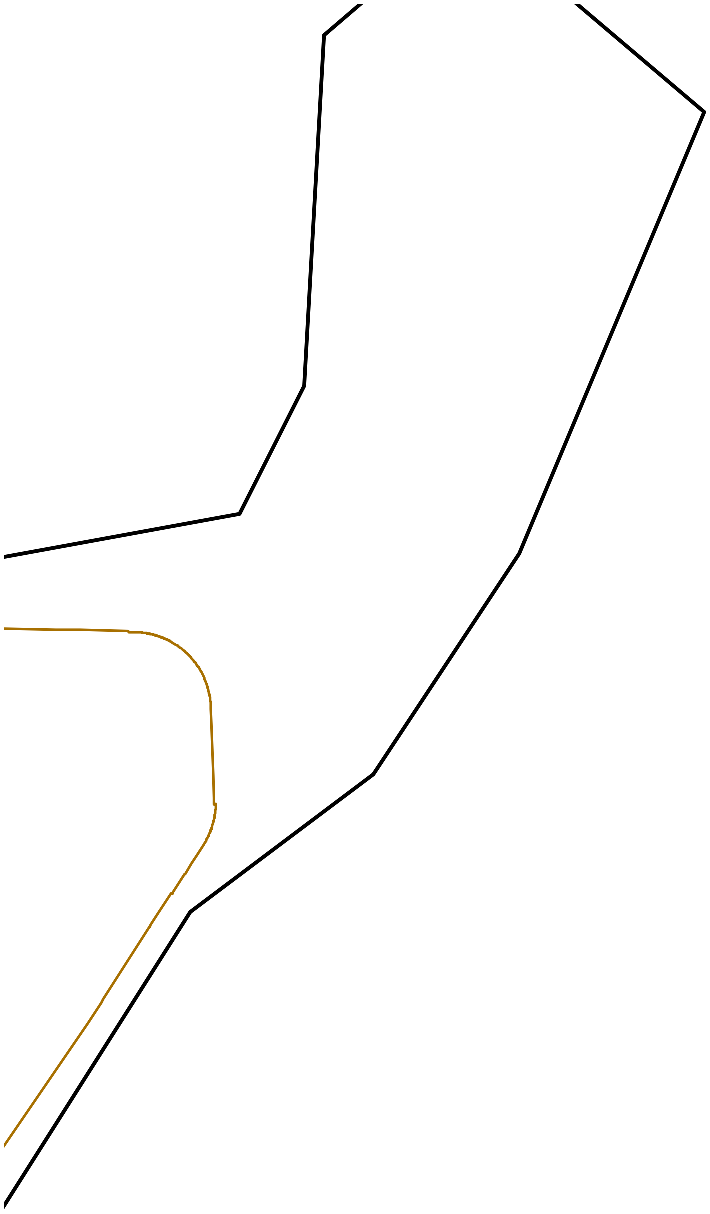
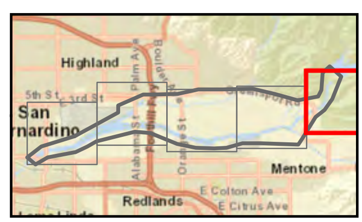


Figure 17
Ridgeline Plot of Distance from Thalweg for the Species of Interest



Legend

- Area Of Interest
- SA River Wash Plan Area



N

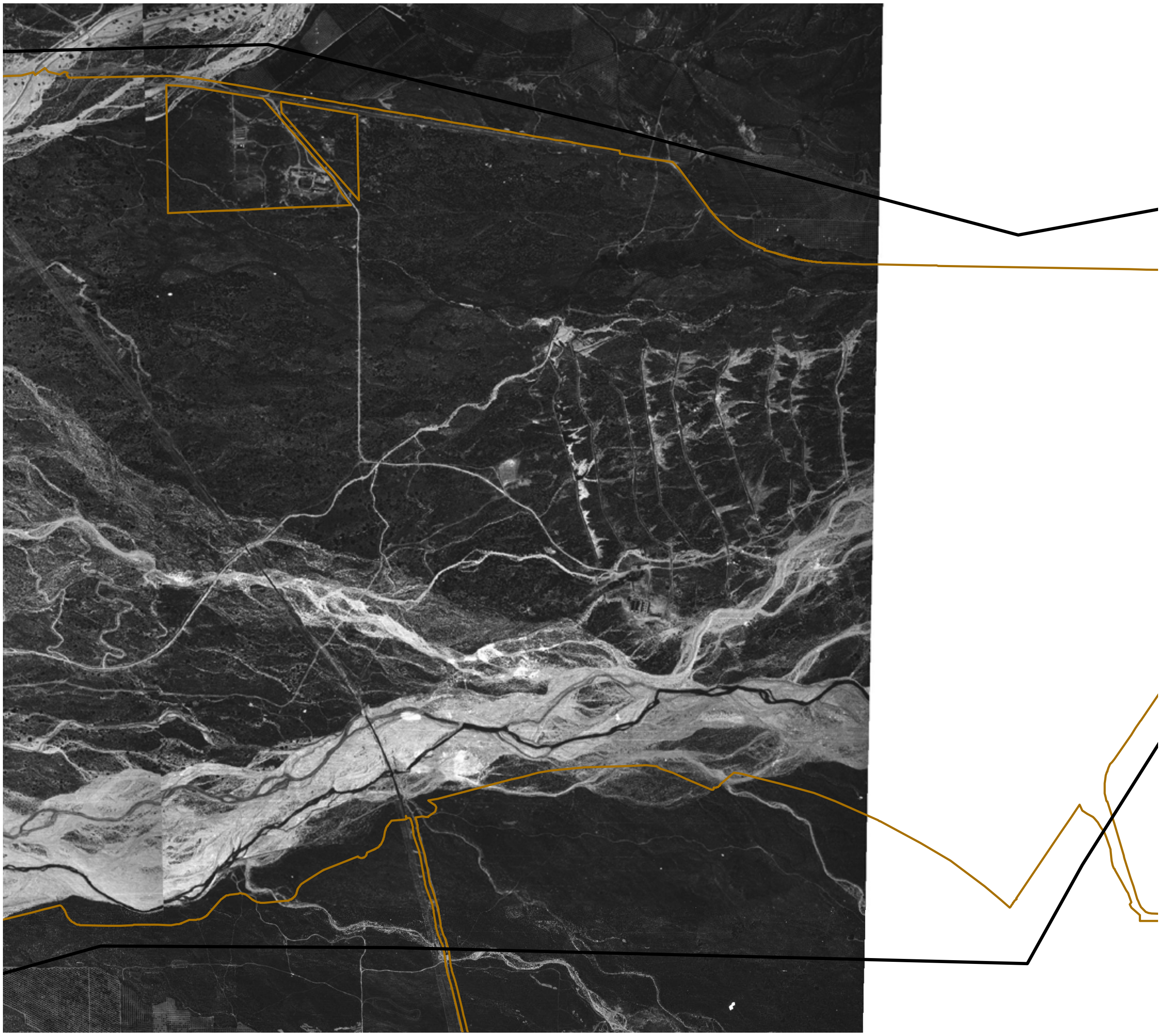
0 0.25 0.5 Miles

1:20,000

1 inch = 1,667 feet

Page 1

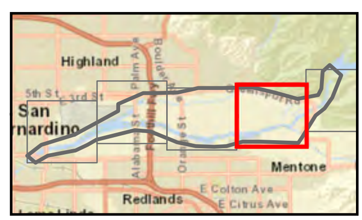
Figure 18 Historic Aerial 1930-1937



Legend

Area Of Interest

SA River Wash Plan Area



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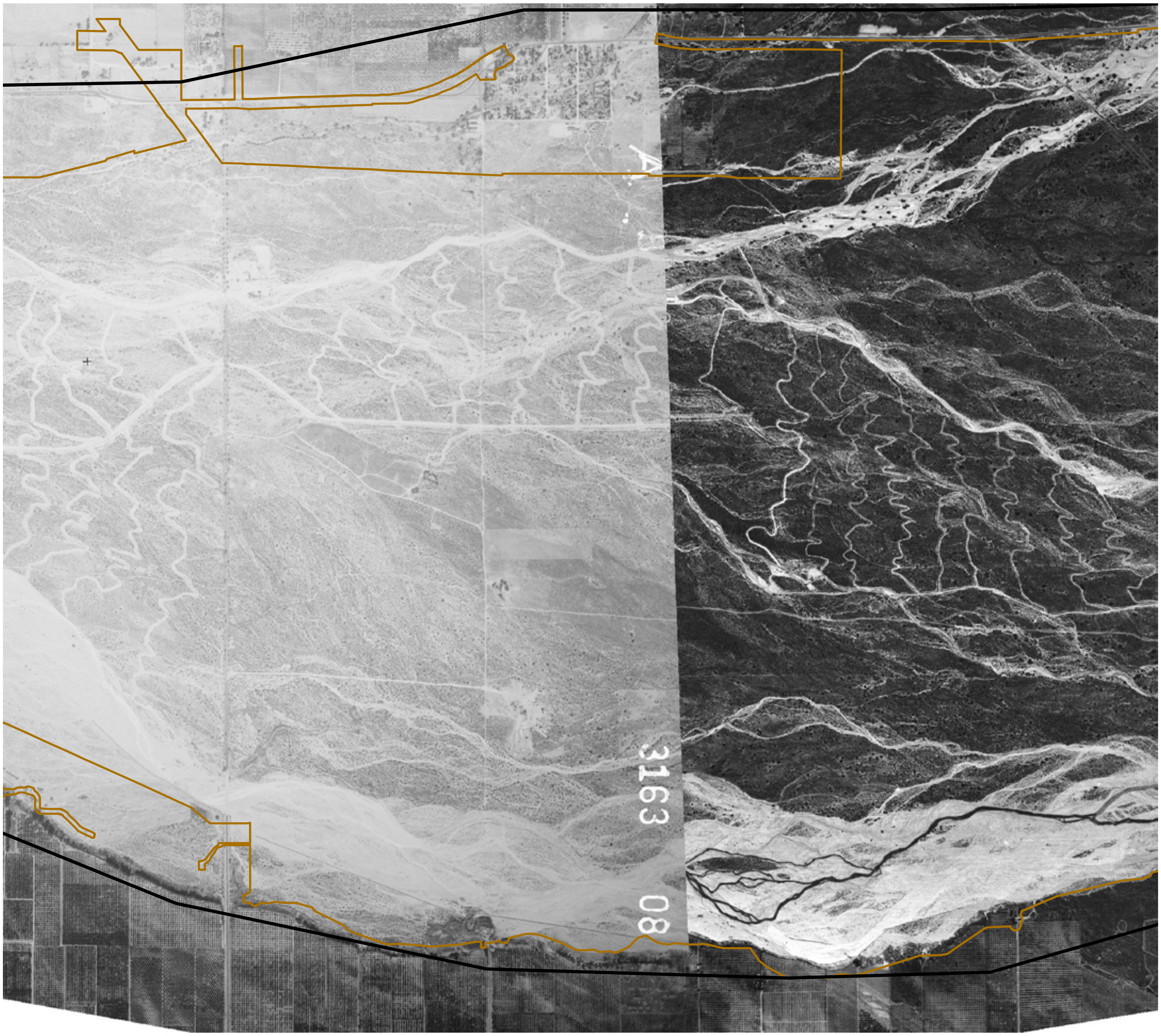
1 inch = 1,667 feet

Figure 18 Historic Aerial 1930-1937



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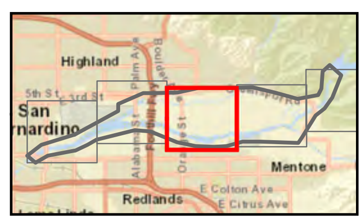
Area Of Interest

SA River Wash Plan Area



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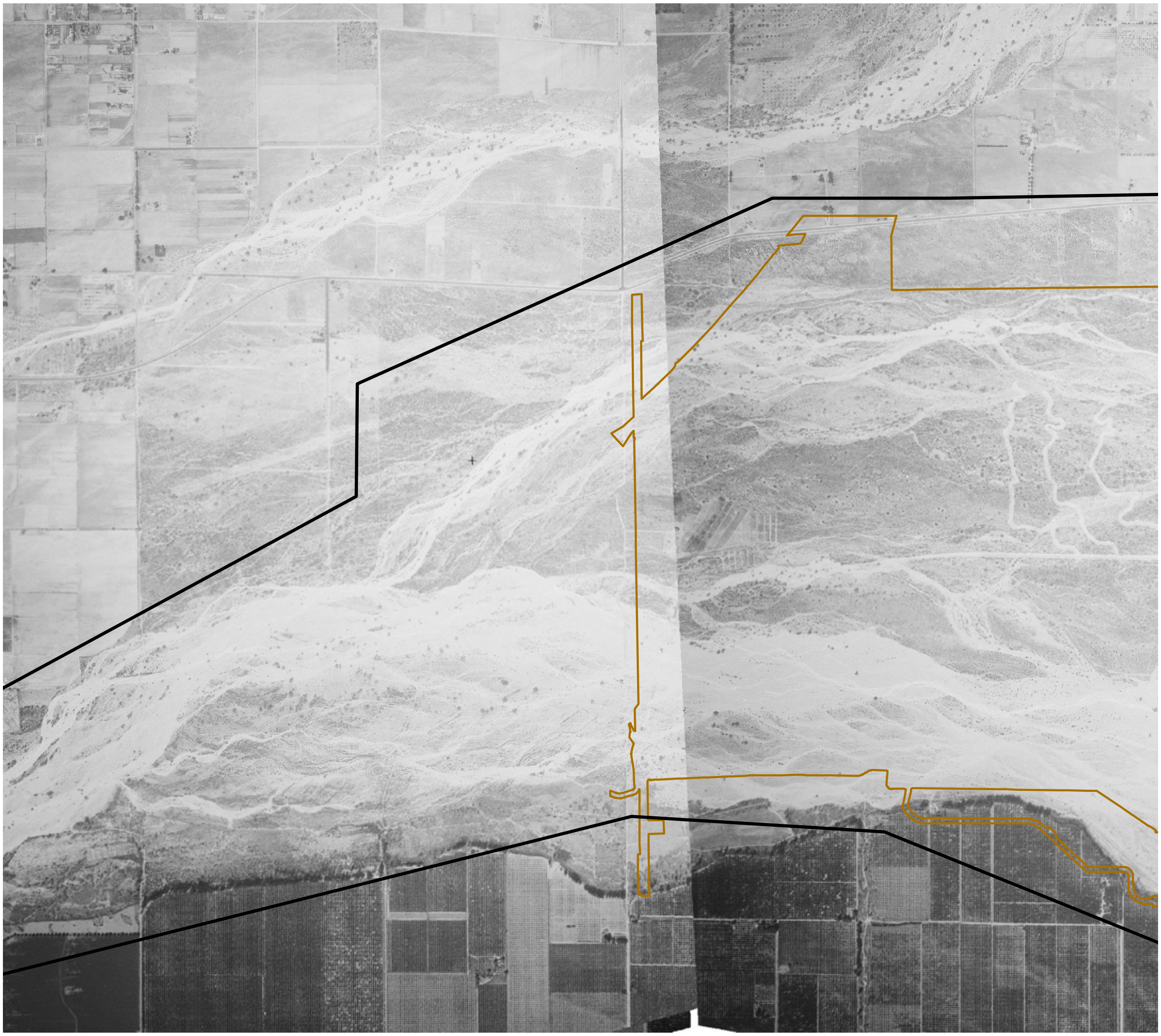
N

1:20,000

1 inch = 1,667 feet

Figure 18 Historic Aerial 1930-1937



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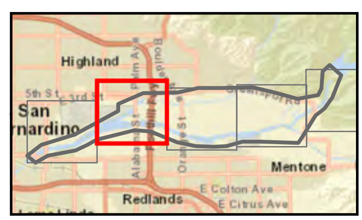
Area Of Interest

SA River Wash Plan Area



0 0.25 0.5 Miles

N

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1 inch = 1,667 feet

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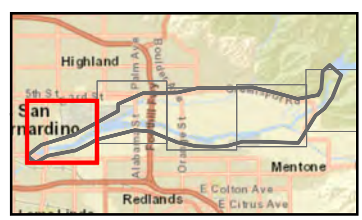
Figure 18 Historic Aerial 1930-1937

Legend

Area Of Interest

SA River Wash Plan Area



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1:20,000

1 inch = 1,667 feet

Figure 18 Historic Aerial 1930-1937

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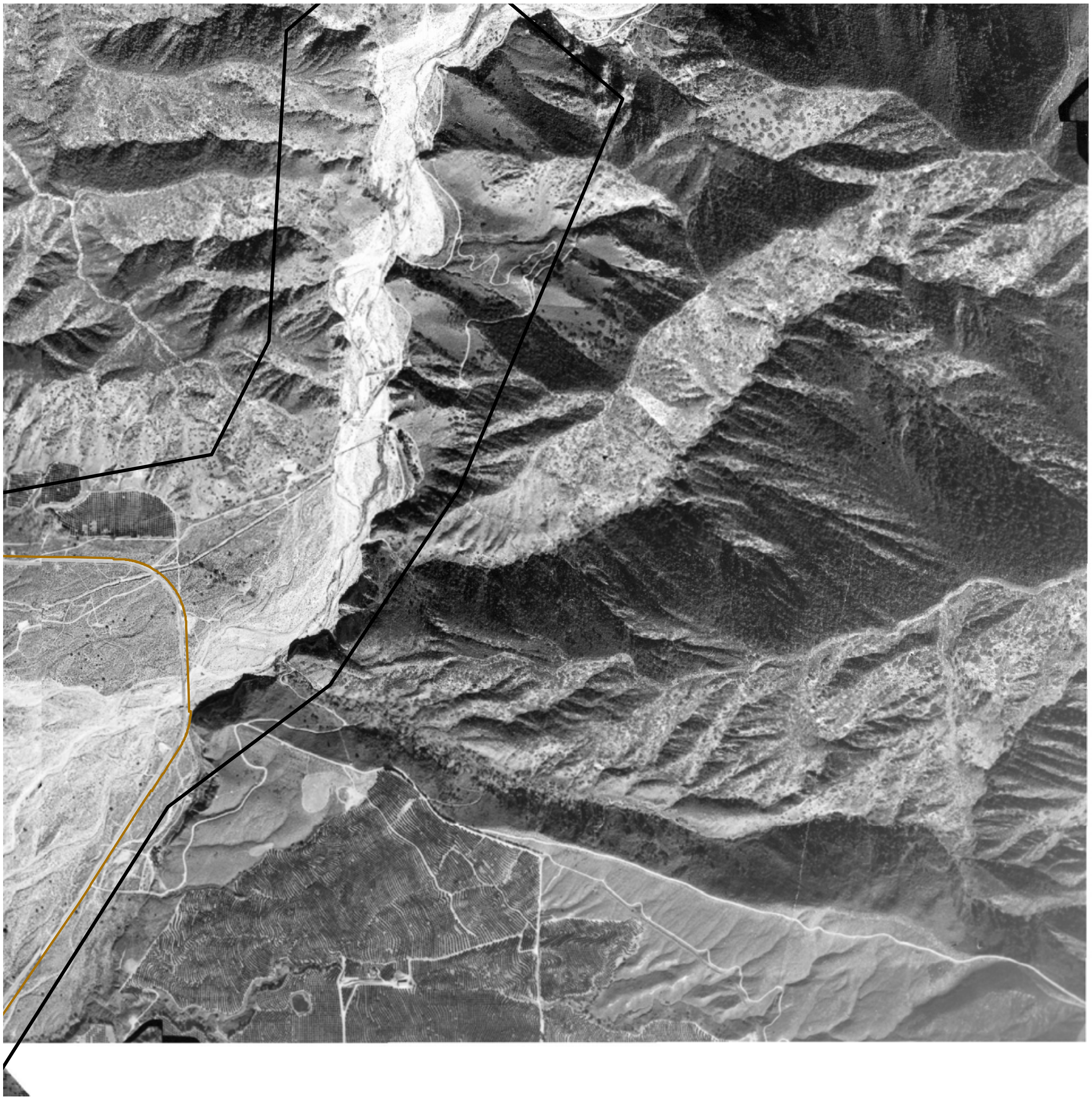
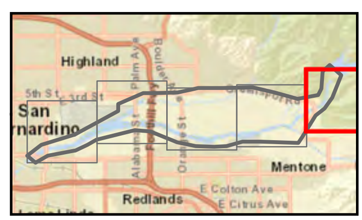


Legend

- Area Of Interest
- SA River Wash Plan Area



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1 inch = 1,667 feet

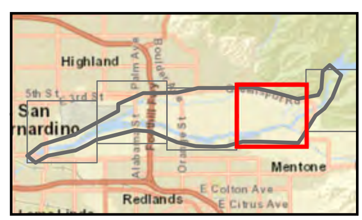
Figure 19 Historic Aerial 1953-1959

ICF

Legend

Area Of Interest

SA River Wash Plan Area



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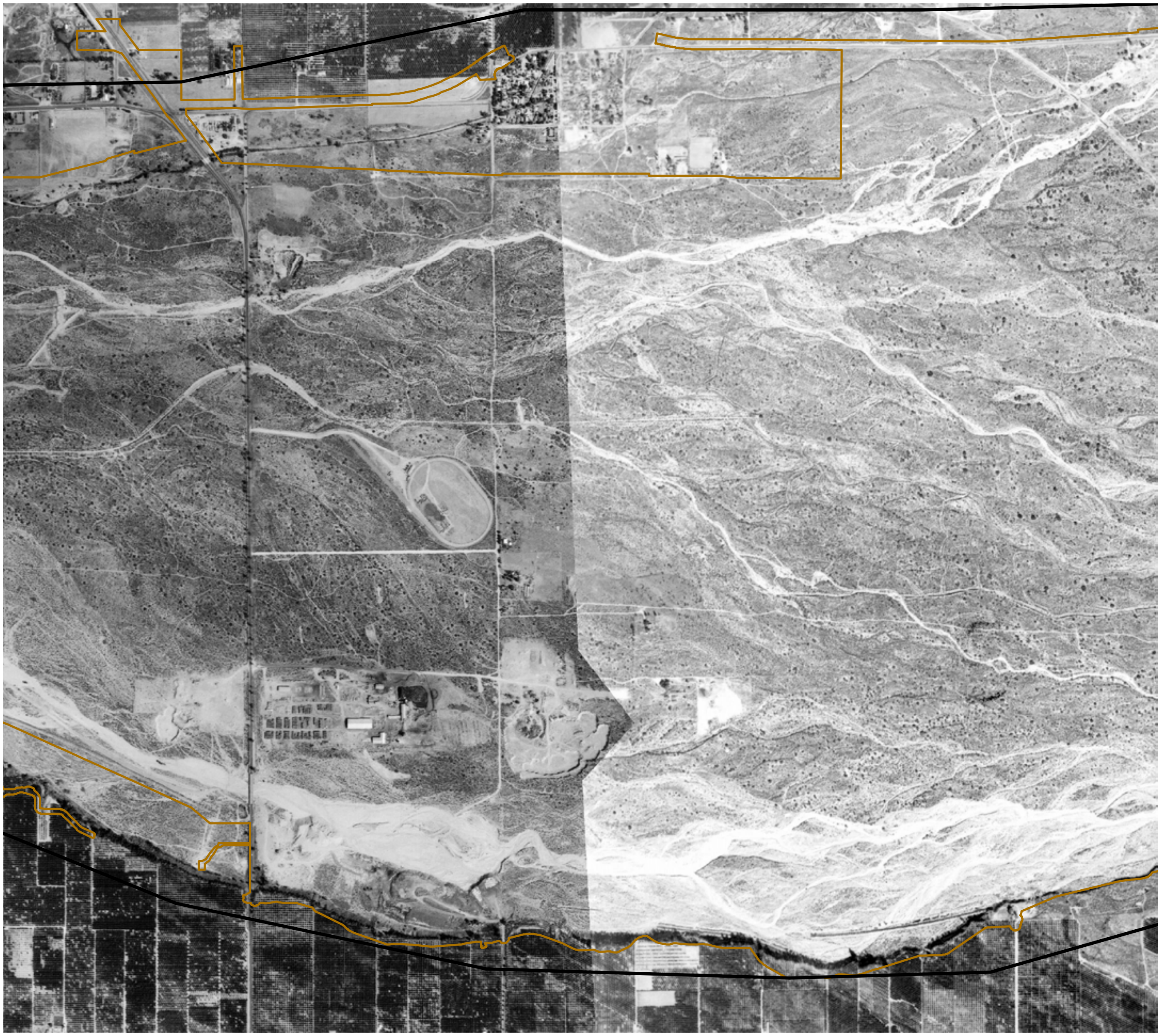
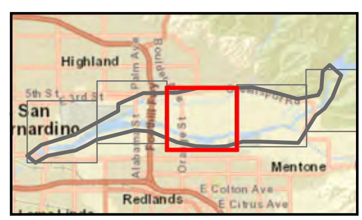
1 inch = 1,667 feet

Figure 19 Historic Aerial 1953-1959



Legend

- Area Of Interest
- SA River Wash Plan Area



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1 inch = 1,667 feet

Figure 19 Historic Aerial 1953-1959

ICF

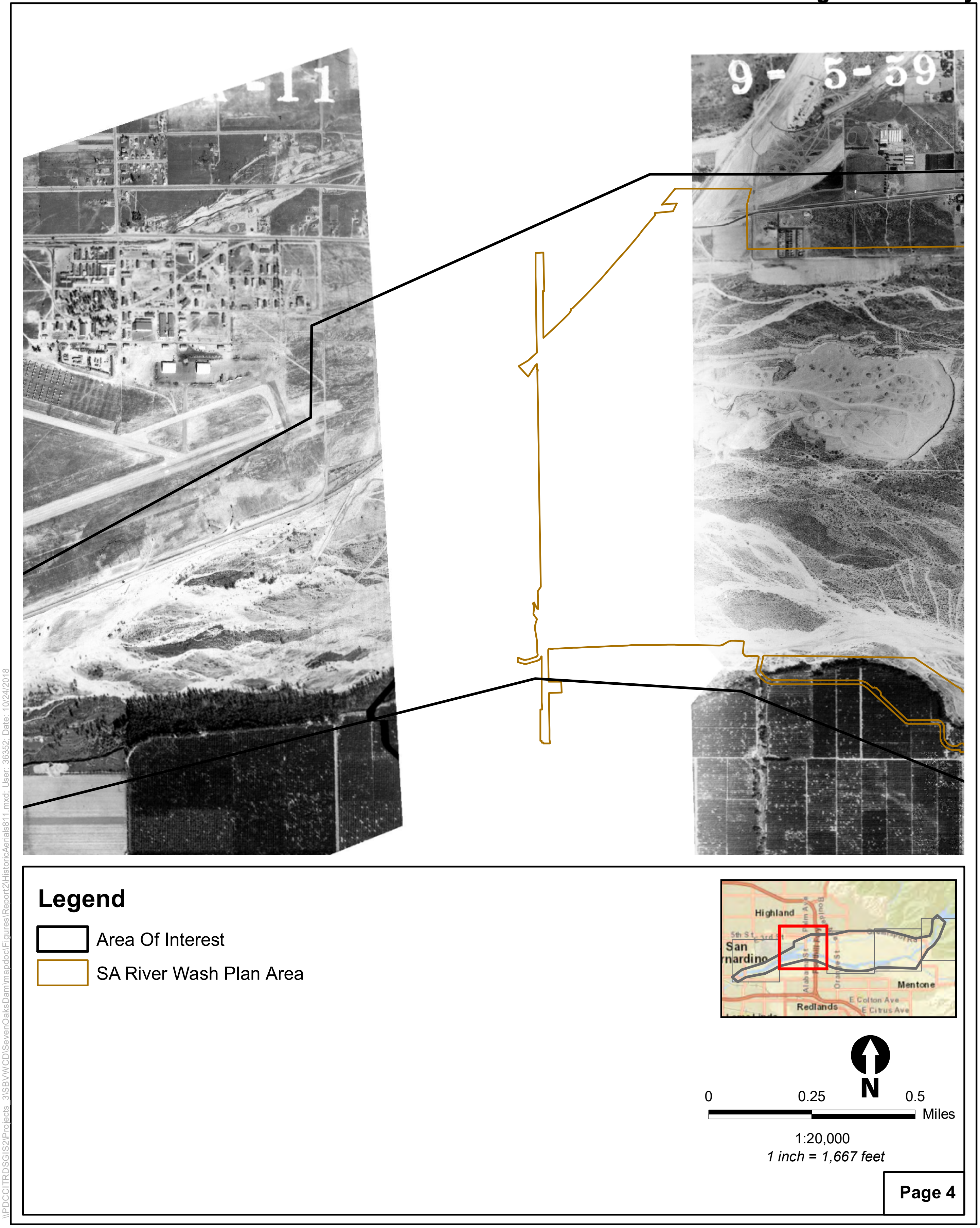
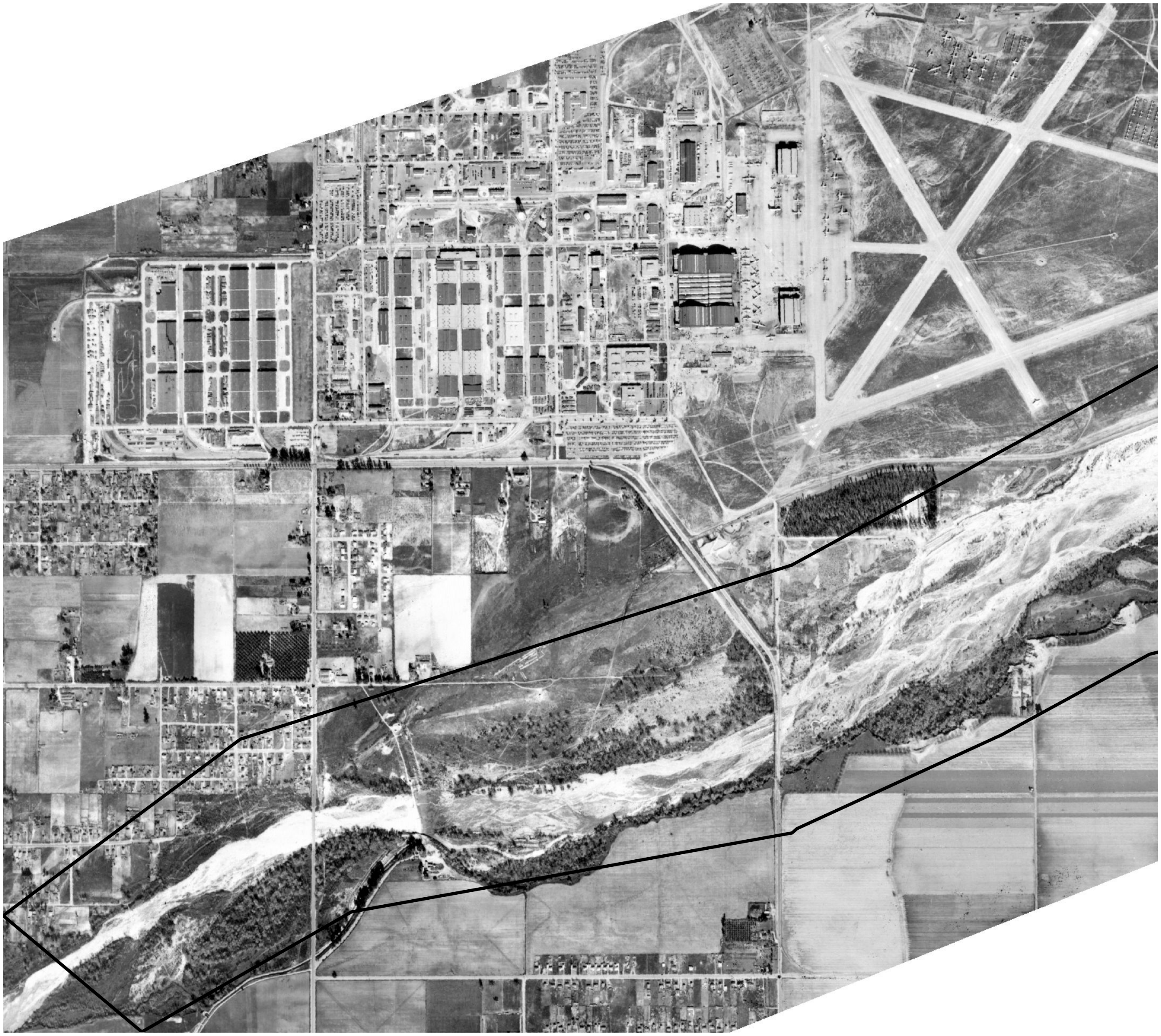


Figure 19 Historic Aerial 1953-1959



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- Area Of Interest
- SA River Wash Plan Area

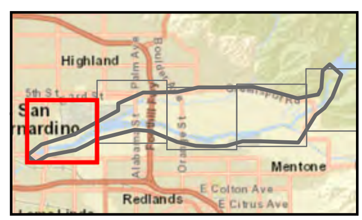

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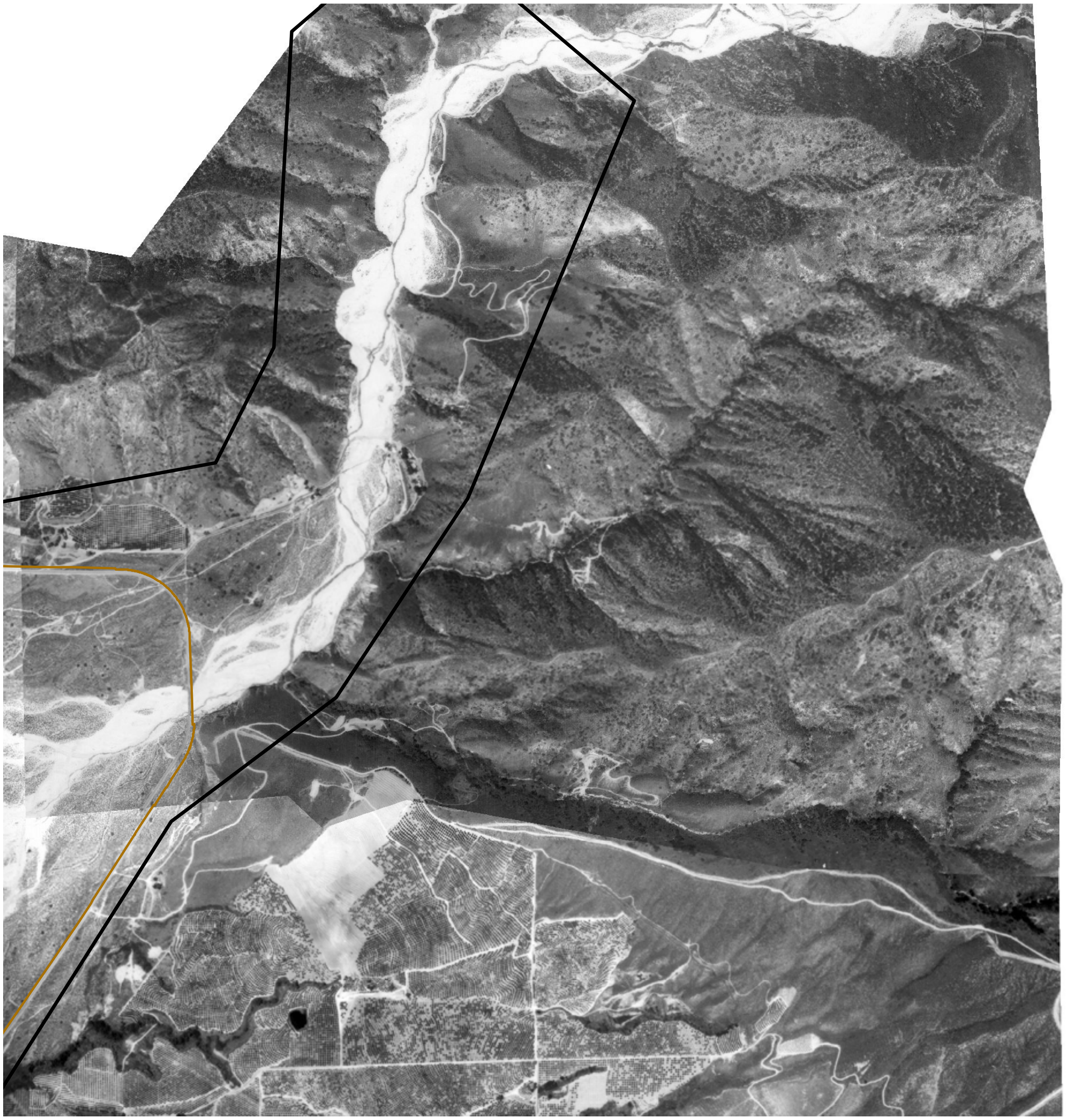
Figure 19 Historic Aerial 1953-1959



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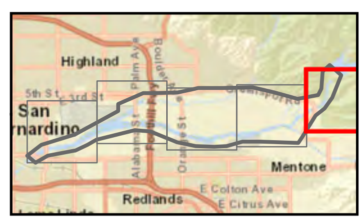
- Area Of Interest
- SA River Wash Plan Area



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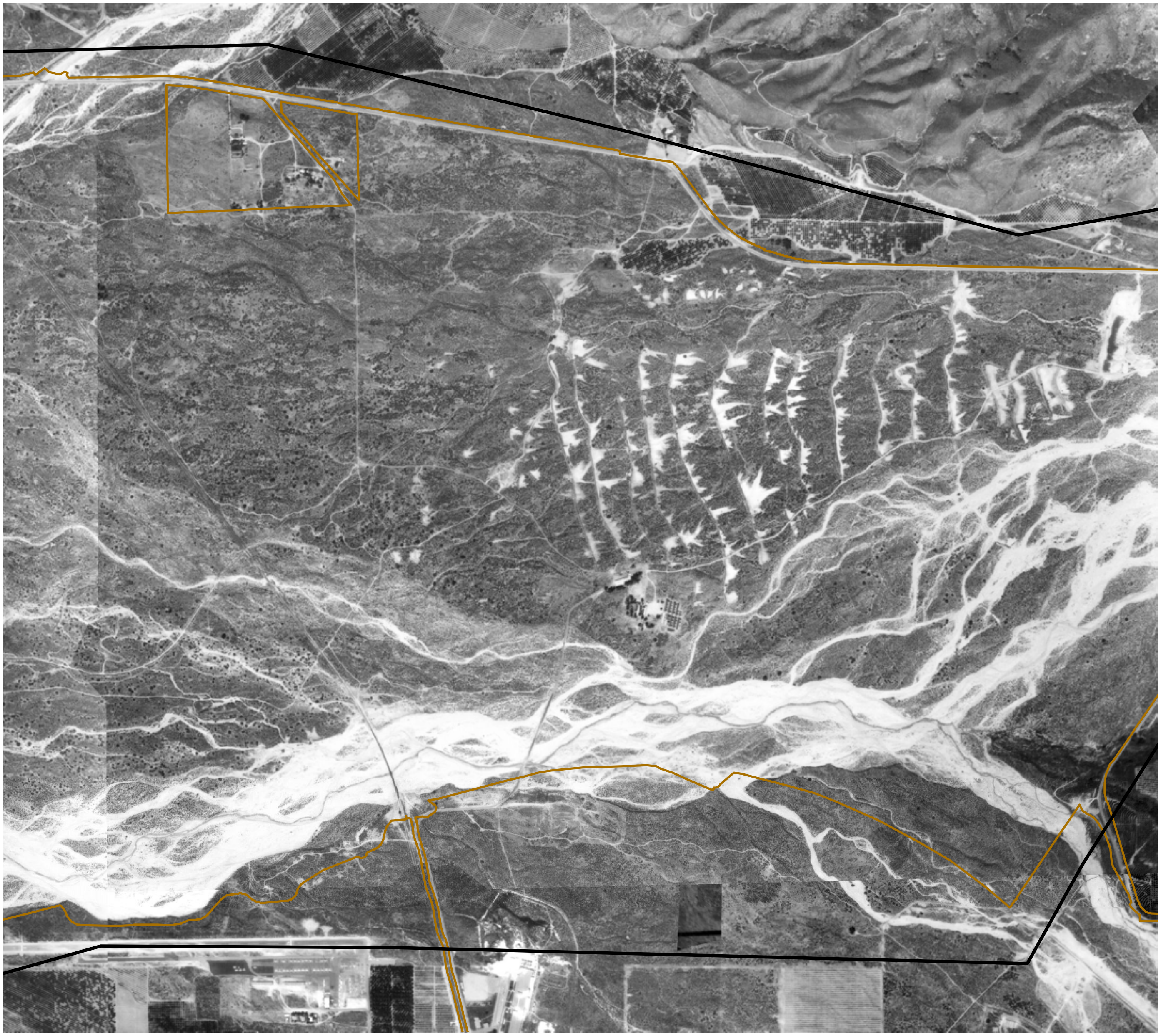
1 inch = 1,667 feet

Figure 20 Historic Aerial May 1968

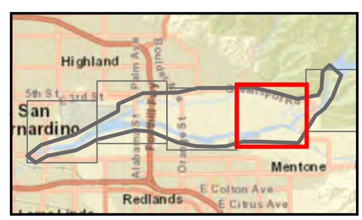
ICF



Legend

Area Of Interest

SA River Wash Plan Area



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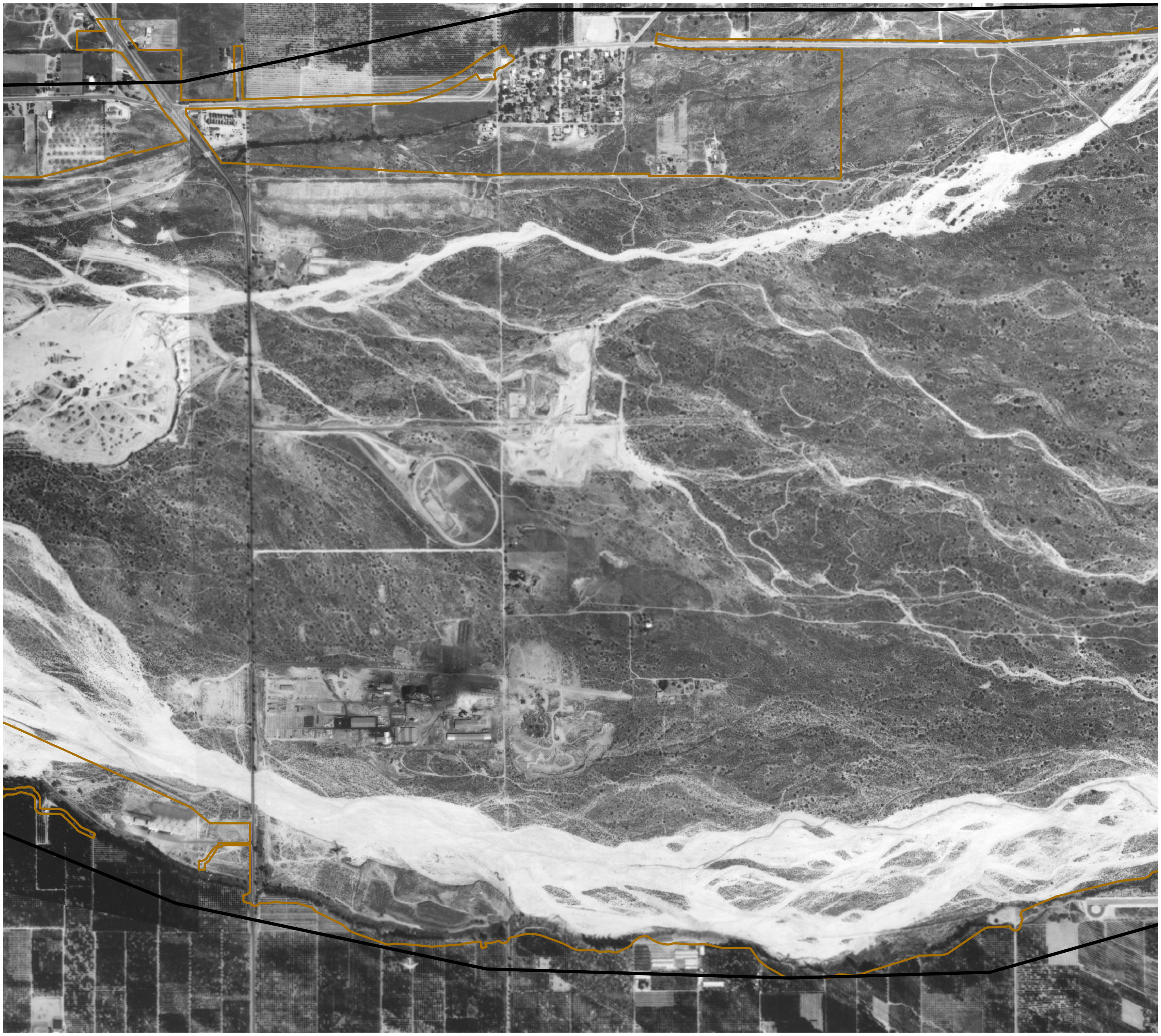
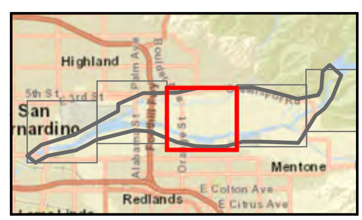
1 inch = 1,667 feet

Figure 20 Historic Aerial May 1968



Legend

- Area Of Interest
- SA River Wash Plan Area



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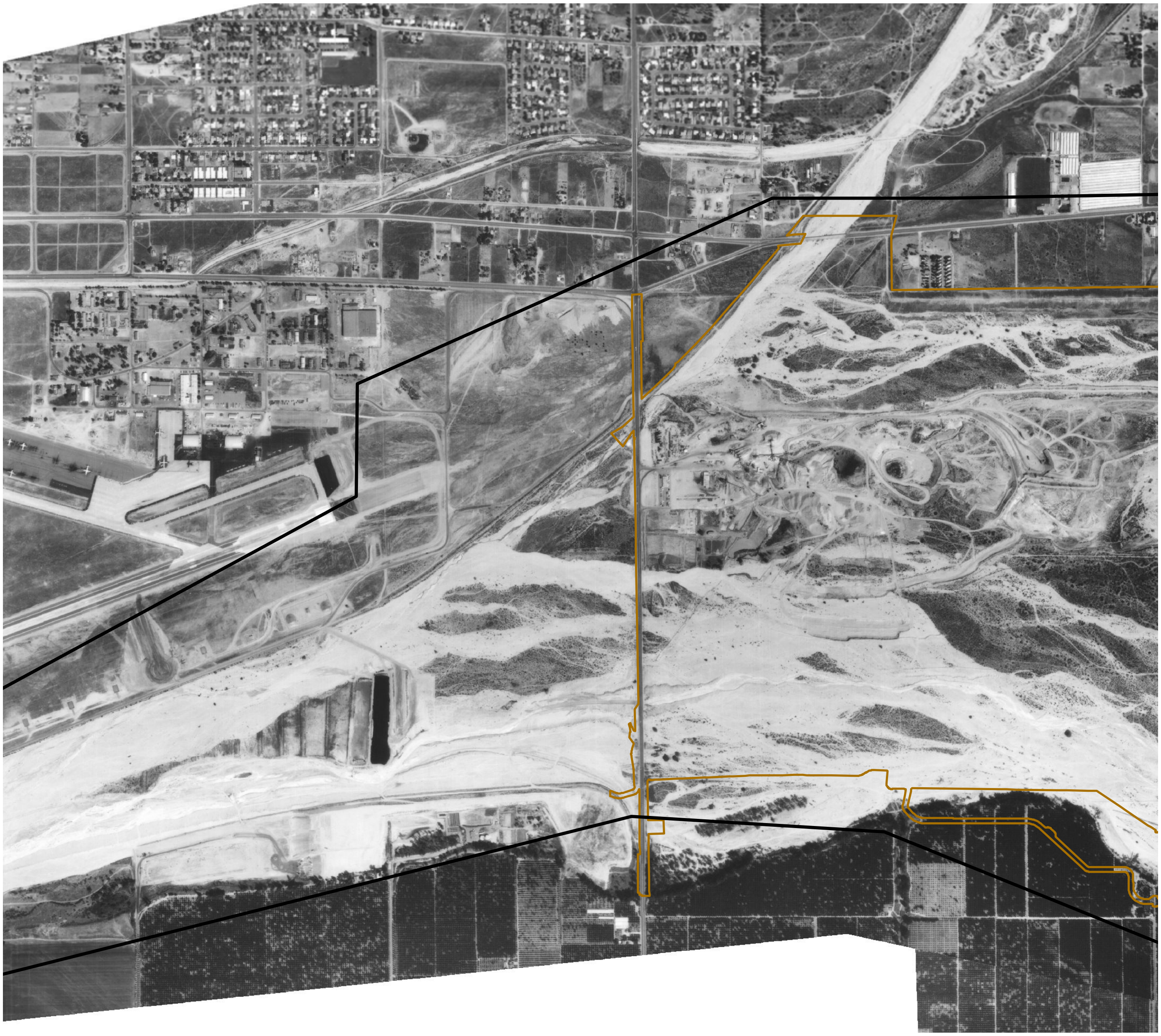
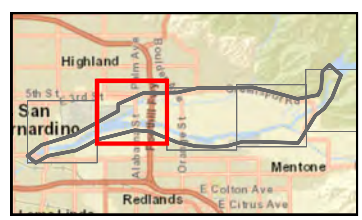
1 inch = 1,667 feet

Figure 20 Historic Aerial May 1968



Legend

- Area Of Interest
- SA River Wash Plan Area



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1 inch = 1,667 feet

Figure 20 Historic Aerial May 1968

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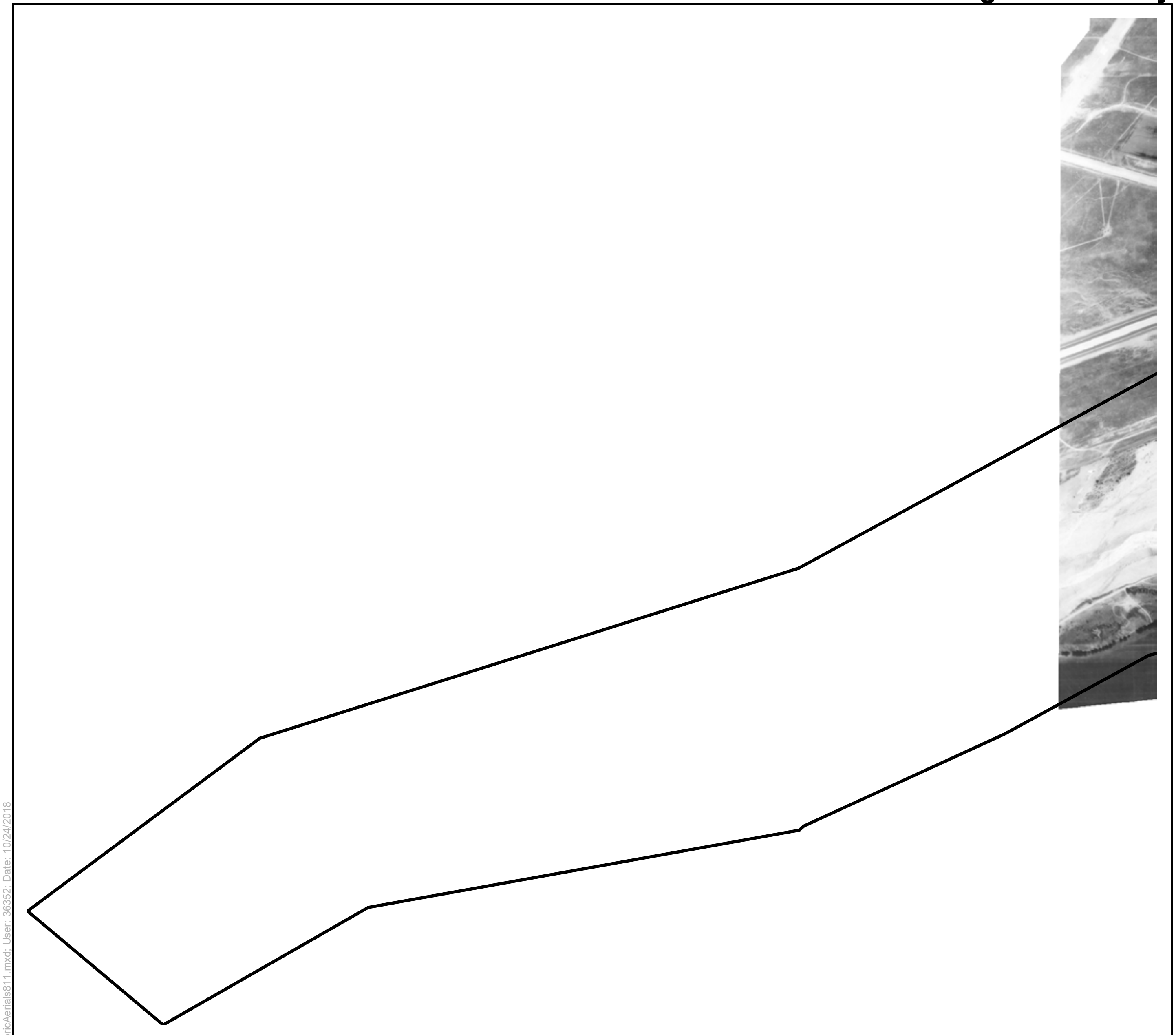

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Area Of Interest

SA River Wash Plan Area

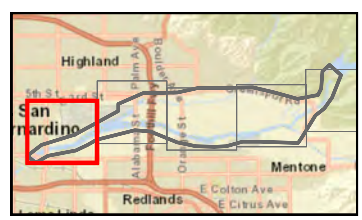

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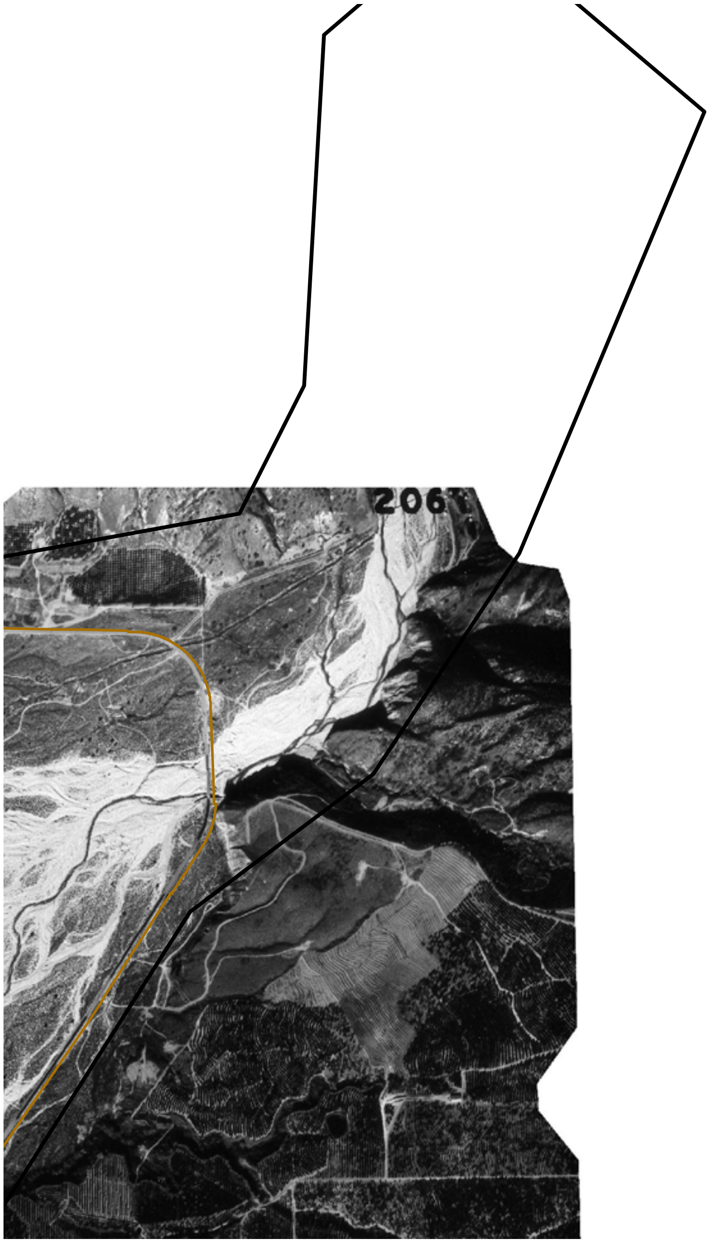
Figure 20 Historic Aerial May 1968



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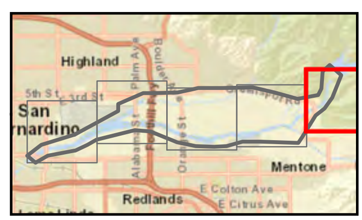
Area Of Interest

SA River Wash Plan Area



N

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1:20,000
1 inch = 1,667 feet

Page 1

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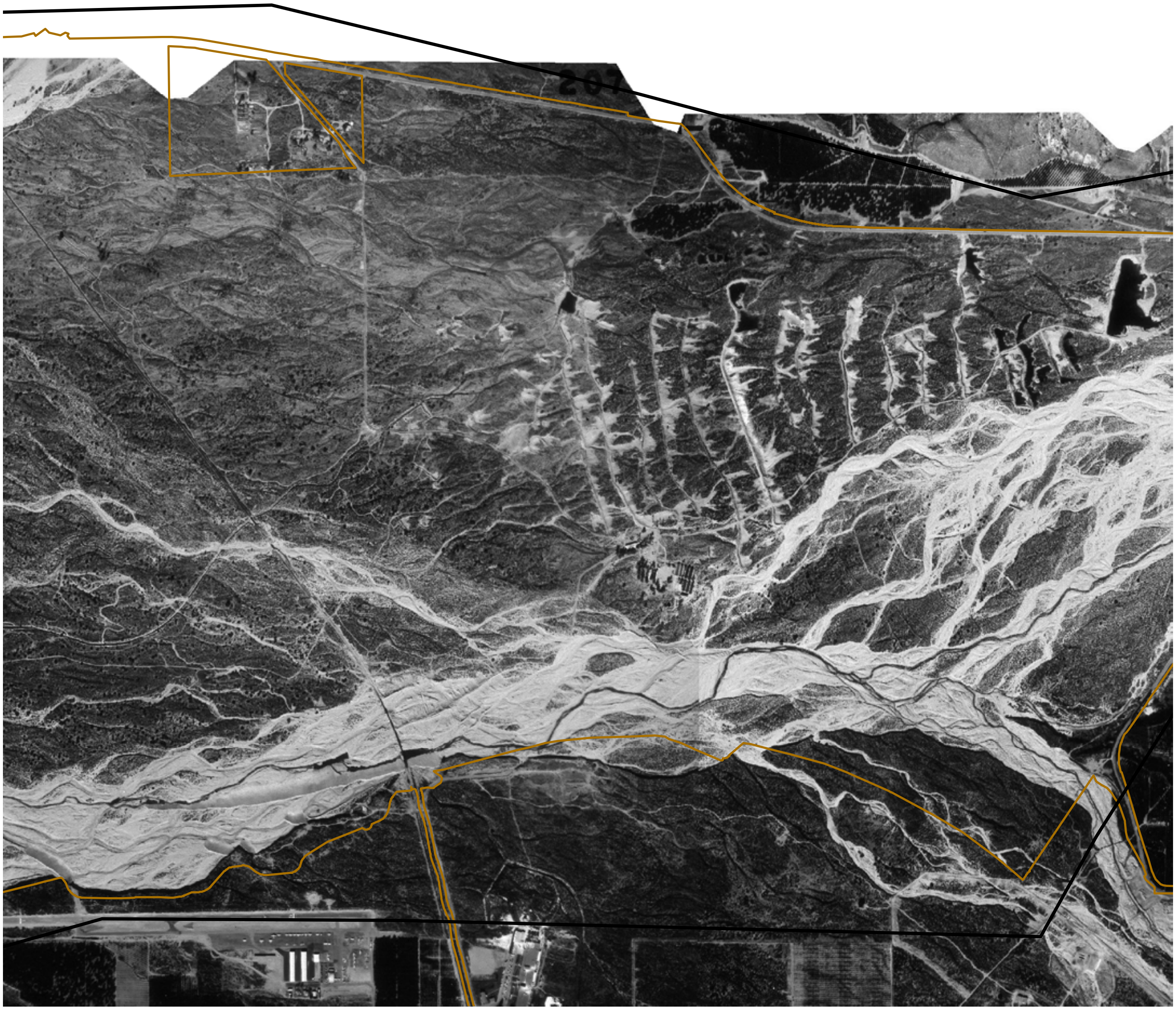
Figure 21 Historic Aerial 1970

ICF



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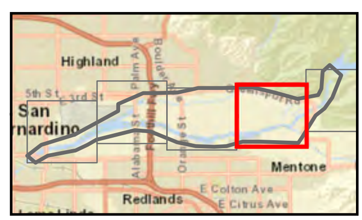
Area Of Interest

SA River Wash Plan Area



N

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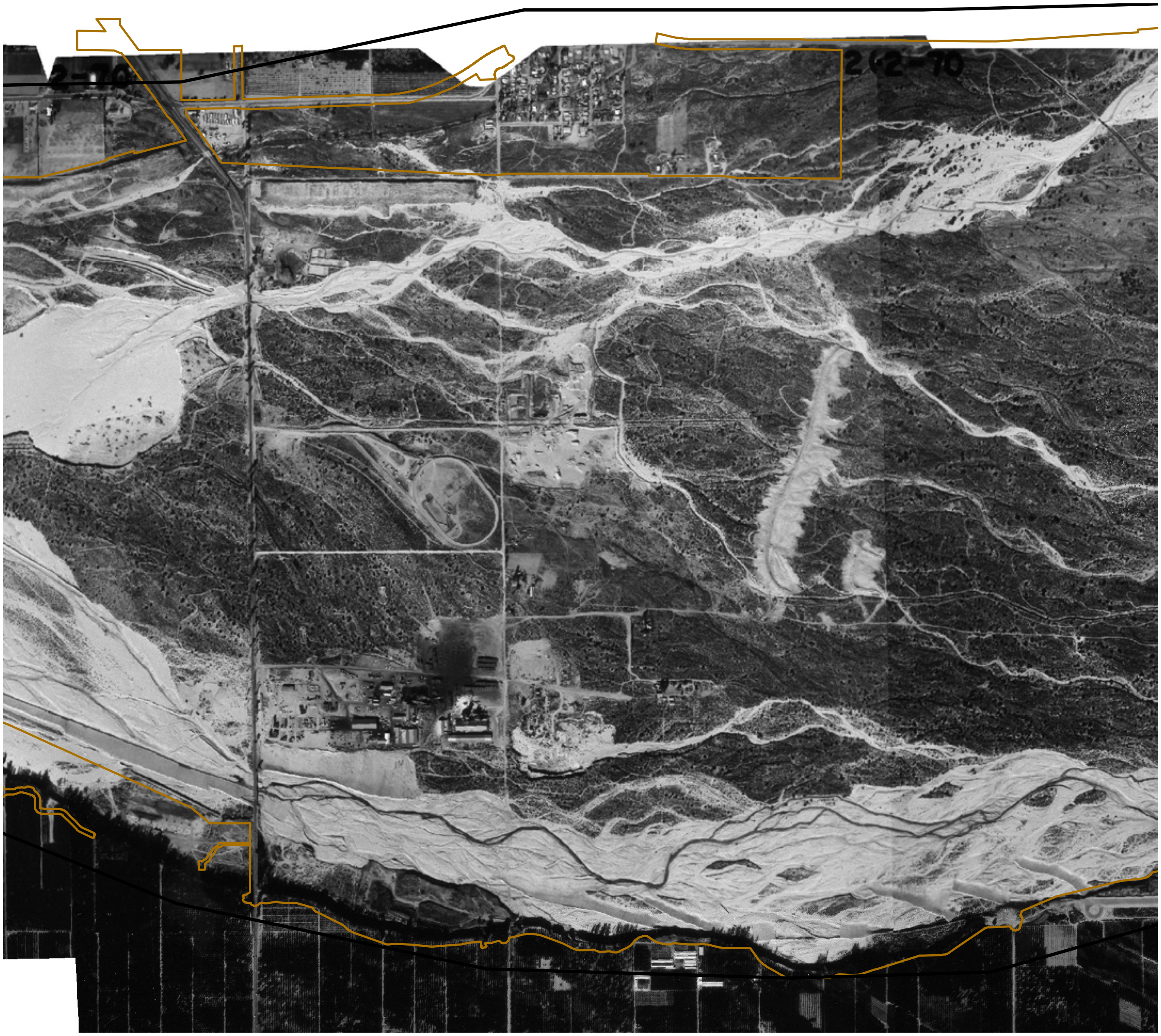
1:20,000

1 inch = 1,667 feet

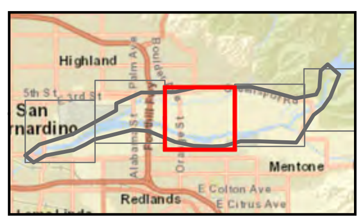
Figure 21 Historic Aerial 1970

ICF



Legend

Area Of Interest
SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000
1 inch = 1,667 feet

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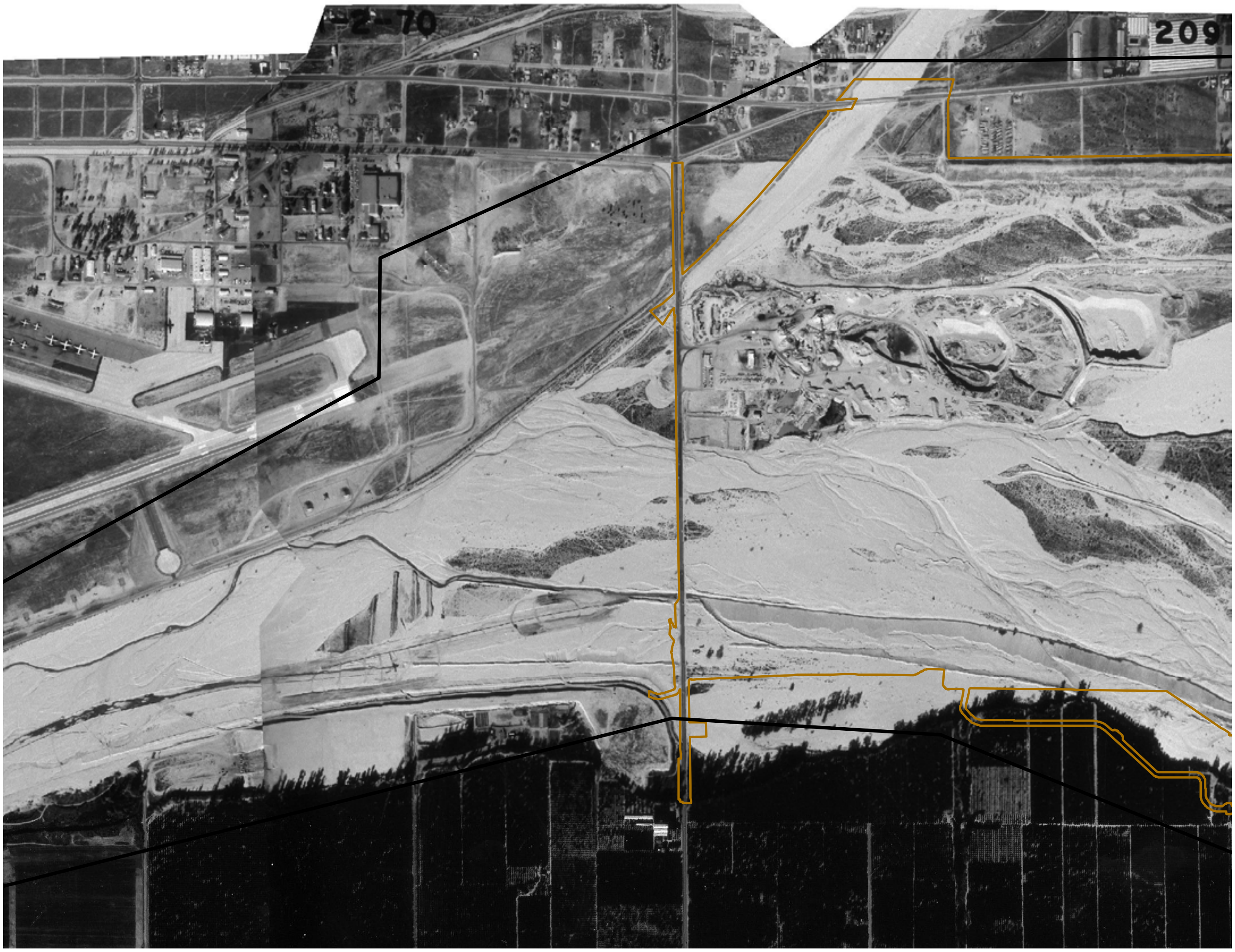
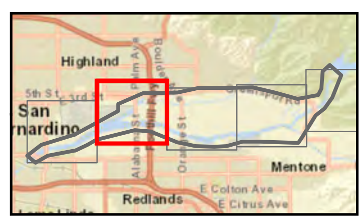
Figure 21 Historic Aerial 1970



Legend

- Area Of Interest
- SA River Wash Plan Area



N

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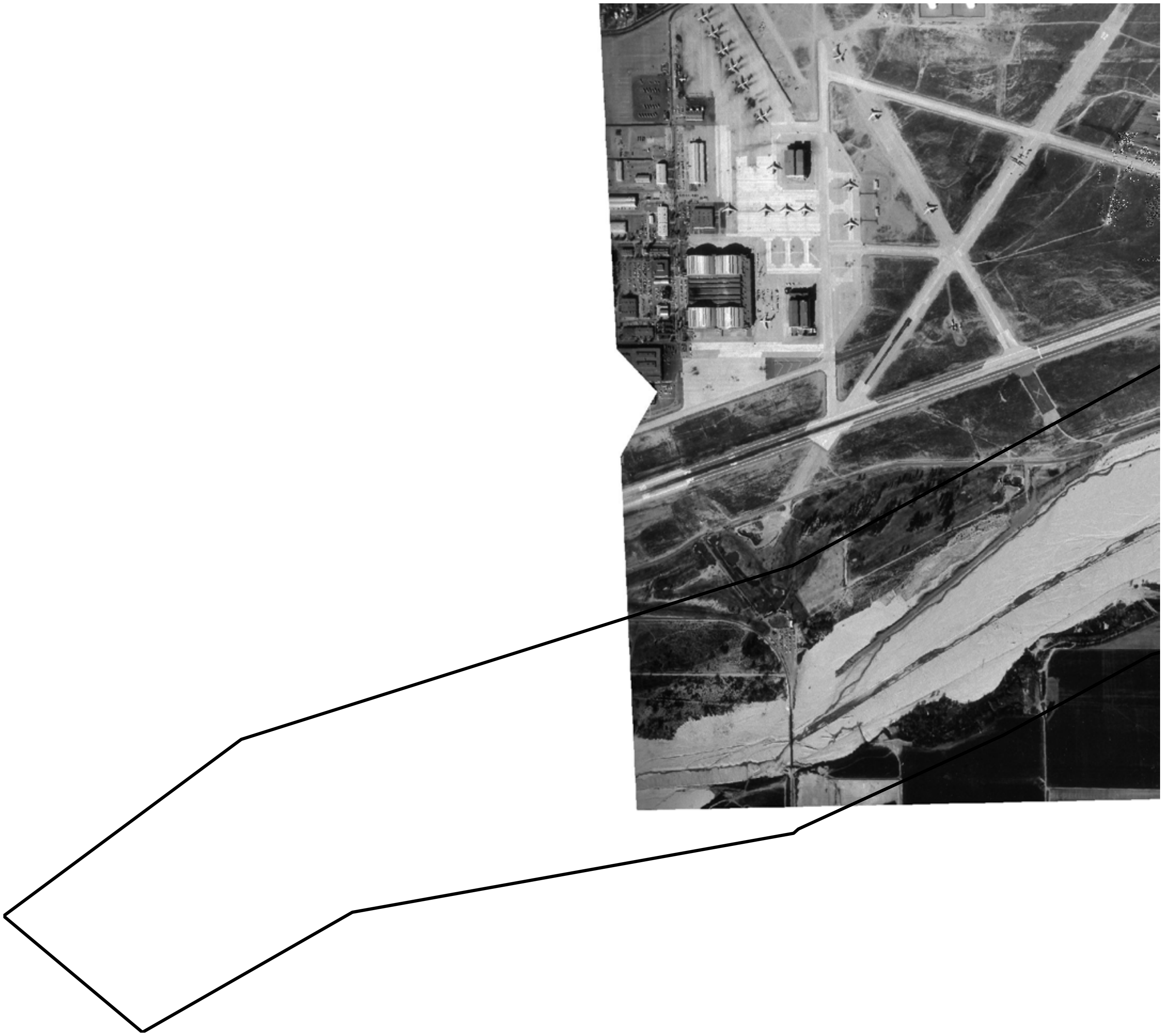
1:20,000

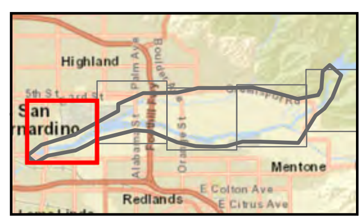
1 inch = 1,667 feet

Figure 21 Historic Aerial 1970



Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000
1 inch = 1,667 feet

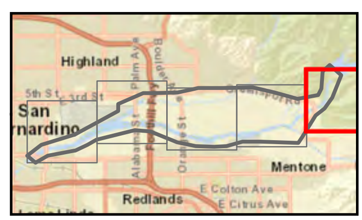
\\PDCCITRDSGIS2\Projects_3\SBVWCD\SevenOaksDam\mapdoc\Figures\Report2\HistoricAerials811.mxd; User: 36352; Date: 10/24/2018

Figure 21 Historic Aerial 1970

ICF

Legend

- Area Of Interest
- SA River Wash Plan Area



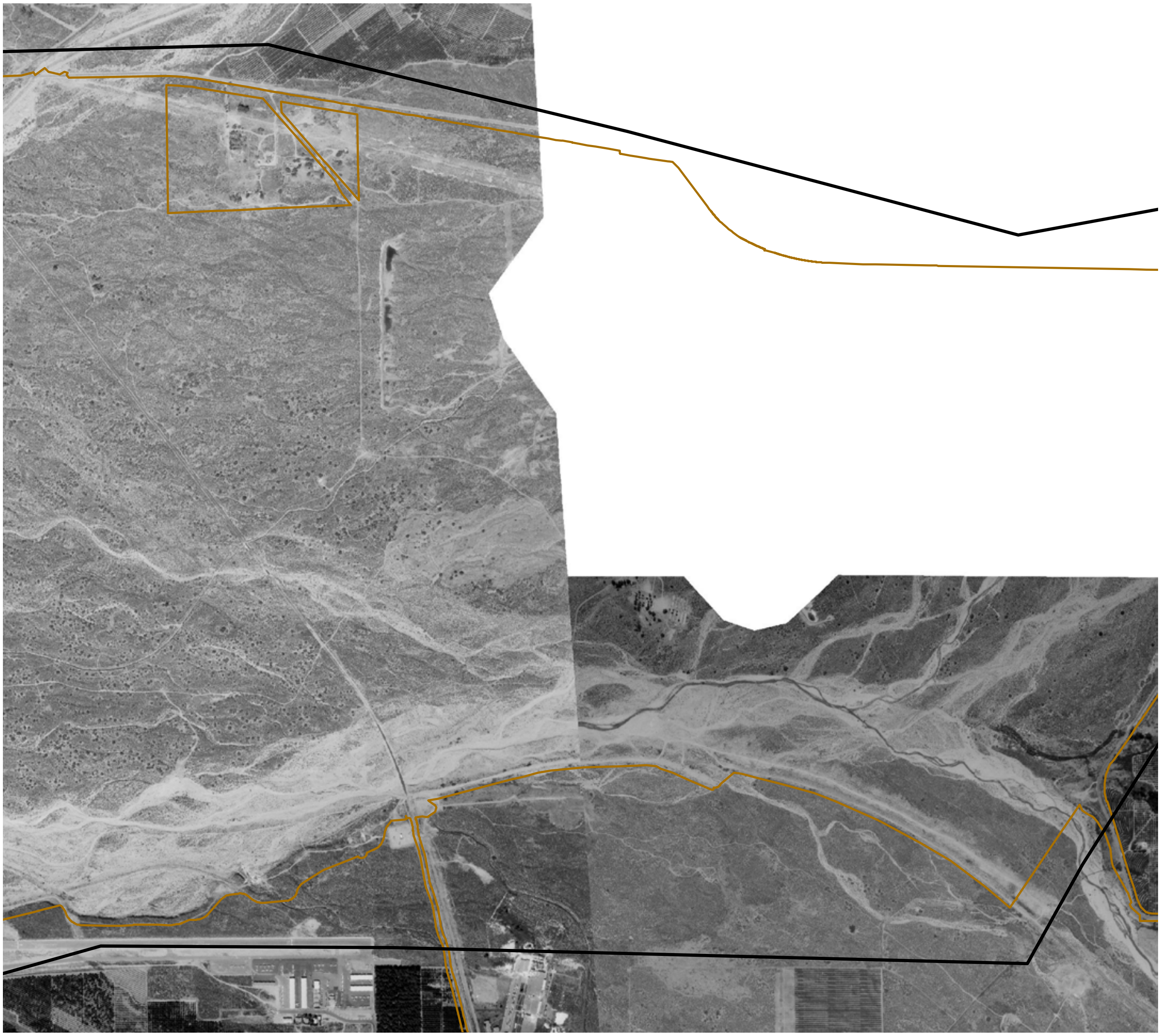
N

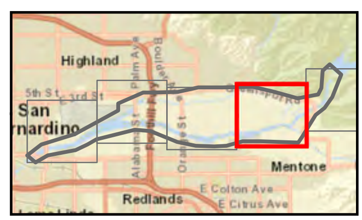
0 0.25 0.5 Miles

1:20,000

1 inch = 1,667 feet

Figure 22 Historic Aerial 1977-1978





Legend

Area Of Interest

SA River Wash Plan Area

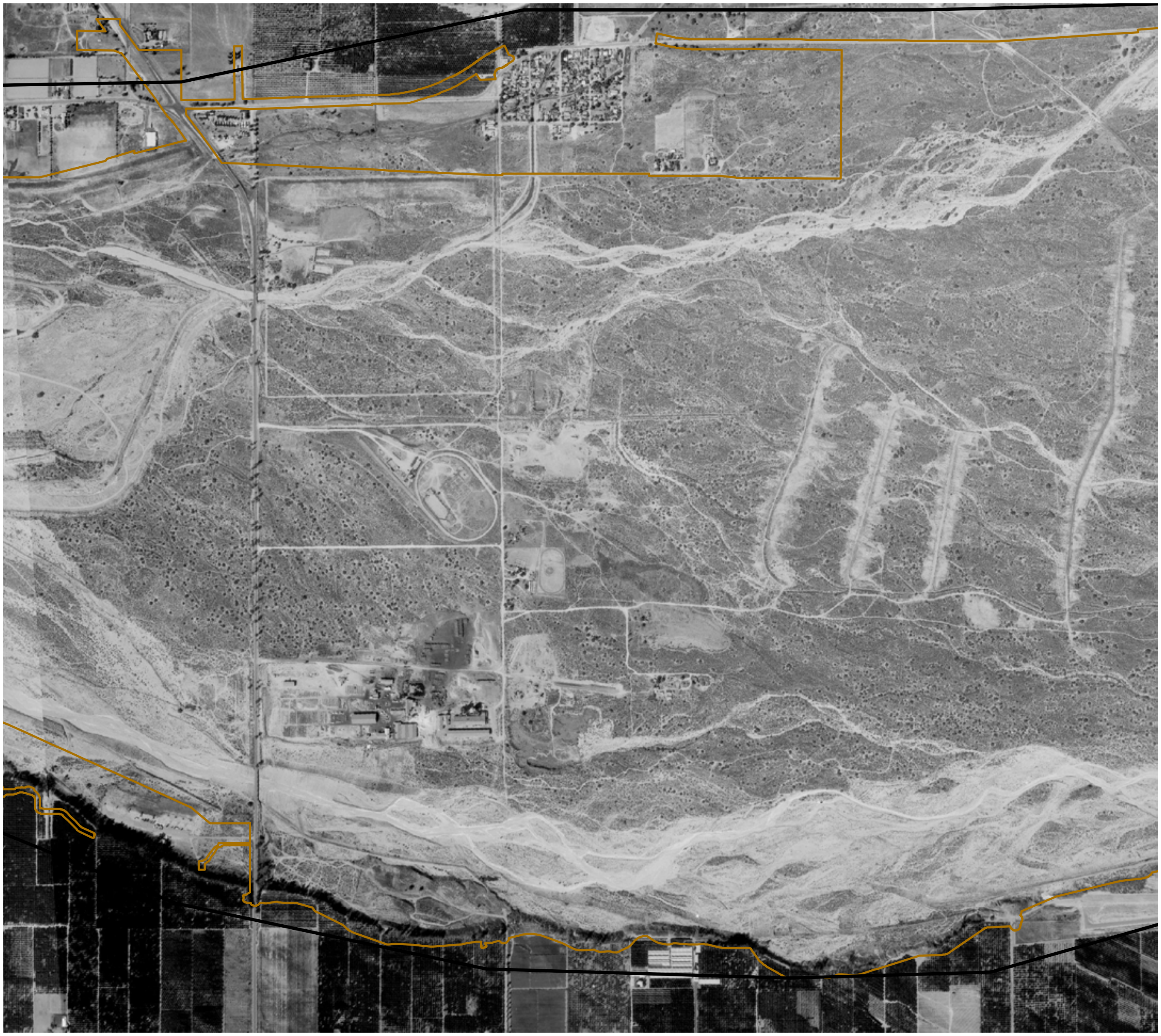
N

0 0.25 0.5 Miles

1:20,000

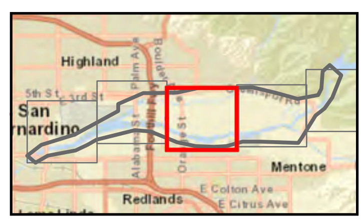
1 inch = 1,667 feet

Figure 22 Historic Aerial 1977-1978



Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000
1 inch = 1,667 feet

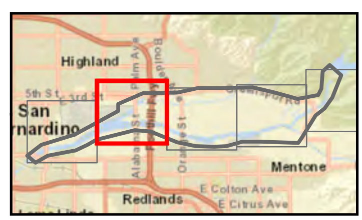
\\PDCCITRDSGIS2\Projects_3\SBVWCD\SevenOaksDam\mapdoc\Figures\Report2\HistoricAerials811.mxd; User: 36352; Date: 10/24/2018

Figure 22 Historic Aerial 1977-1978

Legend

Area Of Interest

SA River Wash Plan Area



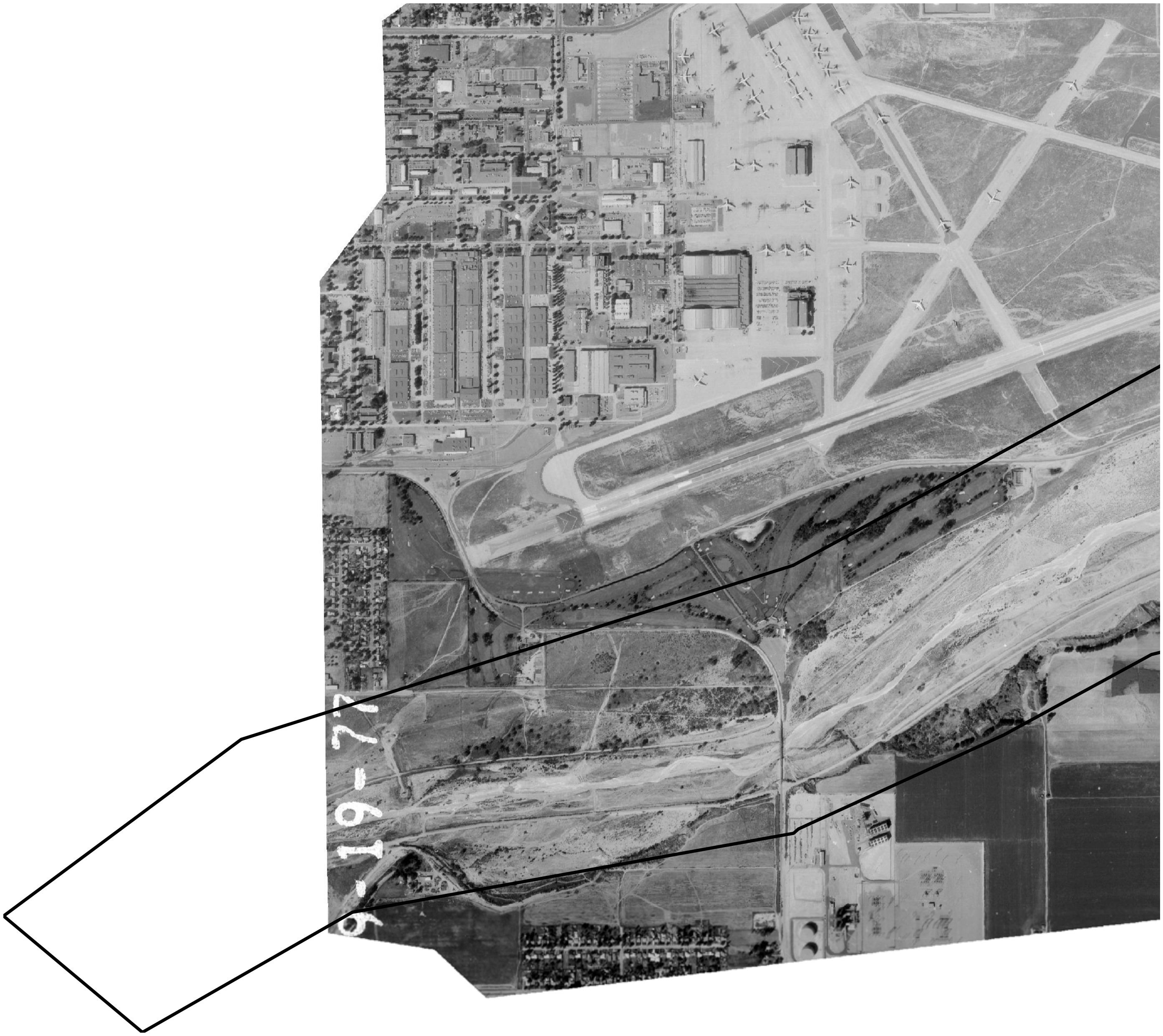
N

0 0.25 0.5 Miles

1:20,000

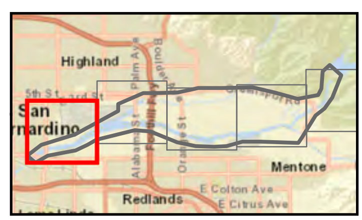
1 inch = 1,667 feet

Figure 22 Historic Aerial 1977-1978



Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

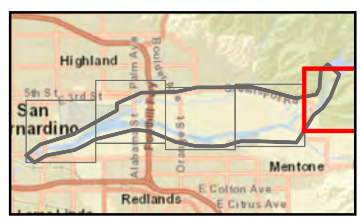
1:20,000

1 inch = 1,667 feet

Figure 22 Historic Aerial 1977-1978

Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

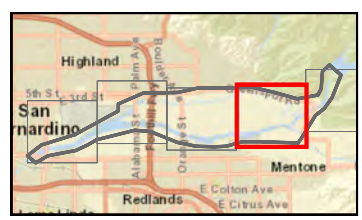
1:20,000

1 inch = 1,667 feet

Figure 23 Historic Aerial 2003

Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000

1 inch = 1,667 feet

Figure 23 Historic Aerial 2003

ICF

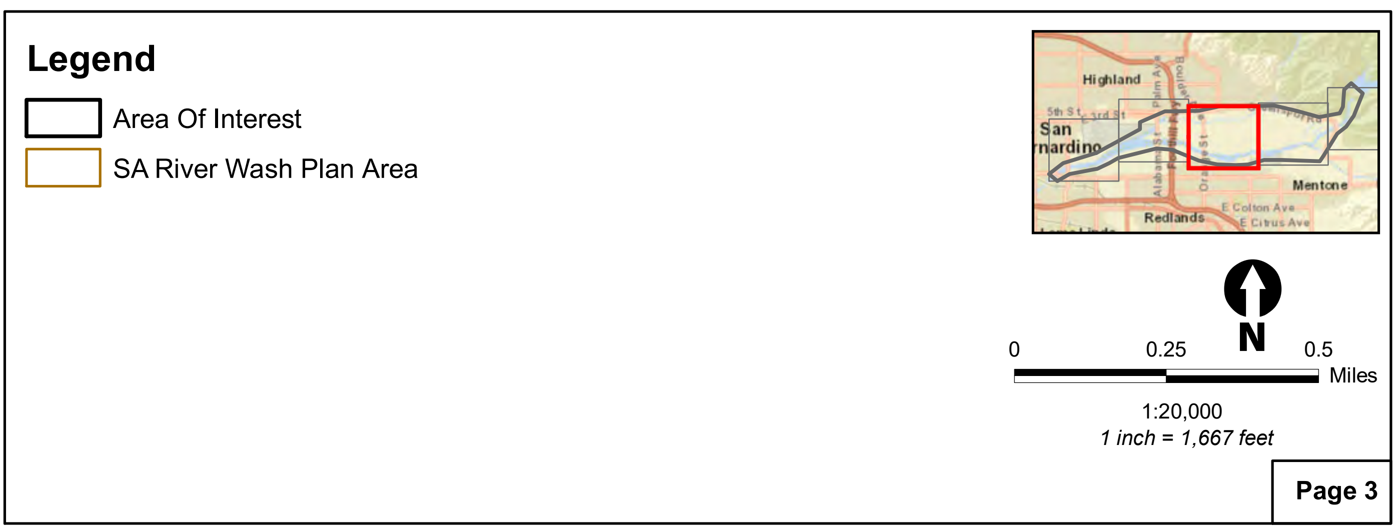
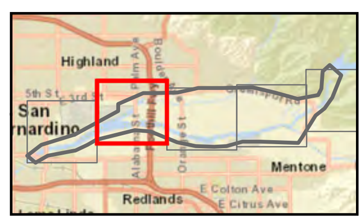


Figure 23 Historic Aerial 2003

Legend

- Area Of Interest
- SA River Wash Plan Area



0 0.25 0.5 Miles

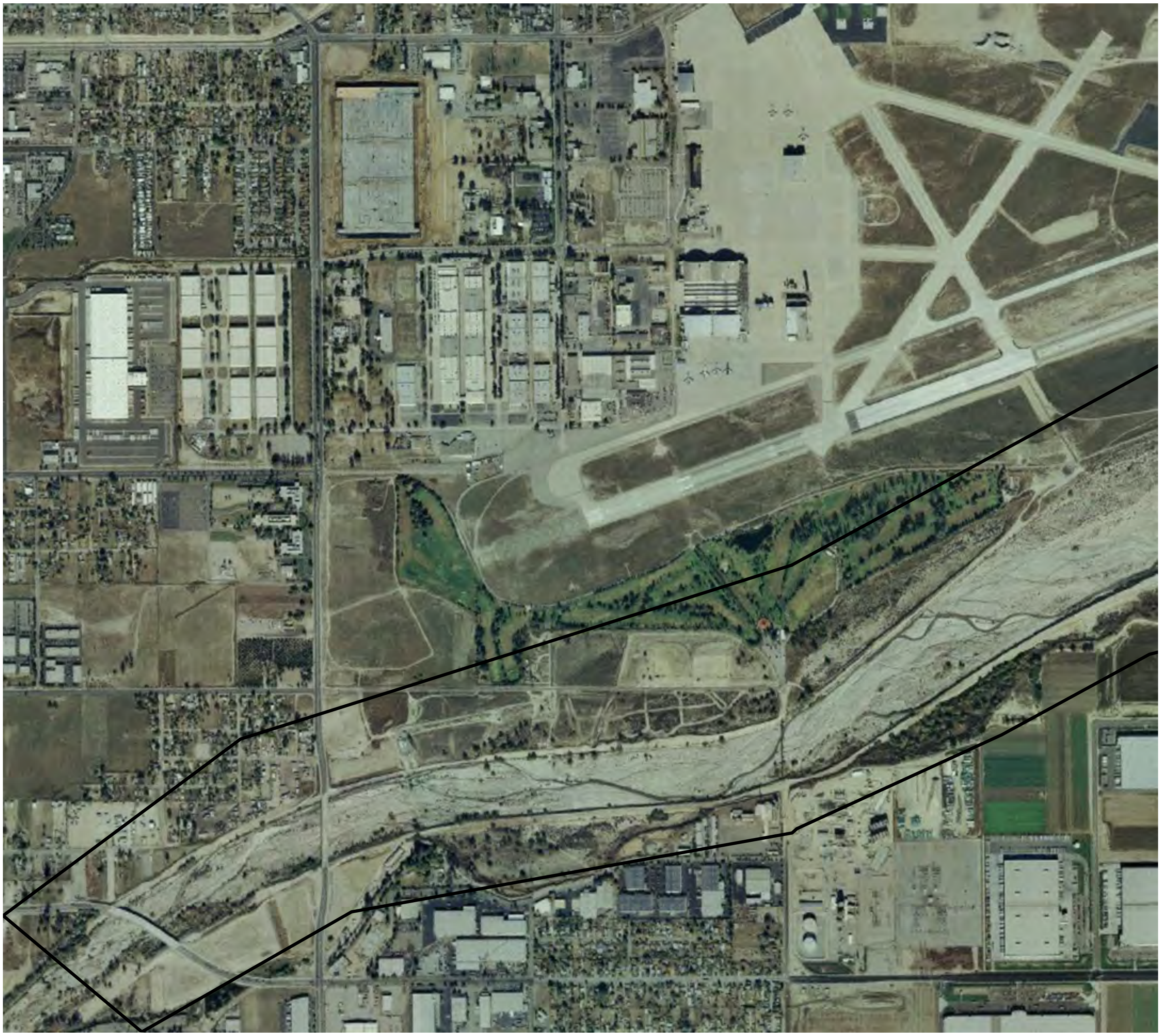
N

1:20,000

1 inch = 1,667 feet

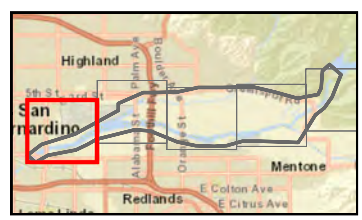
ICF

Figure 23 Historic Aerial 2003



Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000

1 inch = 1,667 feet

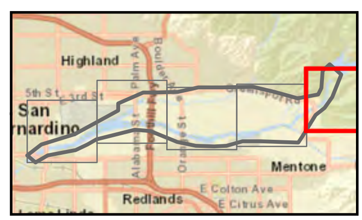
Figure 23 Historic Aerial 2003

ICF

Legend

Area Of Interest

SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000

1 inch = 1,667 feet

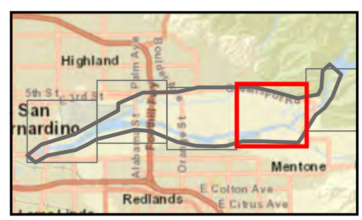
Figure 24 Historic Aerial 2009

ICF

Legend

Area Of Interest

SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000

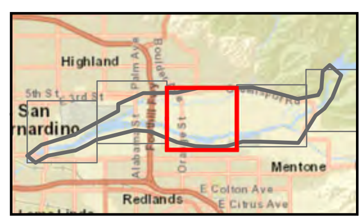
1 inch = 1,667 feet

Figure 24 Historic Aerial 2009

ICF

Legend

- Area Of Interest
- SA River Wash Plan Area



0 0.25 0.5 Miles

1:20,000

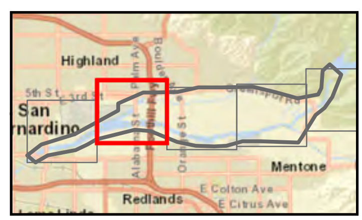
1 inch = 1,667 feet

Figure 24 Historic Aerial 2009

Legend

Area Of Interest

SA River Wash Plan Area



N

0 0.25 0.5 Miles

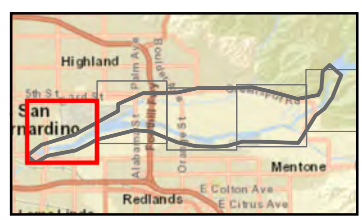
1:20,000

1 inch = 1,667 feet

Figure 24 Historic Aerial 2009

Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

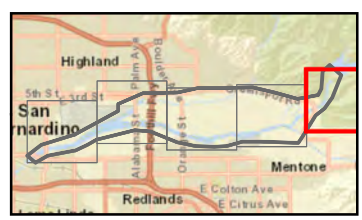
1:20,000

1 inch = 1,667 feet

Figure 24 Historic Aerial 2009

Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000
1 inch = 1,667 feet

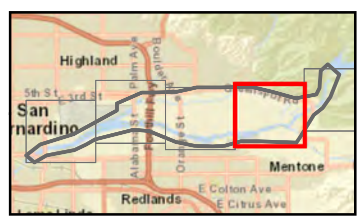
Figure 25 Aerial 2017

ICF

Legend

Area Of Interest

SA River Wash Plan Area



N

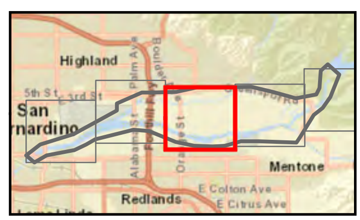
0 0.25 0.5 Miles

1:20,000

1 inch = 1,667 feet

Page 2

Figure 25 Aerial 2017



Legend

Area Of Interest

SA River Wash Plan Area

0 0.25 0.5 Miles

N

1:20,000

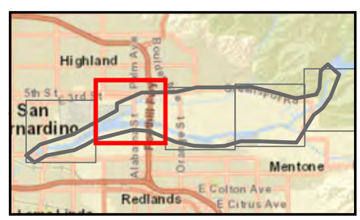
1 inch = 1,667 feet

Figure 25 Aerial 2017

Legend

Area Of Interest

SA River Wash Plan Area



N

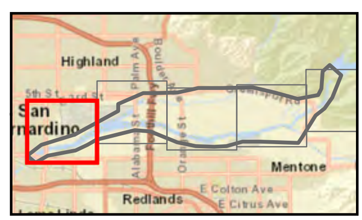
0 0.25 0.5 Miles

1:20,000
1 inch = 1,667 feet

Figure 25 Aerial 2017

Legend

- Area Of Interest
- SA River Wash Plan Area



N

0 0.25 0.5 Miles

1:20,000

1 inch = 1,667 feet

Figure 25 Aerial 2017

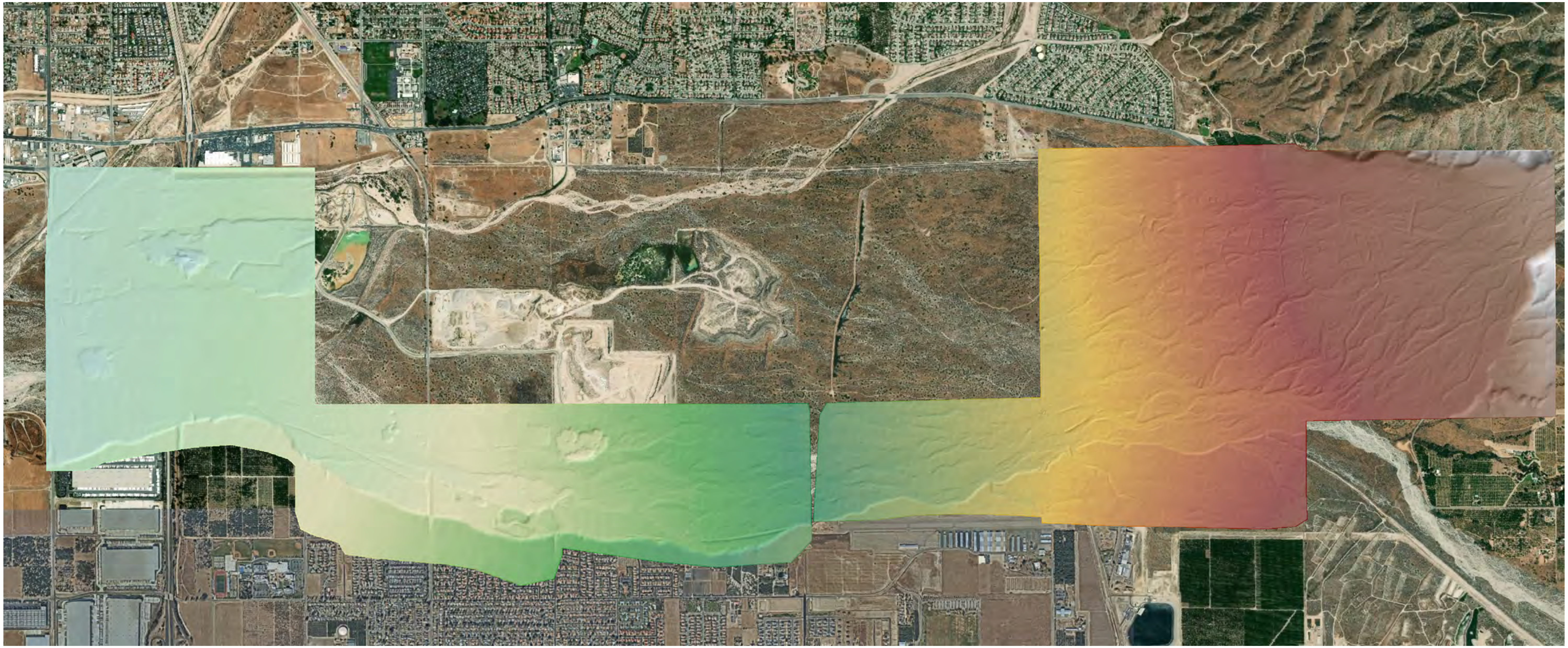


Figure 26
1964 Topographic Coverage

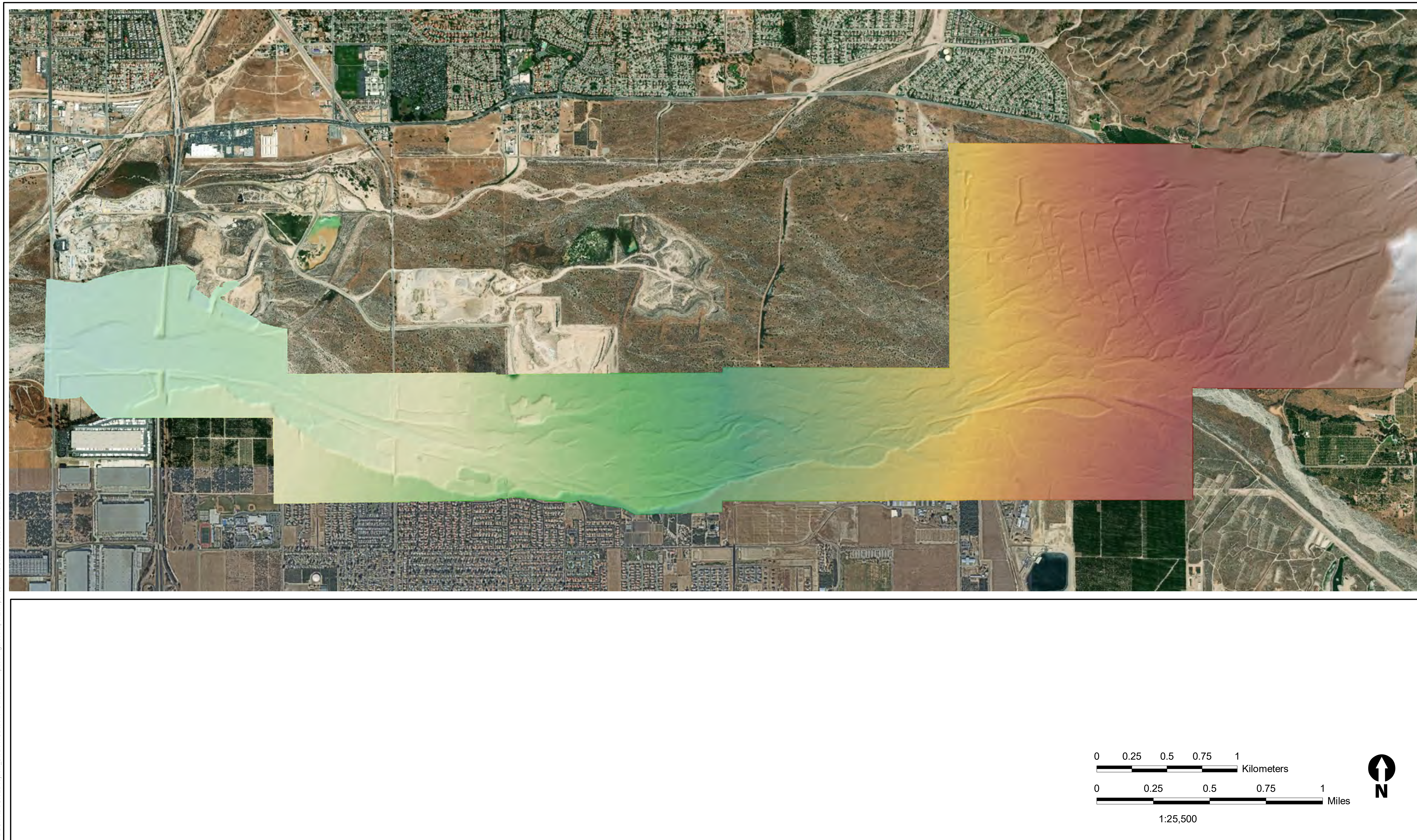


Figure 27
1987 Topographic Coverage

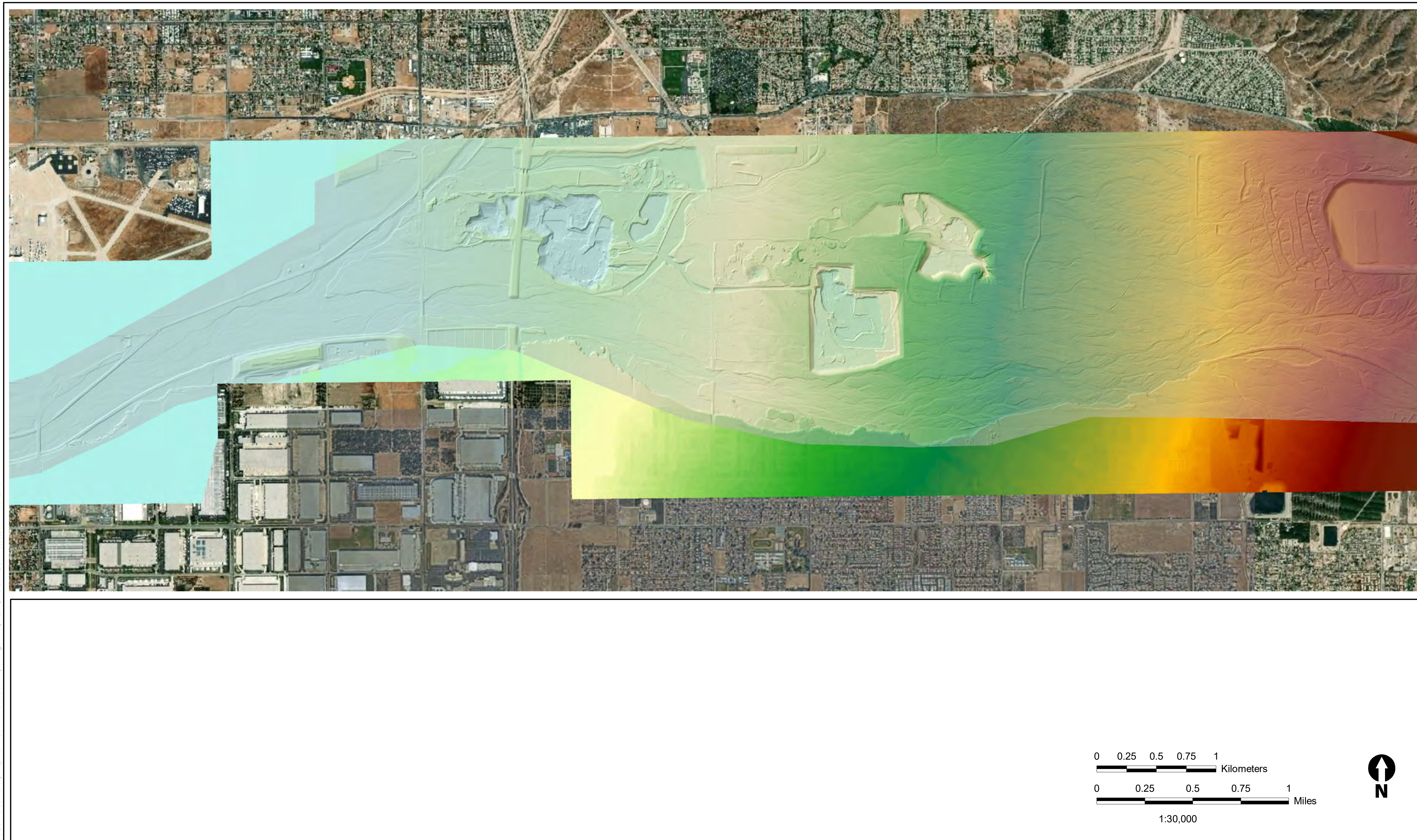
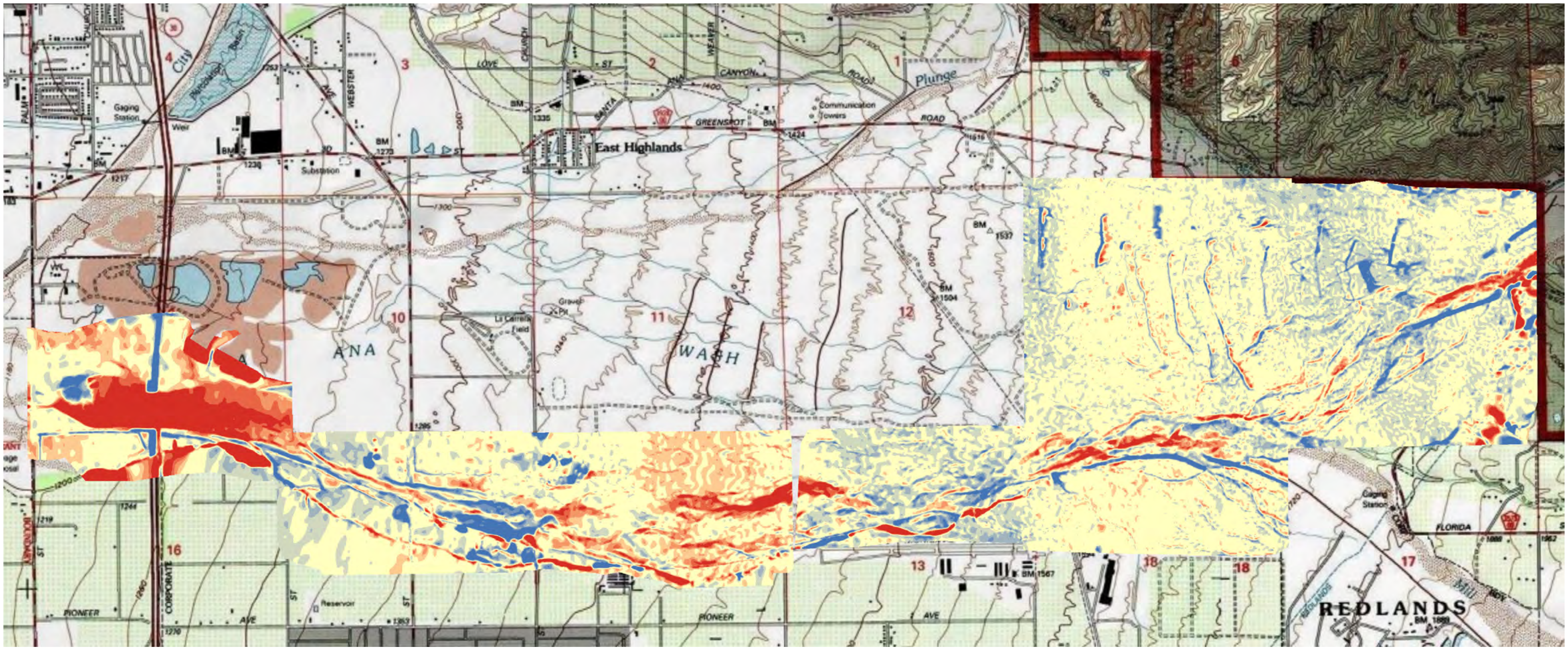


Figure 28
2015 Topographic Coverage



Legend

-155.2438965 - -8	2.000000001 - 4
-7.999999999 - -6	4.000000001 - 6
-5.999999999 - -4	6.000000001 - 8
-3.999999999 - -2	8.000000001 - 999
-1.999999999 - 2	

0 0.25 0.5 0.75 1 Kilometers

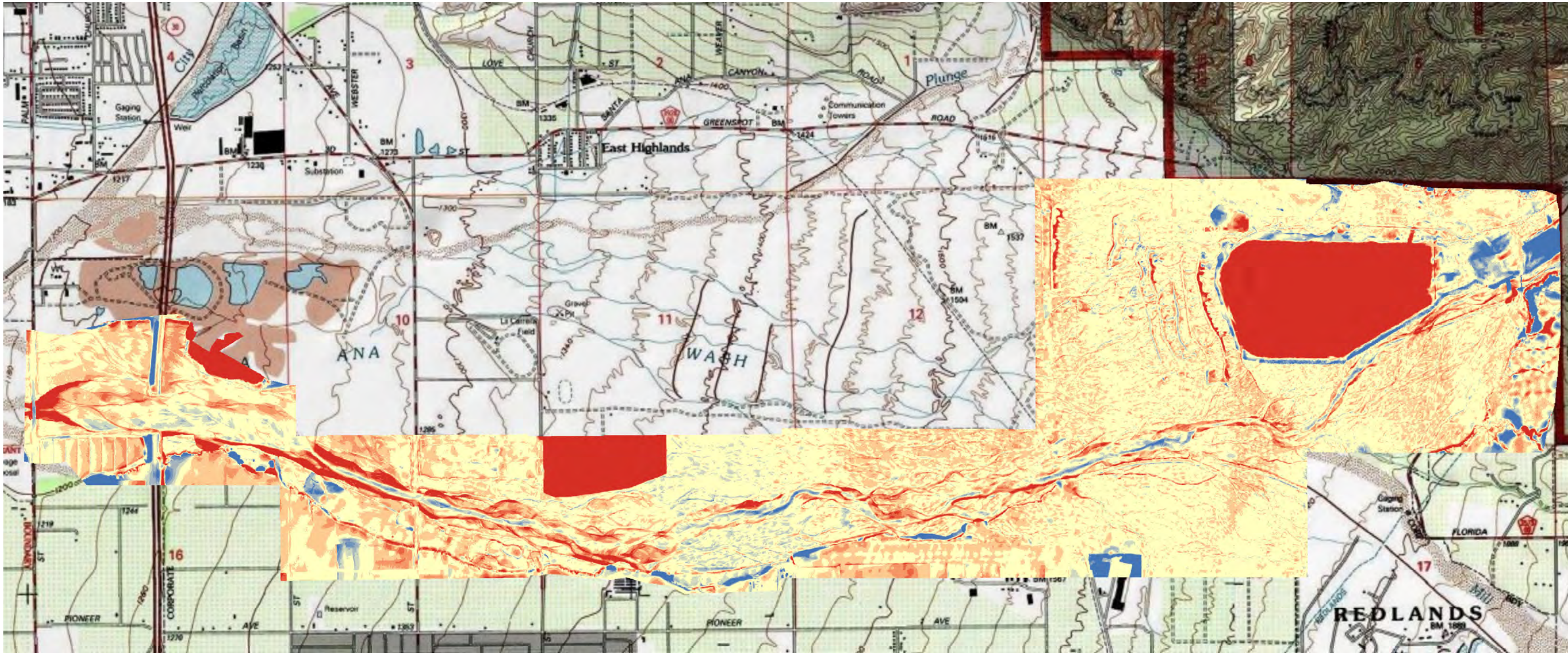
0 0.25 0.5 0.75 1 Miles

1:25,500

N

ICF

Figure 29
Change in Elevation 1964-1987



Legend

-155.2438965 - -8	2.000000001 - 4
-7.999999999 - -6	4.000000001 - 6
-5.999999999 - -4	6.000000001 - 8
-3.999999999 - -2	8.000000001 - 999
-1.999999999 - 2	

0 0.25 0.5 0.75 1 Kilometers

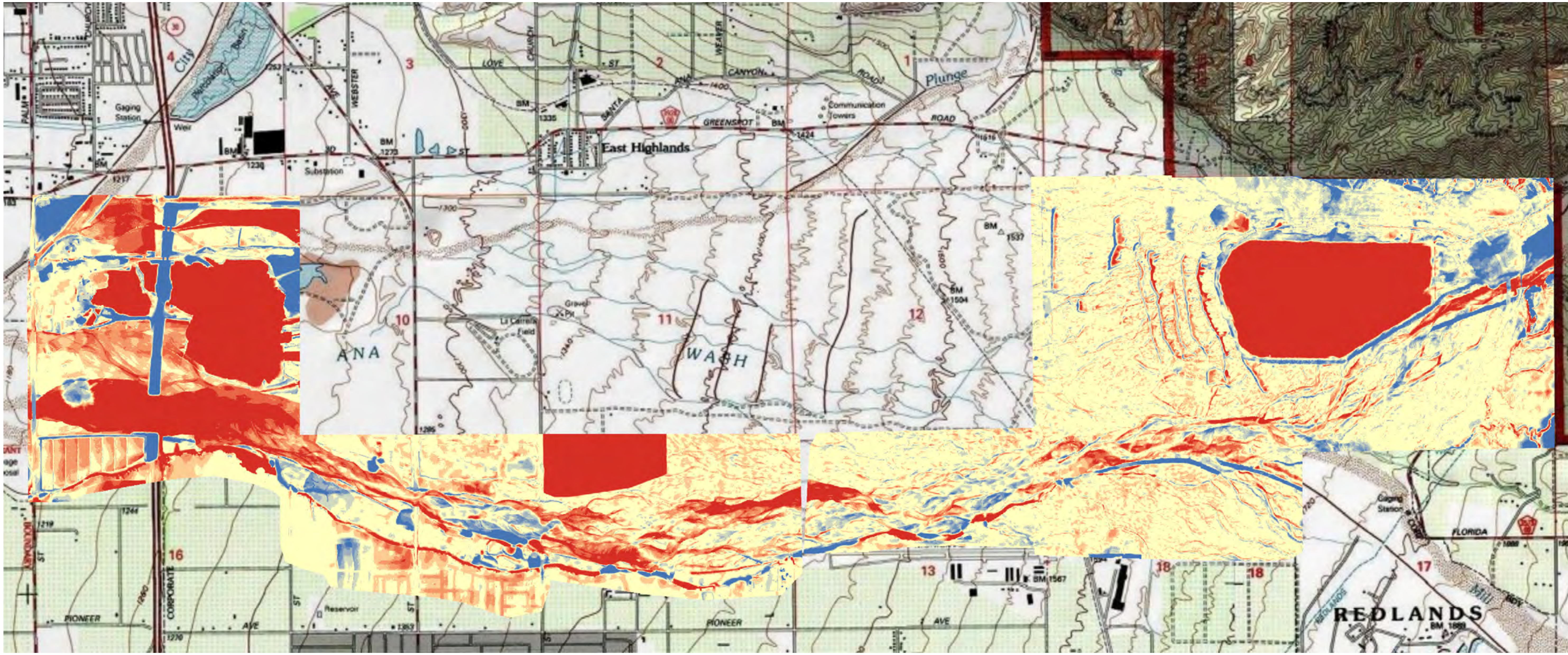
0 0.25 0.5 0.75 1 Miles

1:25,500

N

ICF

Figure 30
Change in Elevation 1987-2015



Legend

-155.2438965 - -8	2.000000001 - 4
-7.999999999 - -6	4.000000001 - 6
-5.999999999 - -4	6.000000001 - 8
-3.999999999 - -2	8.000000001 - 999
-1.999999999 - 2	

0 0.25 0.5 0.75 1 Kilometers

0 0.25 0.5 0.75 1 Miles

1:25,500

N

ICF

Figure 31
Change in Elevation 1964-2015

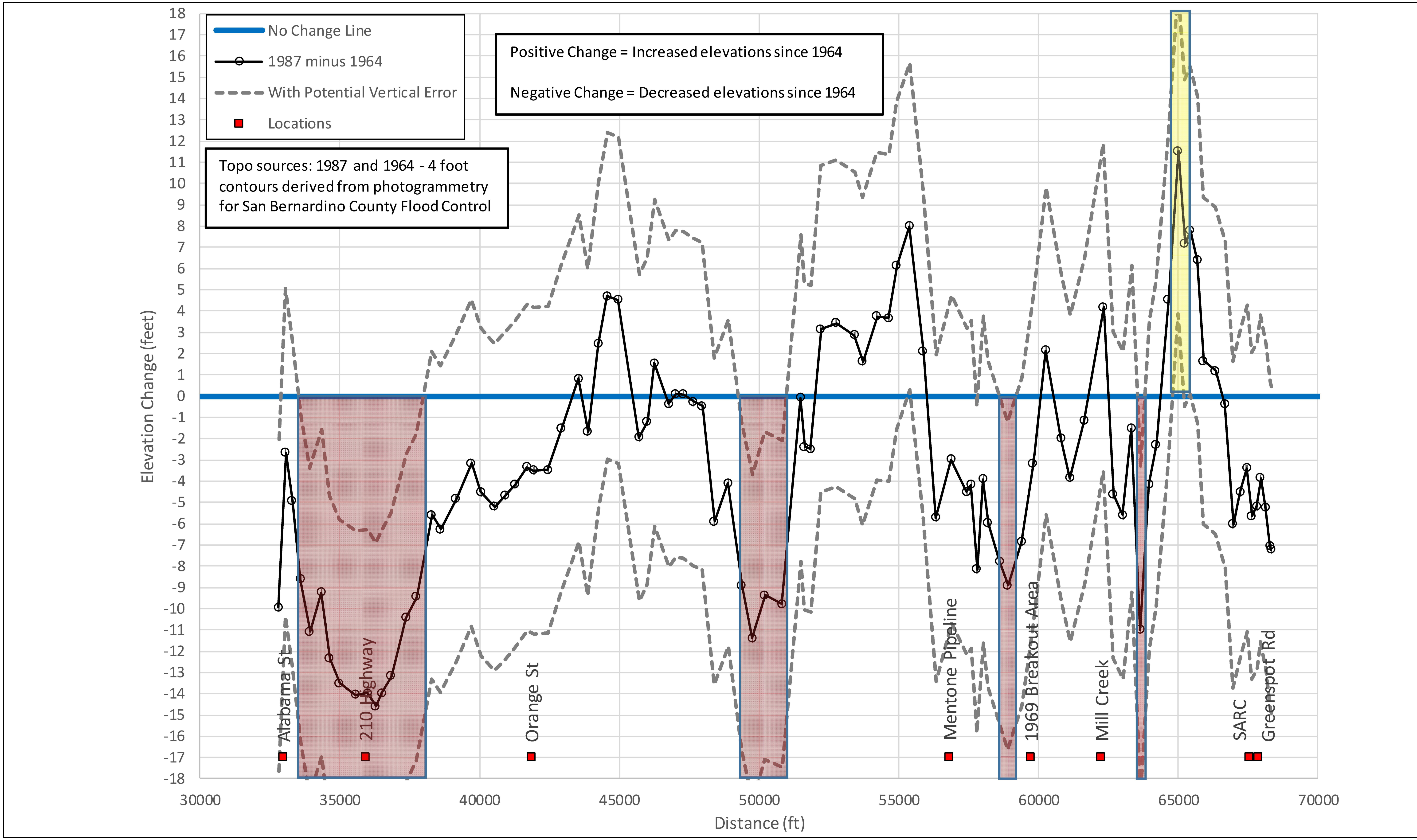


Figure 32
Thalweg Elevation Change from 1964 to 1987

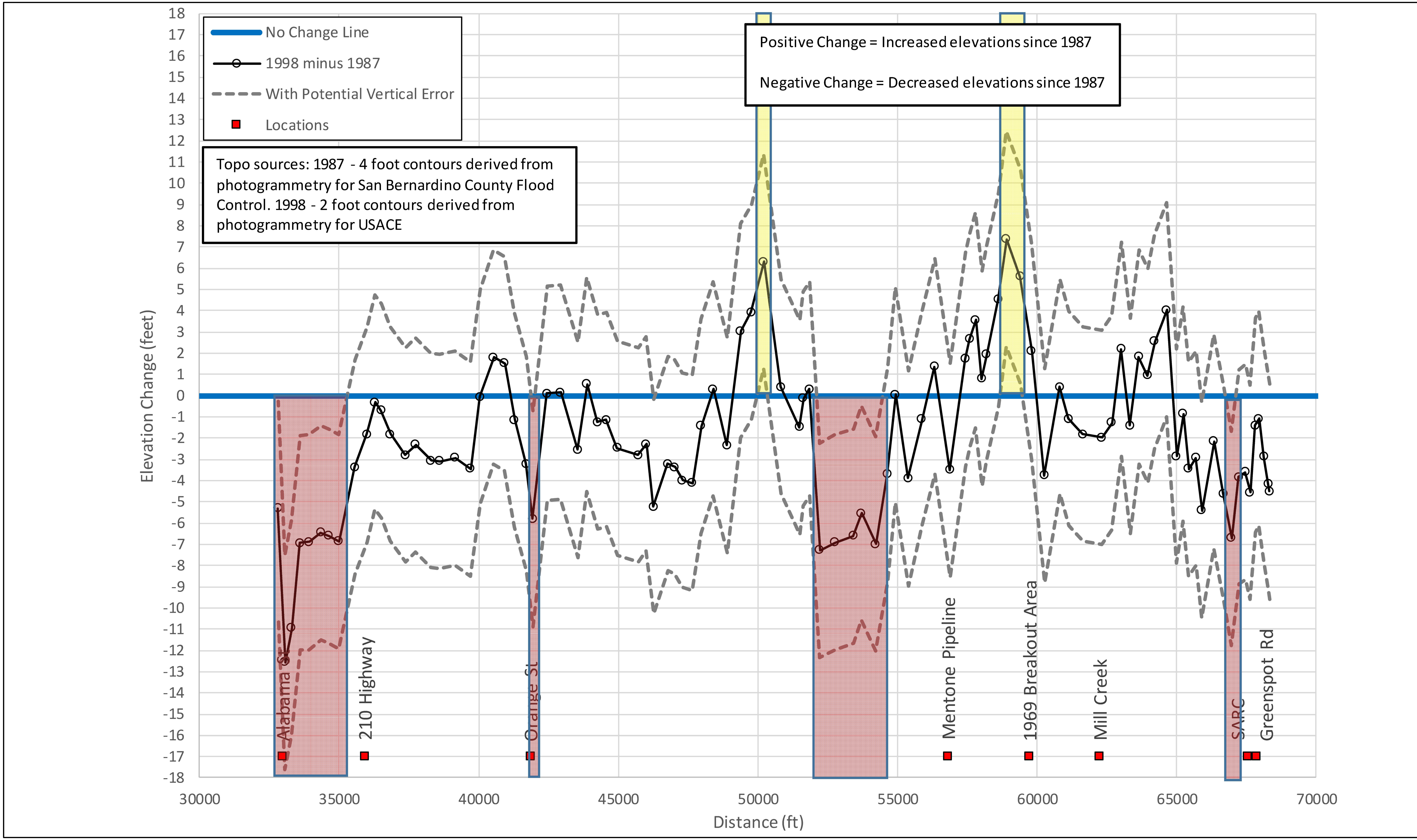


Figure 33
Thalweg Elevation Change from 1987 to 1998

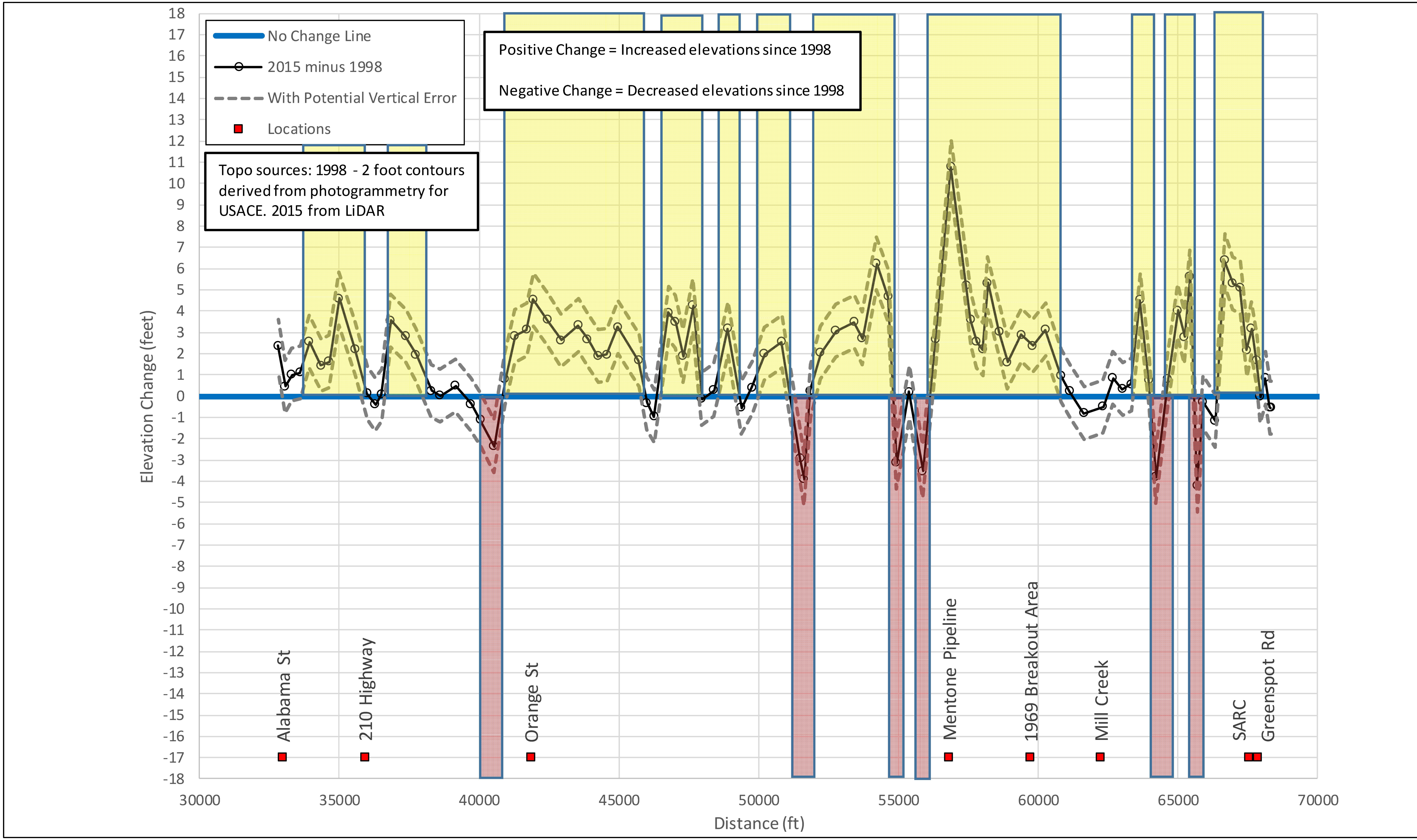


Figure 34
Thalweg Elevation Change from 1998 to 2015

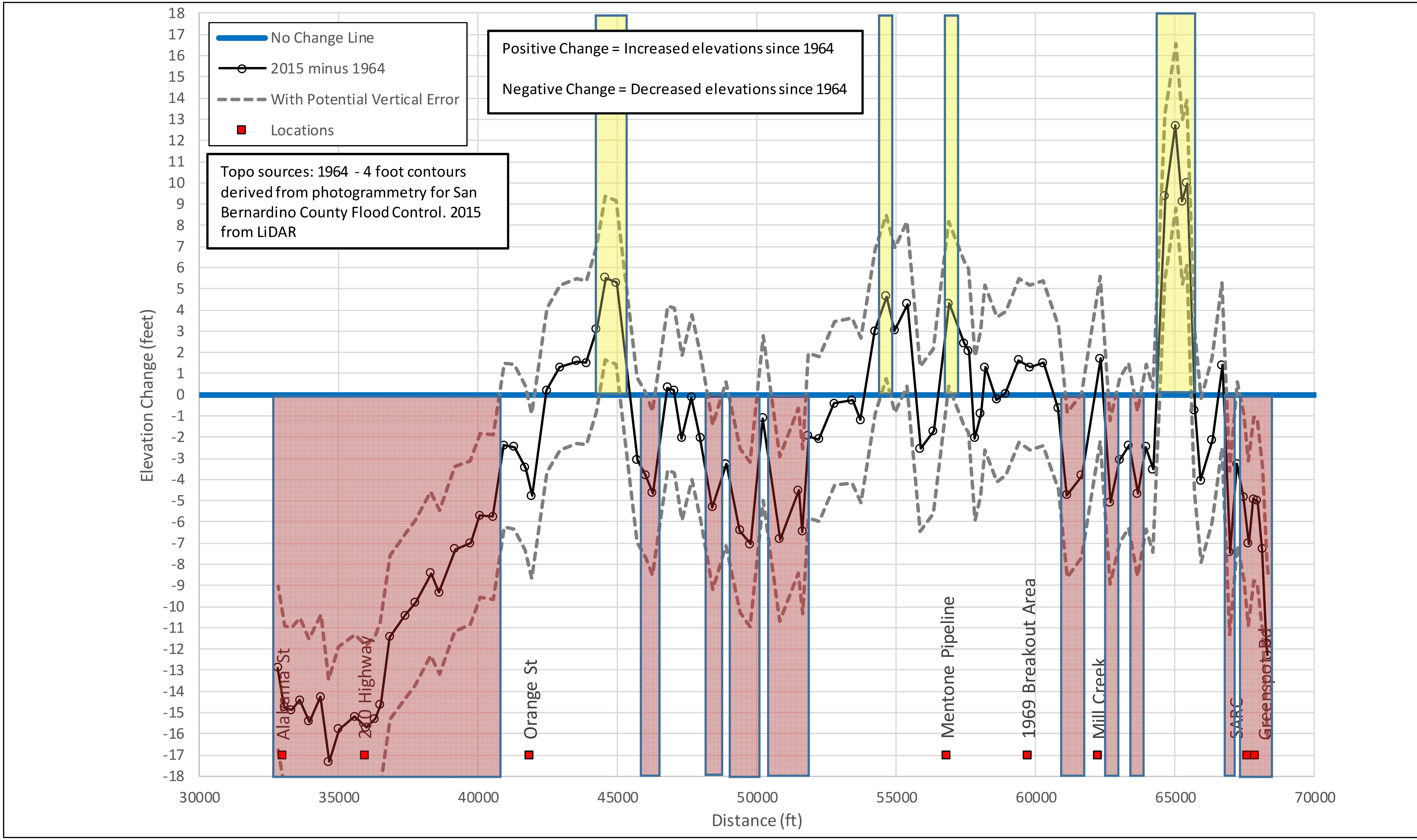


Figure 35
Thalweg Elevation Change from 1964 to 2015

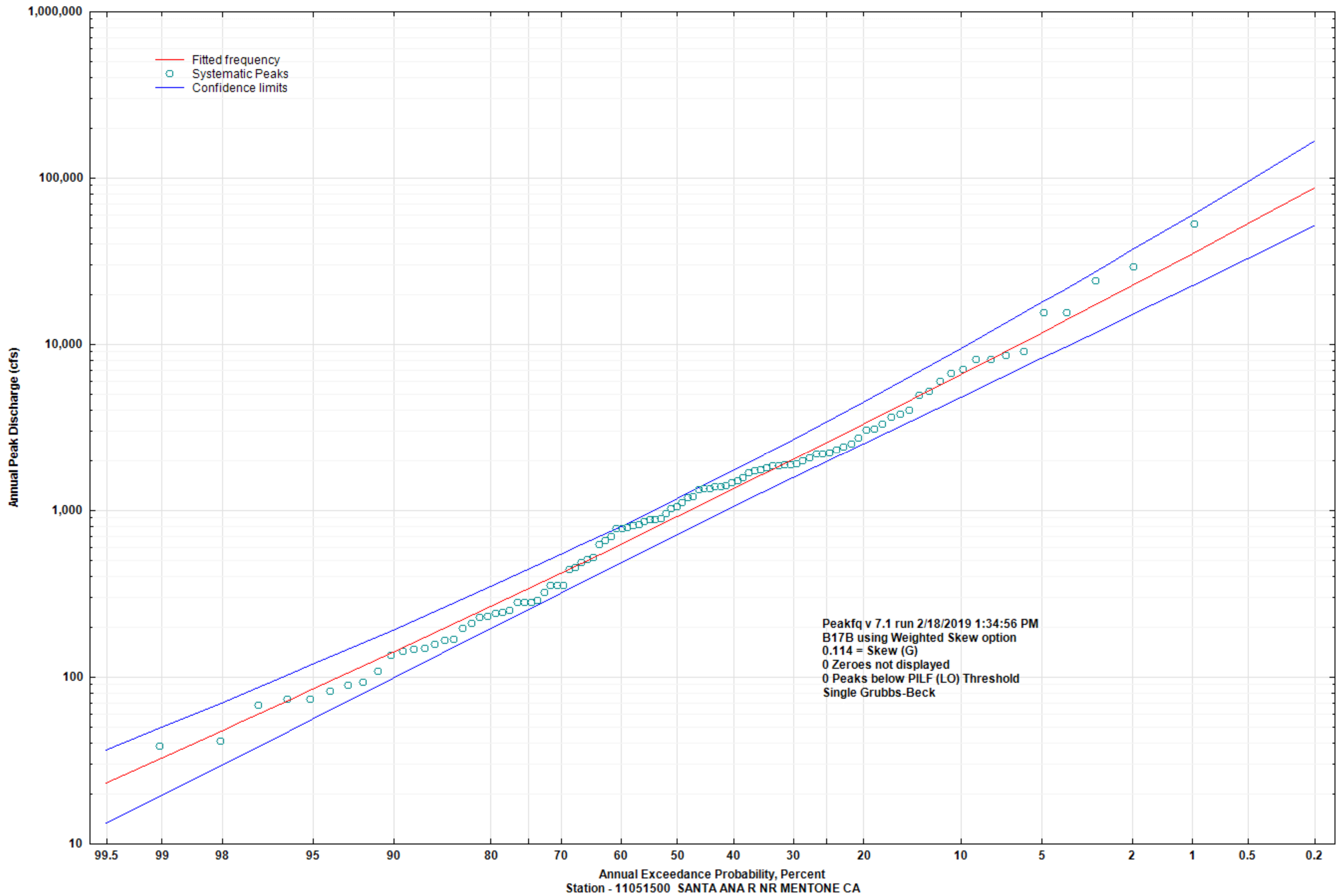


Figure 36
Bulletin 17B Annual Peak Flow Frequency Analysis of USGS Gage 11051500
Santa Ana River near Mentone for pre-dam regulation water years 1897-1998

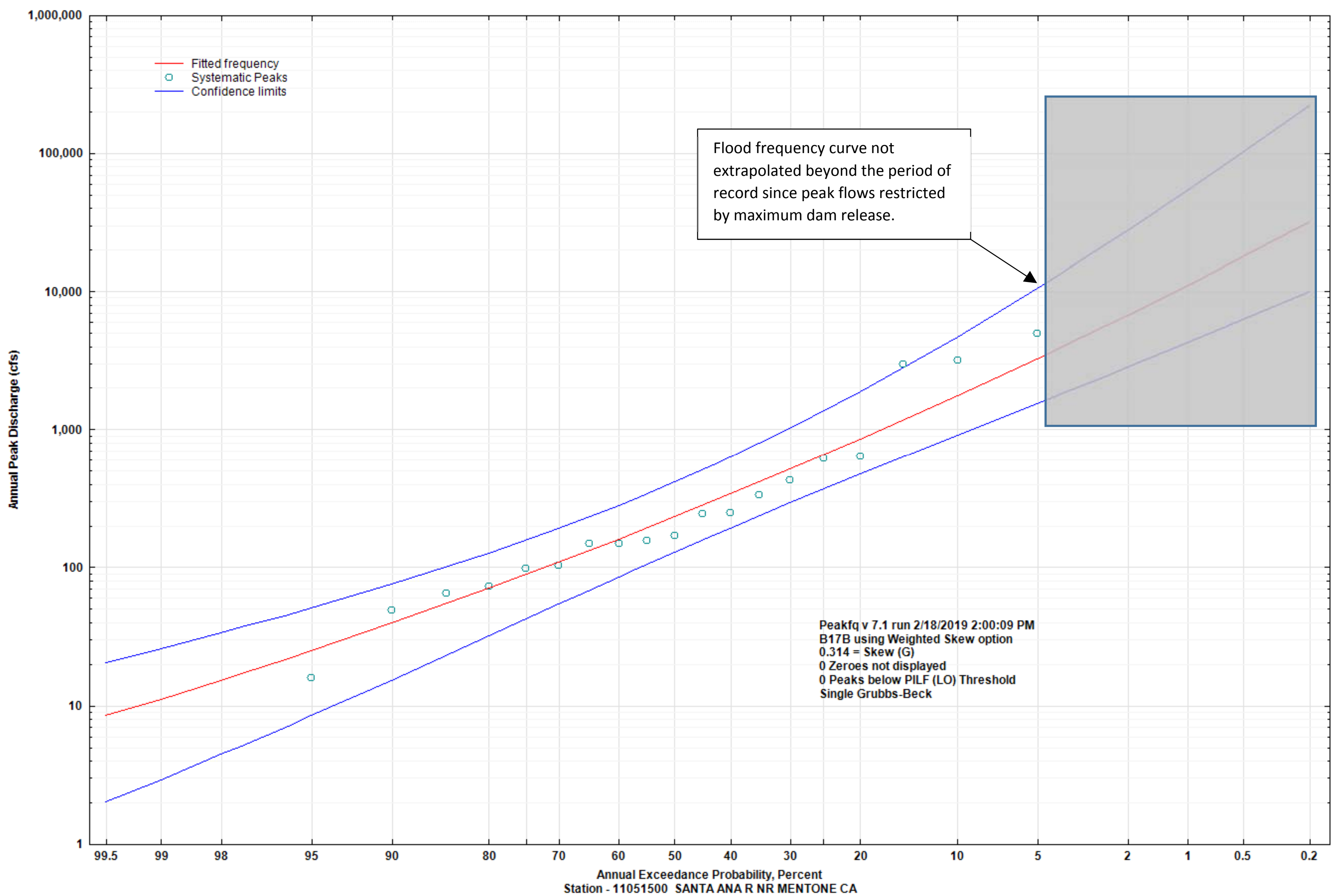


Figure 37
Bulletin 17B Annual Peak Flow Frequency Analysis of USGS Gage 11051500
Santa Ana River near Mentone for pre-dam regulation water years 1999-2017

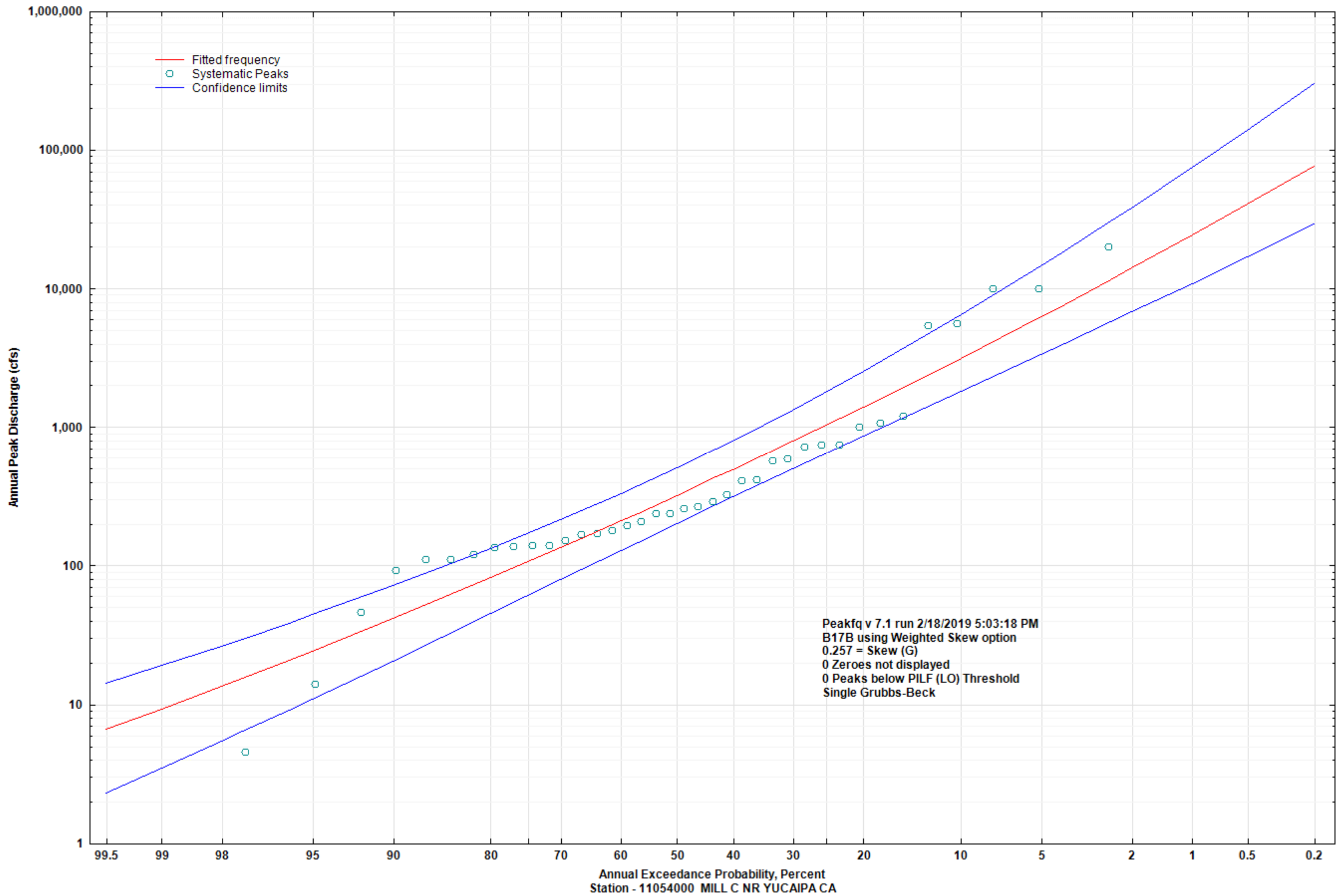
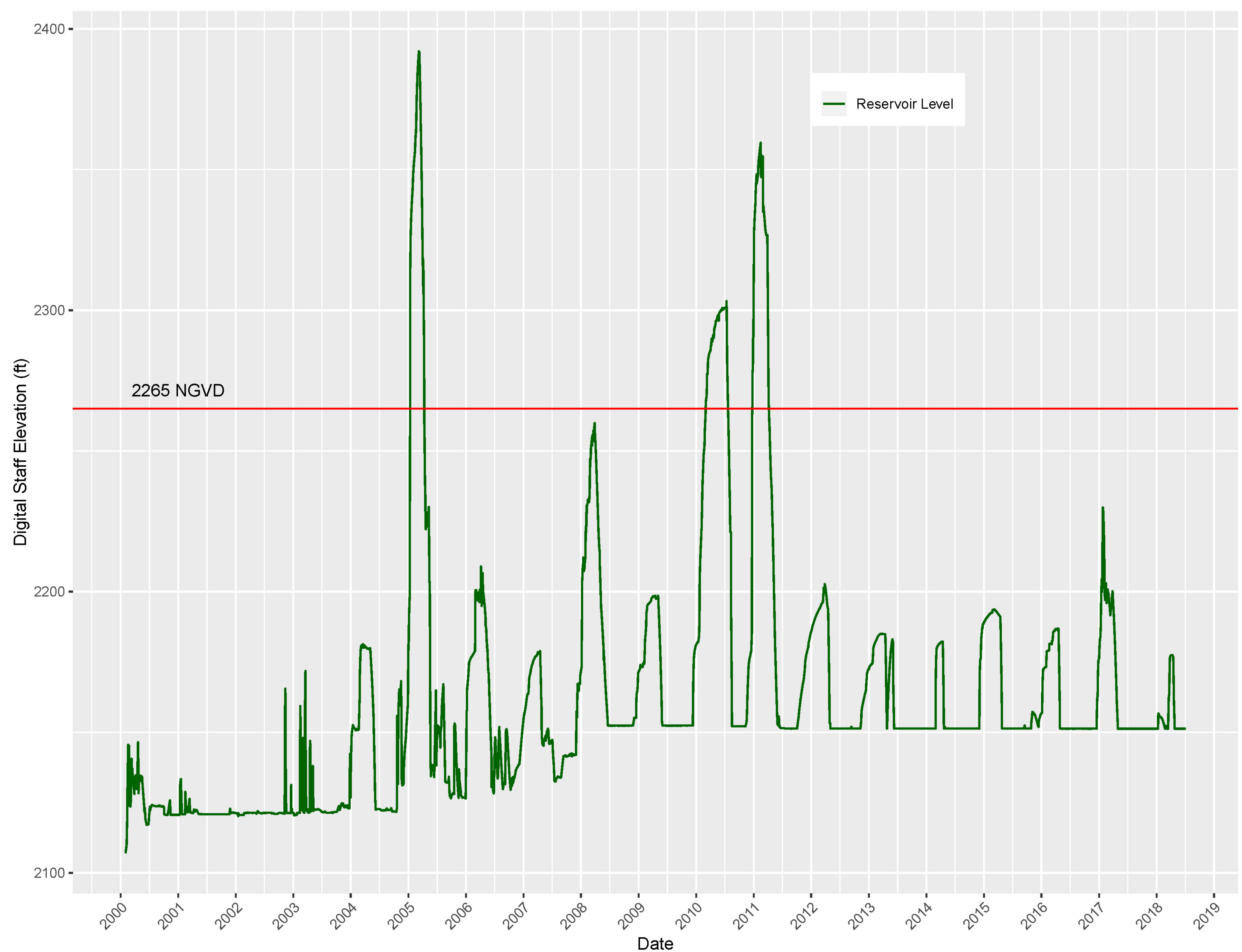


Figure 38
Bulletin 17B Annual Peak Flow Frequency Analysis of USGS Gage 11054000
Mill Creek near Yucaipa for water years 1948-1986



ICF

Figure 39
SOD Water Levels for the Period of Record

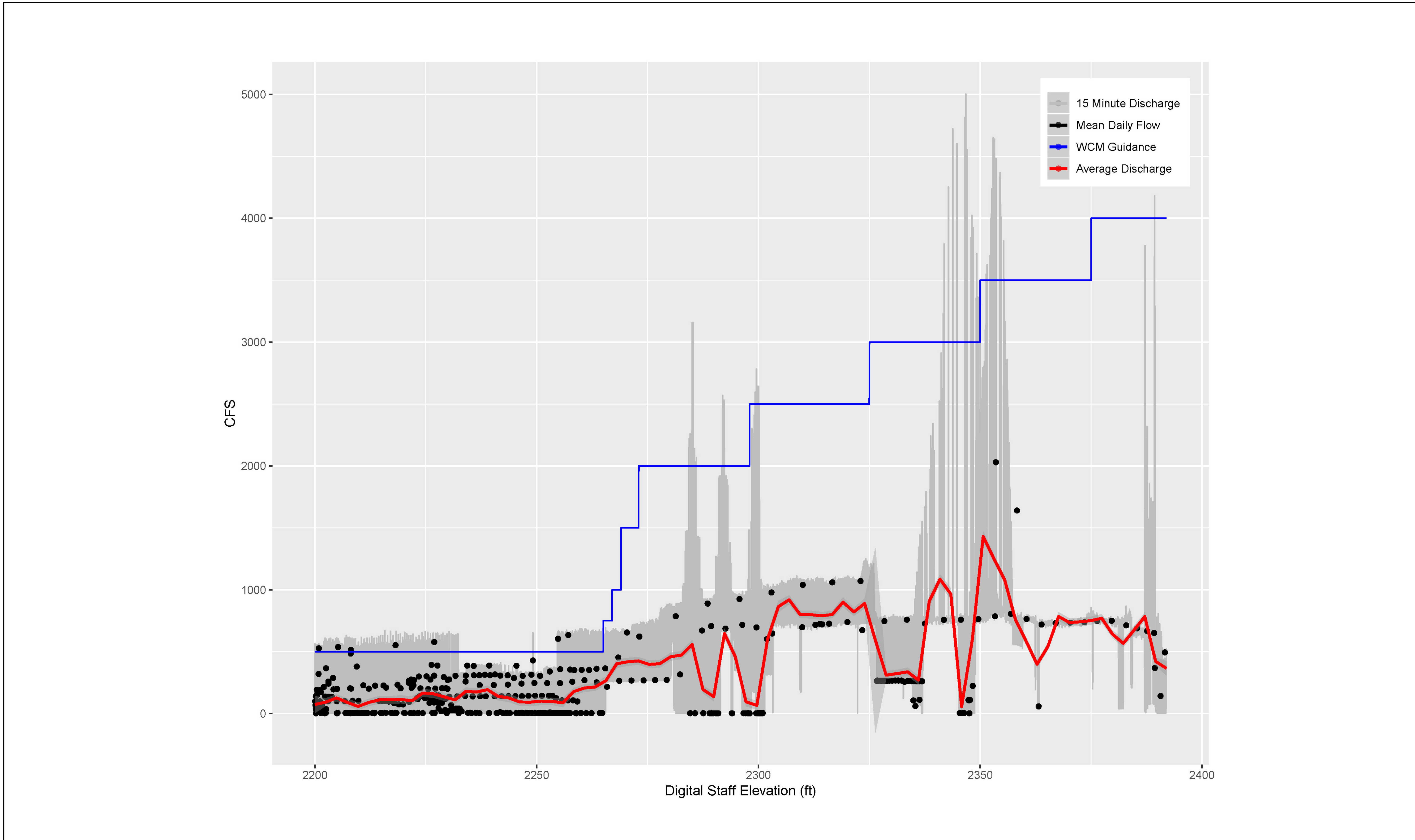


Figure 40
SOD Outflow vs. Guidance for Reservoir Falling State for the Period of Record

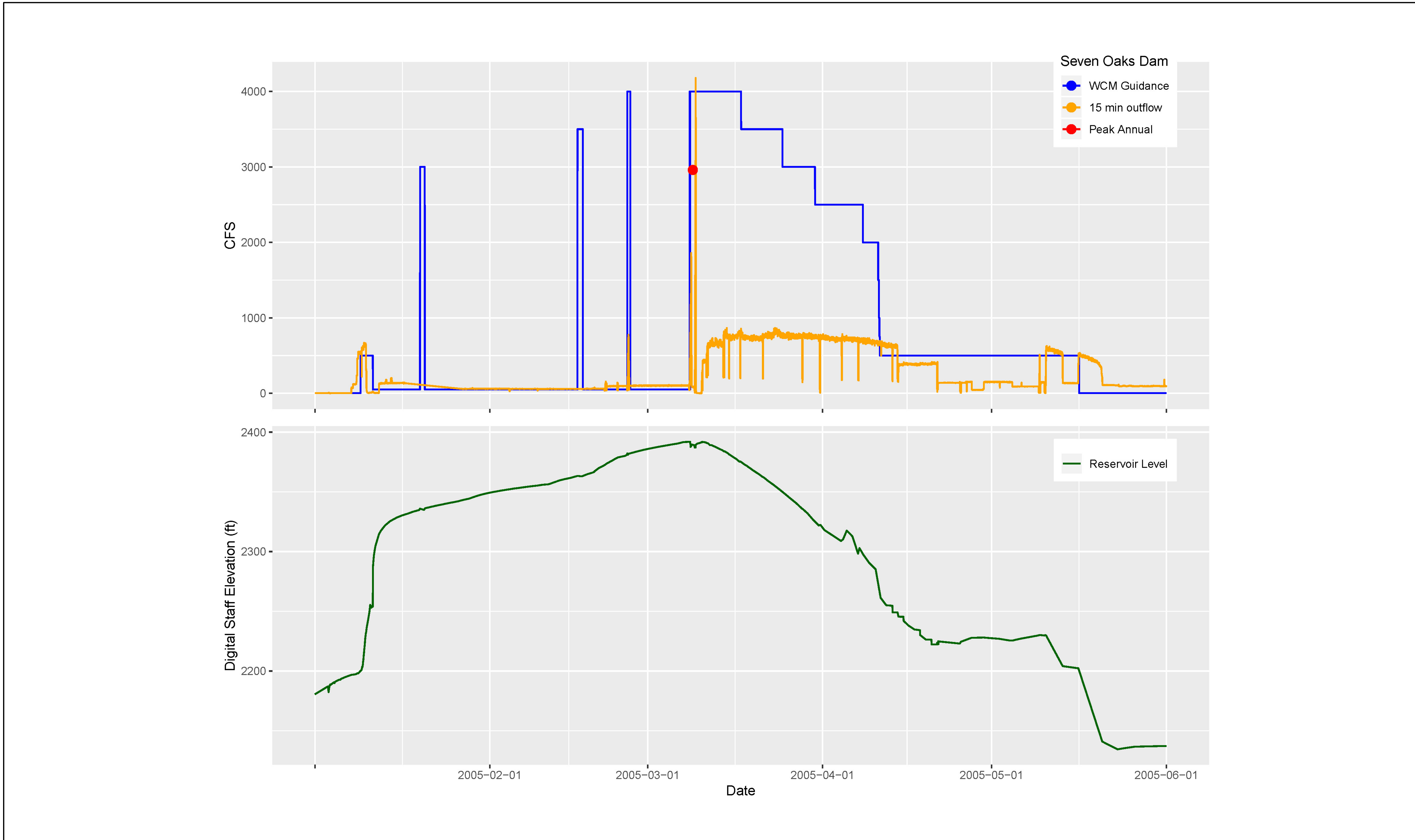


Figure 41
Event #1

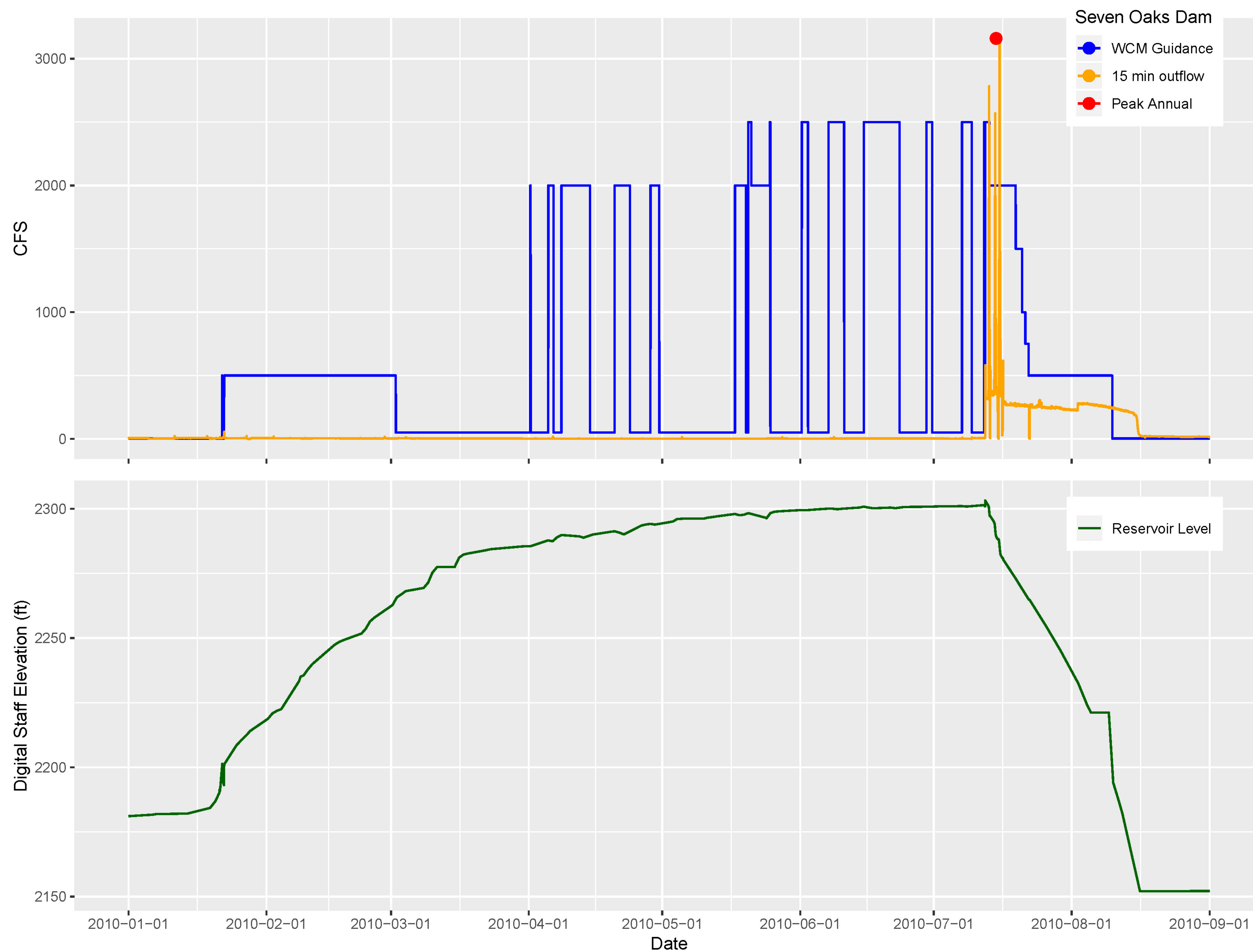


Figure 42
Event #2

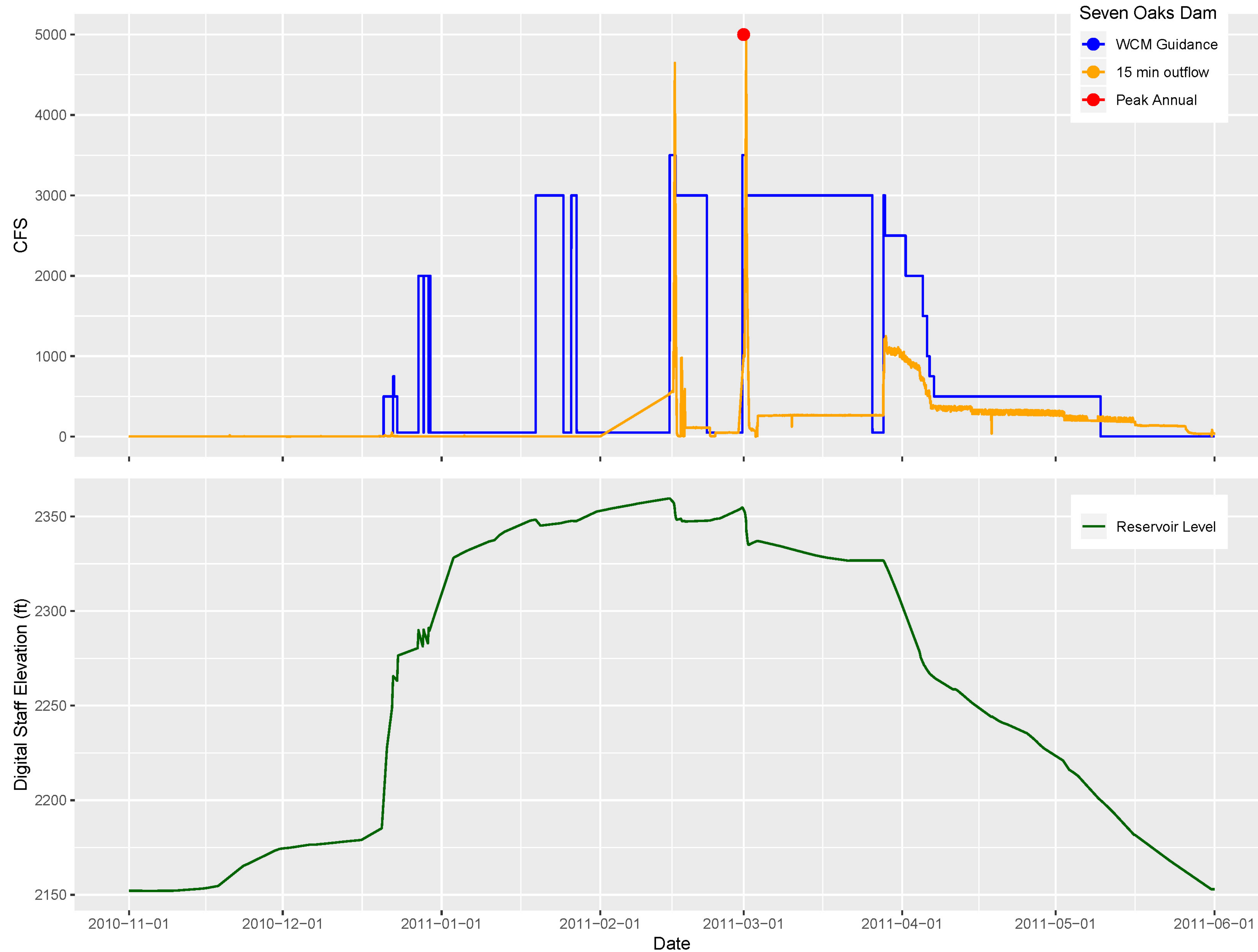
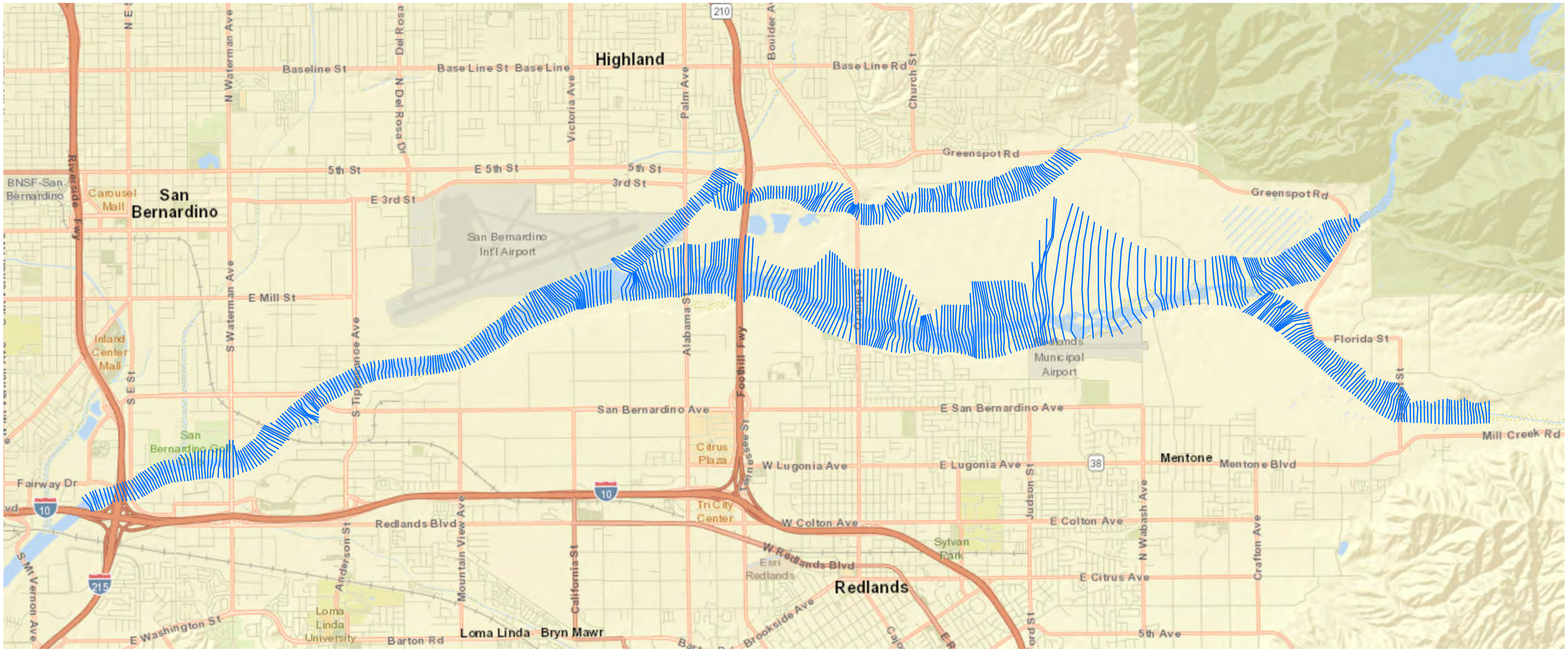


Figure 43
Event #3



Legend

HEC-RAS Modeling Extents

N

0 0.5 1 1.5 2 Miles

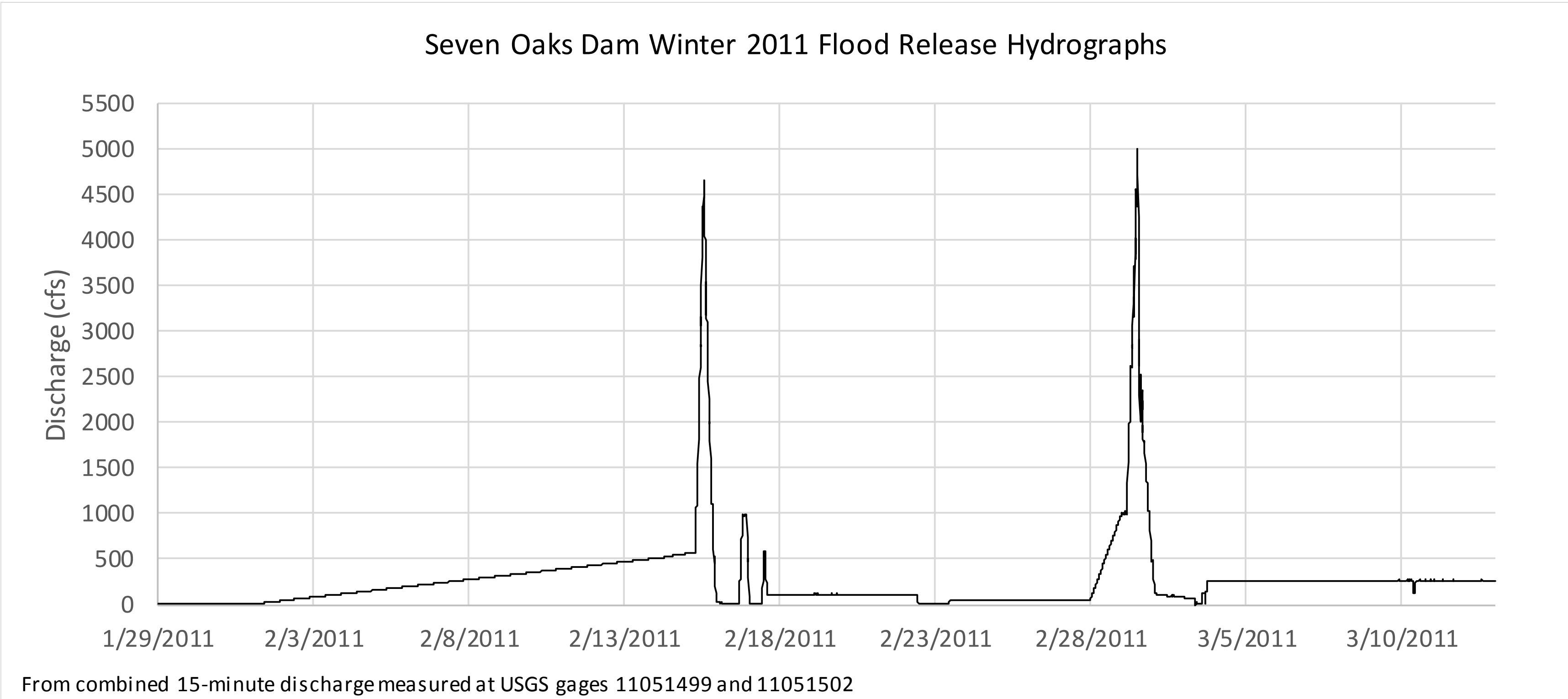
1:56,000

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS

ICF

Figure 44

HEC-RAS Modeling



ICF

Figure 45
Comparison of Seven Oaks Dam Winter 2011 Flow Release Hydrographs

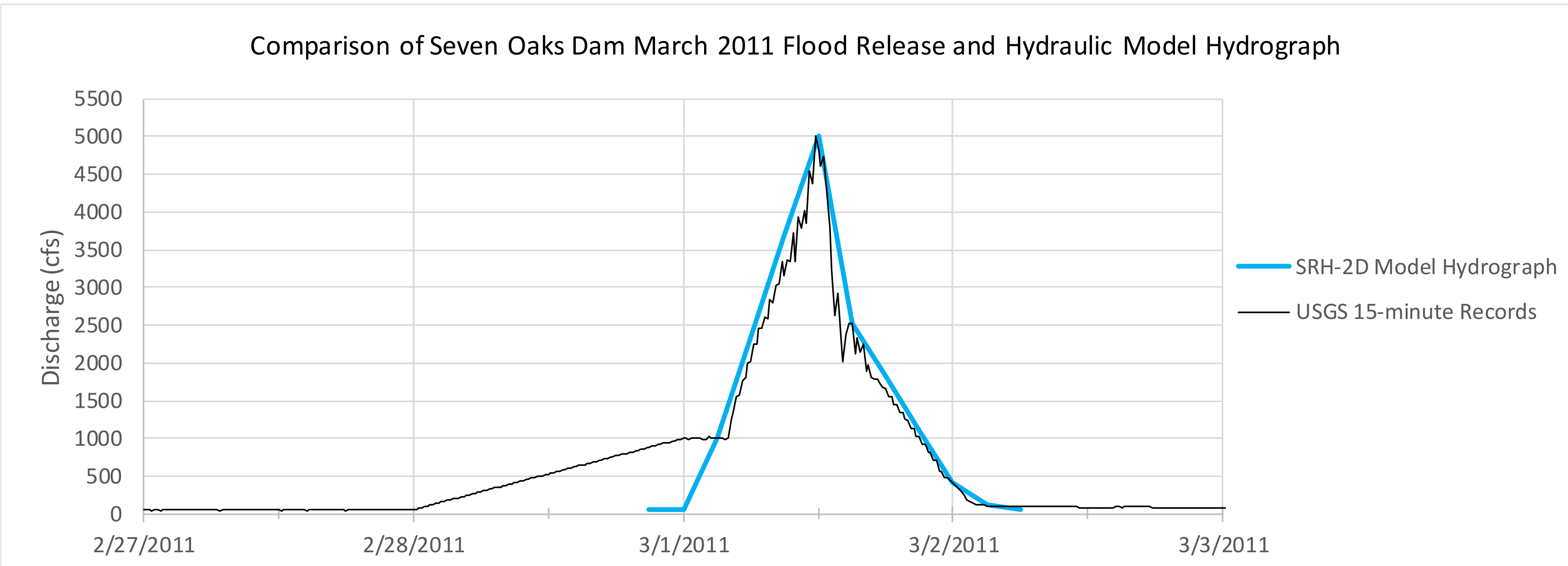


Figure 46
Comparison of Seven Oaks Dam March 2011 Flood Release and Hydraulic Model Hydrograph

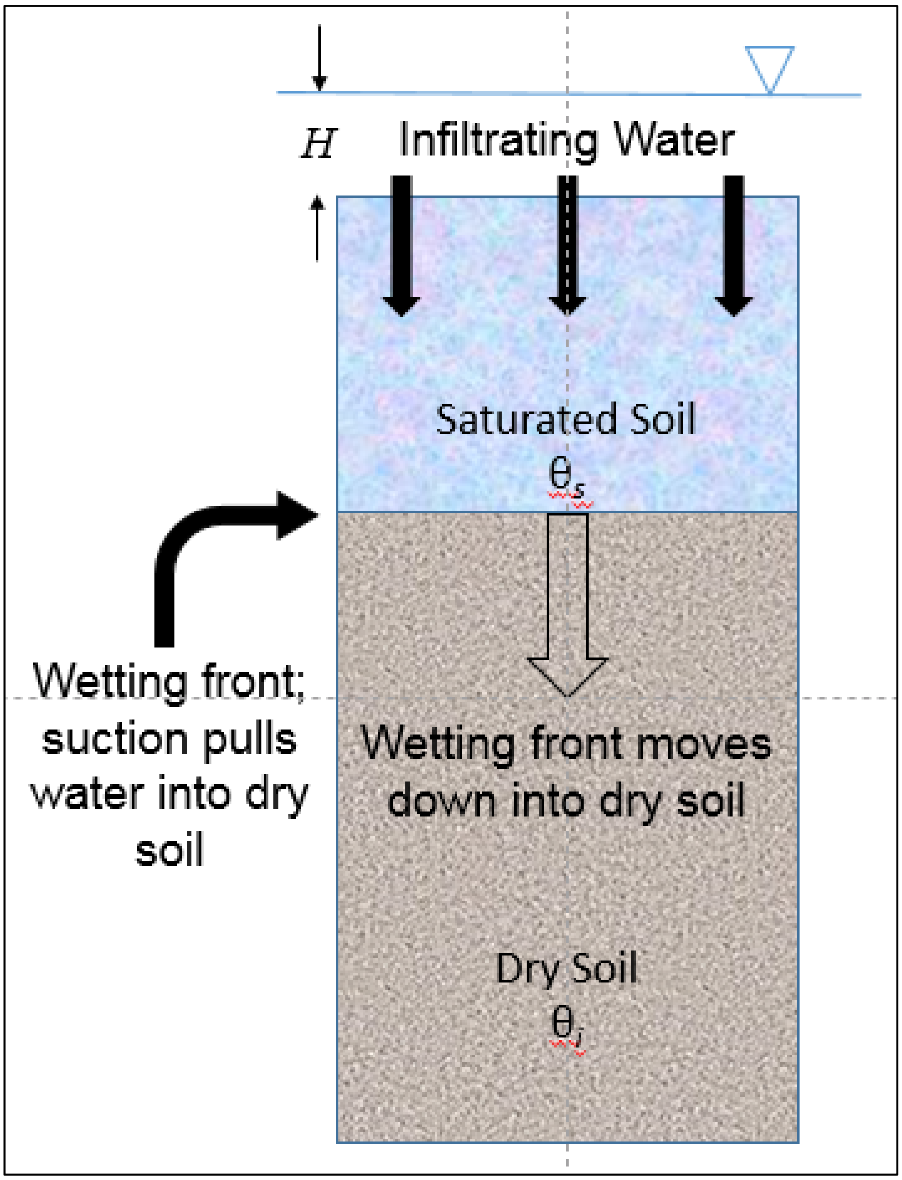


Figure 47
Definition Sketch for the Green-Ampt Model.
Recreated from Figure 10 in Lai 2006

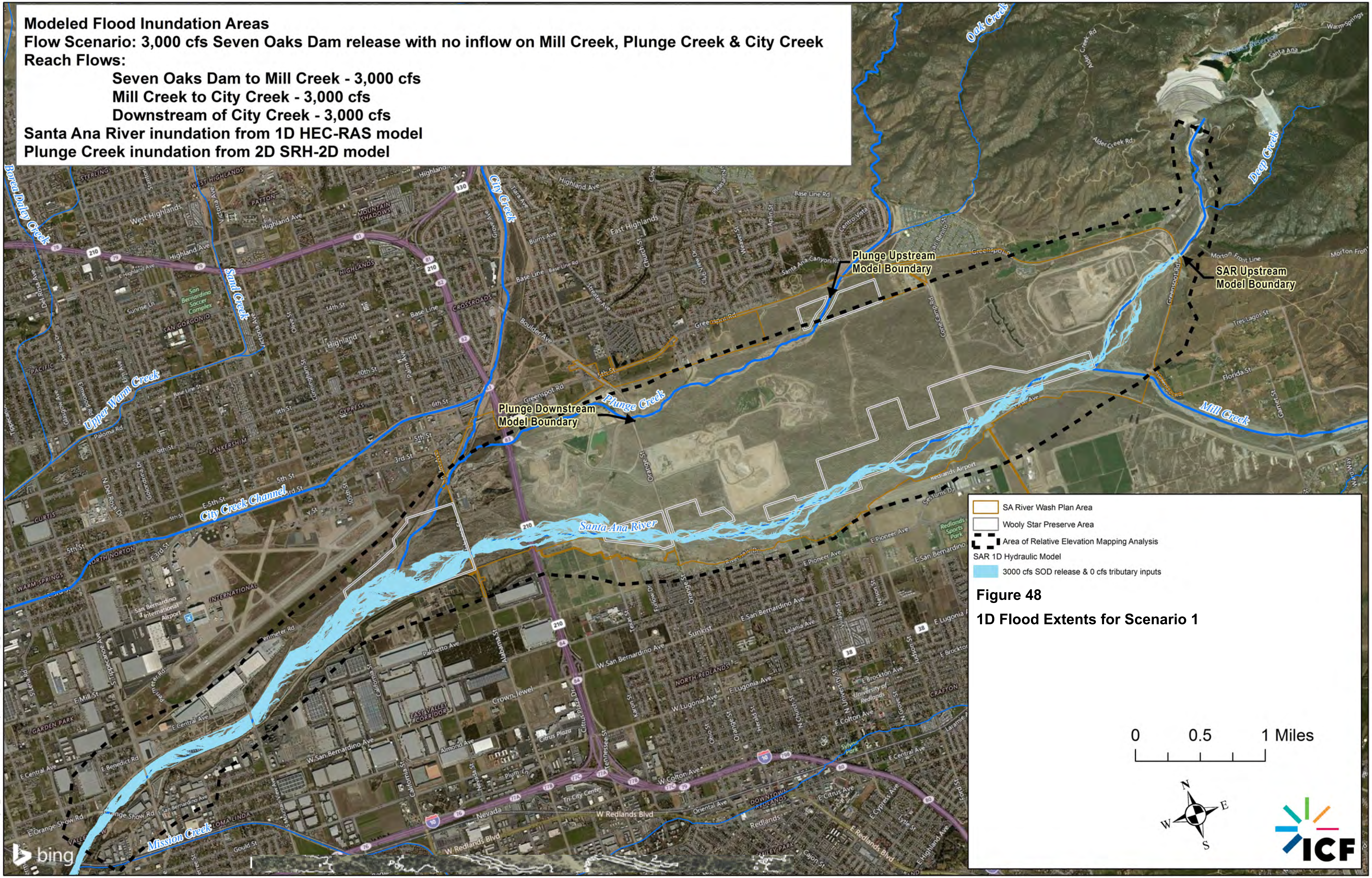


Figure 48

1D Flood Extents for Scenario 1

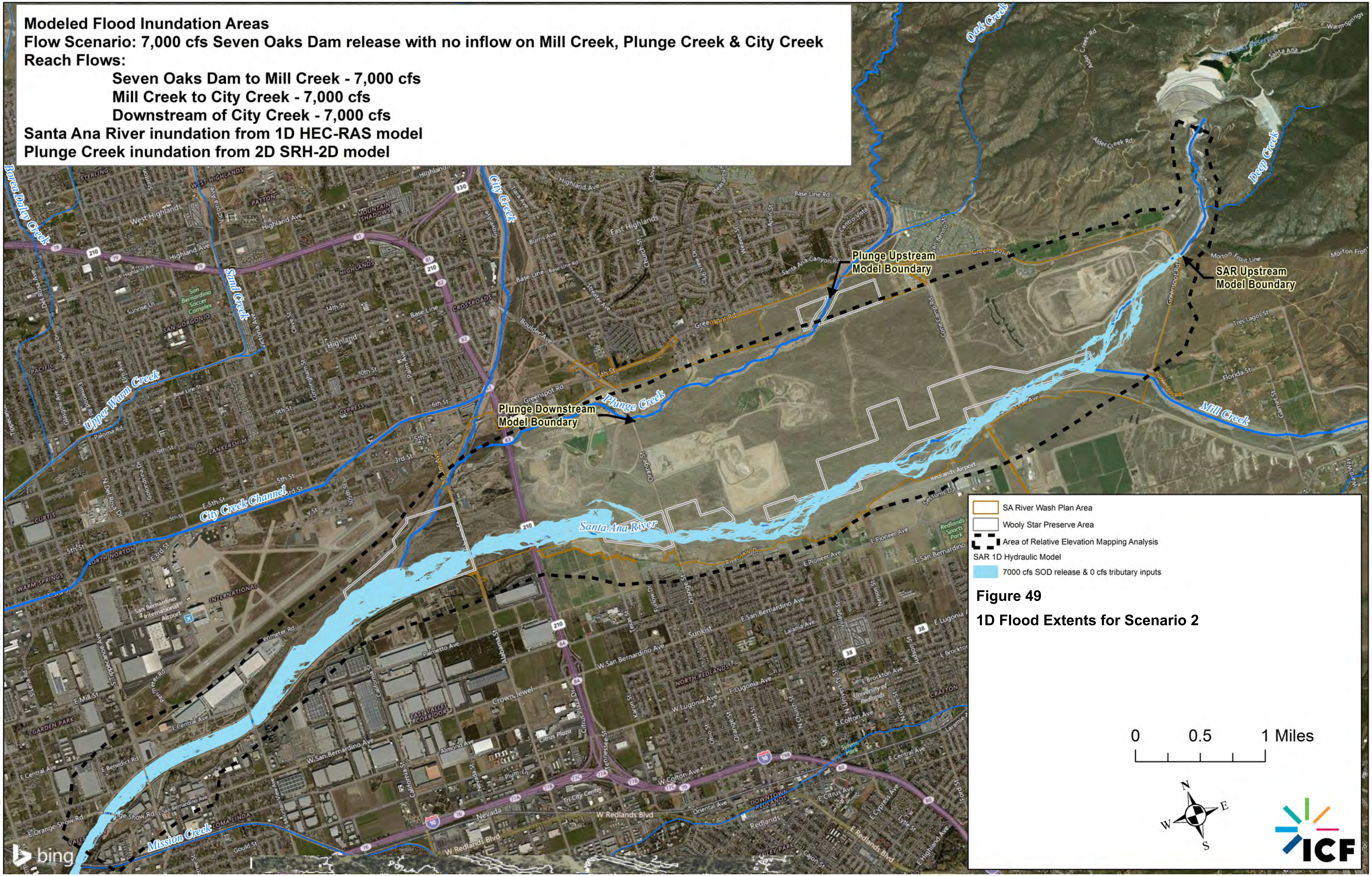


Figure 49

1D Flood Extents for Scenario 2

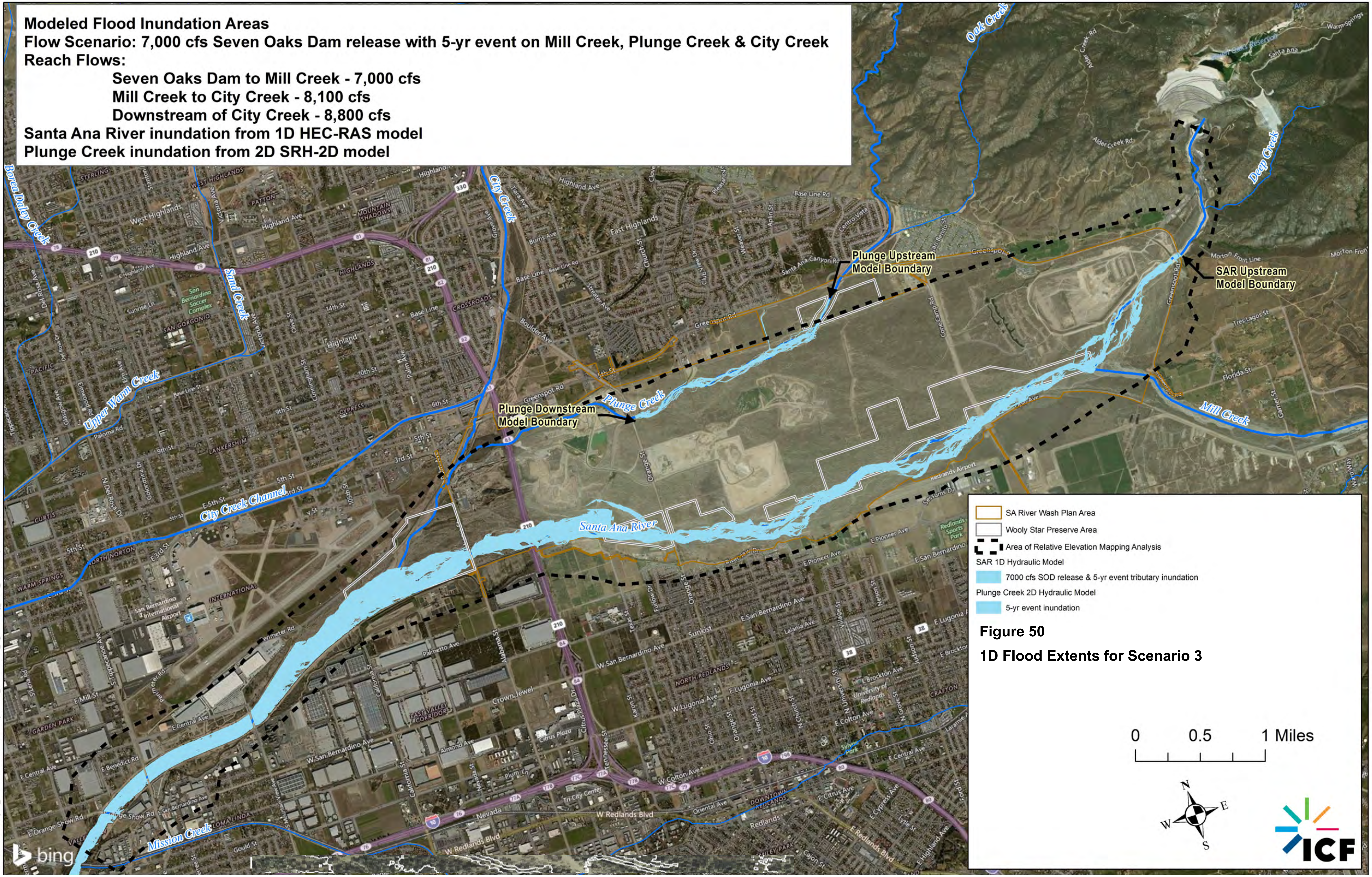


Figure 50

1D Flood Extents for Scenario 3

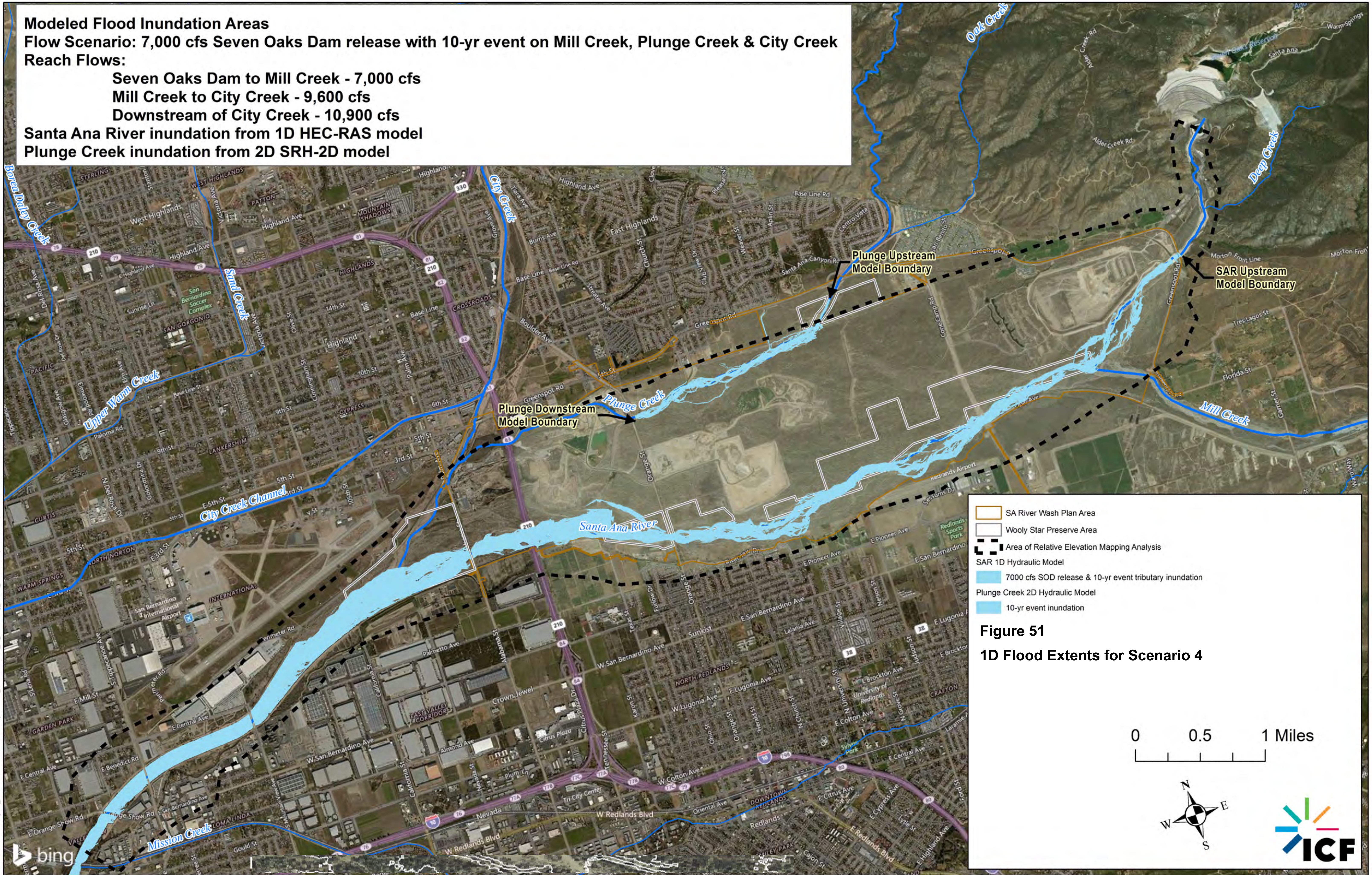


Figure 51

1D Flood Extents for Scenario 4

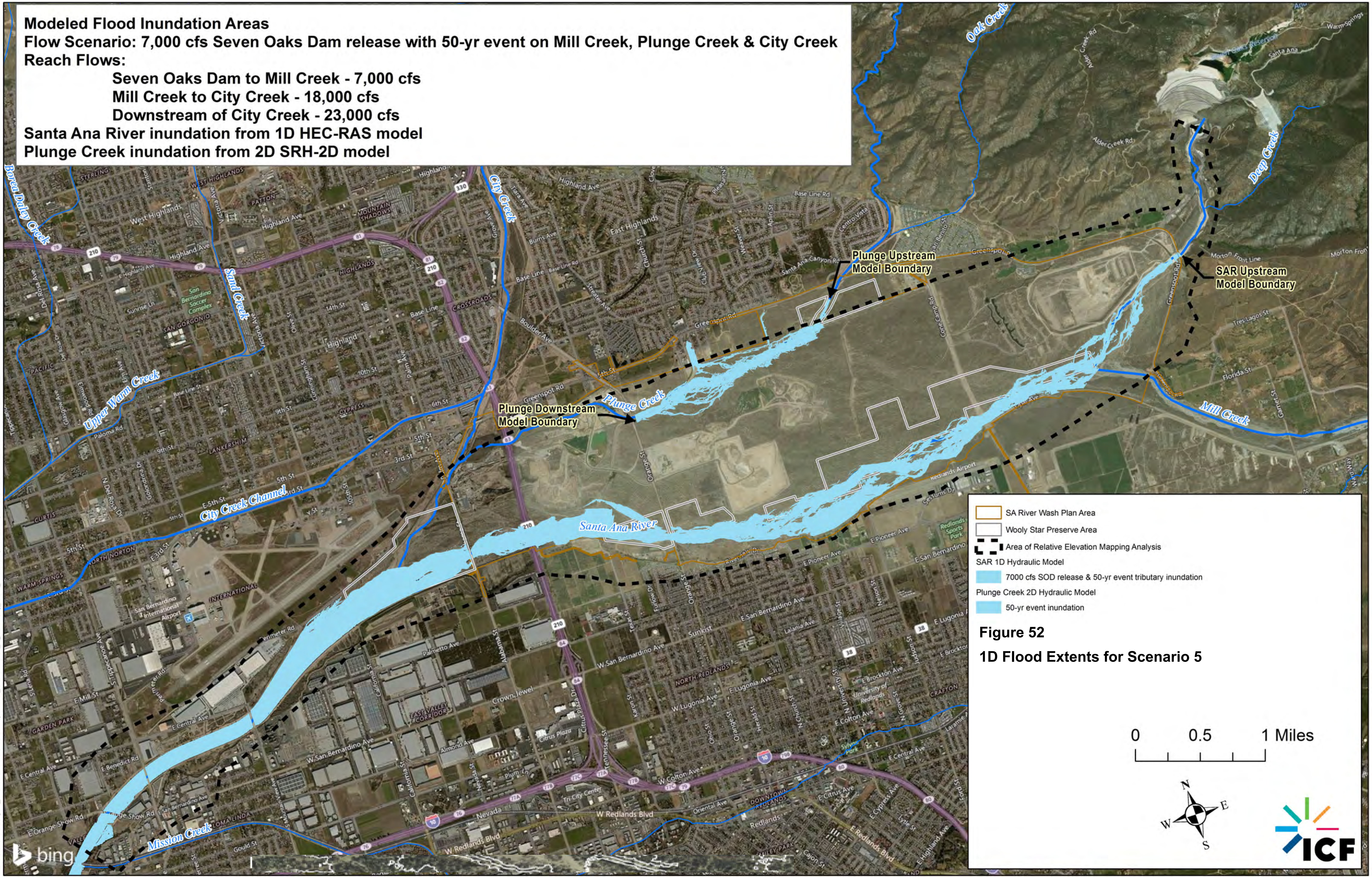


Figure 52

1D Flood Extents for Scenario 5

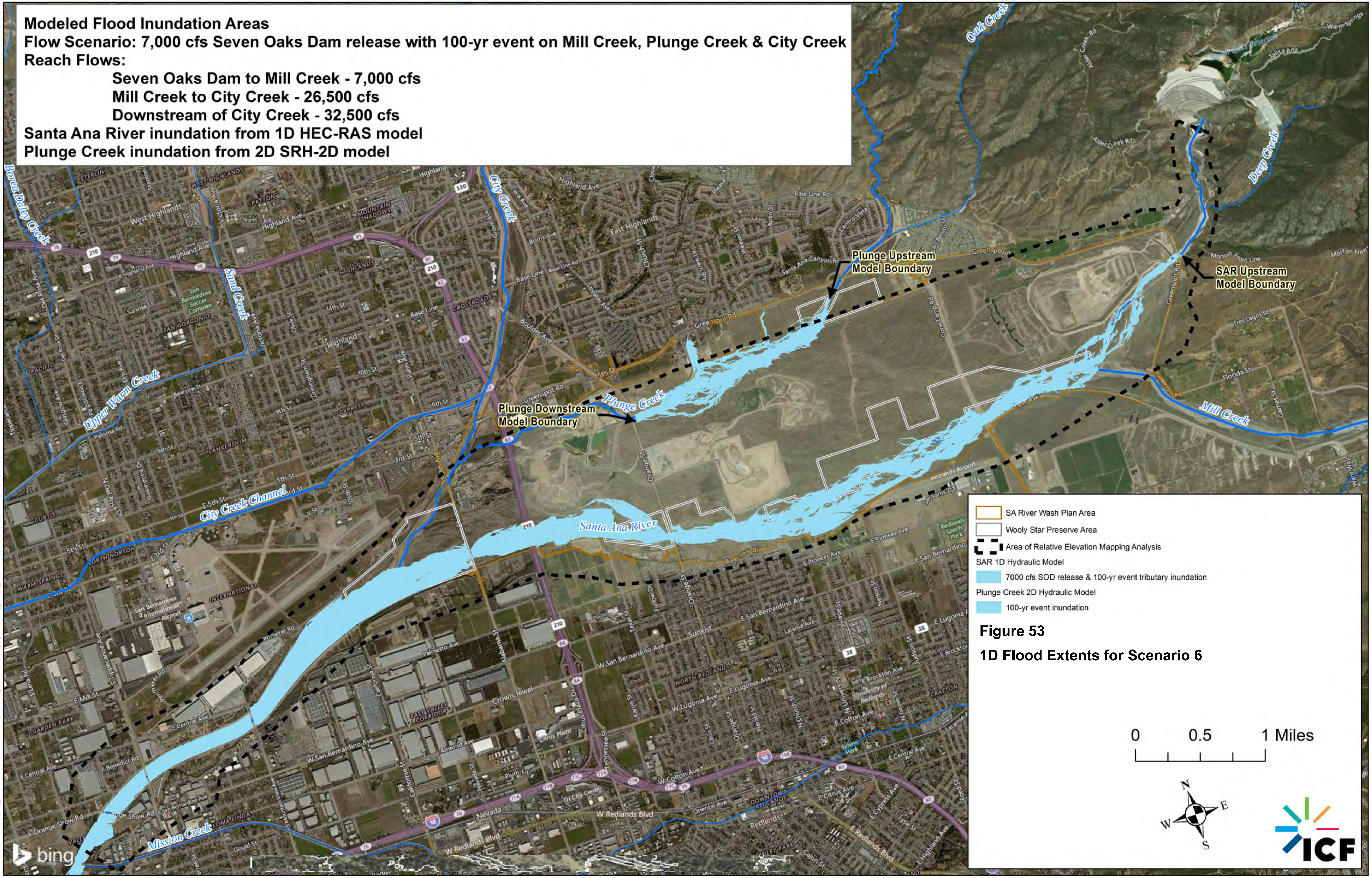
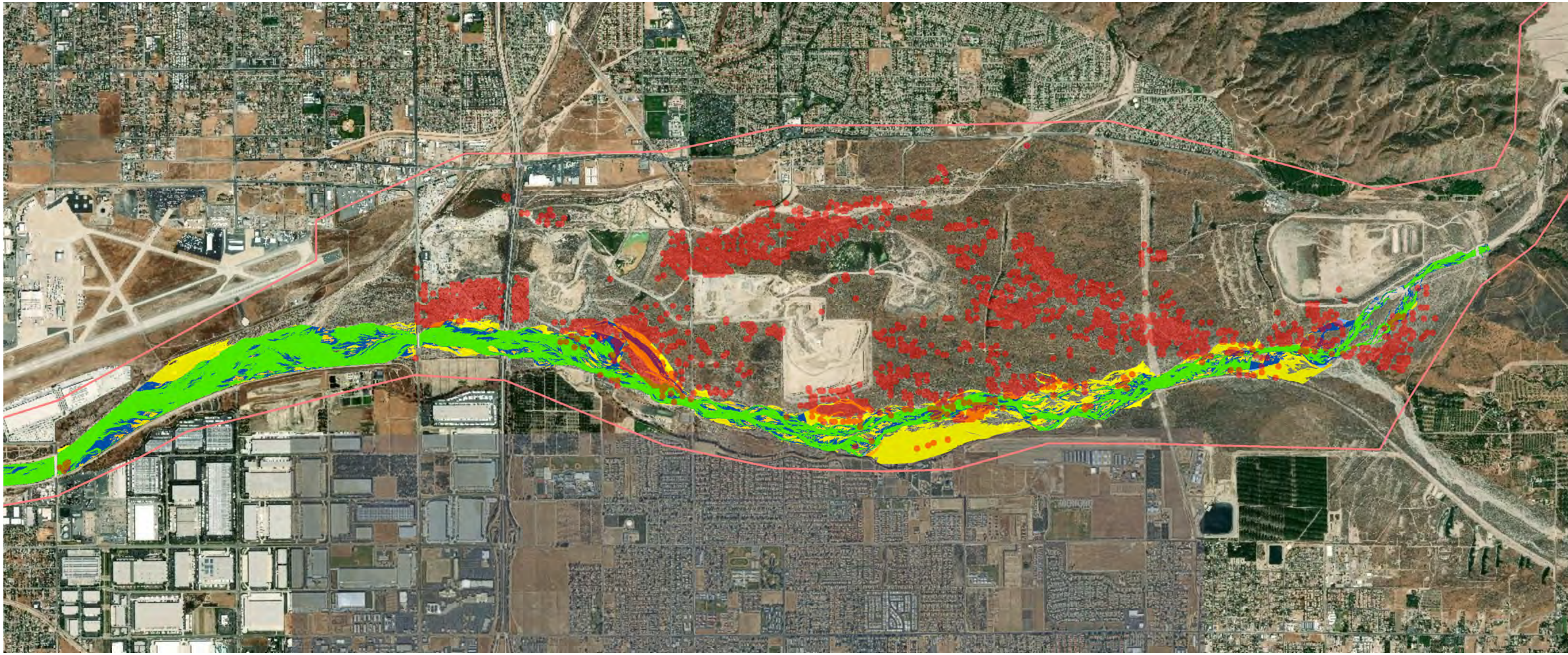


Figure 53

1D Flood Extents for Scenario 6



Legend

- Area Of Interest
- SBKR Present
- d3000trib0
- d6700trib5
- d7000trib0
- d7000trib5
- d7000trib10
- d7000trib50
- d7000trib100

0 0.25 0.5 0.75 1 Kilometers

0 0.25 0.5 0.75 1 Miles

1:35,500

N

ICF

Figure 54

Flood Extents and Santa Ana Woollystar

Figure 55

Flood Extents and Slender-horned Spineflower

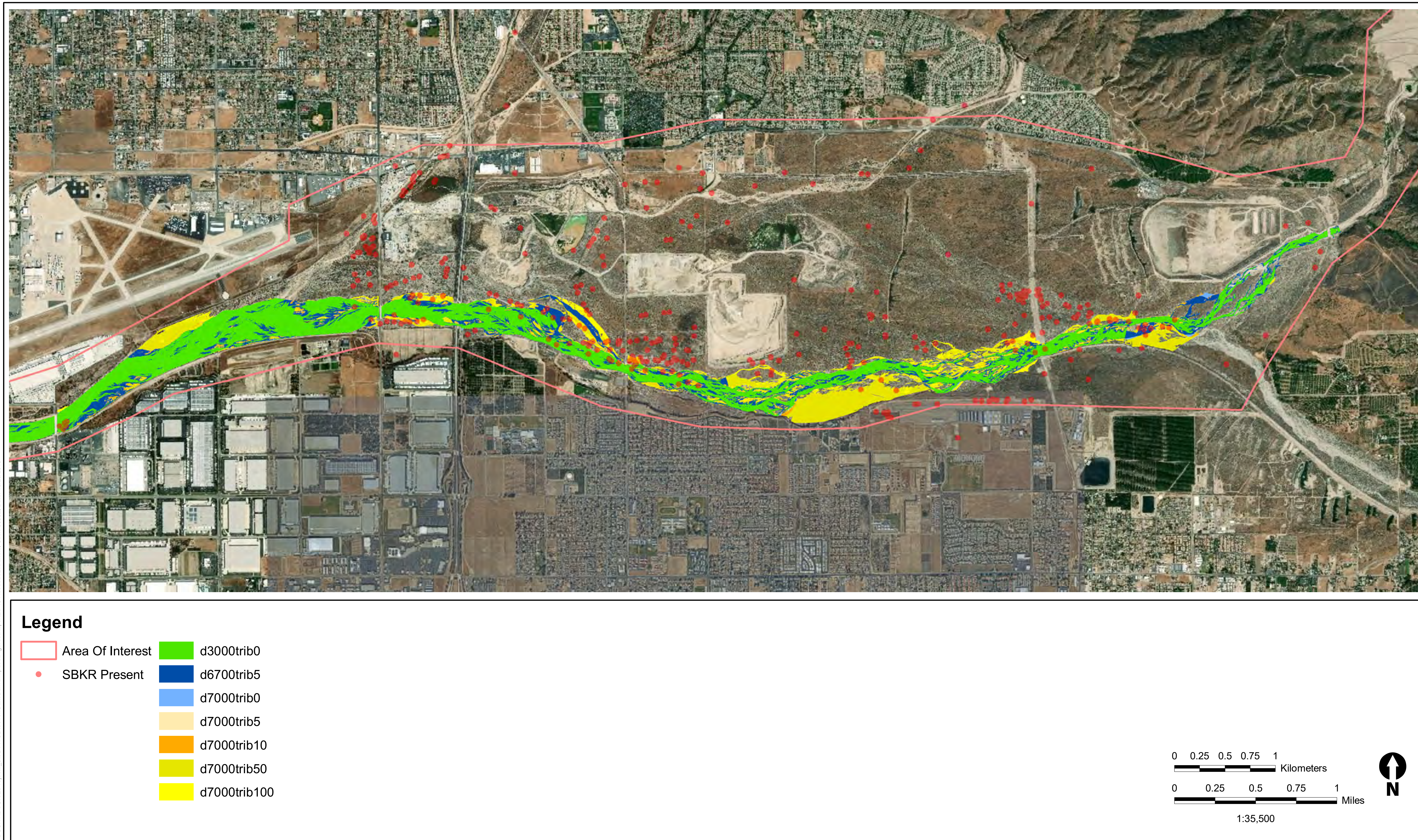


Figure 56

Flood Extents and SBKR

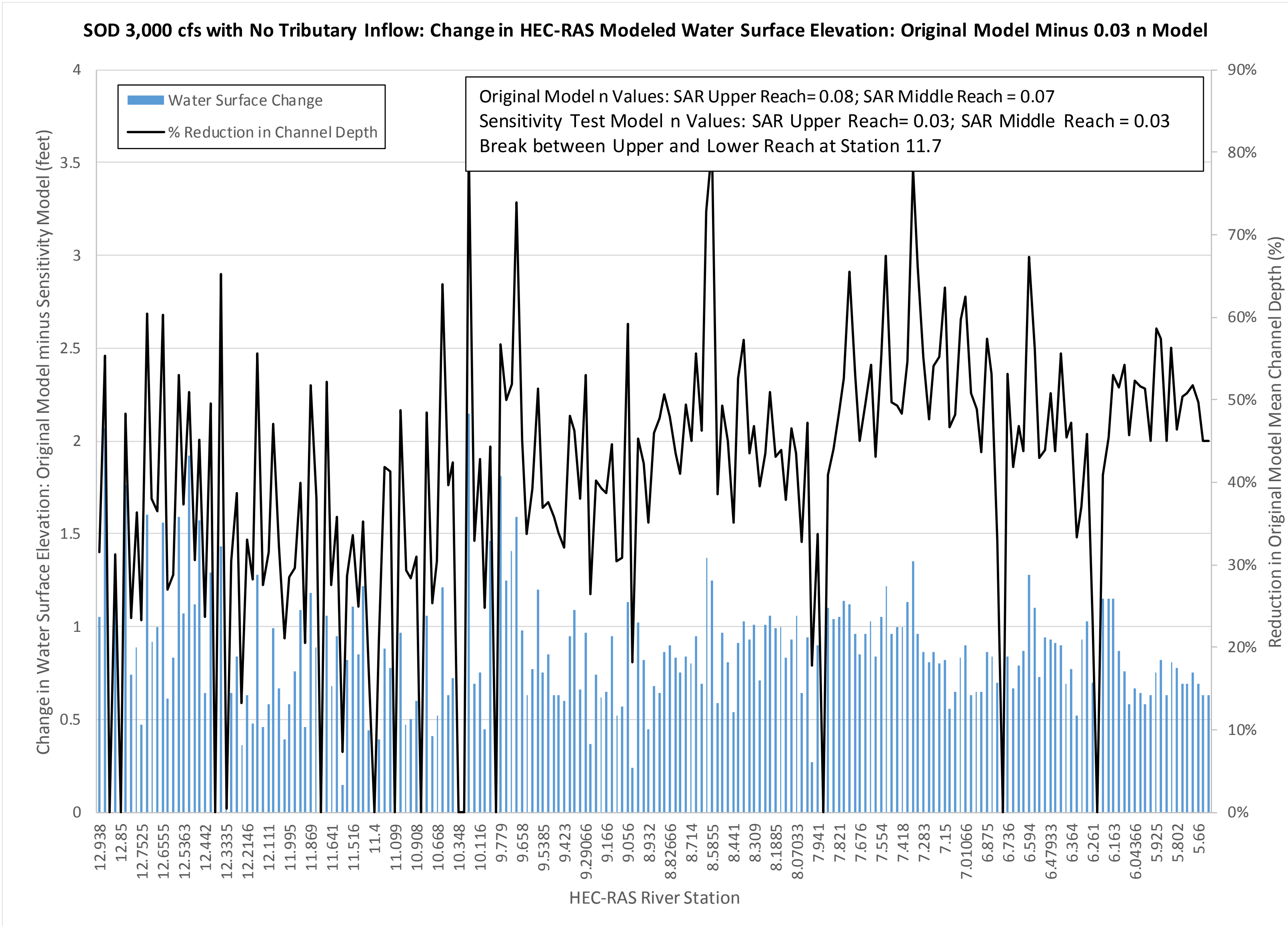


Figure 57
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.03 for Flow Scenario of SOD Release of 3,000 cfs with No Tributary Inflow.

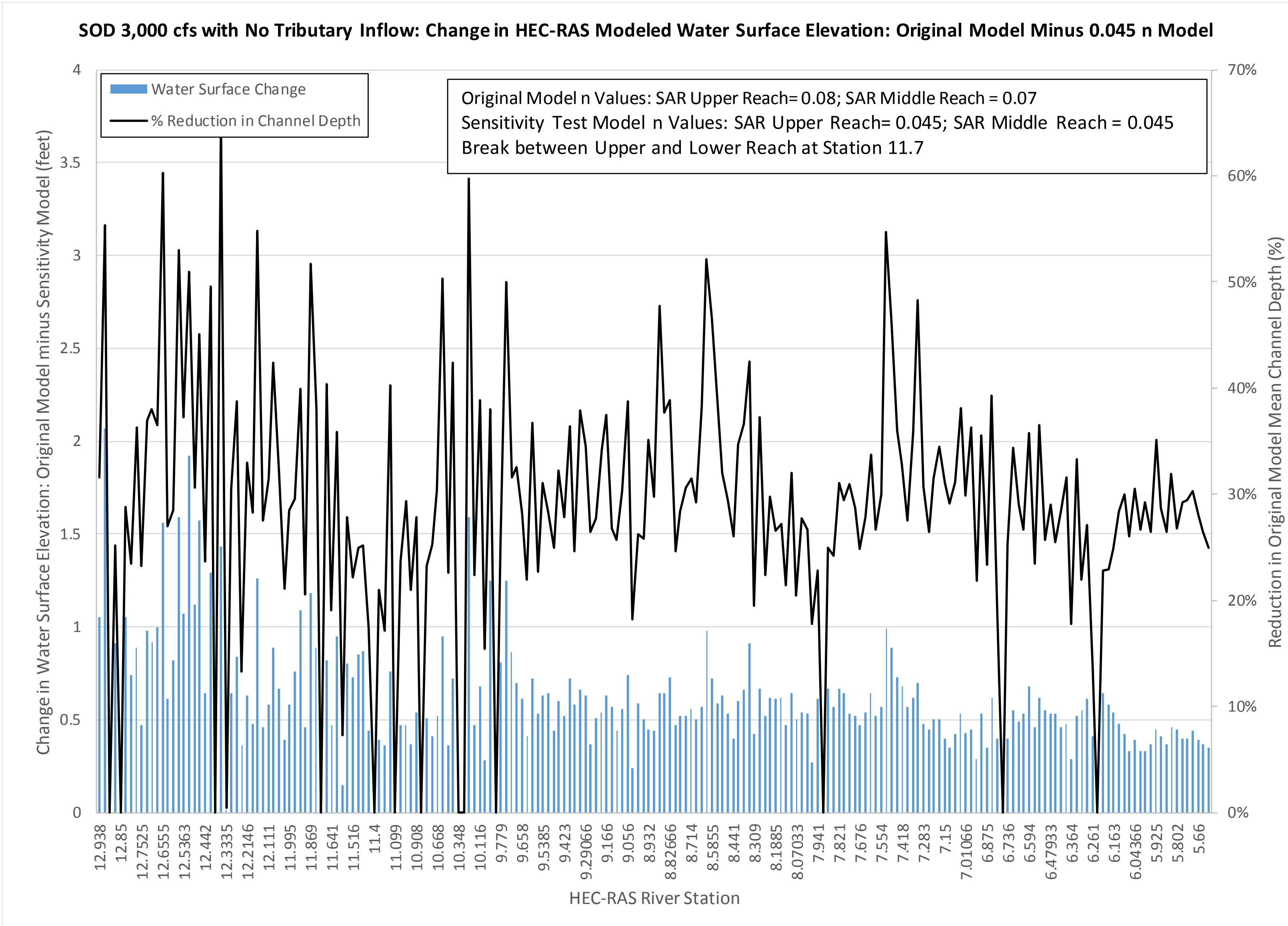


Figure 58
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.045 for Flow Scenario of SOD Release of 3,000 cfs with No Tributary Inflow

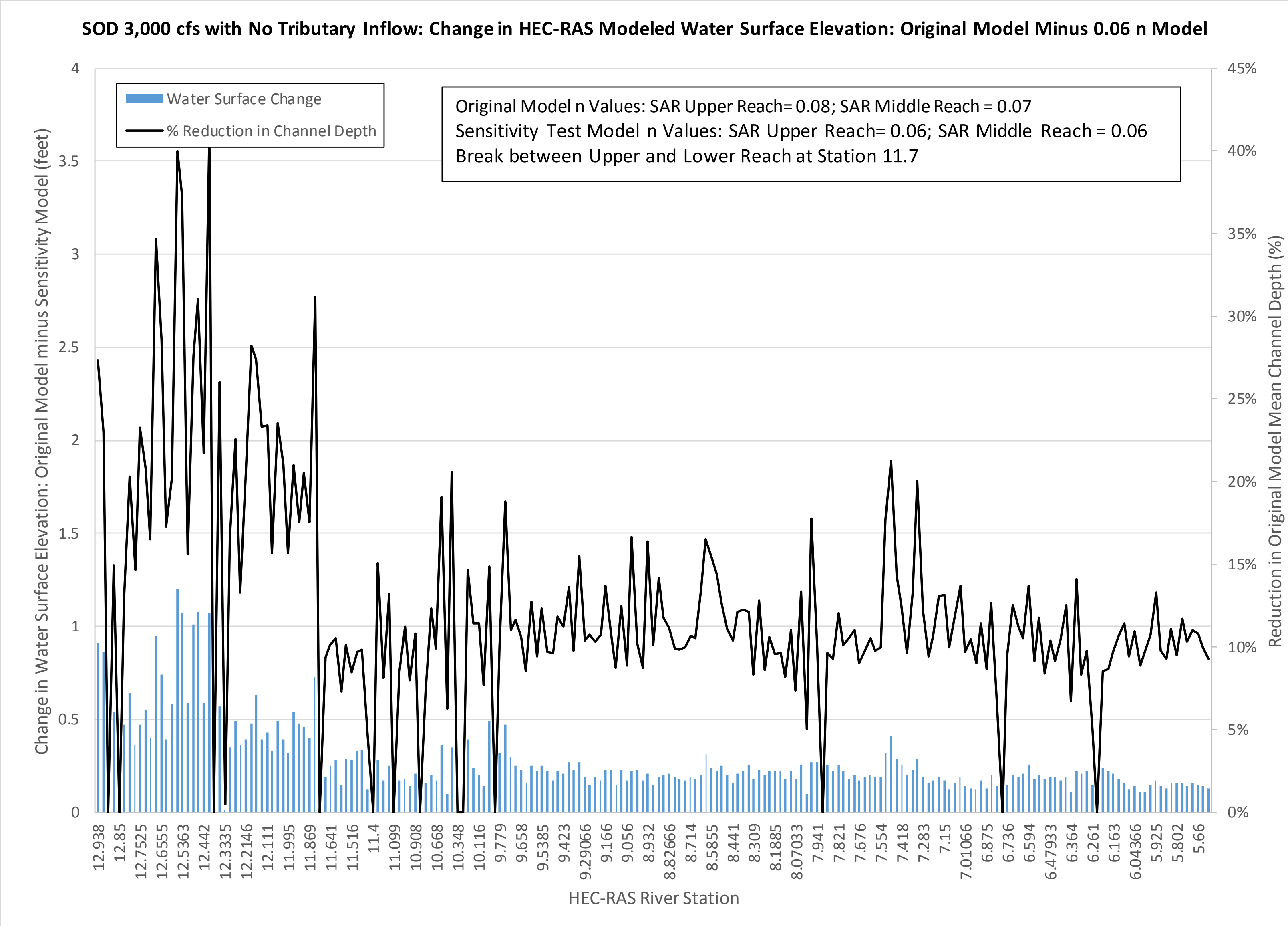


Figure 59
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.06 for Flow Scenario of SOD Release of 3,000 cfs with No Tributary Inflow

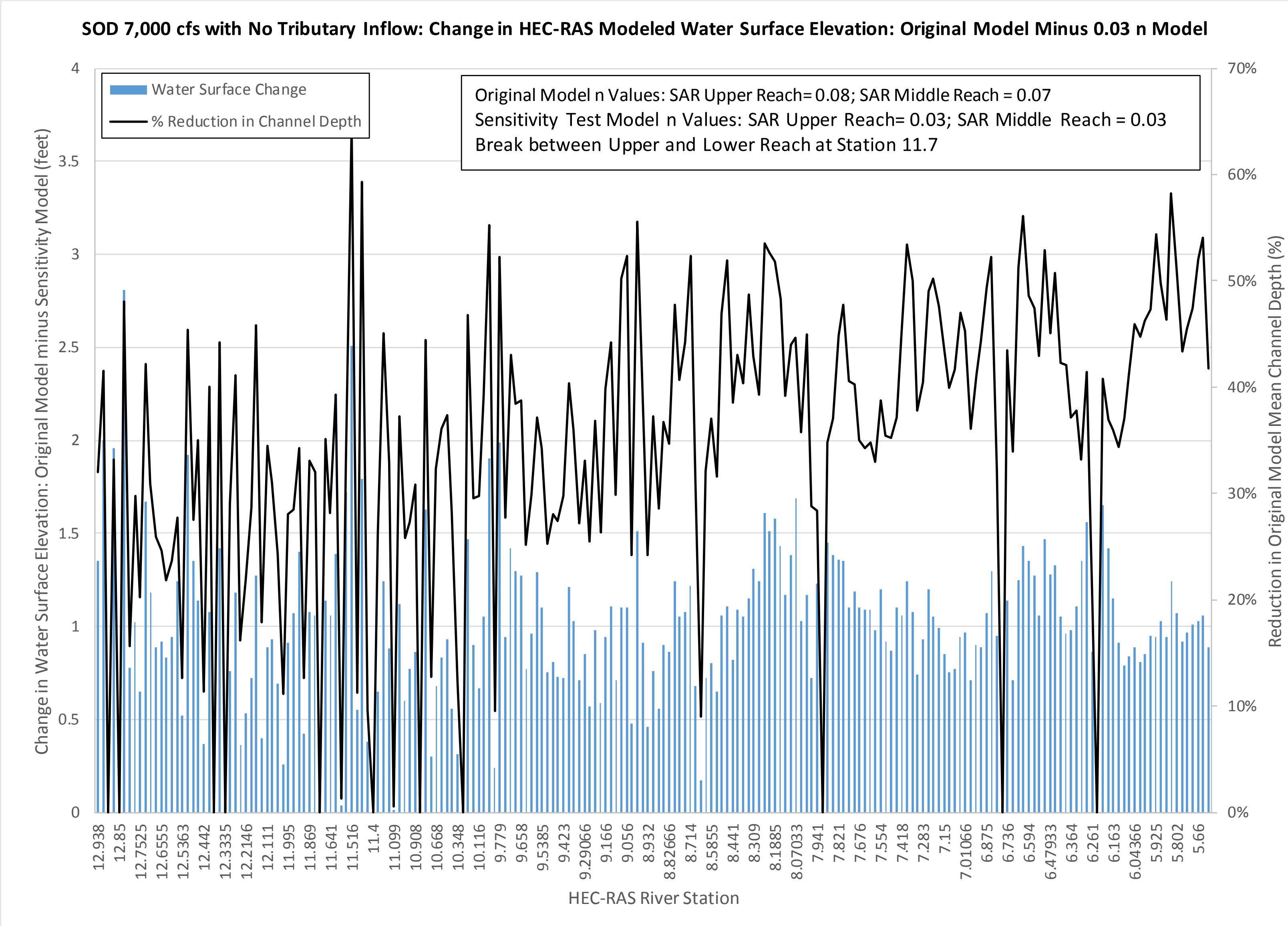


Figure 60
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.03 for Flow Scenario of SOD Release of 7,000 cfs with No Tributary Inflow

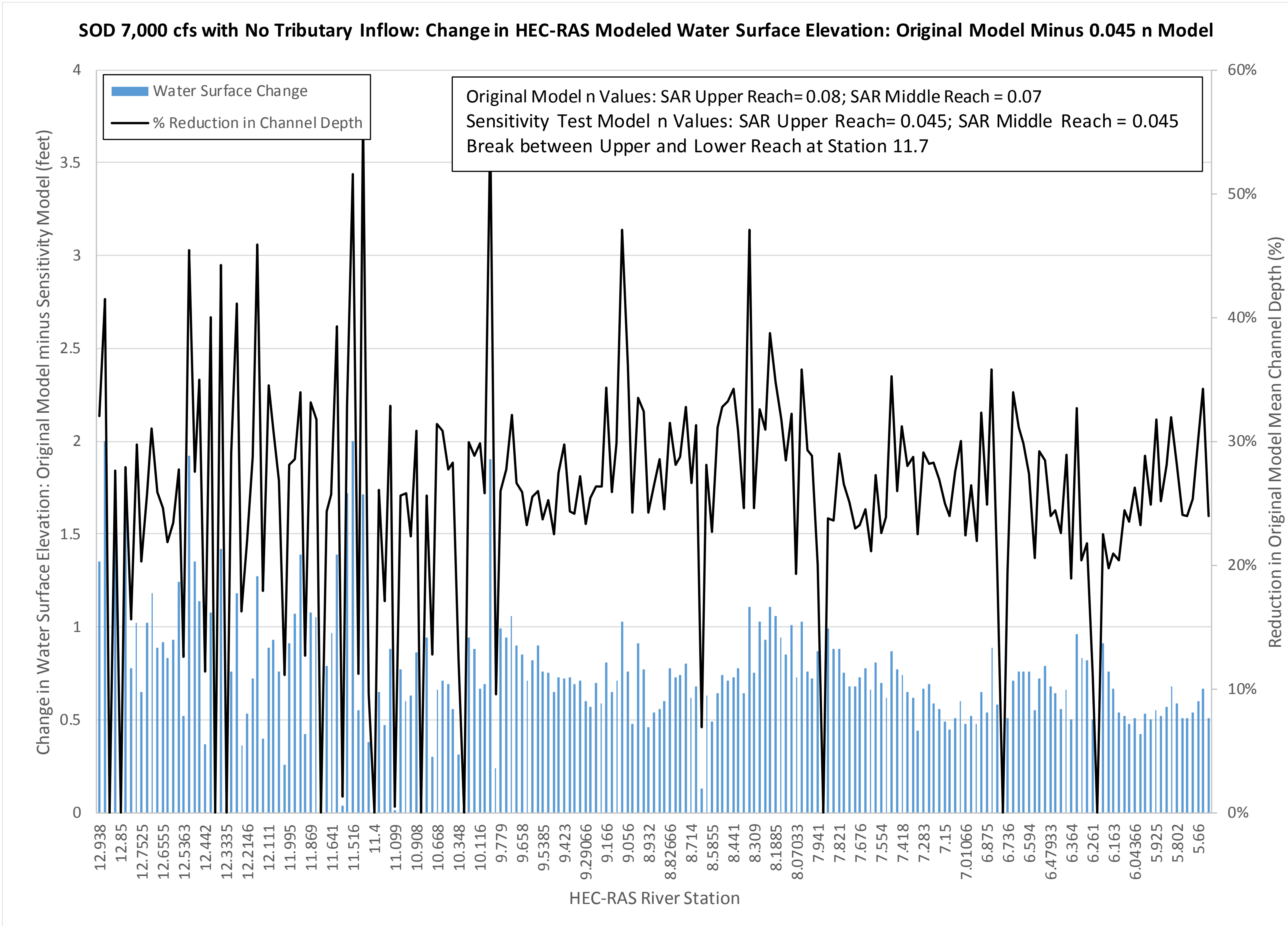


Figure 61
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.045 for Flow Scenario of SOD Release of 7,000 cfs with No Tributary Inflow

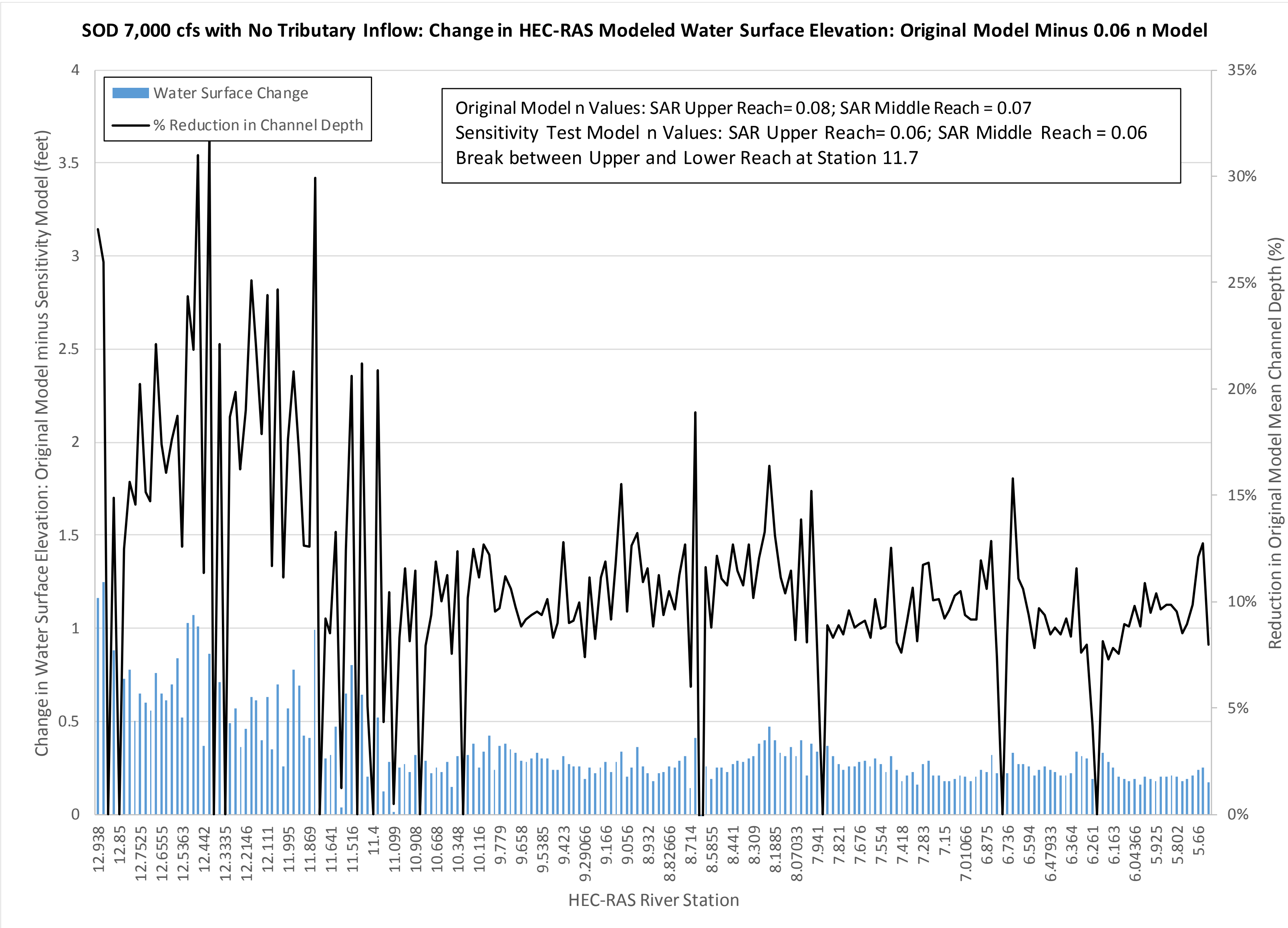


Figure 62
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.06 for Flow Scenario of SOD Release of 7,000 cfs with No Tributary Inflow

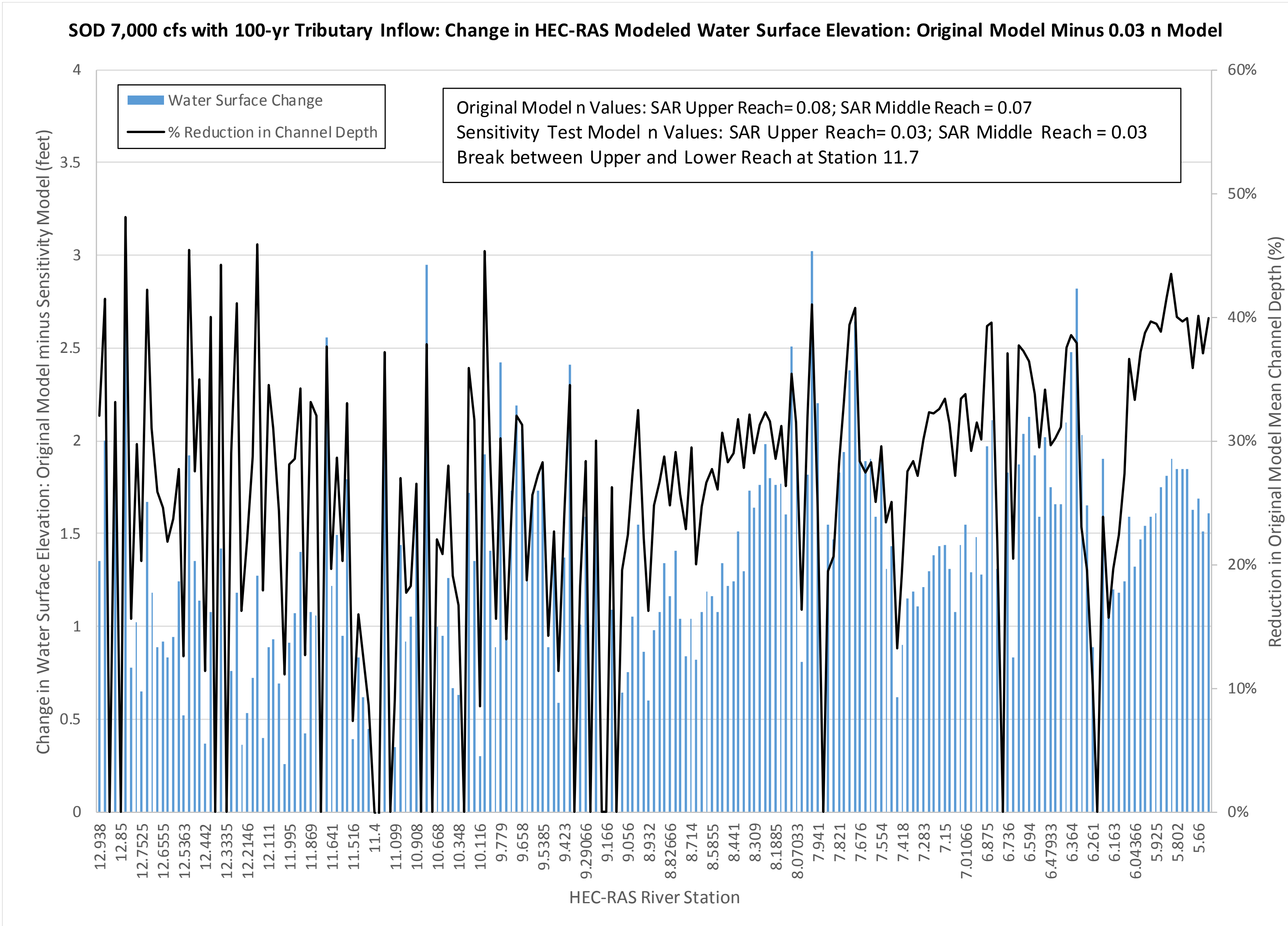


Figure 63
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.03
for Flow Scenario of SOD Release of 7,000 cfs and 100-yr Event Tributary Inflow

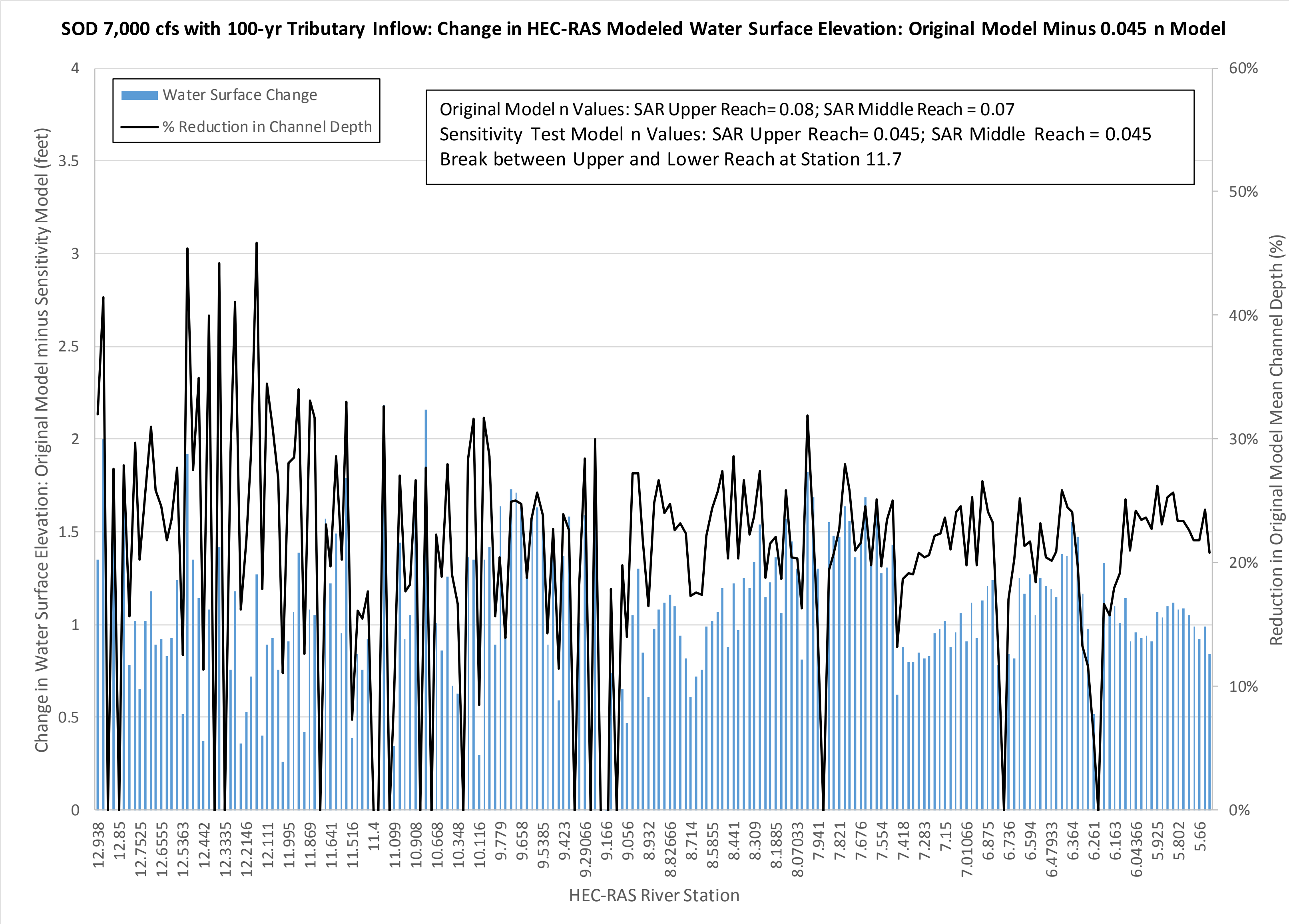


Figure 64
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.045 for Flow Scenario of SOD Release of 7,000 cfs and 100-yr Event Tributary Inflow

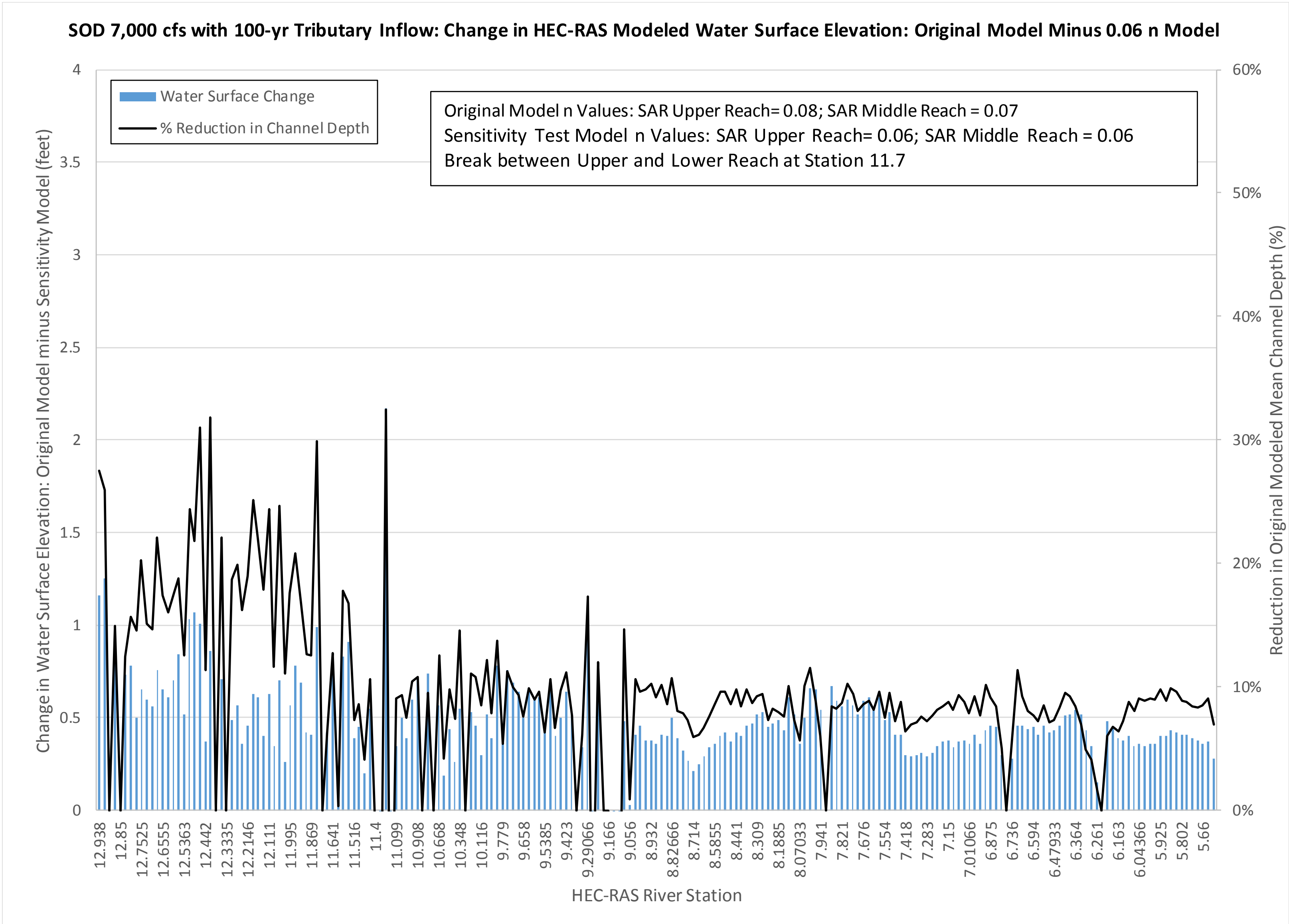
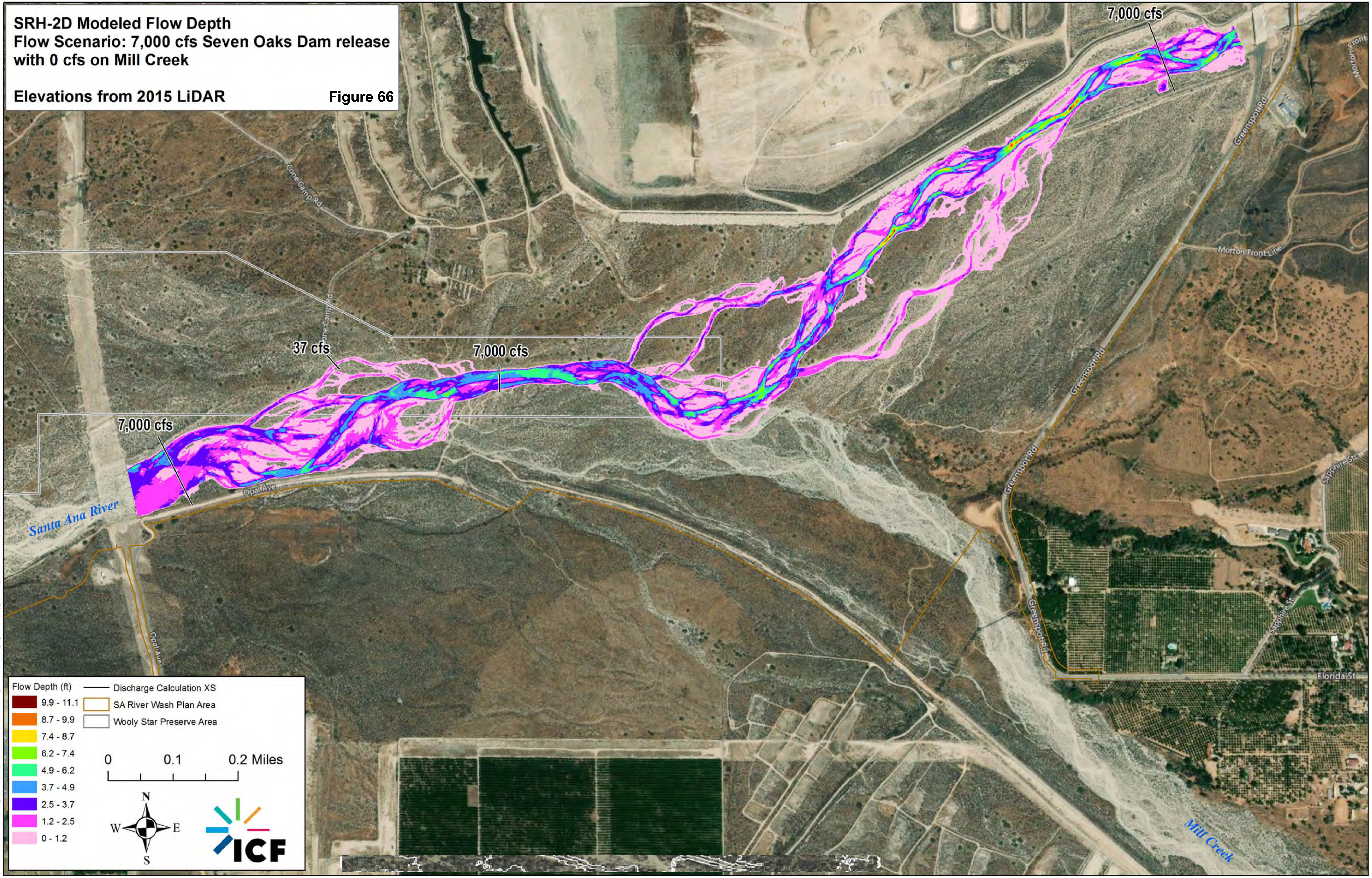


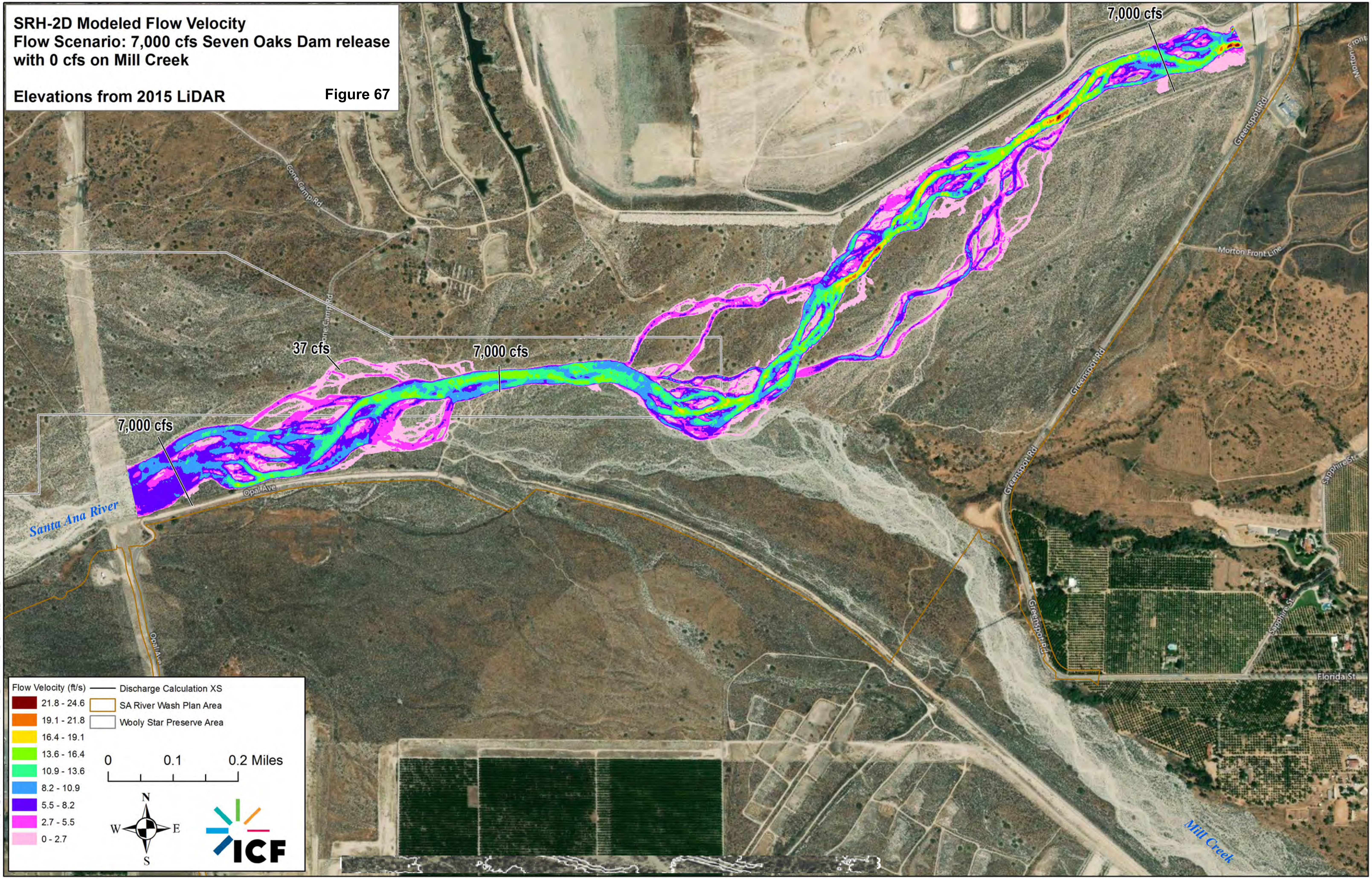
Figure 65
Sensitivity Test of HEC-RAS Model Channel Manning's n Set to 0.06
for Flow Scenario of SOD Release of 7,000 cfs and 100-yr Event Tributary Inflow

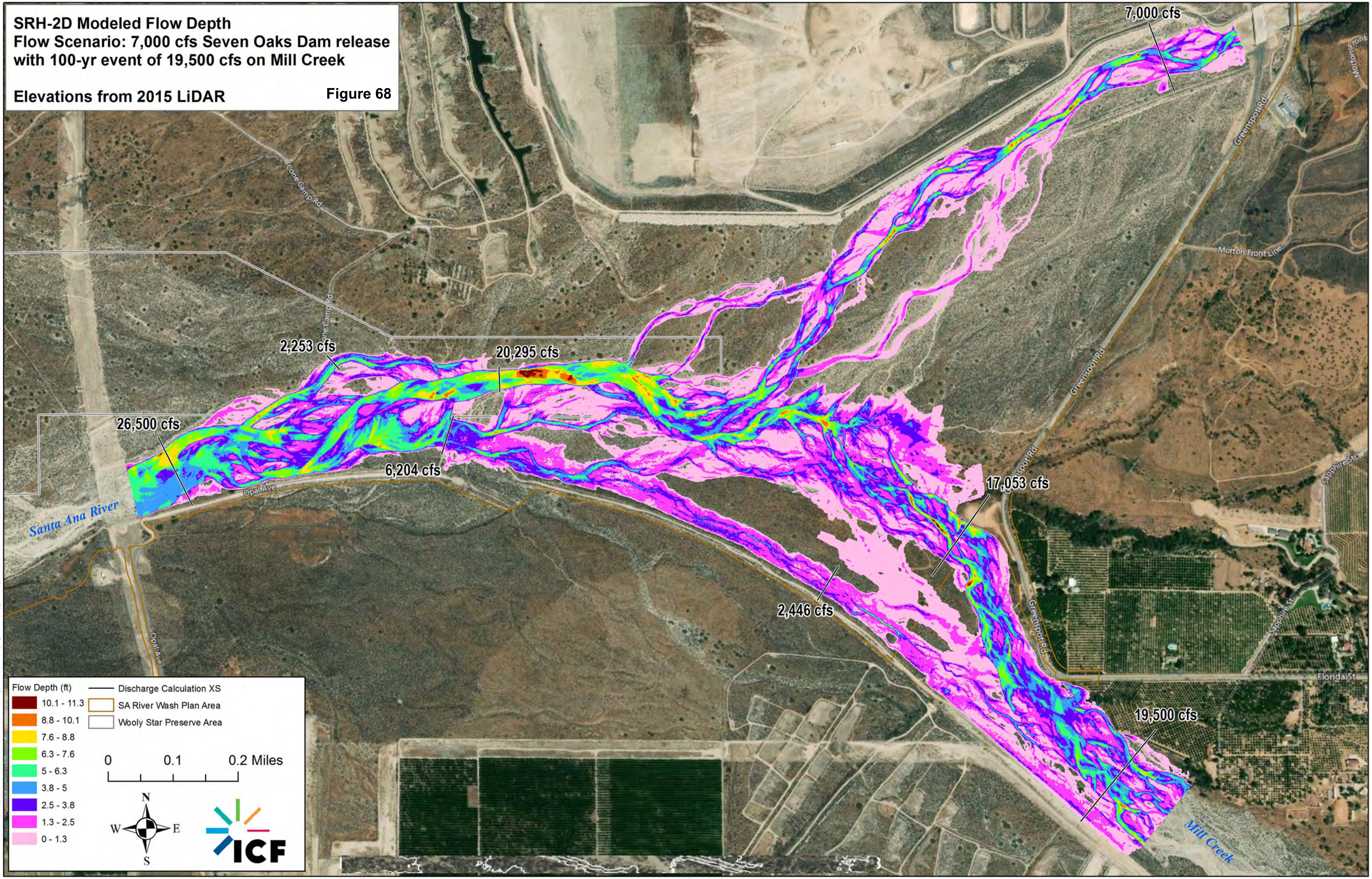


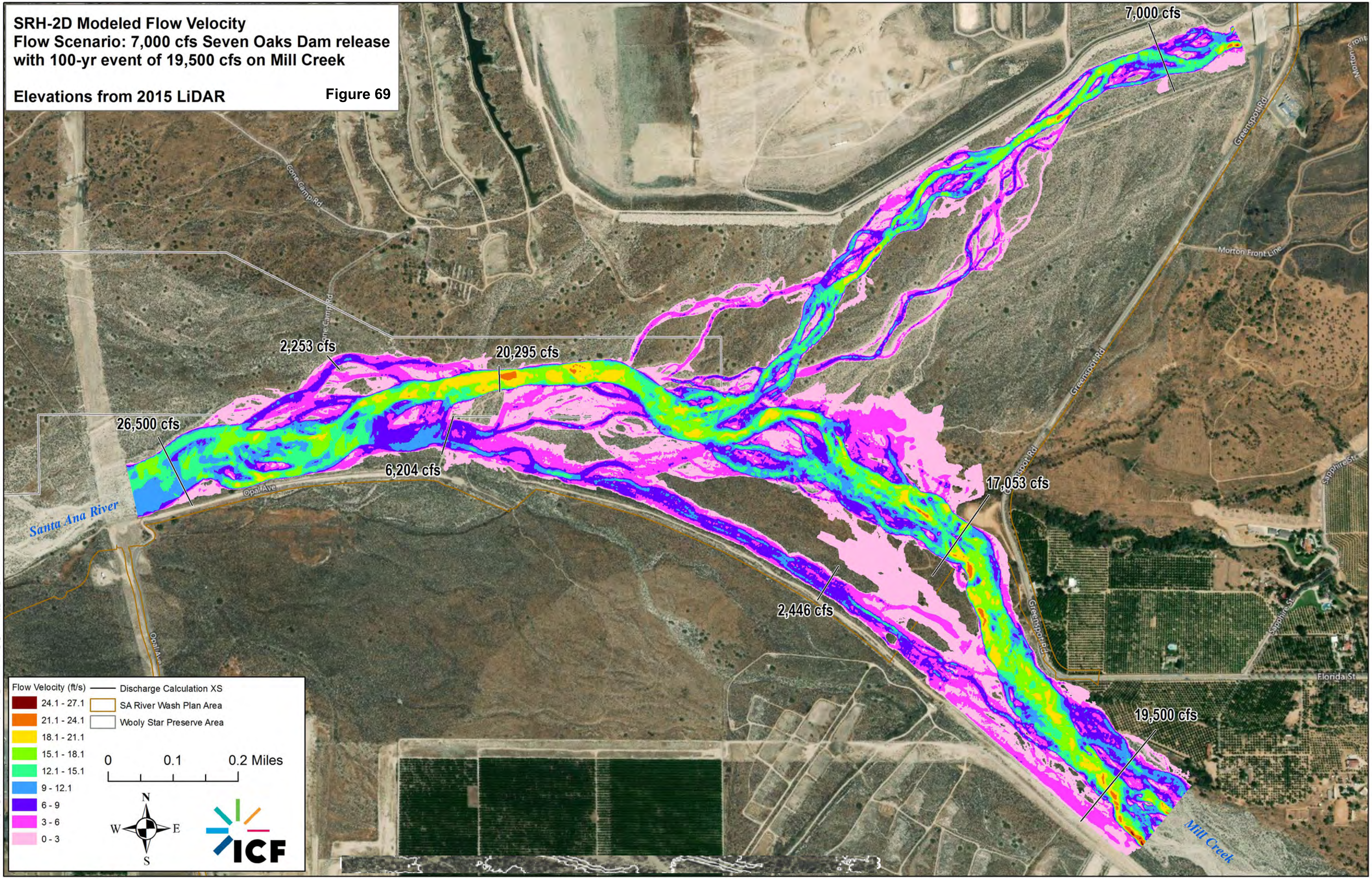
SRH-2D Modeled Flow Depth
Flow Scenario: 7,000 cfs Seven Oaks Dam release with 0 cfs on Mill Creek
Elevations from 2015 LiDAR
Figure 66
7,000 cfs
37 cfs
7,000 cfs
7,000 cfs
Santa Ana River
Mill Creek
Cone Camp Rd
Opal Ave
Greenspot Rd
Morton Front Line
Florida St
Sapphire St
Flow Depth (ft)
9.9 - 11.1
8.7 - 9.9
7.4 - 8.7
6.2 - 7.4
4.9 - 6.2
3.7 - 4.9
2.5 - 3.7
1.2 - 2.5
0 - 1.2
Discharge Calculation XS
SA River Wash Plan Area
Wooly Star Preserve Area
0
0.1
0.2 Miles
N
S
E
W
ICF

SRH-2D Modeled Flow Velocity
Flow Scenario: 7,000 cfs Seven Oaks Dam release with 0 cfs on Mill Creek

Elevations from 2015 LiDAR **Figure 67**




SRH-2D Modeled Flow Depth
Flow Scenario: 7,000 cfs Seven Oaks Dam release with 100-yr event of 19,500 cfs on Mill Creek
Elevations from 2015 LiDAR
Figure 68
7,000 cfs
2,253 cfs
20,295 cfs
26,500 cfs
6,204 cfs
17,053 cfs
2,446 cfs
19,500 cfs
Santa Ana River
Mill Creek
Opal Ave
Greenspot Rd
Morton Front Line
Florida St
Sapphire St
Cone Camp Rd
Flow Depth (ft)
10.1 - 11.3
8.8 - 10.1
7.6 - 8.8
6.3 - 7.6
5 - 6.3
3.8 - 5
2.5 - 3.8
1.3 - 2.5
0 - 1.3
Discharge Calculation XS
SA River Wash Plan Area
Wooly Star Preserve Area
0
0.1
0.2 Miles
N
W
E
S
ICF



SRH-2D Modeled Flow Velocity
Flow Scenario: 7,000 cfs Seven Oaks Dam release with 100-yr event of 19,500 cfs on Mill Creek

Elevations from 2015 LiDAR **Figure 69**

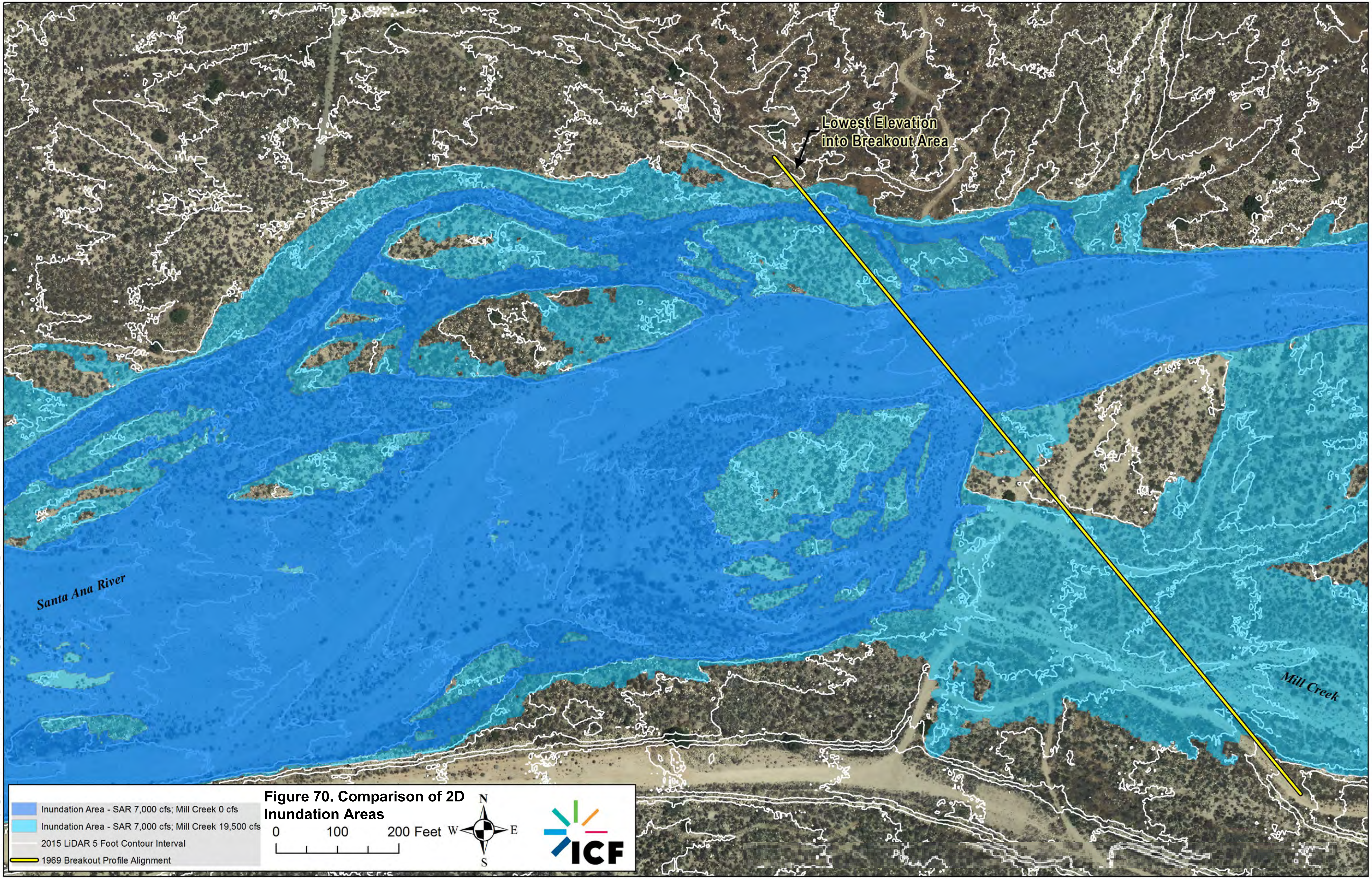


Figure 70. Comparison of 2D Inundation Areas

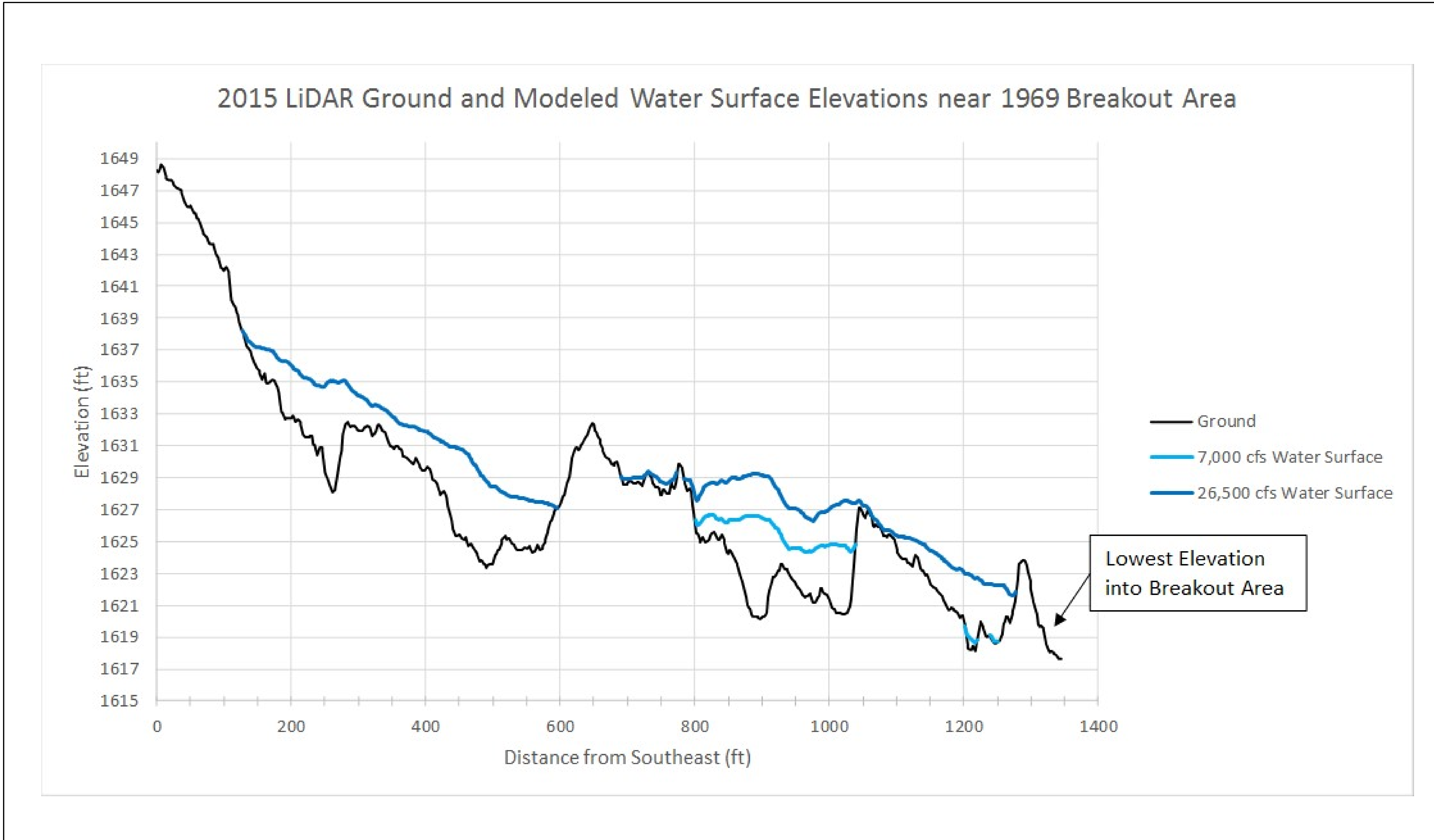


Figure 71
2015 LiDAR Ground and Modeled Water Surface Elevations near 1969 Breakout Area

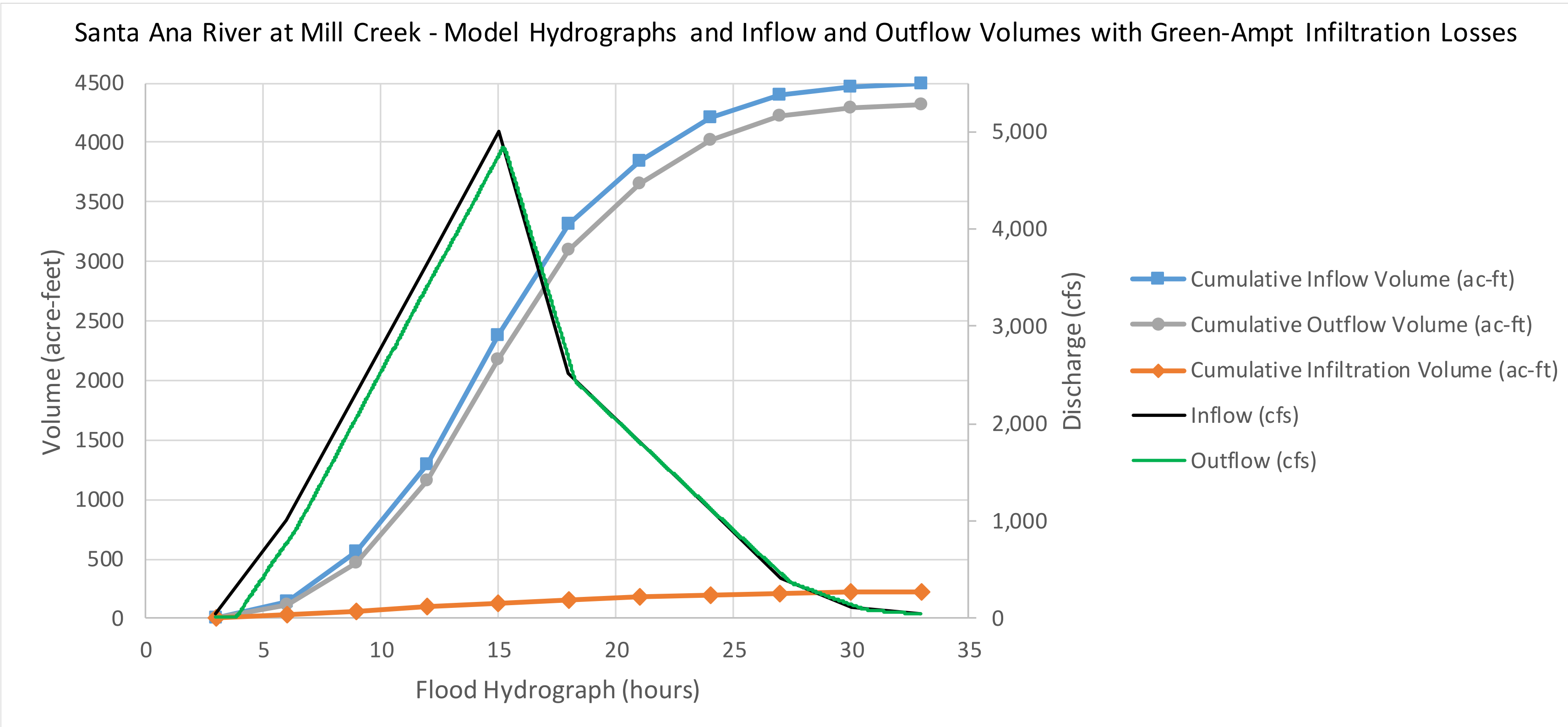


Figure 72
Modeled Hydrographs and Inflow and Outflow Volumes with Green-Ampt Infiltration Losses

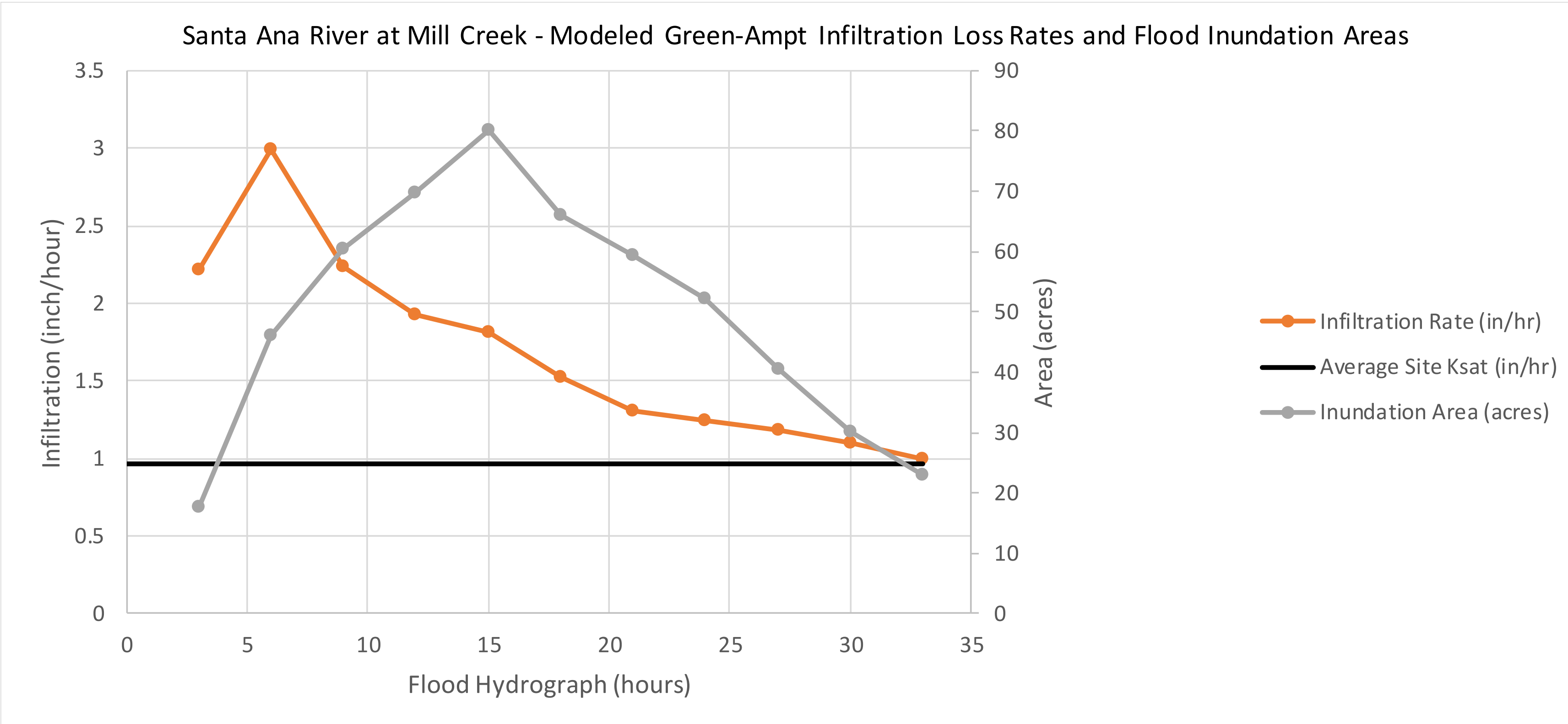
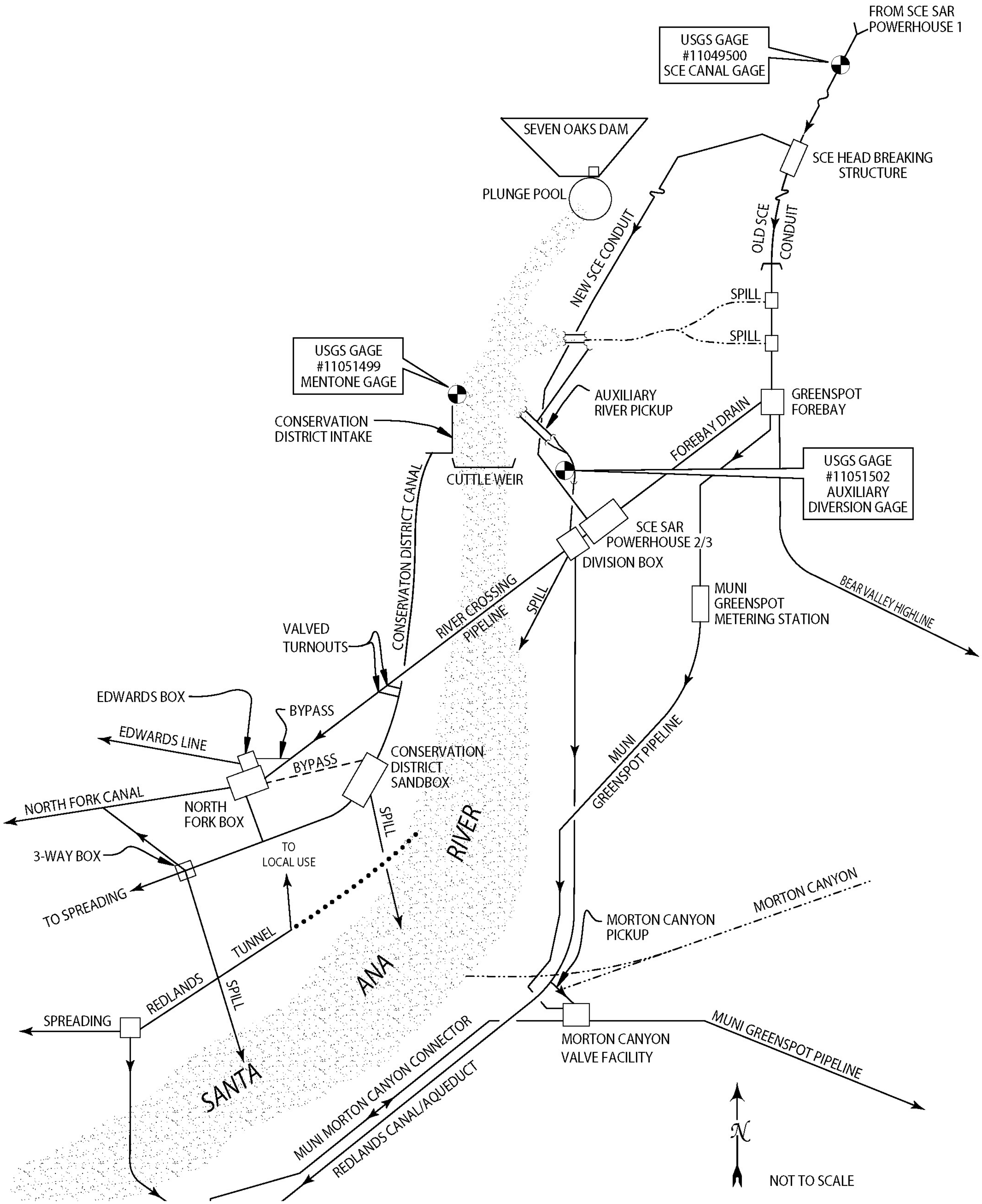


Figure 73
Modeled Green-Ampt Loss Rates and Flood Inundation Areas



Source: SBVMWD 2004

Figure 74
Schematic of Water Control Features and Gages in the Santa Ana River Canyon

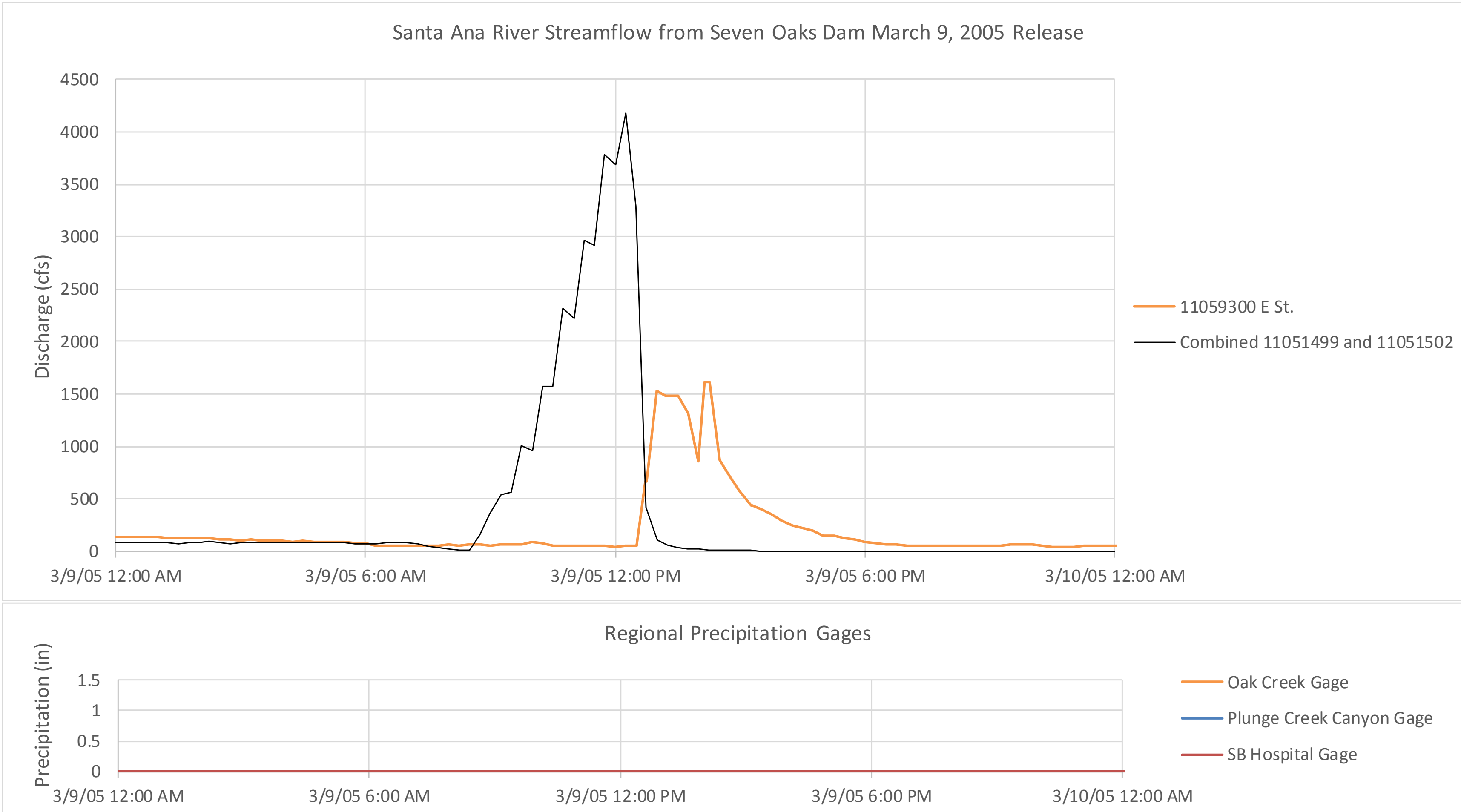


Figure 75
Santa Ana River Flood Hydrographs and Daily Precipitation Hyetographs for the March 9, 2005 Seven Oaks Dam Release

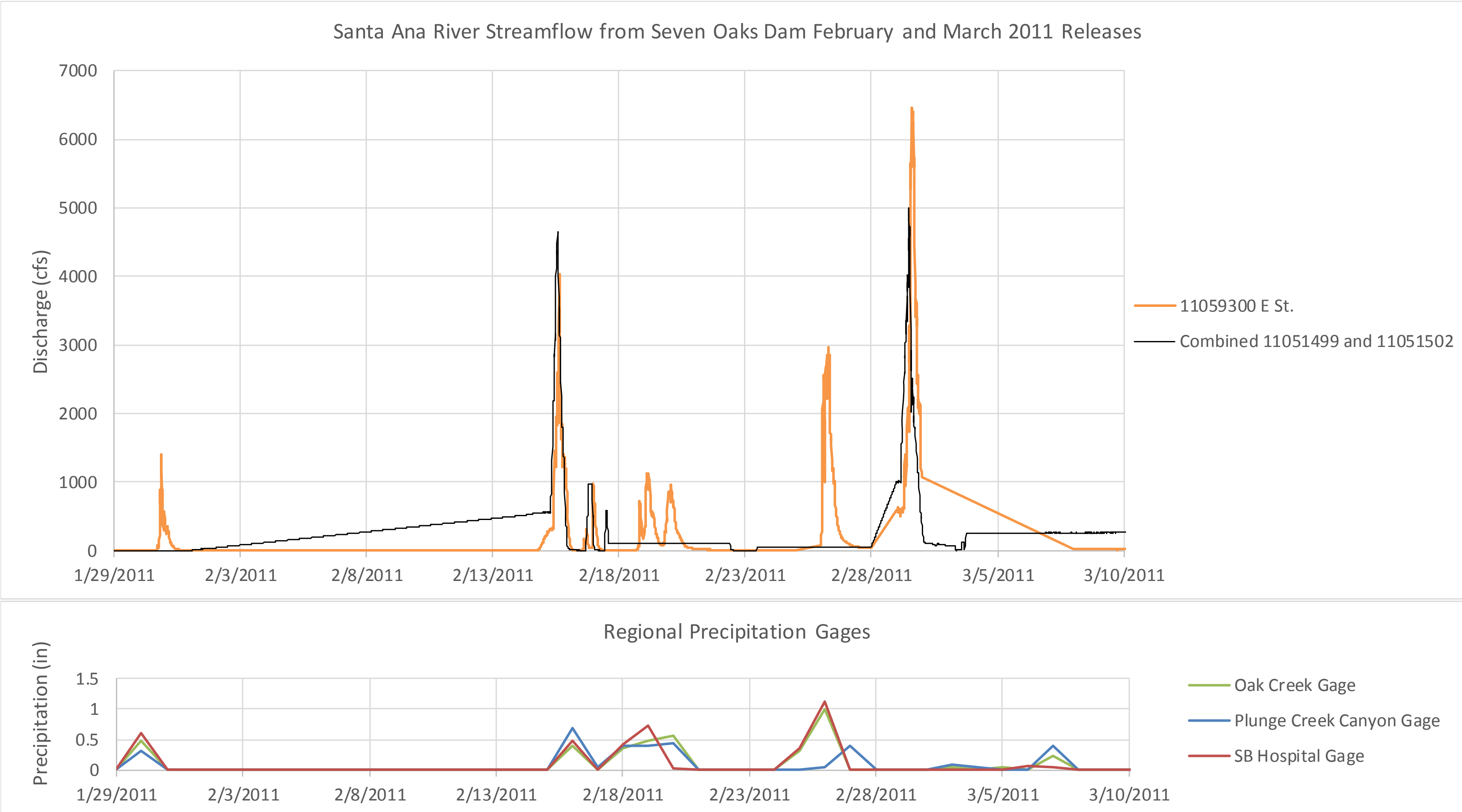


Figure 76
Santa Ana River Flood Hydrographs and Daily Precipitation Hyetographs for the February 15 and March 1, 2011 Seven Oaks Dam Releases

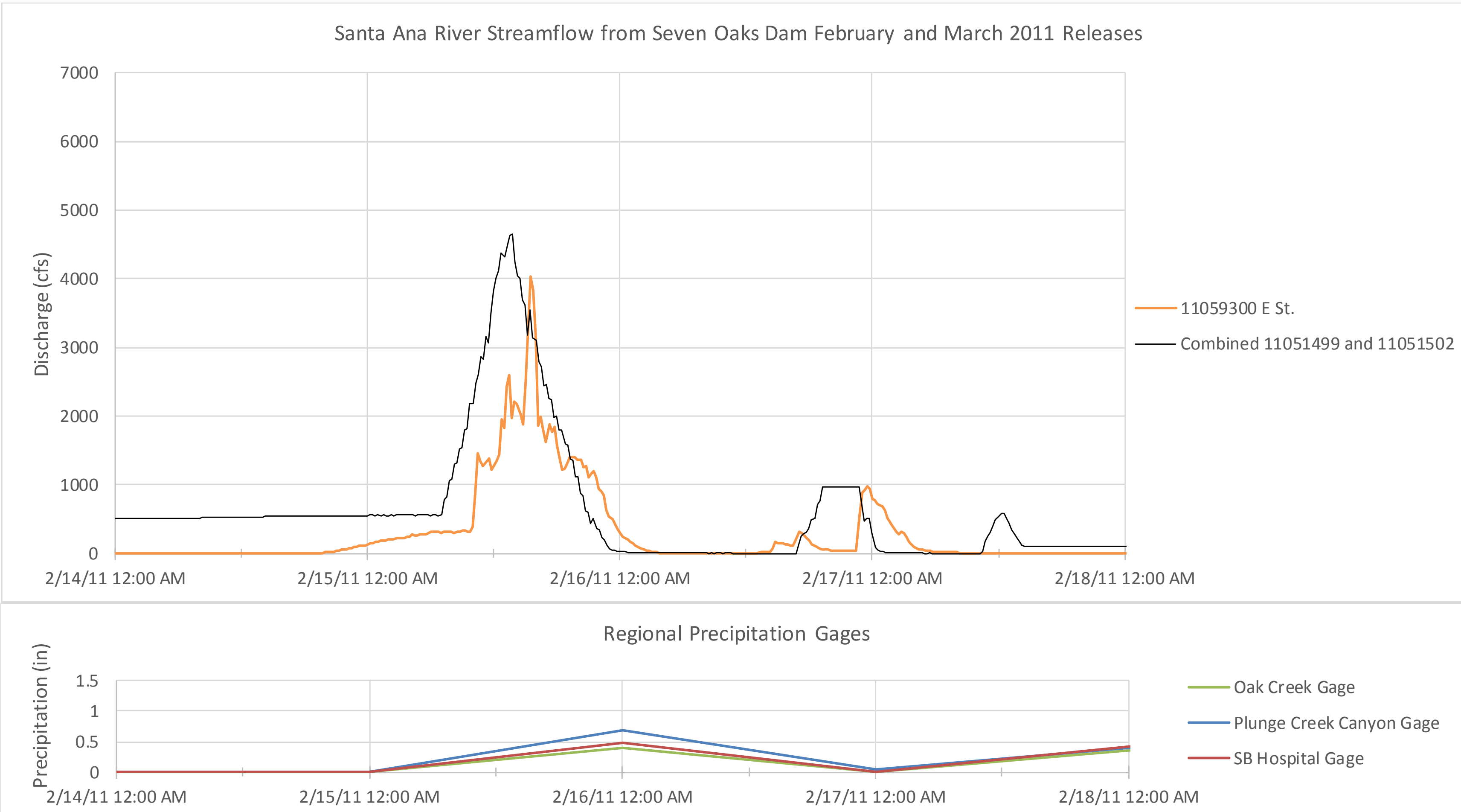


Figure 77
Santa Ana River Flood Hydrographs and Daily Precipitation Hyetographs for the February 15, 2011 Seven Oaks Dam Release

Comparison of HEC-RAS 1D and SRH-2D Modeled Flood Inundation Areas on the Santa Ana River

Flow Scenario: 7,000 cfs Seven Oaks Dam Release with No Inflow From Mill Creek (0 cfs)

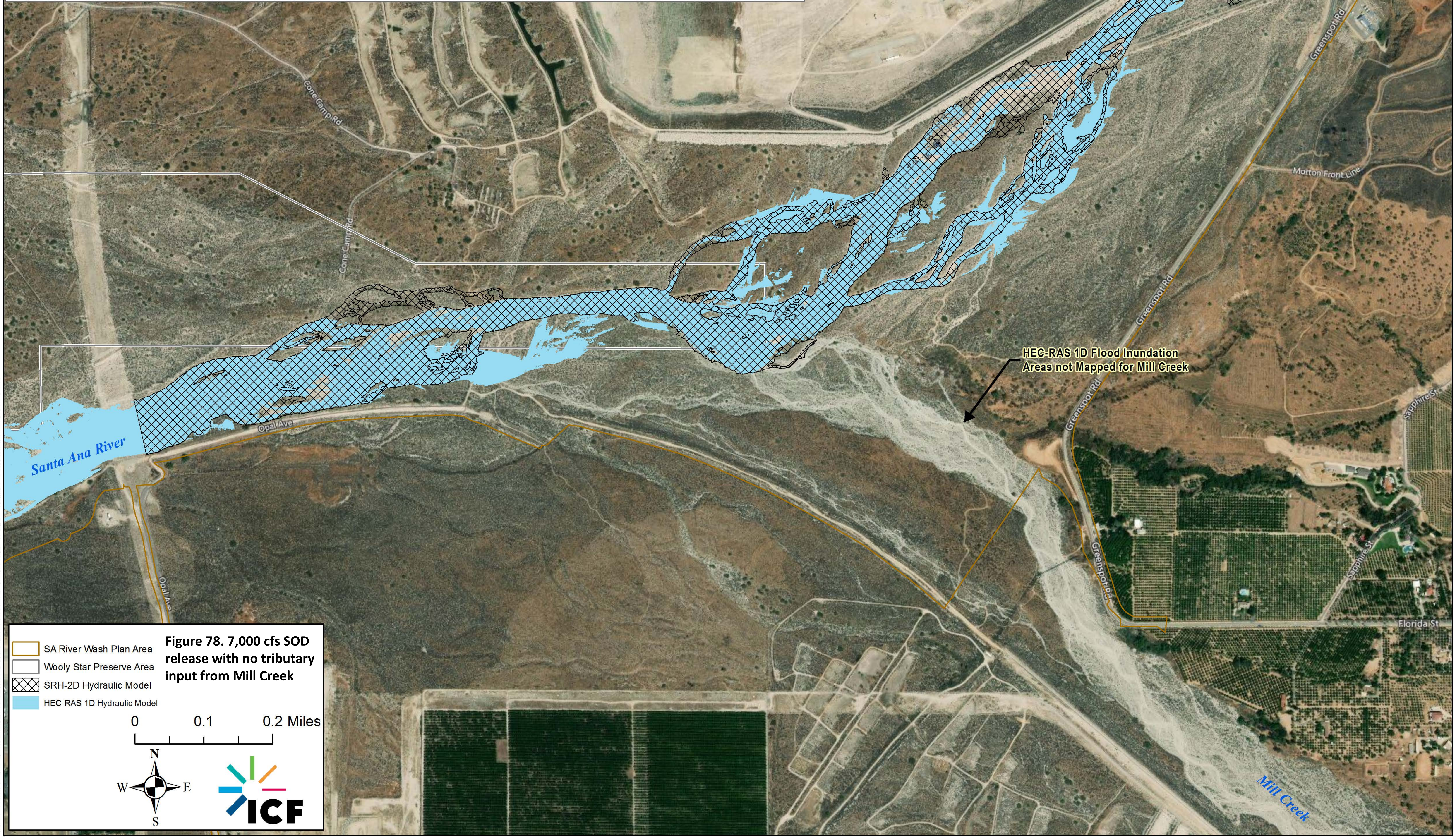


Figure 78. 7,000 cfs SOD release with no tributary input from Mill Creek

Comparison of HEC-RAS 1D and SRH-2D Modeled Flood Inundation Areas on the Santa Ana River

Flow Scenario: 7,000 cfs Seven Oaks Dam Release with 100-yr Event on Mill Creek (19,500 cfs)

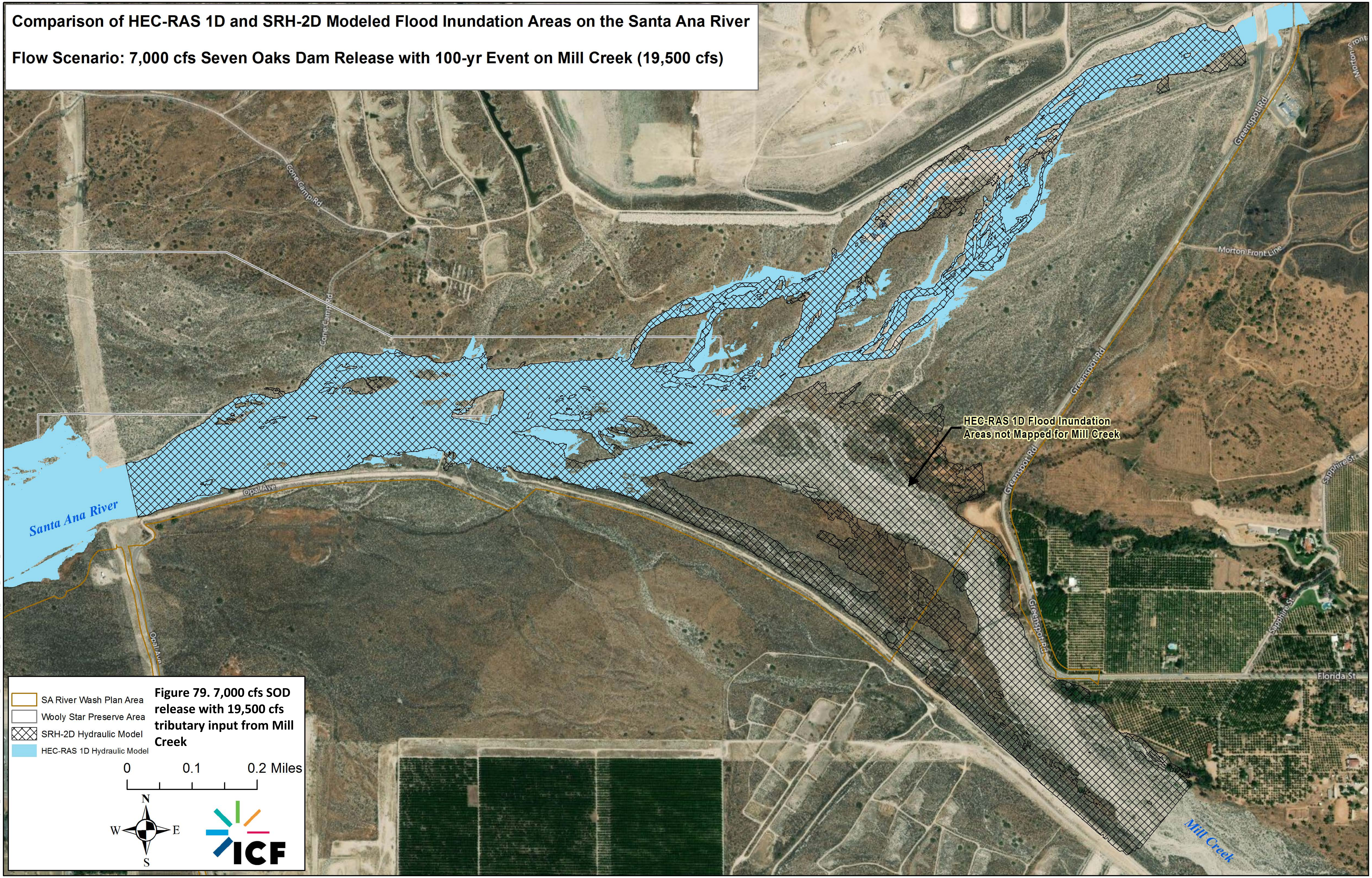


Figure 79. 7,000 cfs SOD release with 19,500 cfs tributary input from Mill Creek

Appendix 1
Science Advisor Feedback and Response Logs

Independent Science Advisor Process

Following the kickoff of the project in June 2018, a science advisory committee was formed to review and guide the HFS. Initial HFS data and results were compiled into presentations and hosted in webinar format (August, October, and November 2018) during the implementation of the first phase of the HFS. In December of 2018, a workshop was hosted by SBVWCD, and state and federal agency staff were invited to engage with the science advisory committee and other stakeholders to review and discuss the results. Following the workshop, a progress report on the HFS was published (December) and distributed to the group.

Science Advisor Input

Committee feedback was initially received in a question and answer session immediately following presentations. Additional coordination with individual science advisors took place via email and phone communication. Summary feedback for meetings and workshops was generally submitted as a series of written questions to which the investigators responded, also in writing, with ICF responses in red where appropriate. Following the December workshop, feedback was submitted as technical memos by Blue Octal and Stillwater Sciences. The feedback, response documents, and technical memos are compiled here in Appendix 1, Science Advisor Feedback and Response Logs. In soliciting feedback from the science advisory committee and larger working group (agency staff, other stakeholders), ICF requested both review of work products, and input on priority areas for investigation.

The Blue Octal memo (12/24/18) addresses the progress report directly, regarding both general and specific issues, as well as providing input on priority areas for future work. ICF has addressed and implemented those issues raised by the memo that fall within the scope of Phase 1, and they are reflected in the final report. Portions of the guidance and feedback contained within the memo are outside the scope of Phase 1 and were therefore not addressed in the final report. These elements will be retained and incorporated into proposed Phase 2 work.

The Stillwater Science memo addresses the study more generally, as well as providing a discussion of the technical challenges associated with modeling braided river networks. The memo also provides input on priority areas and alternative disturbance techniques. Again, those elements presented in this memo that were not directly addressed in the final report will be retained and incorporated into future work.

The feedback received from the working group (science advisory committee, other stakeholders, and agency staff) has been greatly appreciated. The review process has resulted in a revised and expanded final report that is more comprehensive and focused as a result.

Questions for ICF following 8/27/18 telecon presentation

Prepared by:

Blue Octal Solutions, LLC

J. Toby Minear and Mike Lamb

Questions and Comments:

1.) How do hydrologic objectives relate to species goals and what are the quantifiable species goals? E.g. What is the functional model for how X (transporting sediment, depositing sediment, eroding vegetation) results in Y (increasing, stabilizing, spatial diversity) response in species? Is the goal to simply inundate areas with flood water, or is there a requirement to transport sediment or scour plants?

Quantifiable hydrologic objectives could include the following: removal of vegetation (including large woody), removal of fines and organic matter, deposition of clean sediment free sand. What depth of clean sand is unknown. Preferred particle ranges will be provided by laboratory analysis associated with Dr. Sheir's work. Shear stress for scour of vegetation within the study area is unknown. We could potentially use shear stress observations from work in other areas to estimate flow values required within the study area.

Quantifiable species goals for SBKR would be selected based on Dr. Shier's work. Prior to completion of Dr. Shier's study, quantifiable species goals for the species of interest would be new occurrences within flood disturbed areas.

There is no functional model for the degree to which sediment erosion/deposition and vegetation removal affects species responses. We have correlational evidence in the seral stage flood disturbance relationship that indicates that flood disturbance will result in the creation of new habitat.

The goal should be to produce flood events that result in a significant directional change in the species goals. This will have to be offset by potential impacts to pre-existing populations of the species of interest within flood disturbed areas.

2.) Accounting for high flow duration and timing in addition to magnitude and frequency will be important for determining effectiveness on species outcomes. For example, flooding the floodplain habitat when SBKR have young in their dens would be counterproductive. Are duration and timing being addressed?

Duration and timing have not yet been addressed but this seems straightforward. We would need a consensus opinion from species experts on time windows for disturbance. Barring an expert opinion, disturbance within the natural wet season would be the default time window.

3.) What are expected infiltration rates and how will these be incorporated into the hydraulic modeling? Ideas: Use SBVMWD infiltration rates for upper Santa Ana galleries or USGS infiltration estimates from lower Santa Ana RIX reach; Use a hydraulic model that explicitly accounts for infiltration. Can these infiltration volumes be sufficiently quantified to qualify as ground-water inputs?

We are aware of this issue and will be looking into ways to account for it. We are interested in any guidance the group may have in accounting for infiltration losses across an area.

4.) The high flow releases from Seven Oaks Dam to date have been very flashy, which will require careful choice of a hydraulic model that incorporates adequate wetting and drying at these short time-scales. Which hydraulic models are being considered (other than the 1D HEC RAS reach model)? In addition, running HEC-RAS in full unsteady state will be much more realistic than steady state runs.

SRH-2D is the 2D model that will be used and it can be run in the full unsteady state. We will be developing models of actual and synthetic hydrographs from SOD alongside existing flow contributions from Mill and City Creek.

5.) How will the hydraulic model be calibrated and friction coefficients estimated? Will there be a sensitivity analysis performed on the relevant variables? Inundation extents in satellite imagery could also be used for calibration.

Does the group have access to satellite imagery from any known events for which flow data exists? As a first cut, the original roughness coefficients from the ACOE run (Gary Brunner, 1999 ACOE report) will be used. Downstream boundary conditions could be informed by the USGS E St. gage. This location is located well downstream of the study area, but is the closest gaged location. Time permitting, a sensitivity analysis will be performed.

6.) During the initial presentation in June, we heard that the species distribution data had been collected when and where possible and that those data did not adequately reflect the distribution of species. For example, we heard that SBKR populations are densest near the airport (not shown in any of the species distribution slides). In this presentation it seems that the haphazard data is being used to inform distribution. Are these new data in the presentation or could this point be clarified?

Not familiar with any caveats associated with the SBKR data or increased population density at specific sites. Should we include the reach adjacent to the airport into the study area? What is the most recent and accurate data for us to use? Some more recent USFWS records are being digitized and entered into a GIS layer by Valley Conservation District. These new records are now available and will be incorporated into the species distribution map.

Our current strategy with regards to species distribution is to construct an initial "most conservative" distribution map, whereby all known species occurrences are recorded and reflected as the current species distribution. When areas for disturbance are selected, we will query the individual records within the proposed area to classify sample date and methods for individual records.

7.) Is it possible to present the species 'proportional density' data as number of individuals per habitat per area, with associated error bars? If possible, the specific boundaries of individual studies should be identified as well as the spatial resolution at which species were identified to asses sampling bias in the density distributions.

We would need to get the confidence intervals from the specific studies. Boundaries of individual studies aren't in hand. Should recovering this information be a priority? Spatial resolution of species IDs is not in hand either, again is this a priority? Generation of measures of sampling bias is important in the final risk assessment, but may be difficult to accomplish, given the broad range of time periods and potential methods used by individual investigators. Ultimately creating something of this nature may require significant resources to generate.

Representing species density in number of individuals per unit area may potentially be misleading because of the range of studies that have taken place. The data is best viewed as a collection of all physical locations where the species have been observed. We are currently using all available data to give the most conservative (erring on the side of the species) spatial distribution of organisms across the study area. The suggestion by the science advisors to look at floodability for each physical location with a species record is the appropriate next step in this process.

Finally, it is not currently possible to estimate errors or portray specific boundaries of individual studies. This would take additional effort and resources away from the main analysis and is not viewed as a critical next step.

8.) As mentioned in the telecon, the differences in the DEMs are interesting but difficult to interpret without accounting for the associated uncertainty for each surface. We would suggest using Joe Wheaton's GCD (Geomorphic Change Detection) Software to evaluate these data, which should be relatively straight-forward with the current elevation error estimates. The GCD software can be run stand-alone or as an Arc add-on and can be found at: http://gcd.riverscapes.xyz/.

Greg has attempted to implement this and the plugin failed with errors. We could pursue getting support from Joe Wheaton directly to get it working. Is this a priority?

One problem associated with generating finer scale error measurements of the topo DEMs is the method for interpolating that error. It may result in unreasonably large estimates driven by the algorithm driving interpolation of the 3D surface between topo lines. Because of this, the historic topo DEMs have some potentially significant restrictions on the type of analysis that can be applied to them.

We will present the thalweg profile plots with the currently calculated errors (based on control points) and a second method for calculating errors (based on control zone areas).

9.) Are other high flows being considered in addition to the BA/BO recommendations? E.g. pre-dam or others?

Modelling all flood events for the last 100 years may provide some insight. Or simply modelling a range of flows as Brendan has already proposed. As of now, flows up to 7000 CFS from SOD (scenarios including different contributions from Mill and City creeks) plus test flows required to produce overbank flooding are slated for modelling. Once we have buy in from the group on the operating parameters for historic operations at SOD, we will tabulate a list of flows that were possible and model those.

10.) Obtaining or back-calculating Seven Oaks Dam's stage-capacity curve and inflows would be a valuable and useful contribution. These data should be used to model different outflow scenarios of historic flood events (pre- and post-dam) to evaluate whether a revised outflow can achieve the high-flow targets for habitat restoration while working within the SOD's operation control manual. The inflow discharges are necessary to properly model the SOD operation and subsequent outflow scenarios.

This is proposed, but not included in the draft technical report.

11.) It would be a useful baseline to have pre-dam and post-dam plots of annual peak discharge magnitude vs recurrence interval. These will help evaluate how often pre-dam floods with different discharges occurred and the role of floods in the habitats pre-dam. These data should be used in conjunction with the hydraulic modeling to give the expected recurrence interval of different target discharges (e.g., to inundate a certain elevation above channel, suspend sand, etc).

This is completed and included in the draft technical report.

Stillwater Sciences COMMENTS ON THE 8/27/18 PRESENTATION

1. It would be very useful to plot observations of Woolly-Star, SBKR, and Spineflower in terms of elevation relative to thalweg and distance from the thalweg, and possibly distance downstream of the dam to see if that plays a role. This is probably best done using only observations recorded after the last big flood.

On the to-do list. All observations post-date the 1968 flood event which was the last major event to re-work significant portions of the floodplain. This work was completed and is included in the draft technical report (10/17/18).

2. The elevation plots have lots of negative values, which are presumably from the large excavation pits. Are these used by any of the species of interest? If not, can we mask them in the histograms and maps?

Masking them from the histograms is low priority given the limited time and resources. The majority of future effort will be focused on modelling flows.

3. As recommended by Mike and Toby on the call, please include the uncertainty in the topographic differencing and elevation relative to the thalweg.

On the to-do list. This work was completed and is included in the draft technical report (10/17/18).

4. What is causing the striping perpendicular to the channel in the relative elevation plots in 1964 and 1987 (most noticeable on slides 37 and 38)? Is it something to do with how the slope is detrended or the contour interval of the original plots? We ask because it might have an implication for the plot we ask for in the first comment.

This is likely to be an artifact of the DEM interpolation algorithm. It may have some influence on the thalweg plots, but general trends should be visible. Using vector contour lines prior to DEM gets around this problem.

5. To what degree have levees and sediment excavation constrained the valley width through the reach?

We can locate various levees and highlight their presence on the map. We can also produce map images that illustrate channel constraint. The downcutting highlighted in the presentation appears to be associated with two bridge approaches, but there's no direct evidence they're related. Could be borrowing of materials for the bridge approach construction or channelization downstream.

6. How has the channel width changed through time spatially? Does narrowing occurring where the channel is downcutting? We ask to get a better picture of the channel dynamics in Reach C. The HEC RAS model will be useful to figure this out.

We will consider examining this issue using flow recurrence, once priority modeling has been completed.

7. What causes the change in the noise and minimum elevation of the reservoir levels after 2008 (This may have been covered in the site visit)?

Unknown as to what the cause of the noise or the elevation change are. We have forwarded this question to staff at SBVWCD and will pass on any response. No response from SBVWCD (10/17/18).

9. It seems like the recommended flow release settings aren't being followed for any of the spills. One of these is presumably not associated with maintenance, but the flow releases were well below the guidance for all three events. I know it will be difficult to change the guidance, but is it possible to get the dam operators to at least follow the guidance discharges?

We have been updated with some additional information regarding the dam operator's guidance. A write-up of this is in the works. This work was completed and is included in the draft technical report (10/17/18).

10. The longitudinal pattern of surface grain size through the project reach will be helpful.

We are collaborating with Debra Shier's lab to collect particle sizes for the top 6" of soil at some sites within the study area. This will likely not be a longitudinal series across the study area, and no other sediment data currently exists.

11. It would be very useful to know the pre-dam and post-dam hydrology in the study reach. To what degree has the hydrology been changed?

Flood recurrence estimates for pre and post dam condition have been completed and are included in the draft technical report.

12. There are lots of SBKR and woolly-star observations in the lower reaches where the floodplain is elevated relative to the channel due to incision between 1964 and 1987. It would be interesting to know how this habitat being maintained in the absence of flooding and periodic resupply of sediment.

Short answer on this is that it's not being maintained. It's in the process of undergoing succession from intermediate into mature RAFSS and over time the density of the three species of interest is expected to decline within that area, as well as all areas not receiving flood disturbance. Specific timelines for succession are not available, and the rate of succession is estimated by various experts to be between 40 and greater than 1000 years.

Other comments:

1. In the event that high flows will be re-routed toward the floodplain, is there a large enough source of sand to deposit on the floodplain and will that sand be suspended in the main channel and at any structure attempting to divert flow onto the floodplain?

It is implied in the BA/BO that trapped sediment behind SOD could be used as a source of clean sand for ecological applications within the study area. Whether movement of that material from behind the dam is feasible is outside the scope of this study. Regarding resuspension of placed sand, that will depend on flows. Our analysis will include some estimation of particle sizes mobilized by modeled flows. We will look into how sediment size is suspended throughout the water column during a modeled flood event.

2. In reach C, rather than diverting flow and sediment on the floodplain is it possible to widen the channel corridor to allow the braided channel to form its own floodplain inset below the elevated floodplain downstream?

This action is probably not possible because of the presence of listed species within the proposed action area. One could speculate that over time, some smaller proportion of the habitat within the active channel still receiving flood disturbance will be eventually be converted into suitable habitat.

3. There was a lot of discussion about the manual and related modeling/flow topics. Wendy knows Moosub Eom, USACE LA District H&H/Sediment Modeler Lead because she worked closely with him when he was at CDM Smith. Seems like it might be helpful to get some intel directly from him, but not sure if this is ok given the lawsuit/third party review contract. Let Wendy know if it is helpful for her to set up an informal chat with Moosub.

We appreciate the offer, but guidance from the legal team is to restrict contact with ACOE.

HFS October Webinar Notes Provided by ICF (10/01/18)

Group Feedback on the 1D model

The current 1D model runs do not take into account infiltration losses. Once a subset of appropriate scenarios are agreed on by the group, losses will be estimated. ICF will look to run a flood scenario in unsteady conditions to determine the travel time of the flood hydrograph through the study reach.

Friction coefficients are those specified by the ACOE during the Phase II GDM (U.S. Army Corps of Engineers 1988). If the group has images of the river in flood with channel conditions similar to the 2015 LiDAR topography, or appropriate gage data with a stage vs discharge curve, we will look to calibrate channel friction coefficients.

U.S. Army Corps of Engineers. 1988. "Santa Ana River Design Memorandum Number 1. Phase 2. GDM on the Santa Ana River Mainstem, Including Santiago Creek. Volume 4. Mill Creek Levee." Final Report. Army Engineer District Los Angeles, CA. http://www.dtic.mil/docs/citations/ADA204545.

Journal articles linking particle size to plant succession stage in the study area

Burk, Jack H., C. Eugene Jones, William A. Ryan, and John A. Wheeler. 2007. "FLOODPLAIN VEGETATION AND SOILS ALONG THE UPPER SANTA ANA RIVER, SAN BERNARDINO COUNTY, CALIFORNIA." Madroño 54 (2): 126–37. https://doi.org/10.3120/0024-9637(2007)54[126:FVASAT]2.0.CO;2.

Lucas, S. D., J. A. Wheeler, Y. C. Atallah, S. E. Walker, C. E. Jones, and J. H. Burk. 2016. "Long-term Impacts of Dam Construction on Plant Succession and Survival of an Endangered Species." Ecosphere 7 (5): e01235.

Calculated recurrence values

PDF figure package showing peak annual recurrence values for Mill Creek. From the discussion on Monday. These are figures depicting calculated peak annual recurrence values using different data sources. The Mill Creek near Mentone historic peak gage data is suspect and produces lower values than ACOE and ICF calculated values.

Picking 2D modeling locations

There is a general consensus in the group that figures illustrating species distributions and flood extents would be valuable for guiding input on which locations to conduct the 2D flow simulations. We are in process to produce these figures and will have them for the group shortly.

Modeling historic flood events

During the discussion, the 1969 flood event and breakout event were brought up as being potentially useful for calibrating proposed flows. The logic is that the '69 event is associated with pioneer RAFSS seral stages (best habitat for species of interest). Simulating flows for the '69 event would then give us an idea of what type of flows would be needed to produce ecologically meaningful flood disturbance within the study area.

Two potential issues with this approach are the following: 1) We don't know the distribution of flows during the 1969 event in terms of how much of the total flow stayed in the main channel and how much broke out into the terrace; and 2) A manmade structure (reported as a trestle bridge) in the main SAR channel trapped sediment and debris, caused backwatering, and could have promoted the breakout event. How do we account for that?

Setting meaningful flow values for future simulations.

During the meeting we discussed the SOD rising condition constraint on flow contributions. This makes high flow releases from SOD during high flow events for the watershed unlikely. Moving forward, likely scenarios would include a range of flows for SOD without modeled contributions from Mill and other tributaries.

Additional scenarios could include a range of high flow events from tributaries with the 50 cfs contribution from SOD, but this starts to move away from the HFS objectives to model contributions from SOD.

Proposed scenarios for SOD high flow releases include 3000, 4000, and 7000. 3000 and 4000 are proposed as being possible, based on previously observed peak outflows. 7000 is proposed because it is understood to be the maximum output the dam is capable of.

Some speculation regarding the dam's performance during extreme weather events was made during the meeting. Please see Plate 8-01, 8-01A and 8-02 of the Water Control Manual (U.S. Army Corps of Engineers 2003) illustrating expected outflows associated with 82K, 85k, and 185k cfs flood events.

U.S. Army Corps of Engineers. 2003. "Water Control Manual Seven Oaks Dam & Reservoir Santa Ana River, San Bernardino County, California." U.S. Army Corps of Engineers, Los Angeles District.

HFS October Webinar Feedback Provided by EHL/CBD (10/01/18)

EHL and Center for Biological Diversity have reviewed the materials to date and appreciate the progress. We ask that the High Flow Study consultant team consider the follow as it moves forward. Responses would be appreciated, and we are available for further discussion by phone.

1) For the study results to be useful, we must make sure its methods are sound. 2D modeling is not sufficient to predict outcomes; rather, sediment transport modeling is needed.

This is a reasonable request, but it is our understanding that this is an iterative process. We are not proposing to cease investigations once 2D modeling is complete. The 2D modeling is currently being used to more accurately predict flow paths and areas of inundation at different flow magnitudes than was determined over the entire study area using the 1D model. The output from the 2D modeling will be coupled with calculations to predict the sizes (e.g., sand, gravel, cobble) and mode (e.g., bedload, suspended load) of sediment transport both within the channel and on the terrace. To reaffirm, we are not performing a mobile bed model analysis in which the ground surface (i.e., morphology) continually adjusts in the model in response to erosion and deposition over the duration of the flood event. Prior to considering sediment transport models, we need to identify specific points of interest to focus future work. Conducting sediment transport modeling for the entire study area is beyond the scope and resources of the HFS in its current form.

The HEC-RAS work is complete and served its purpose of providing an initial look at flood extents over the entire study area. 2D modeling had begun and is an accurate approach to assessing where water will, and won't, go based on topographic conditions. To get at error estimating, we can do a sensitivity analysis (alter the roughness values by a certain percentage) to show how the predicted flooding would change. It's not expected to be very significant.

EHL and CBD have concerns that HEC-RAS and other models may potentially miss valuable alternative routes or outcomes. They need assurance that the 1D/2D iterative approach contains the vast majority of probable outcomes. Assurance can come from Stillwater and Blue Octal. But ICF will need to get Stillwater/Blue Octal to explicitly endorse the approach.

The issue being discussed centers around a model that predicts how the morphology will change due to erosion and deposition from sediment transport. ICF will be evaluating sediment transport. The current plan is to take the 2D hydraulic model results from a static bed model and determine where sediment may erode or deposit. This is not the same as a mobile bed model in which the model itself is continually adjusting bed elevations in response to modeled sediment transport. This is something that can be done with the software being used. However, as Toby said during the webinar (and Brendan concurs), just because the model can do it doesn't necessarily mean it should be done. There are major assumptions made using this type of modeling, and the model runs are data intensive and can take a long time to run.

Our suggestion is to begin with the first approach (static bed model), prepare conclusions about sediment transport, then discuss with the group before committing to do a mobile bed model. We will be evaluating sediment transport, just not a full evaluation of the entire study area using the mobile bed model.

2) While we concur with the modeling of scenarios using 100-year flood events on the tributaries, it is not clear if the full historic record of flood events is being reflected. Is the 1969 event being used as the 100-year event? What about the 1939 event? There may actually be *higher* flows from the tributaries going into the system from the 100-year event than currently indicated. If not already being done, we suggest using the full historic record in the modeling effort.

We are using flood recurrence values for the tributaries that are based on statistical analysis of the entire period of record, and not tied to estimates of flooding linked to particular events (e.g., 1939 and 1969). The Mill Creek near Mentone gage has peak flows for 1939-1965. It does not cover the March 1938 flood event nor the January 1969 flood event. The largest flood over the period is 1,500 cfs from 12/23/1945. As discussed during the webinar, we don't believe the peak flow record for this gage is accurate. The Mill Creek Yucaipa gage has peak flows for 1920-1938 and 1948-1986. The gage has an estimated value of 18,100 cfs for 3/2/1938 and estimated value of 20,000 cfs for 1/25/1969 (largest on record). We're using a flow value of 19,500 cfs for the 100-yr event on Mill Creek.

2) We need to look at resource impacts downstream from the City Creek-Santa Ana River confluence.

What is the next step for resolving this? Assuming this means getting USFWS involved to find out what potential impacts to downstream species may result from high flows within the study area.

3) We concur that it is not realistic to plan for High Flow Releases using the emergency spillways, and that otherwise, 7000 cfs is the maximum SOD release due to construction constraints. However, it should be acknowledged that for enough water to accumulate behind the dam to achieve 7000 cfs *and* for such flows to be released coincident with peak tributary flows, the current operating manual will have to be revised (noting that prior manuals did not have such constraints).

We are uncertain as to the constraints associated with prior iterations of the WCM. Based on guidance from Conservation District, we are avoiding proposing or modeling scenarios that imply operations outside the WCM guidelines.

4) We do not recommend looking at earthmoving (to facilitate overbank flows) until at a minimum we better understand how the system works per comments 1 and 2 above – sediment transport and full range of historic flows. More generally, there are serious problems with introducing more disturbance, that is earthmoving, into a system already disturbed and in flux. There is a large chance of unintended consequences, such as for downstream impacts, e.g., less water for SBKR habitat rejuvenation at the City Creek confluence if water is diverted onto the WSPA.

We share your concern with regards to manipulation of the floodplain to promote overbank flows. We concur with your statement that the probability of negative or unintended outcomes associated with such activities is high. This may be something that needs to be decided by the litigants with advice from the science advisors.

Our current position on proposed manipulations is that these simulations would illustrate the amount and extent of effort required to promote overbank flows. This is a valuable exercise in estimating the potential impacts associated with these activities. Calculating potential impacts can assist in conducting risk assessments and help guide decision making. We think these modeled manipulations are valuable from that perspective.

Science Advisor Gerald Braden (representing EHL) feedback provided 10/26/18.

- 1930-1937 Historic Aerial. City Cr was not a major contributor to SBKR and target species' habitats. Plunge, Santa Ana and Mill were shaping the alluvial fan habitats. There were numerous breakout points on the Santa Ana besides the 69' breakout.
- 1953-59 Historical Aerial. Plunge has been re-routed to City by mining operations. City has been channelized. The 69' breakout is still active as are other breakouts downstream and appear to be excellent target species habitats. SBKR habitat is beginning to develop at the "new" City/Santa Ana confluence near Norton AFB.
- 1698 Historical Aerial. The 69 breakout area is essentially compromised by vegetation maturation. The Santa Ana channel between Mill and City has shifted and scoured to the south. EMWD spreading basin have expanded adjacent to Mill potentiating channelization of Mill above the Mill/Santa Ana confluence. The insipient target species' habitats near Norton AFB are beginning to scour. Mining activity (diverting Plunge) have expanded.
- 1977-78 Historical Aerial. The 69' breakout area continues to degrade. The RR trestle is gone w/ no evidence of debris potentiating renewal of the 69" breakout. Small downstream areas suggest new breakout areas but the locations are few and far between. Mill above Santa Ana is now entrenched and held so by a dike. SBKR habitat at and above the Santa Ana confluence are developing. A reticulate pattern, meaning habitat for the target species, is developing in the Santa Ana north and downstream of the Redlands Airport.
- There was no current aerial of the project area, but there is one on Google Earth. Essentially, the habitat at the confluence of Santa Ana and City has established as pioneer and intermediate. The SOD has prevented flows that otherwise, in the past, shaped the alluvial fan don't occur. The habitat on the WSPA and other outbreak areas is maturing.
- The historic photos, current high density FWS SBKR records, and personal experience tell a story. Alluvial fans are dynamic, anthropogenic disturbances in the past started at least 80yrs ago and involved the redistribution of stream flows and concomitantly, habitat and the erosion/redistribution of substrates. Alluvial fan species and habitats adapt to these changes over many years, in this case 80+. FWS SBKR records demonstrate the highest SBKR concentrations occur at the City/Santa Ana confluence, continuing up the Santa Ana to the Redlands airport, not at the 69' breakout or the WSPA.
- The current ICF high flow exercise is hamstrung by the failure to examine, in depth, the historic processes that form the current distribution of the target species, and coupling that with ICF's hydrologic analyses which ostensibly is trying to define what flow regimes or break out points will benefit the target species in the long-term.
- The current ICF high flow exercise is compromised by assuming the WCM is the definitive document. The basis of the EHL/CBD lawsuit is ACE failing to comply with the SOD BA/BO in addition to unaddressed SAS SOD impacts, not the WCM.
- The historic photos demonstrate a 1 or 2d hydrologic model is unlikely to be helpful in identifying potential breakout areas because the breakout areas occurred due to **historic erosion and deposition** that reshaped the alluvial fan. Yes, the potential flows have changed due to the SOD. To my mind, it makes better sense to begin with an erosion deposition model. In short, a model more approximate to the alluvial process that shaped the current distribution of the target species.

This feedback will be addressed following release of the October Status Report on the HFS and completion of the scheduled December workshop.

Appendix 2
SOD Operating Parameters for the Period of Record

Figures A2.1–A2.19. This series of two-part figures depicts the following: The bottom plot is water level in feet, the top plot is the WCM guidance for the concordant water level (blue line), combined outflow for the Mentone gages (orange line), and the peak annual flow as reported for the USGS gages (red dot). The entire series is justified by water year (October 1 to September 30). The 18 years the dam has been in operation make up the series. Water year is the abbreviated calendar year.

Figure A2-01
Water Year 2000

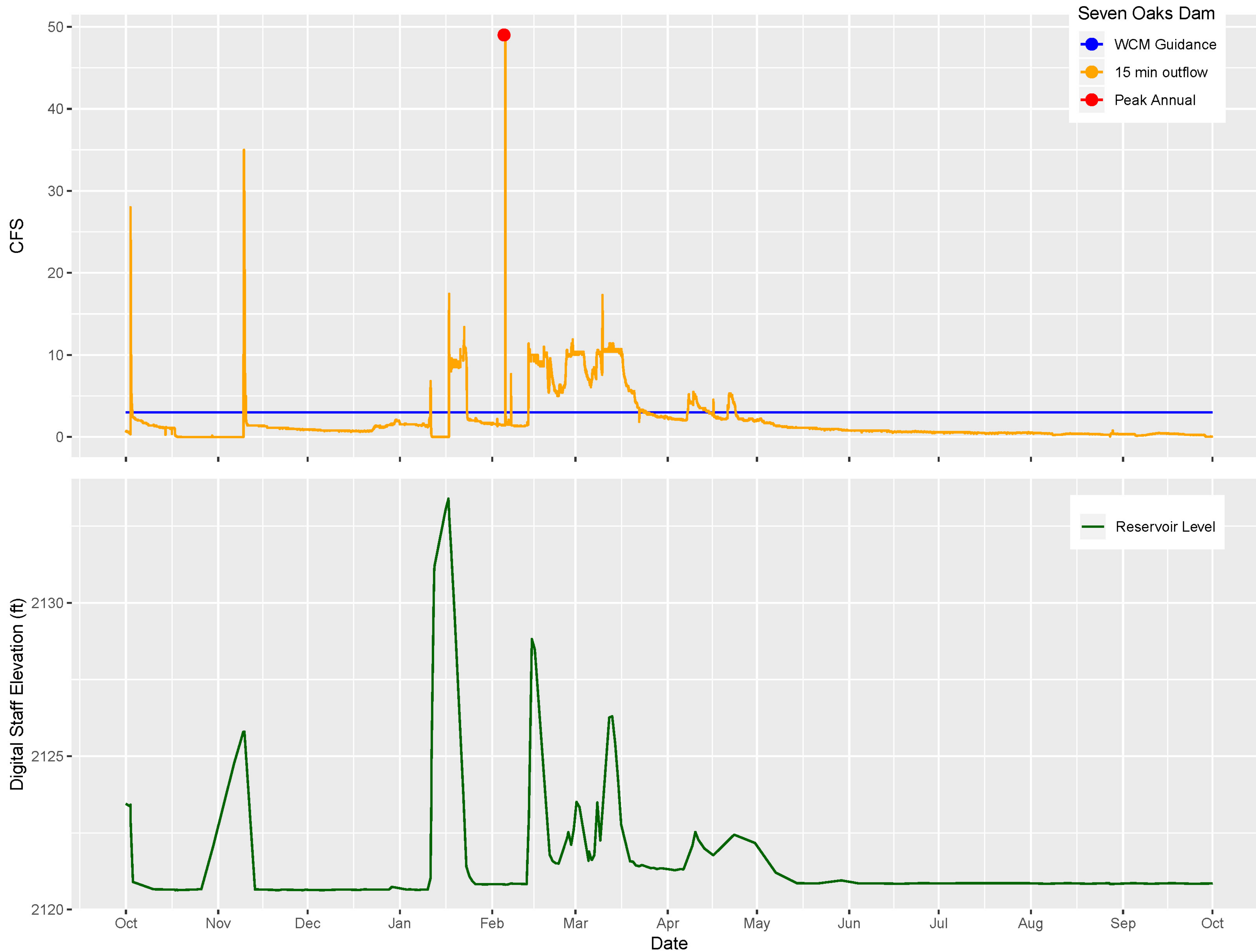


Figure A2-02
Water Year 2001

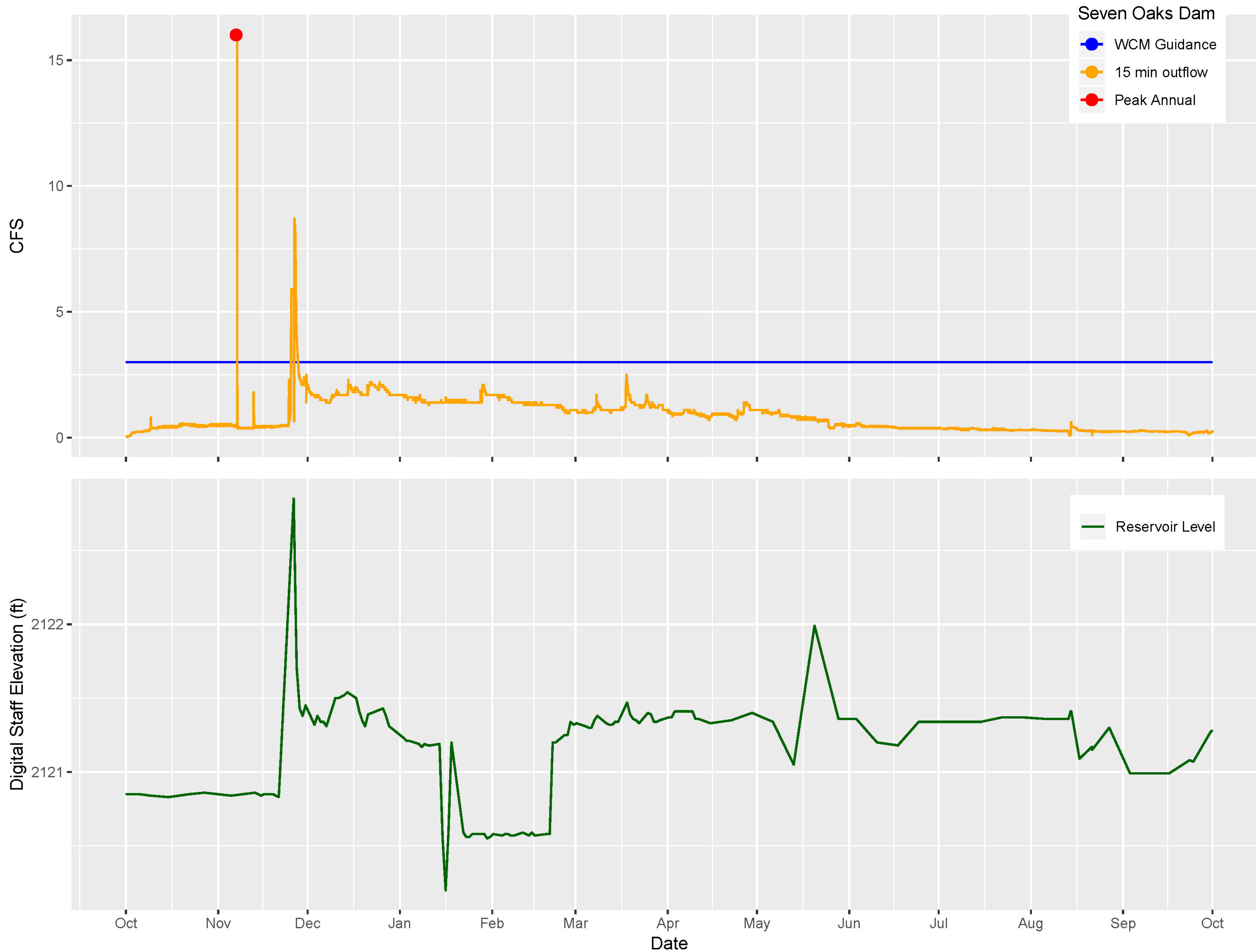


Figure A2-03
Water Year 2002

Figure A2-04
Water Year 2003

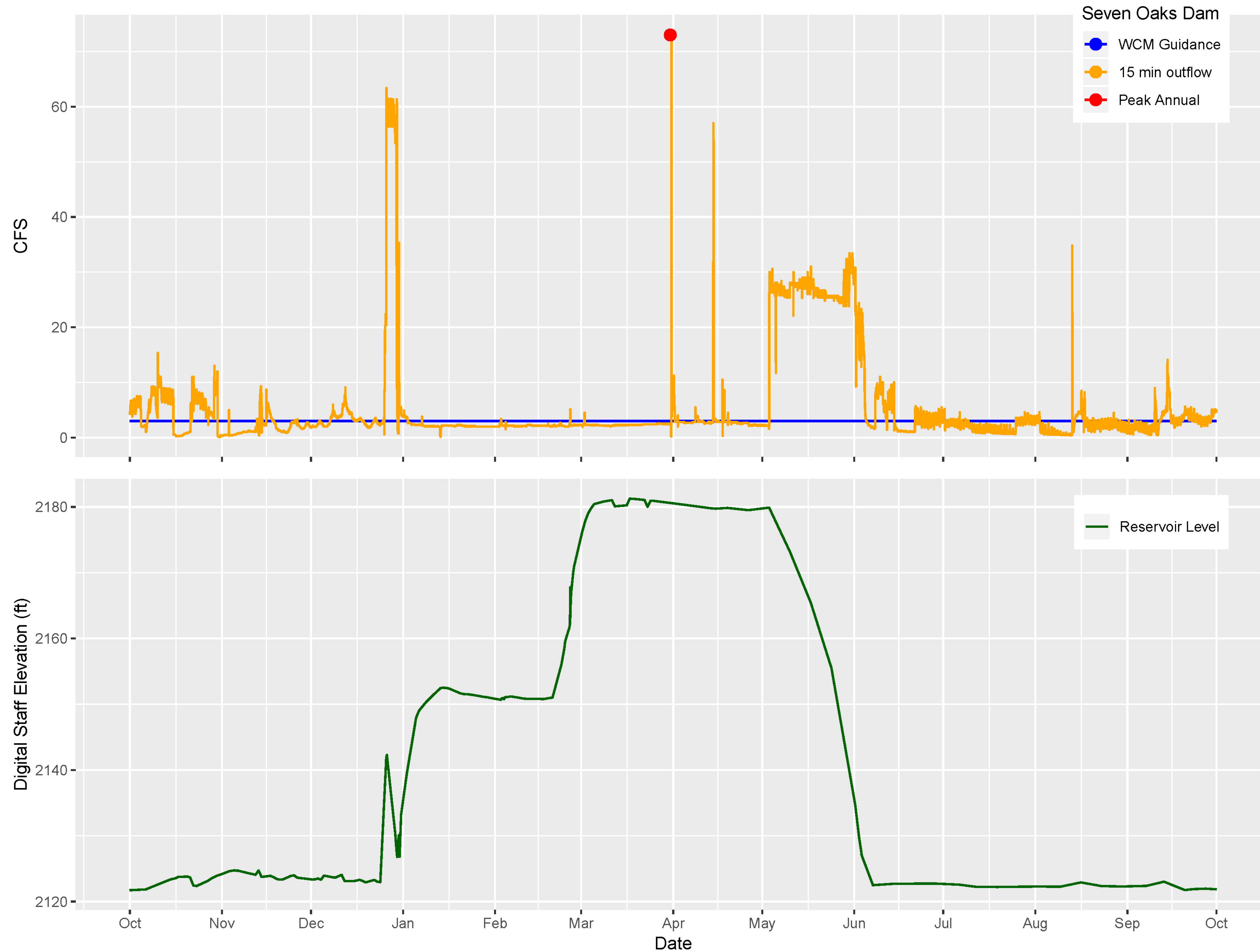


Figure A2-05
Water Year 2004

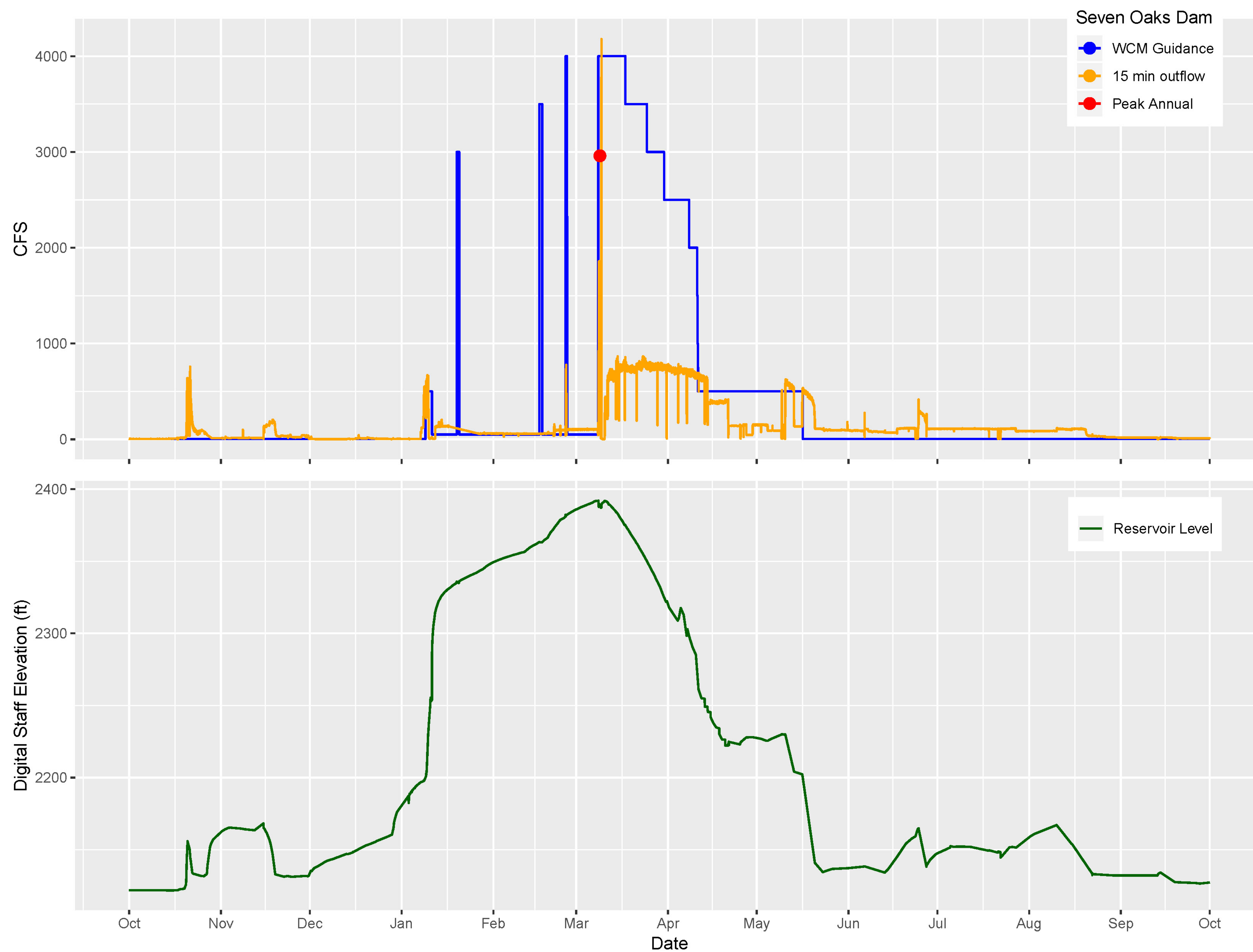


Figure A2-06
Water Year 2005

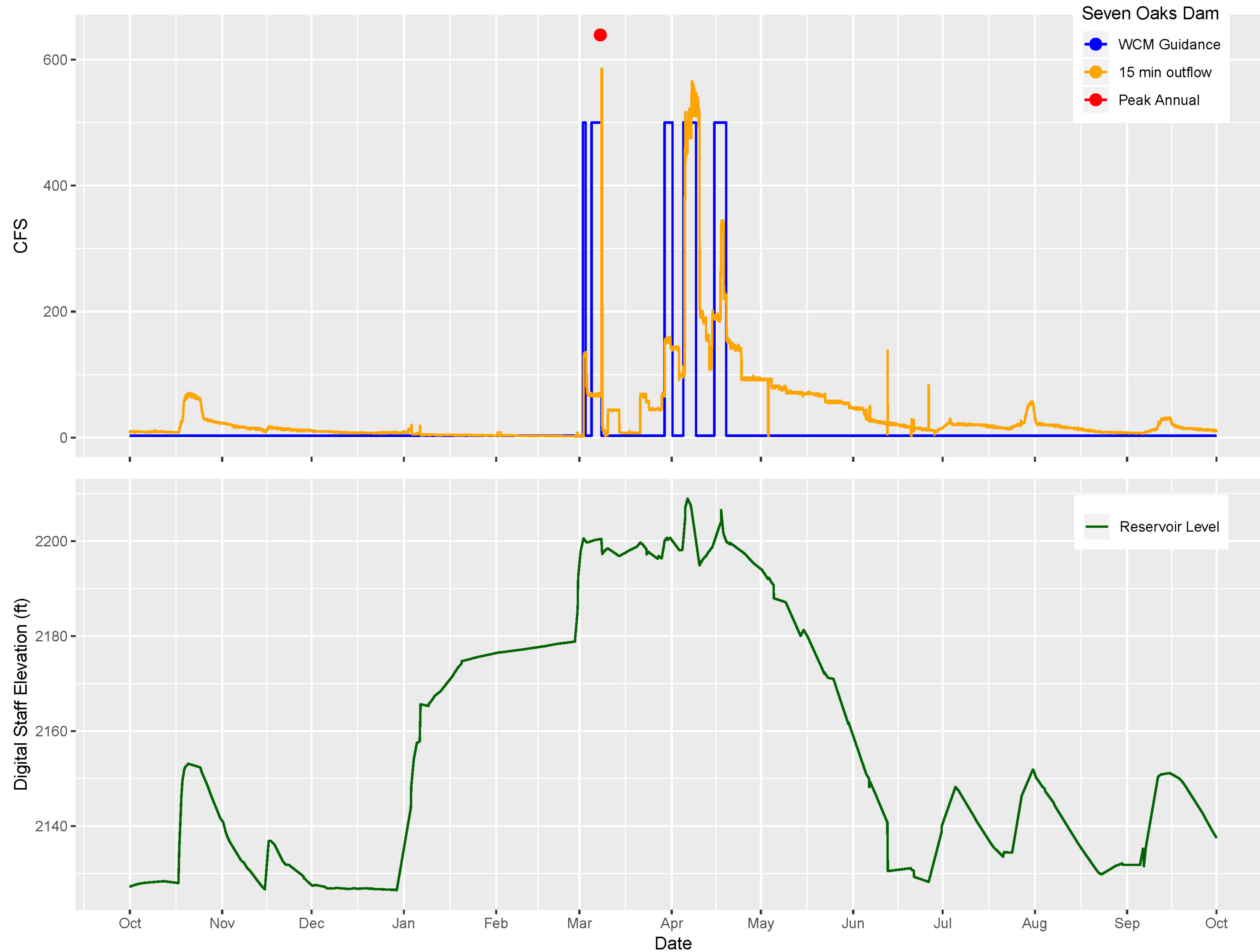
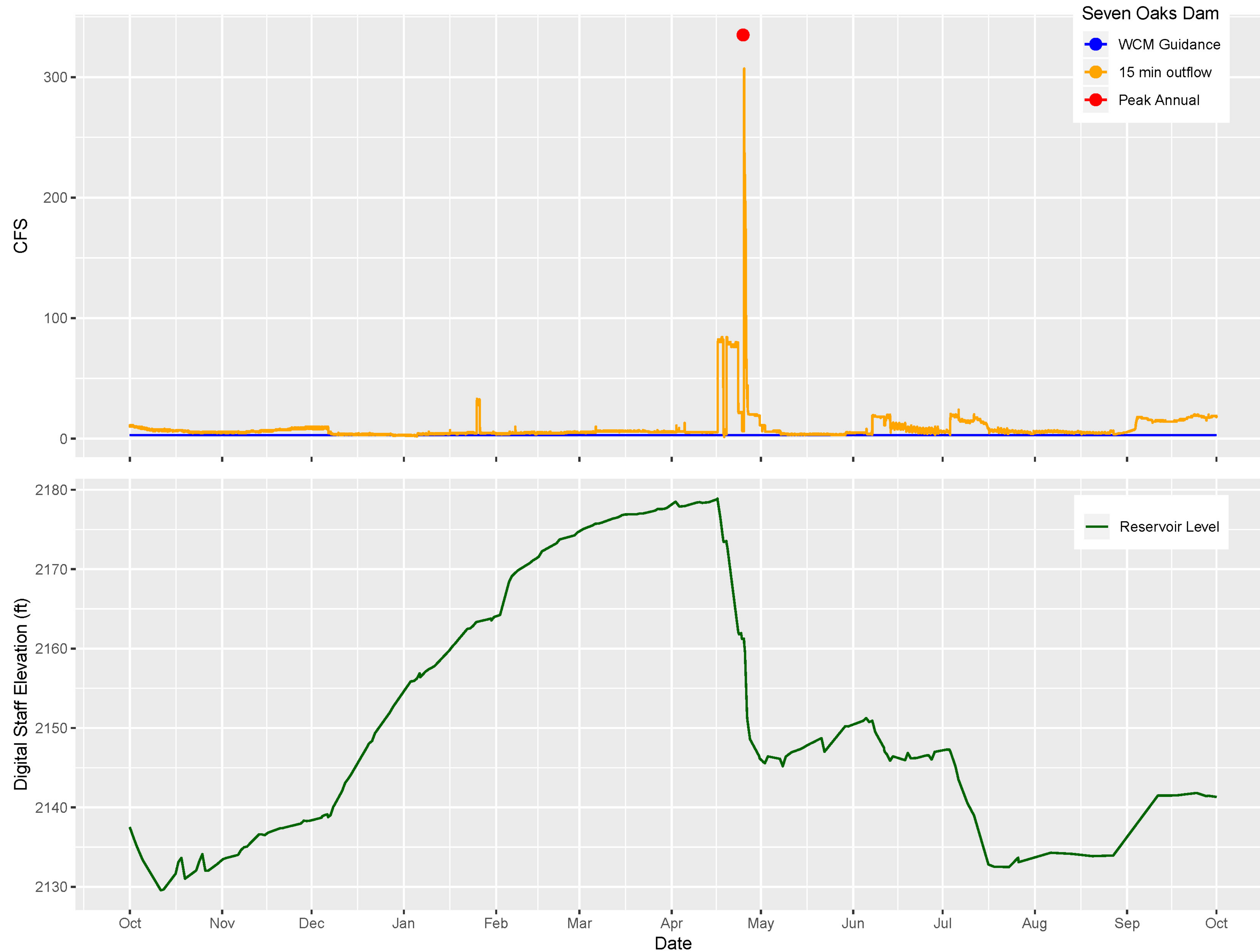


Figure A2-07
Water Year 2006



ICF

Figure A2-08
Water Year 2007

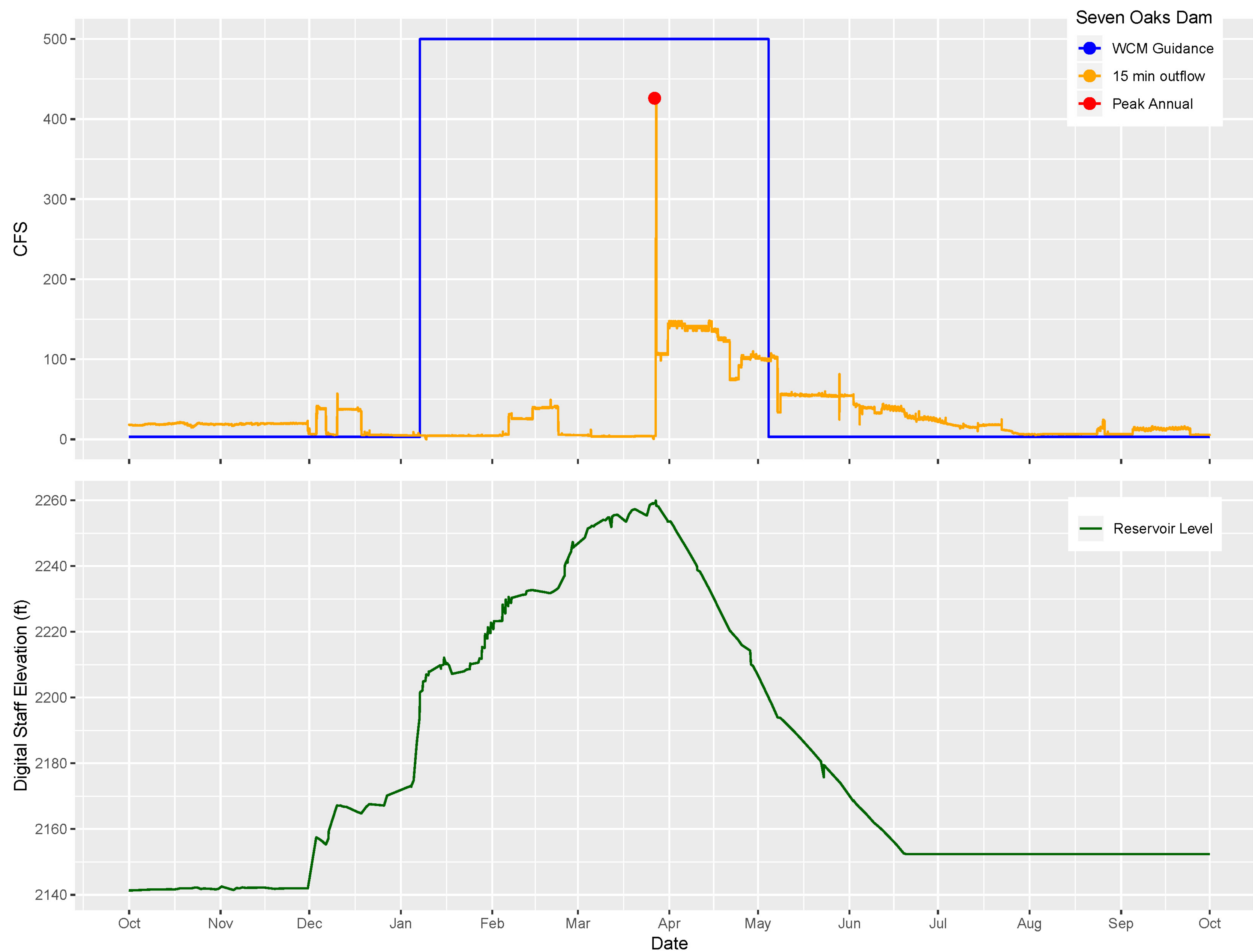


Figure A2-09
Water Year 2008

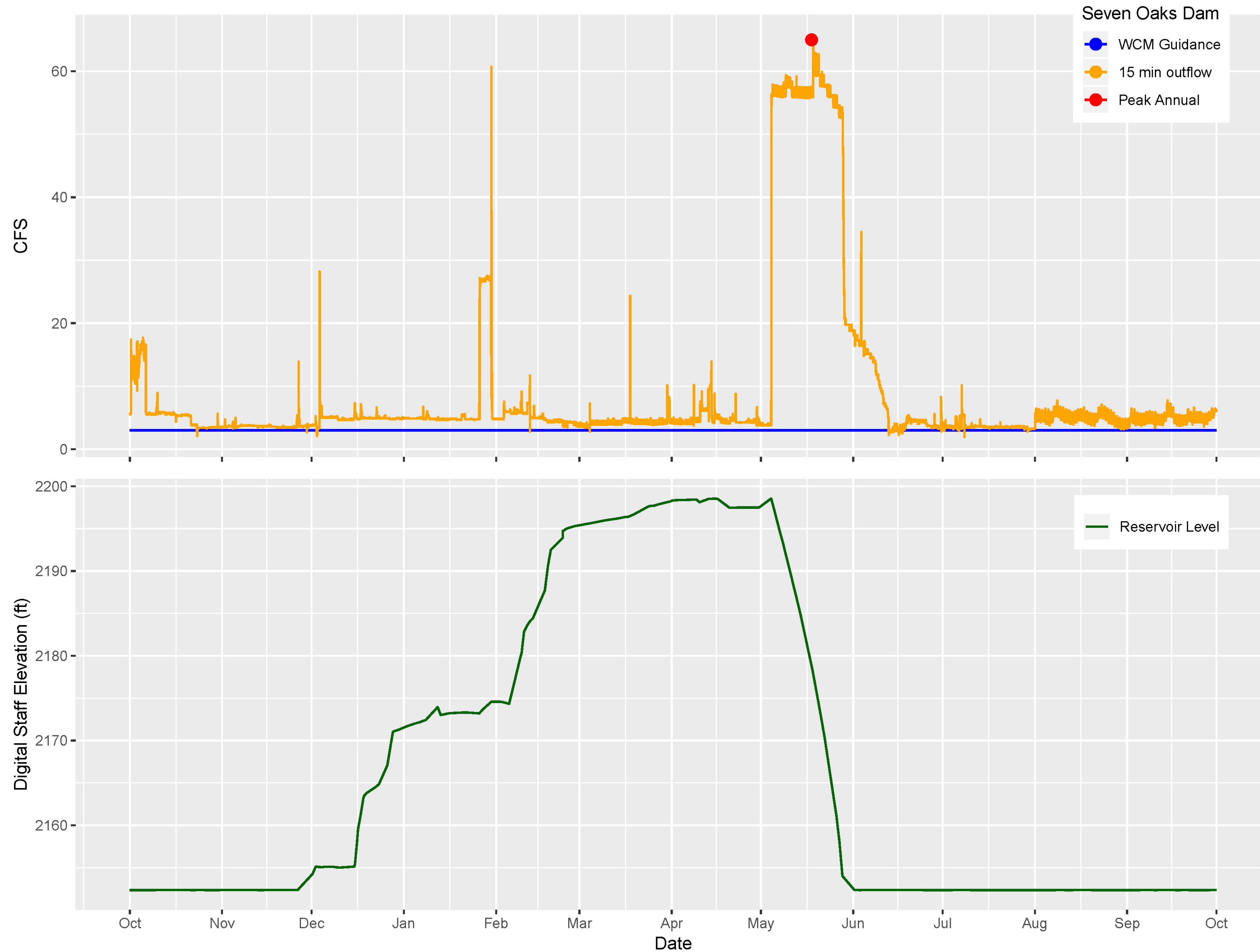


Figure A2-10
Water Year 2009

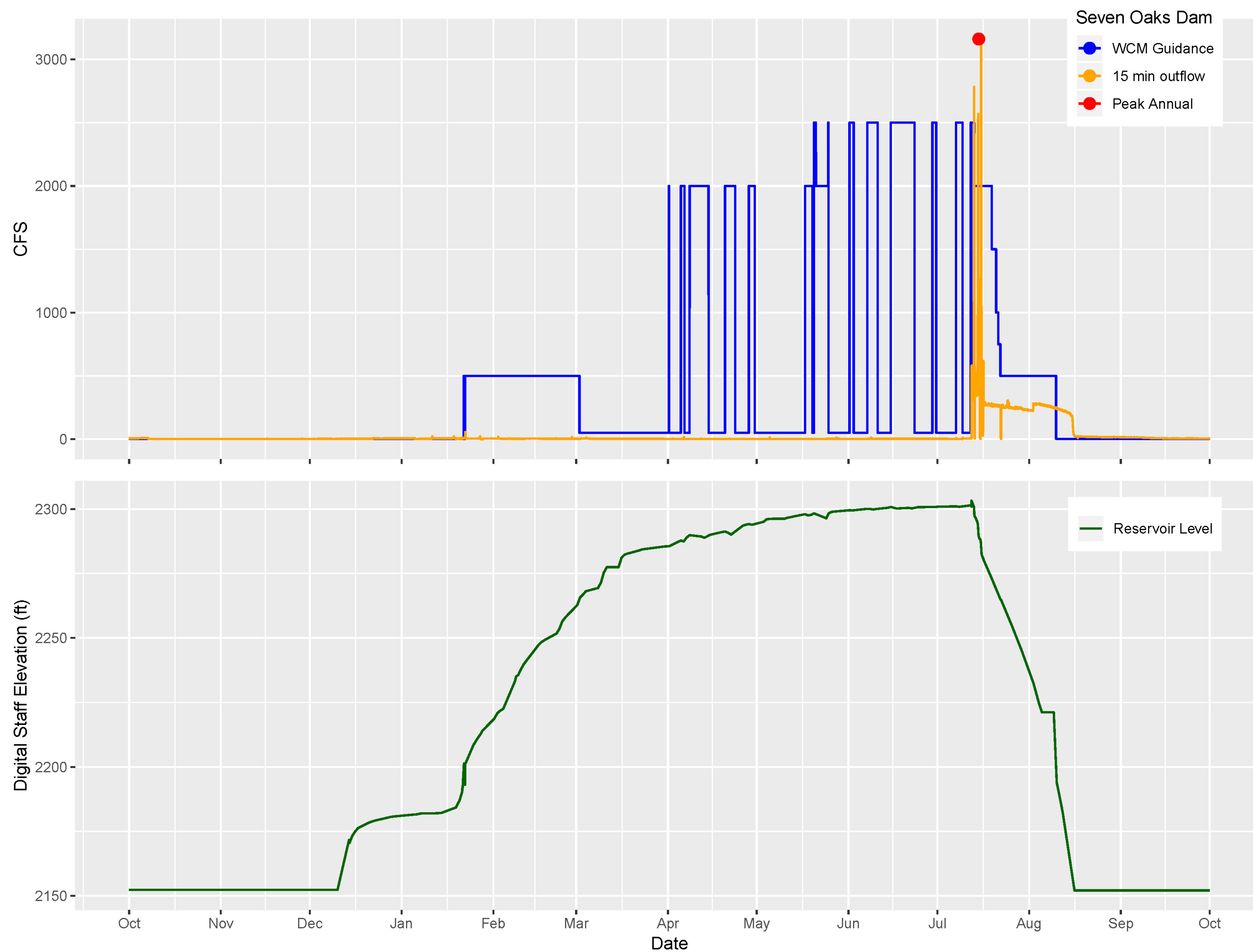


Figure A2-11
Water Year 2010

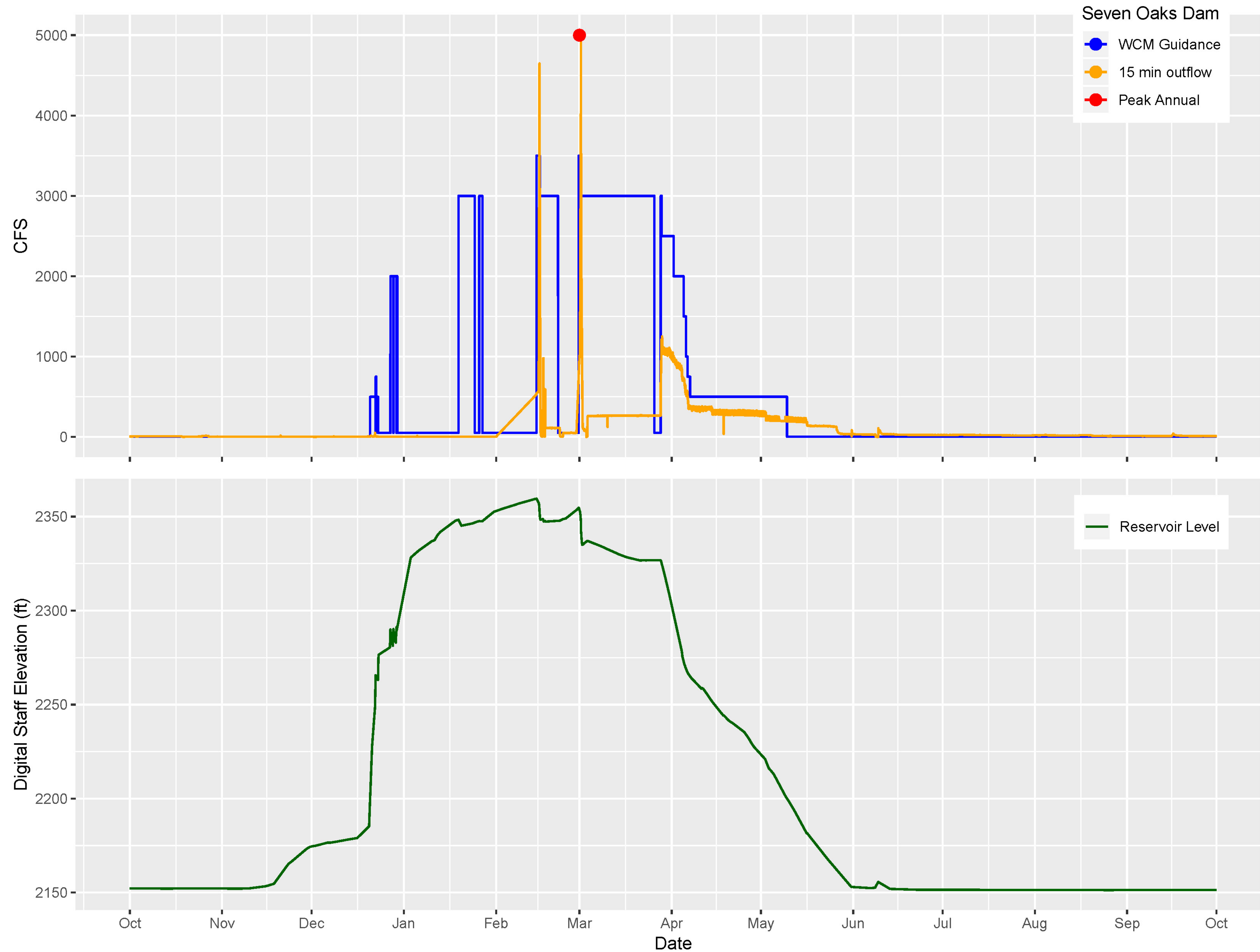


Figure A2-12
Water Year 2011

Figure A2-13
Water Year 2012

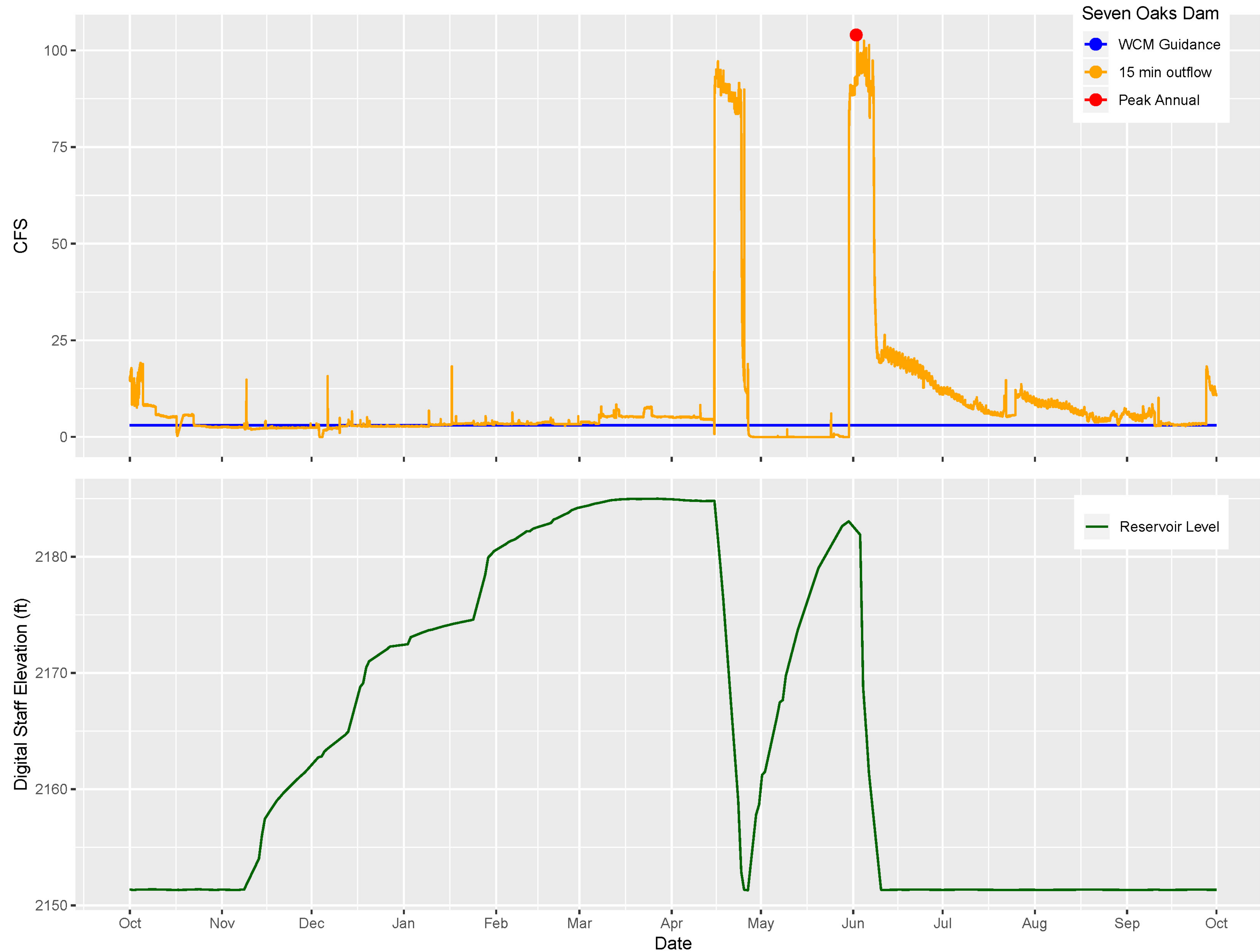


Figure A2-14
Water Year 2013

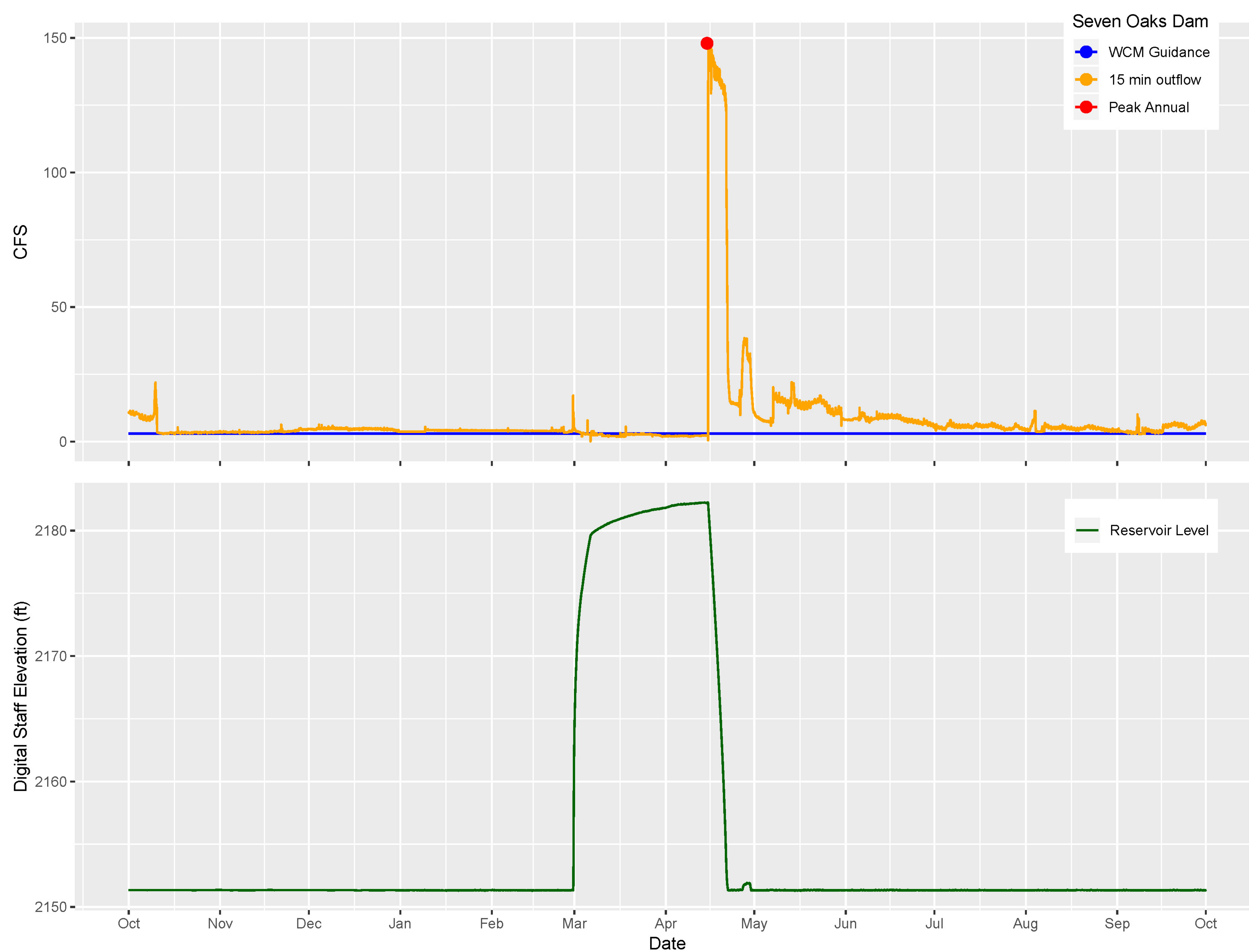


Figure A2-15
Water Year 2014

Figure A2-16
Water Year 2015

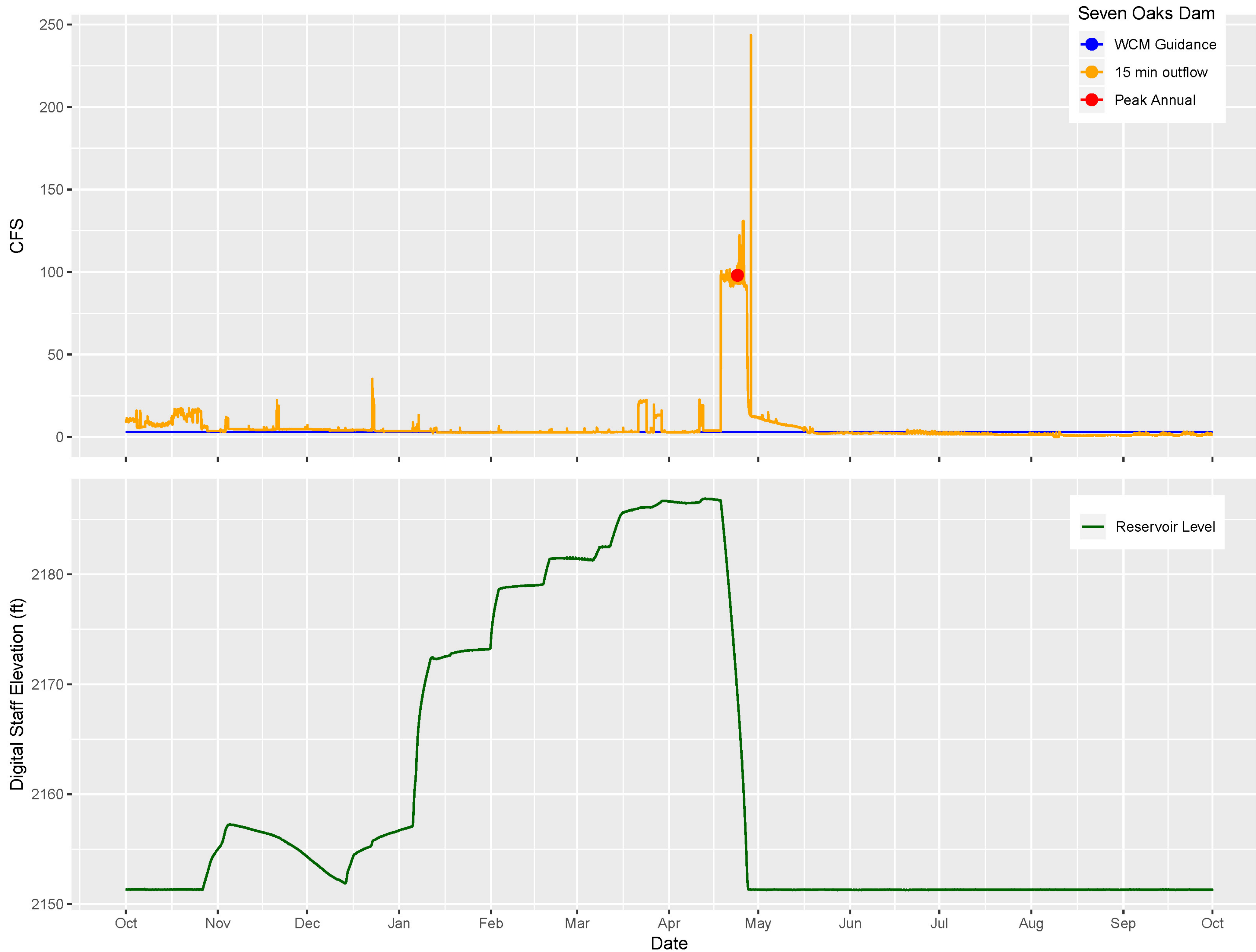


Figure A2-17
Water Year 2016

ICF

Figure A2-18
Water Year 2017

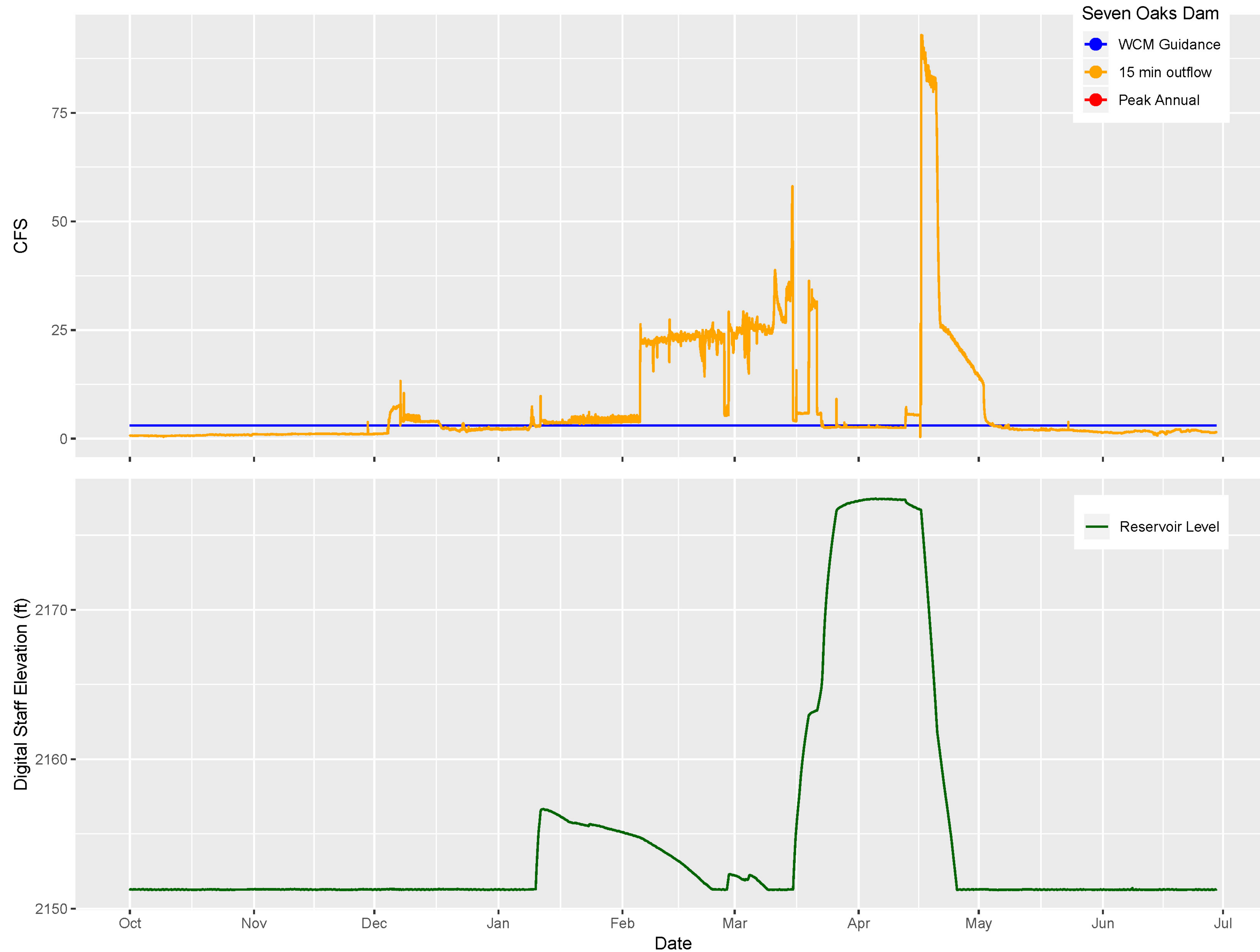


Figure A2-19
Water Year 2018

Appendix 3
Curriculum Vitae for the Independent Science Advisors

Justin Toby Minear

Earth Science and Observation Center
Cooperative Institute for Research in Environmental Sciences
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Professional Preparation

Colorado College, Colorado, USA Biology, B.A., 1998
University of California, Berkeley, USA Environmental Planning, M.L.A., 2003
University of California, Berkeley, USA Environmental Planning, Ph.D., 2010

Appointments

Since 2016, Research Scientist II, Cooperative Institute for Research in Environmental Sciences
2015-2016, Research Hydrologist, United States Geological Survey, National Research Program
2009-2015, Research Hydrologist, United States Geological Survey, California Water Science Center
2001-2009, Instructor / Lecturer / Graduate Student Teacher / Graduate Student Researcher, University of California, Berkeley

Related Publications

- **Minear JT**, & SA Wright, 2016. Water-surface elevations, depths, velocities, and temperature data collected for the NASA/JPL AirSWOT campaign on the Sacramento River, near Colusa, CA, for the period March – May, 2015. USGS Report, 45 pp.

- **Minear JT** & SA Wright, 2013. Hydraulic and Geomorphic Assessment of the Merced River and Historic Bridges in Eastern Yosemite Valley, Yosemite National Park, California. United States Geological Survey Open-File Report: 2013-1016, 88pp.

- **Minear, JT** & SA Wright, 2012. Utilizing Terrestrial Laser Scanning to Estimate Hydraulic Roughness in Gravel-bed Rivers. In: Proceedings of the American Society of Civil Engineers, Hydraulic Measurements and Experimental Methods Conference, August 12-15, 2012, Snowbird, UT.

Related Presentations

- **American Geophysical Union – Fall Meeting *(invited)*** Dec, 2015
  'Computing Realtime Streamflow Using Emerging Technologies: Non-contact radar'
  Authors: **JT Minear** (presenter), J Fulton, D Bjerklie, J Jones
- **American Geophysical Union – Fall Meeting *(invited)*** Dec, 2014
  'Near-field Oblique Remote Sensing of Stream Water-surface Elevation, Slope, and Surface Velocity'

Authors: **JT Minear** (presenter), P Kinzel, JM Nelson, R McDonald, SA Wright

- **American Geophysical Union – Fall Meeting *(invited)*** Dec, 2013
  '4D Terrestrial LiDAR Data Collection: Geomorphic and Hydraulic Applications'
  Authors: **JT Minear**, SA Wright, P Kinzel, A Draut, J Logan

Other Significant Publications

- Durand M, Gleason CJ, Garambois PA, Bjerklie D, Smith LC, Roux H, Rodriguez E, Bates PD, Pavelsky TM, Monnier J, Chen X, Di Baldassarre G, Fiset JM, Filpo N, Frasson RPM, Fulton J, Goutal N, Hossain F, Humphries E, **Minear JT**, Mukolwe MM, Neal JC, Ricci S, Sanders BF, Schumann G, Schubert JE, & L Vilmin, 2016. An intercomparison of remote sensing river discharge estimation algorithms from measurements of river height, width, and slope. *Water Resources Research*.

- Stern M, Flint L, **Minear JT**, Flint A, & SA Wright, 2016. Characterizing historical and future trends of streamflow and sediment supply of the Sacramento River Basin, California using Hydrological Simulation Program – FORTRAN (HSPF). *Water*, 8(10), 432.

- East AE, Pess GR, Bountry JA, Magirl CS, Ritchie AC, Logan JB, Randle TJ, Mastin MC, **Minear JT,** Duda JJ, Liermann MC, McHenry ML, Beechie TJ & PB Shafroth, 2015. Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change. *Geomorphology*, 228, 765-786.

- **Minear JT** & GM Kondolf, 2009. Estimating Reservoir Sedimentation Rates at Large Spatial and Temporal Scales: A Case Study of California. *Water Resources Research*, 45, 8pp.

Synergistic Activities

- Lead PI for NASA Surface Water and Ocean Topography (SWOT) Mission Calibration and Validation Team (US Project) (2016-present)
- Member of NASA Surface Water and Ocean Topography (SWOT) Mission Science, Discharge Algorithm, and Science Application Teams (2015-present)
- Member of USGS Non-contact streamgaging working group (2012-present)

Ph.D. Thesis Advisors

G. Mathias Kondolf and William E. Dietrich (University of California, Berkeley)

Collaborators

L.C. Smith (UCLA), T. Pavelsky (UNC), M. Durand (OSU), C. Gleason (UMass), C. Chen (NASA-JPL), E. Rodriguez (NASA-JPL), M. Lamb (CalTech), G. Schumann (NASA-JPL), S. Wright (USGS), M. Marineau (USGS), J. Fulton (USGS), A.E. East (USGS), G. Kondolf (UC Berkeley), W.E. Dietrich (UC Berkeley).

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Appointments

Professor of Geology, Geological and Planetary Science, California Institute of Technology, 2014 – present.
Geology Option Representative, Geological and Planetary Science, California Institute of Technology, 2014-present.
Assistant Professor, Geological and Planetary Sciences, California Institute of Technology, 2009 – 2014.
Postdoctoral Fellow, Geological Sciences, University of Texas, Austin, Advisor: David Mohrig, 2008 – 2009.
Scientist, St. Anthony Falls Laboratory, Minneapolis, Minnesota, Advisors: Gary Parker & Chris Paola, 2000 – 2001.

Education

Ph.D. Earth and Planetary Science, University of California, Berkeley, Advisor: William Dietrich, 2008. Dissertation: *Formation of Amphitheater-headed Canyons*.
M.S. Oceanography, University of Washington, Seattle, Advisor: Jeffrey Parsons, 2003. Thesis: *High-density suspensions formed under waves.*
B.S. Geophysics *high distinction* & B.S. Geology *magna cum laude*, University of Minnesota, Minneapolis, 2001.

Honors and Awards

James B. Macelwane Medal, American Geophysical Union, 2017
Fellow, American Geophysical Union, 2017
Keynote Lecturer, Steepest Descent Meeting, Vienna, 2017
Royal Academy of Engineering Distinguished Visitor, Imperial College - London, 2015
NASA Group Achievement Award, MSL Curiosity Mission Science, 2015
Editor's Citation for Refereeing for *Reviews of Geophysics*, 2014
Editor's Citation for Refereeing for *Geophysical Research Letters*, 2013
Luna B. Leopold Young Scientist Award, American Geophysical Union, 2012
Robert P. Sharp Capstone Lecture, American Geophysical Union, 2012
Editor's Citation for Excellence in Refereeing for *JGR-Earth Surface*, 2009
Louderback Award for Outstanding Scholarship, University of California, 2007
Kobe International School of Planetary Sciences Scholarship, Japan, 2004
NASA Fellowship for Mars Valley Networks Workshop, Hawaii, 2004
National Defense Science and Engineering Graduate Fellowship, 2001-2004
Academic Rewards for College Scientists (ARCS) National Scholarship, 2001-2004
Aldrich Award for Academic Excellence, University of Minnesota, 2001
Field Mentor Grant, Association of American State Geologists, 2000
Dennis Scholarship for Academic Excellence, University of Minnesota, 2000
W.A. Hoyer National Scholarship, Society of Professional Well Log Analysts, 2000

Selected Professional Service and Experience

Team Member, Mars Exploration Rover *Opportunity*, 2016 – present.
Team Member, Mars Science Laboratory rover *Curiosity*, 2014 – present.
Designed infographic on fires and debris flows, LA Times (front page), 2014, 2015.

Outreach with Pasadena Unified School District including laboratory demonstrations and tours, 2009 - present.

Interviewee for local and national news on natural hazards and related public concerns (16 events, 2009-2015).

Caltech's Watson public lecture: "When Rocks Roll: How Sediment Transport Shapes Planetary Surfaces," March, 2014.

Developed and led workshop on sediment transport in steep rivers for the annual meeting of the National Association of Geoscience Teachers, 2011.

Designed an informational geologic sign at Box Canyon State Park, Idaho, 2010.

Founder and moderator of "GeomorphLectures" Wiki that facilitates transfer of educational materials in geomorphology, 2010 – present.

Co-convener: *Earth and Planetary Surfaces General Poster Session*, AGU 2009 – present.

Caltech Geology Option Representative (2014-present), Member of the Caltech Undergraduate Transfer Admissions Committee (2013-present), and eight other committees in GPS (2010-present).

Reviewer for more than forty international scholarly journal and funding agencies.

Member: American Geophysical Union, European Geophysical Union, Geological Society of America, Society for Sedimentary Geology – SEPM.

Courses Taught

Ge13: Mentor for *Scientific Writing Tutorial*, Spring 2010, Spring 2011, Winter 2016.

Ge40: *Special Problems for Undergraduates*, Spring 2010, Fall 2010, Spring 2011, Winter 2014, Spring 2014.

Ge125: *Geomorphology*, Fall 2010, Fall 2012, Fall 2014, Fall 2016.

Ge126: *Topics in Geomorphology:*

Winter 2010: *Geomorphology and Wildfire*
Winter 2011: *Sediment Transport Physics*
Winter 2012: *Alluvial Fans and Pediments*
Winter 2013: *Organic Carbon and Landscapes* (with J. West and W. Fischer)
Winter 2014: *Erosion of Rock by Wind*
Winter 2015: *Soil Production in Steep Landscapes*
Winter 2016: *Morphodynamics with Gary Parker*

Ce/Ge/Ge222 (also Ge192): *Earthquake Source Processes*, *Debris Flows, and Soil Liquefaction* (with Ampuero, Andrade and Lapusta), Spring 2012, Spring 2013.

Ge193: *Subglacial hydrology and erosion* (with V. Tsai), Winter 2013

Ge121: *Advanced Field Mapping*:

Spring 2012: *Death Valley and Carrizo Plain*
Fall 2013: *The Channeled Scablands of eastern Washington*
Fall 2015: *Inverted Channels of Southern Utah*
Fall 2017: *Rivers without vegetation in Death Valley*

Student and Postdoctoral Research Advised

High school students: Conor O'Toole (2010), Khadijah Omerdin (2012-2013), Gheorghe Schreiber (2013), Jay Yalamanchili (2015).

Undergraduate students: Peter Buhler (2009 - 2010), Eric Kleinsasser (2010), Mariya Levina (2010), Cindy Tran (2010 –2011), Will Steinhardt (2011), Odin Marc (2010 - 2011), Mathieu Lapôtre (2010-2011), Connor O'Toole (2011), Cailan Halliday (2011), Aaron Tran (2012), Daniel Lo (2012), Fanny Brun (2013), Michael Jensen (2013), Hima Hassenruck-Gudipati (2013-2014), Julianne Preimesberger (2014), Elliot Simon (2014), Sam Holo (2015), Kirby Sikes (2015-2016), Brian Zdeb (2016), Jose Silvestre (2017), Sarah Steele (2017), Lydia Kivrak (2017), Erich Herzig (2016-2018).

PhD students as secondary advisor: Brent Minchew (2011), Luca Malatesta (2011-2016), Kirsten Siebach (2011-2012), Robert Wills (2013 – 2016), Abbey Nastan (2013-2014), Yanzhe Zhu (2016-present).

PhD students as primary advisor:

Ajay Limaye (2009- 2014; now postdoctoral scholar U. Minnesota)
Joel Scheingross (2009- 2015; now postdoctoral scholar GFZ-Potsdam)
Jeff Prancevic (2010 – 2016; now postdoctoral scholar ETH-Zurich)
Mathieu Lapôtre (2012 – 2017; Ehlmann co-advised; now postdoctoral scholar Harvard)
Austin Chadwick (2014 – present)
Alistair Hayden (2014 – present)
Madison Douglas (2017 – present)

Postdoctoral scholars:

Ryan Ewing (2010 – 2011; now Assistant Professor, Texas AM)
Ben Mackey (2010 – 2011; now Natural Hazards Analyst, Otago Regional Council, NZ)
Phairot Chatanantavet (2010 – 2013; now Postdoctoral Scholar, U. Arizona)
Adam Booth (2012-2013; now Assistant Professor, Portland State)
Roman DiBiase (2011–2014; now Assistant Professor Penn State)
Dirk Scherler (2013-2014; J.-P. Avouac main advisor; now Assistant Prof. at GFZ-Potsdam)
Vamsi Ganti (2012-2014; now Assistant Professor U.C. Santa Barbara)
Isaac Larsen (2013-2015; now Assistant Professor, U. Massachusetts-Amherst)
Florent Gimbert (2013-2015; V. Tsai main advisor; now Postdoc GFZ-Potsdam)
Marisa Palucis (2014-2017; now Assistant Professor, Dartmouth)
Mark Torres (2015-2017; W. Fischer co-advisor; now Assistant Professor, Rice U.)
Lizzy Trower (2015-2017; W. Fischer co-advisor; now Assistant Professor, U.C. Boulder)

Invited Seminars

2017: American Geophysical Union, New Generation of Scientists; European Geophysical Union, Planetary Geomorphology and Steepest Descent Lecture; University of Basel, Switzerland.

2016: University of California - Santa Barbara; University of Oregon; Jet Propulsion Laboratory, Director's conference; University of California – Santa Cruz.

2015: Brown University; Binghamton Symposium on experimental geomorphology; Imperial College, London.

2014: Rice University, University of California-Los Angeles, Caltech-GPS Division Seminar, Brown University, Earnest C. Watson public lecture at Caltech, Texas A&M; Stanford University.

2013: University of British Columbia, Geography; Simon Fraser University, Geography; Harvard University, EPS; Caltech, Board of Trustees; University of California – Los Angeles; ETH, Zurich, Switzerland; WSL, Zurich, Switzerland; IRSTEA, Grenoble, France; NASA Jet Propulsion Laboratory; Geological Society of America Annual Meeting; American Geophysical Union Annual Meeting; Stratodynamics Workshop, Nagasaki, Japan.

2012: Caltech, The Associates; University of Colorado, Boulder; University of Southern California, Earth Science; University of California, Santa Cruz, Earth Science; American Geophysical Union; Robert P. Sharp Capstone Lecture, AGU.

2011: University of California, Riverside, Earth Sciences; University of Illinois, Champaign, Geology; University of Wyoming, Geology and Geophysics; Titan Surface Processes Workshop, Pasadena.

2010: American Geophysical Union; California Institute of Technology, Board of Trustees, Keck Institute for Space Sciences & GPS Geoclub seminar; University of Washington, Seattle, School of Oceanography; Chevron Corporation; University of Pittsburg, Civil and Environmental Engineering.

2009: University of California, Santa Barbara, Earth Science; California Institute of Technology, Environmental Science and Engineering & GPS Division seminar; University of Arizona, Tucson, Geosciences; University of California, Berkeley, Civil and Environmental Engineering; University of Texas, Austin, School of Geosciences.

2008: University of Texas, Austin, RioMar Workshop & School of Geosciences; U.S. Geological Survey, Menlo Park; University of California, Berkeley, Earth and Planetary Science.

2007: Rice University, Earth Science; California Institute of Technology, Geological and Planetary Sciences; Massachusetts Institute of Technology, Earth and Planetary Sciences; University of Wisconsin, Madison, Geology and Geophysics.

Refereed Publications

*Please see **http://geomorph.caltech.edu/publications** for an up-to-date publication list and PDF downloads for in-review and published articles.*

Google Scholar citation h-index = 30; i10-index = 58; Citations = 2638.

* denotes a graduate student, post-doctoral scholar or Lamb group staff author
**denotes a Caltech undergraduate student or high school student intern author

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89. *Torres, M. A., Limaye, A. B., Ganti, V., Lamb, M. P., West, A. J., and Fischer, W. W., 2017, Model predictions of long-lived storage of organic carbon in river deposits, *Earth Surface Dynamics*, doi:10.5194/esurf-2017-29.
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86. *Palucis, M.C. and Lamb, M.P, 2017, What controls channel form in steep mountain streams? *Geophysical Research Letters*, 44, doi:10.1002/2017GL074198.
85. Ewing, R.C., *Lapotre, M.G.A., Lewis, K.W., Day, M., Stein, N., Rubin, D.M, Sullivan, R., Banham, S., Lamb, M.P., Bridges, N.T., Gupta, S., Fischer, W.W., 2017, Sedimentary processes of the Bagnold Dunes: Implications for the eolian rock record of Mars, *J. Geophysical Research – Planets*, 122, doi:10.1002/2017JE005324..
84. *Trower, E., Lamb, M.P., Fischer, W.W., 2017, Experimental evidence that ooid size reflects a dynamic equilibrium between rapid precipitation and abrasion rates, *Earth and Planetary Science Letters*.
83. *DiBiase, R.A., Lamb, M.P., *Ganti, V. and *Booth, A.M., 2017, Slope, grain size and roughness controls on hillslope sediment transport in steep landscapes, *J. Geophysical Research - Earth Surface.*
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80. *Scheingross, J.S., **Lo, D.Y., and Lamb, M.P., 2016, Self-formed waterfall plunge pools in homogeneous rock. *Geophysical Research Letters, 43,* doi:10.1002/2016GL071730.
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77. *Ganti, V., *Chadwick, A., *Hassenruck-Gudipati, H., Lamb, M.P., 2016, Avulsion cycles and their stratigraphic signature on an experimental backwater-controlled delta, *Journal of Geophysical Research - Earth Surface*,121, doi:10.1002/2016JF003915.
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75. *Lapotre, M.G.A., Lamb M.P. and R.M.E. Williams, 2016, Canyon formation constraints on the discharge of catastrophic outburst floods of Earth and Mars, *Journal of Geophysical Research - Planets*, 121, p. 1-32, doi: 10.1002/2016JE005061.
74. *Ganti, V., *Chadwick, A.J., *Hassenruck-Gudipati, H.J., *Fuller, B.M., Lamb, M.P., 2016, Experimental river delta size set by multiple floods and backwater hydrodynamics, *Science Advances*, 2, no. 5, e1501768, doi:10.1126/sciadv.1501768.
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67. *Lapotre, MGA and Lamb, MP, 2015, Hydraulics of floods upstream of horseshoe canyons and waterfalls. *Journal of Geophysical Research - Earth Surface*. doi: 10.1002/2014JF003412.
66. Kite, E.S., Howard, A.D., Lucas, A.S., Armstrong, J.C., Aharonson, O., and Lamb, M.P., 2015, Stratigraphy of Aeolis Dorsa, Mars: Stratigraphic context of the great river deposits, *Icarus*, doi: 10.1016/j.icarus.2015.03.007.
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59. *Ganti, V., Chu, Z., Lamb, M.P., Nittrouer, J.A., Parker, G., 2014, Testing morphodynamic controls on the location and frequency of river avulsions on fans versus deltas: Huanghe (Yellow River), China, *Geophysical Research Letters*, doi: 10.1002/2014GL061918.
58. *Gimbert, F., Tsai, V.C., Lamb, M.P., 2014, A physical model for seismic noise generation by turbulent flow in rivers, *JGR-Earth Surface*, doi: 10.1002/2014JF003201.
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55. **Buhler, P.B., Fassett, C., Head, J.W., Lamb, M.P., 2014, Timescales of fluvial activity and intermittency in Milna Crater, Mars, *Icarus*,doi:10.1016/j.icarus.2014.06.028.
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53. *Scheingross, J.S., **Brun, F., **Lo, D.Y., **Omerdin, K., and Lamb, M.P., 2014, Experimental evidence for bedrock erosion by suspended sediment. *Geology*, doi:10.1130/G35432.1.
52. *Limaye, A.B.S. and Lamb, M.P., 2014, Numerical simulations of bedrock valley evolution by meandering rivers with variable bank material, *Journal of Geophysical Research – Earth Surface,* v. 119, doi:10.1002/2013JF002997.
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46. *Limaye, A.B.S. and Lamb, M.P., 2014, A vector-based method for bank material tracking in coupled models of meandering and landscape evolution, *Journal of Geophysical Research – Earth Surface,* VOL. 118, 1–17, doi:10.1002/2013JF002854.

45. *Booth, A.M., Lamb, M.P., Avouac, J.-P., Delacourt, C., 2013, Landslide velocity, thickness and rheology from remote sensing: La Clapiere landslide, France, *Geophysical Research Letters*, v. 40, p. 1-6, doi:10.1002/grl.50828.
44. *DiBiase, R.A., *Limaye, A.B., *Scheingross, J.S., Fischer, W.W. and Lamb, M.P., 2013, Deltaic deposits at Aeolis Dorsa: Sedimentary evidence for a large body of water in the northern plains of Mars, *Journal of Geophysical Research - Planets*, v. 118, p. 1-18, doi: 10.1002/jgre.20100.
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41. Grotzinger, J.P., *Hayes, A.G., Lamb, M.P., McLennan, S.M., 2013, Sedimentary processes on Earth, Mars, Titan and Venus, In *Comparative Climatology of Terrestrial Planets*, Mackwell, S., Bullock, M. and Harder, J., eds., University of Arizona Press.
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Manuscripts in Review

- *Trower, E.J., O'Reilly, S.S., Gomes, M., Cantine, M., Stein, N., Grotzinger, H., Strauss, J.V., Lamb, M.P., Grotzinger, J.P., Knoll, A.H., Fischer, W.W., in review, Active ooid growth driven by sediment transport in a high energy shoal, Little Ambergris Cay, Turks and Caicos, British Overseas Territories. J. Sedimentary Research
- *Lapotre, M.G.A., Lamb, M.P., in review, Substrate controls on valley formation by groundwater on Earth and Mars.
- Allen, G.H, Pavelsky, T.M., Barefoot, E.A., Lamb, M.P., Butman,D, Tashie, A., Gleason, C.J., in review, Similarity of stream width distributions across headwater systems.
- *Prancevic, J.P., Lamb, M.P., *Palucis, M., Venditti, J., in review, Enhanced stability of experimental hillslopes and channel beds to seepage-induced mass failure, J. Geophysical Research-Earth Surface.
- *Ayoub, F., Jones, C.E., Lamb, M.P., Holt, B., Shaw, J.B., Mohrig, D., Wagner, W., in review, Inferring surface currents within submerged, vegetated deltaic islands from multi-pass airborne SAR.
- Edgar, L., Grotzinger, J.P., Southard, J.B. and Lamb, M.P., in review, 3-D outcrop analysis reveals lower-regime bedforms in pyroclastic-surge deposits in southern New Mexico, with implications for Mars. Journal of Volcanology and Geothermal Research.

Other Publications

2. Lamb, M.P., 2008, *The Formation of Amphitheater-Headed Canyons*, PhD dissertation, University of California, Berkeley, California, 297 pp.
1. Myrow, P.M., Lamb, M., Lukens, C., Houck, K., Kluth, C., and Parsons, J., 2004, *Hyperpycnal wave-modified turbidites of the Pennsylvanian Minturn Formation, north-central Colorado*: Geological Society of America Field Trip Guide, 28 p.

DEBRA M. SHIER
Brown Endowed Associate Director
Recovery Ecology
San Diego Zoo Institute for Conservation Research
15600 San Pasqual Valley Road
Escondido, CA 92027
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DEGREES

University of California, Davis	Ph.D. Animal Behavior Emphasis in Wildlife Conservation 2004
	M.S. in Animal Behavior 2003 Emphasis in Wildlife Conservation
San Francisco State University	M.A. in Biology 2002 Emphasis in Ecology and Systematics
University of California, Santa Barbara	B.S. Biopsychology 1992

RESEARCH AND ACADEMIC POSITIONS

Brown Endowed Associate Director, Applied Animal Ecology, San Diego Zoo Institute for Conservation Research, 2013- present.

Brown Endowed Scientist, Applied Animal Ecology, San Diego Zoo Institute for Conservation Research, 2009-2013.

Adjunct Assistant Professor, Department of Ecology and Evolutionary Biology, University of California, Los Angeles 2010 – present.

Millennium Postdoctoral Fellow sponsored by Allison Alberts and Ronald R. Swaisgood, Applied Animal Ecology, San Diego Zoo Institute for Conservation Research 2006-2008.

PEER REVIEWED PUBLICATIONS

Shier, D.M. Navarro, A., Thomas, S. and Ryder, O.A. Assessment of post-translocation population viability in the federally endangered Stephens' kangaroo rat (*Dipodomys stephensi*) via Bayesian clustering and parentage analysis of microsatellite data, Biological Conservation, In review.

Baker, L. Milnes, M.R., Fraser, D. **Shier, D.M.** Validation of a fecal glucocorticoid assay for the endangered Stephens' kangaroo rat (*Dipodomys stephensi*) using behavioral and pharmacological tests, In review.

Chock, R. **Shier, D.M**. and Grether, G.F. In press. Body size, not phylogenetic relationship or residency status, drives interspecific dominance interactions in the little pocket mouse (Perognathus longimembris) community. Animal Behavior.

Grueber, C, Reid-Wainscoat, E., Fox, S., Belov, K. **Shier, D.M**., Hogg, C.J., and Pemberton, D. 2017. Increased generations in captivity increases vulnerability of Tasmanian Devils to vehicle strike following release of to the wild, Scientific Reports, 7: 2161

Harvey, B.D.; Vanni, K.N.; **Shier, D.M** and Grether, G 2017. Experimental test of the mechanism underlying sexual segregation at communal roosts of harvestmen (Prionostemma spp.)", Ethology, 123(8):516 – 525.

Hennessy, S. McCullough; Deutschman, D. H.; **Shier, D. M**. and Swaisgood, R.R. 2016. Experimental habitat restoration for conserved species using ecosystem engineers and vegetation management", Animal Conservation, 19(6):506 - 514.

Shier, D.M. 2015. Developing a standard for evaluating reintroduction success using IUCN Red List indices, Animal Conservation, 18(5):411 – 412.

Grether, G.F., Levi, A. Antaky, C. and **Shier, D.M**. 2014. Communal roosting sites are potential ecological traps: experimental evidence in a Neotropical harvestman, Behavioral Ecology and Sociobiology, Vol 29 1629-1638.

Shier, D.M., Lea, A. J. & Owens, M.A. 2012**.** Beyond masking: Endangered Stephen's kangaroo rats respond to road noise with footdrumming, Biological Conservation, 150(1):53 – 58.

Shier, D.M. & Swaisgood, R.R., 2012. Fitness Costs of Neighborhood Disruption in Translocations of a Solitary Mammal Conservation Biology, 26(1):116 – 123.

Shier, D.M. and Owings, D.H. Effects of Social Learning on Predator Training and Post-Release Survival in Juvenile Black-Tailed Prairie Dogs (*Cynomys ludovicianus*) Animal Behavior. 2007, Vol. 73, 567-577.

Shier, D.M. and Randall, J.A. Use of different signaling modalities to communicate status by dominant and subordinate Heermann's kangaroo rats (*Dipodomys heermanni),* Behavioral Ecology and Sociobiology. 2007, Vol. 61, 1023-1032.

Shier, D.M. Family Support Increases the Success of Translocated Prairie Dogs, Conservation Biology, 2006. Vol. 20(6), 1780-1790.

Shier, D.M. and Owings, D.H. Effects of predator training on behavior and post-release survival of captive prairie dogs (*Cynomys ludovicianus*), Biological Conservation, 2006, Vol.132, 126-135.

Shier, D.M. and Randall, J.A. Spacing as a Predictor of Social Organization in Kangaroo Rats (*Dipodomys heermanni arenae*), Journal of Mammalogy, 2004 Vol. 85(5), 1002-1008.

Shier, D.M. For Crying Out Loud: Dangers and Opportunities of Communicating in the Public Domain, Journal of Comparative Psychology, 2002, Jun. Vol. 116(2), 194-196.

Randall, J.A., Rogovin, K.A. & **Shier, D.M**. Footdrumming as anti-predator behavior in a social gerbil, *Rhobomys opimus*, Behavioral Ecology and Sociobiology, 2000 Vol. 48(2), 110-118.

Shier, D.M. and Yoerg, S.I., What Footdrumming Signals in Kangaroo Rats (*Dipodomys heermanni*), Journal of Comparative Psychology, 1999, Vol. 113(1), 66-73.

Yoerg, S.I. and **Shier, D.M**., Maternal Presence and Rearing Condition Affect Responses to a Live Predator in Kangaroo Rats (*Dipodomys heermanni arenae*), Journal of Comparative Psychology 1997, Vol. 111(4), 362-369.

BOOK CHAPTERS

Shier, D.M. 2016. Manipulating animal behavior to ensure reintroduction success, Book Chapter, in The Conservation Behavior Framework, edited by David Saltz and Oded Berger Tal, pp. 275-304.

Moehrenschlager, A., **Shier, D.M**., Moorhouse, T.P & Stanley Price, M.R. 2013. Righting past wrongs and insuring the future: challenges and opportunities for effective reintroductions amidst a biodiversity crisis, Book Chapter, in Key Topics in Conservation, edited by David MacDonald, pp. 405-429.

Shier, D.M. Book Chapter: Prairie dogs as Exotic Pets In: Exotic Pet Behavior Valarie V. Tynes, DVM, (Editor), 2010, Wiley & Sons.

NON PEER-REVIEWED REPORTS and PUBLICATIONSPr

Calatayud, N. Gardner, N. **Shier, D.M**. 2017, Captive Breeding and Reintroduction of the Mountain Yellow-legged Frog (*Rana muscosa*) 2015 Annual Report, 1-43.

Wisinski, C. Hennessy, S.M. Montagne, J.P., Marczak, S. Stevens, S., Hargis, M. Shier, D.M., Swaisgood, R.R., Nordstrom, L.A., 2017. An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County, 1-104

Wang, Thea and Shier, Debra M, 2017. Effects of Anthropogenic Lighting On San Bernardino Kangaroo Rat (*Dipodomys merriami parvus*) Foraging Behavior, Persistence and Fitness final report, 1-32

King, S. and **Shier, D.M**, 2017. Pacific Pocket Mouse Conservation Program, 2016 Annual Report. 1-10.

Shier, D.M. 2017 Captive Breeding, Anti-Predator Behavior and Reintroduction of the Pacific Pocket Mouse (*Perognathus Longimembris Pacificus*), Annual Report2014-2016, 1-146.

Shier, D.M. and Navarro, A., 2016. Range-Wide Genetics of the Stephens' Kangaroo Rat (*Dipodomys Stephens*i)", 1-33.

Shier, D.M. and Reid-Wainscoat, E., 2016. An assessment of translocation strategies aimed to reduce dispersal and increase survival post-release for the Tasmanian devil (*Sarcophilus harrisii*), 1-53.

Shier, D.M, 2016. Translocation Model for the endangered Stephens' kangaroo rat, 1-23.

Wang, T. and **Shier, D.M**, 2016. Range-Wide Genetics of the Endangered San Bernardino Kangaroo Rat, (*Dipodomys merriami parvus*), 1-9.

Shier, D.M., Montagne, J.P., Hennessy, S.M., Wisinski, C., Nordstrom, L.A., and Swaisgood, R.R. 2016, Translocation Model for the California Ground Squirrel (*Otospermophilus beecheyi*) to Facilitate California Grassland Ecosystem Recovery, 1-25.

Hennessy, S.M., Wisinski, C. Montagne, J.P., Marshall, K. Shier, D.M. and Nordstrom, L.A., 2016, An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County, 1-102.

Wang, T. and **Shier, D.M**, 2016. Effects of Anthropogenic Lighting on San Bernardino kangaroo rat (*Dipodomys merriami parvus)* Foraging Behavior, Persistence and Fitness for the period September 2014 to December 2015, 1-12.

Shier, D.M. 2016 Captive Breeding, Anti-Predator Behavior and Reintroduction of the Pacific Pocket Mouse (*Perognathus Longimembris Pacificus*), Annual Report for the period January 2015 - December 2015, 1-43.

Calatayud, N. Gardner, N. Shier, D.M. 2016, Captive Breeding and Reintroduction of the Mountain Yellow-legged Frog (*Rana muscosa*) 2015 Annual Report", 1-36.

Shier, D.M. 2015 Captive Breeding, Anti-Predator Behavior and Reintroduction of the Pacific Pocket Mouse (*Perognathus Longimembris Pacificus*), Annual Report for the period June 2014 - December 2014, 1-56.

Shier, D.M. and Wang, T. 2015 Behavioral Ecology, Stress, Genetics and Translocation of the Endangered Stephens' kangaroo rat (*Dipodomys stephensi*) Report to USFWS for the Period January 2014-December 2014.

Wisinski, C. Montagne, J.P., Marczak, S. **Shier, D.M**., Nordstrom, L.A. Swaisgood, R.R., 2015, An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County, 1-78.

Santana, F. and Shier, D.M, Mountain Yellow--Legged Frog (Rana Muscosa) Captive Breeding and Reintroduction, Report to USFWS for the Period January 2013-December 2013, 1-20.

Wisinski, C. Montagne, J.P., Marczak, S. **Shier, D.M**., Nordstrom, L.A. Swaisgood, R.R., 2014, An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County, 1-76.

Shier, Debra M and Wang, T, 2014. Translocation of the Endangered San Bernardino Kangaroo Rat, (*Dipodomys Merriami Parvus)* annual report for the period January to December 2012, 1-7.

Shier, D.M. and Wang, T. 2014 Behavioral Ecology, Stress, Genetics and Translocation of the Endangered Stephens' kangaroo rat (*Dipodomys stephensi*) Report to USFWS for the Period January 2013-December 2013.

Shier, D.M. 2014 Captive Breeding, Anti-Predator Behavior and Reintroduction Of The Pacific Pocket Mouse (*Perognathus Longimembris Pacificus*), Annual Report For the period June 2013 - December 2013, 1-41

Shier, D.M. 2013 Captive breeding, Anti-predator behavior and Reintroduction of the Pacific Pocket Mouse (*perognathus longimembris pacificus*) annual report to California Department of Fish and Wildlife for the Period June 2012 to December 2012.

Shier, D.M. and Wang, T, 2013. Translocation of the Endangered San Bernardino Kangaroo Rat, (*Dipodomys Merriami Parvus)* annual report for the period January to December 2012, 1-10.

Wisinski, C. Montagne, J.P., Marczak, S. **Shier, D.M**., Nordstrom, L.A. Swaisgood, R.R. Ph.D., 2013, An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County, 1-54.

Shier, D.M. 2013 Behavioral Ecology and Translocation of the Endangered Stephens' kangaroo rat (*Dipodomys stephensi*) Report to USFWS for the Period January 2012-December 2012.

Shier, D.M. 2012 Behavioral Ecology and Translocation of the Endangered Stephens' kangaroo rat (*Dipodomys stephensi*) Report to USFWS for the Period January 2011-December 2011.

Shier, D.M. 2012 Behavioral Ecology and Translocation of the Endangered Pacific Little Pocket Mouse (*Perognathus longimembris pacificus*) Report to USFWS for Phase III for the Period January 2011-December 2011.

Shier, D.M. & W. Miller. Genetic Management Plan for Captive Propagation of the Pacific Pocket Mouse (*Perognathus longimembris pacificus*) Report to USFWS, November 2011.

Shier, D.M. 2011 Behavioral Ecology and Translocation of the Endangered Pacific Little Pocket Mouse (*Perognathus longimembris pacificus*) Report to USFWS for Phase III for the Period January 2010-December 2010.

Shier, D.M. 2011 Behavioral Ecology and Translocation of the Endangered Stephens' kangaroo rat (*Dipodomys stephensi*) Report to USFWS for the Period January 2010-December 2010, pages 1-64.

Shier, D.M. 2010 Behavioral Ecology and Translocation of the Endangered Pacific Little Pocket Mouse (*Perognathus longimembris pacificus*) Report to USFWS for Phase III for the Period January 2009-December 2009.

Shier, D.M. 2010 Behavioral Ecology and Translocation of the Endangered Stephens' kangaroo rat (*Dipodomys stephensi*) Report to USFWS for the Period January 2009-December 2009, pages 1-32.

Shier, D.M. 2009 Behavioral Ecology and Translocation of the Endangered Pacific Little Pocket Mouse (*Perognathus longimembris pacificus*) Report to USFWS for Phase III for the Period January 2008-December 2008, pages 1-63.

Shier, D.M. 2009 Behavioral Ecology and Translocation of the Endangered Stephens' kangaroo rat (*Dipodomys stephensi*) Report to USFWS for the Period January 2008-December 2008, pages 1-28.

Shier, D.M. Translocation. In: Encyclopedia of Applied Animal Behaviour & Welfare Daniel Mills (editor), CABI Publishing, In press.

Shier, D.M. 2008 Behavioral Ecology and Translocation of the Endangered Pacific Little Pocket Mouse (*Perognathus longimembris pacificus*) Report to USFWS for Phase III for the Period January 2007-December 2007, pages 1-57

Shier, D.M. Hot on the tail of North America's Smallest Mouse2007. Zoonooz, Conservation Corner, Dec. 2007, pages. 8-9.

Shier, D.M.. Family support increases the success of translocated prairie dogs. The Conservation Behaviorist. May 2006, pages 9-11.

Shier, D.M. 2007 Behavioral Ecology and Translocation of the Endangered Pacific Little Pocket Mouse (*Perognathus longimembris pacificus*) Report to USFWS for Phase I and Phase II for the Period May 2006-December 2006, pages 1-13

Shier, D.M. Translocations are more successful when prairie dogs are moved as families *in* Conservation and Management of the Black-tailed Prairie Dog, John Hoogland, Editor, Island Press, 2006, p. 189.

GRANTS, CONTRACTS & FELLOWSHIPS

Research Awards

Post-Ph.D

U.S. Department of Forestry *Rana muscosa* conservation at the San Diego Zoo Institute for Conservation Research, January – December 2018, Co-Pi Natalie Calatayud 2017 $93,726.

U.S. Fish and Wildlife. *Rana muscosa* post-release surveys 2017. $20,000.

San Diego Foundation, *An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County* CO-PI Ronald R. Swaisgood, 2017 $123,875

California Department of Fish and Wildlife, Section 6 Grant, Captive Breeding and Reintroduction of the Pacific Pocket Mouse (*Perognathus longimembris pacificus*), 2016 $349,041

American Zoological Association Conservation Endowment Fund, Applying SNP-Derived Genotyping to the Captive Management of the Critically Endangered Mountain Yellow-Legged Frog, *Rana muscosa* 2016 $17,882.00

U.S. Department of Forestry *Rana muscosa* conservation at the San Diego Zoo Institute for Conservation Research, November 16, 2015-December 31, 2016, Co-Pis Natalie Calatayud and Ronald Swaisgood 2016 $ 180,352.70.

San Diego Foundation, *An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County* CO-PI Ronald R. Swaisgood, 2016 $193,656.

California Energy Commission, Assessing California's mitigation guidelines for burrowing owls impacted by habitat development and project activities: better science, better conservation, better economic outcomes, Co-PIs Ronald Swaisgood, Lisa Nordstrom, Sarah Hennessy, James Sheppard, 2016 $598,671.

U.S. Fish and Wildlife Service. Conservation and Breeding of the endangered Pacific Pocket Mouse Phase 3. 2016 $193,000.

San Diego Foundation, *An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County* CO-PI Ronald R. Swaisgood, 2015 $178,331.

City of Rancho Cucamonga Contract. Assessing the use of culverts by kangaroo rats and other small mammals. 2015 $451,120.

US Navy Contract, 2015 The Effects of Artificial Lighting on Pacific Pocket Mouse, Camp Pendleton 2015. $199,851.14.

U.S. Department of Forestry *Rana muscosa* conservation at the San Diego Zoo Institute for Conservation Research, October 1, 2014-November 15, 2015, Co-PIs Natalie Calatayud and Ronald Swaisgood 2014 $ 115,374.38.

USFWS Contract, Range-Wide Genetics of the Endangered San Bernardino Kangaroo Rat, (*Dipodomys Merriami Parvus*), 2014 $69,174.31.

USFWS Contract. Effects of Anthropogenic Lighting on SBKR Foraging Behavior, Persistence and Fitness, 2014 $83,693.97.

Riverside County Habitat Conservation Agency (RCHCA), *Behavior and Ecological Approaches to Translocation in Stephens' kangaroo rat*. CO-PI Ronald R. Swaisgood, 2014, $56,546.

San Diego Foundation, An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County, 2014. Co-PIs Lisa Nordstrom, James Sheppard, Ronald Swaisgood $25,380.00.

California Department of Fish and Wildlife, Section 6 Grant, Captive Breeding and Reintroduction of the Pacific Pocket Mouse (*Perognathus longimembris pacificus*), 2014 $500,648.80.

California Department of Fish and Wildlife, LAG Grant, Range-wide genetics of the Endangered Stephens' kangaroo rat, (*Dipodomys stephensi*), 2013, $25,497.

San Diego Foundation, *An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County* CO-PI Ronald R. Swaisgood, 2013 $221,683.

U.S. Department of Forestry *Rana muscosa* conservation at the San Diego Zoo Institute for Conservation Research, Co-PIs Frank Santana and Ronald Swaisgood, 2013, $102,990.

Riverside County Habitat Conservation Agency (RCHCA), *Behavior and Ecological Approaches to Translocation in Stephens' kangaroo rat*. CO-PI Ronald R. Swaisgood, 2013, $60,500.00.

San Diego Foundation, *An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County* CO-PI Ronald R. Swaisgood, 2012 $221,683.

California Department of Fish and Game, Section 6 Grant, Captive Breeding and Reintroduction of the Pacific Pocket Mouse (*Perognathus longimembris pacificus*), 2012 $344,540.00.

Riverside County Habitat Conservation Agency (RCHCA), *Behavior and Ecological Approaches to Translocation in Stephens' kangaroo rat*. CO-PI Ronald R. Swaisgood, 2012, $114,000.00

San Diego Foundation, *An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County* CO-PI Ronald R. Swaisgood, 2011 $221,683.

Eastern Municipal Water District (EMWD), Translocation of the Endangered San Bernardino Kangaroo Rat, (*Dipodomys Merriami Parvus*), 2012 $363,889.34

Riverside County Habitat Conservation Agency (RCHCA), *Behavior and Ecological Approaches to Translocation in Stephens' kangaroo rat*. CO-PI Ronald R. Swaisgood, 2011, $120,000.

San Diego Foundation, *An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County* CO-PI Ronald R. Swaisgood, 2011 $236,153.

Riverside County Habitat Conservation Agency (RCHCA), *Behavior and Ecological Approaches to Translocation in Stephens' kangaroo rat*. CO-PI Ronald R. Swaisgood, 2010, $173,000.

Riverside County Habitat Conservation Agency (RCHCA), *Behavior and Ecological Approaches to Translocation in Stephens' kangaroo rat*. CO-PI: Ronald R. Swaisgood, 2009. $156,000.

Marine Corp Camp Pendleton *Population Survey of the Endangered Pacific Pocket Mouse.* 2008. $55,000

USFWS, *Behavioral Ecology and Translocation of the Endangered Pacific Pocket Mouse*. 2007.

$234,000

J. Dallas Clark Postdoctoral Fellowship. $80,000/year 2006-2010.

OTHER HONORS & AWARDS

Prtizker Environment and Sustainability Education Fellowship Recipient, Institute of the Environment, UCLA, 2017
Honorable Mention, Warder Clyde Allee Competition, Animal Behavior Society, 2005
Outstanding teaching award, University of California, Los Angeles, 2004
Outstanding teaching award, University of California, Los Angeles, 2003
Outstanding teaching award, University of California, Los Angeles, 2002
Phi Sigma Member (National Honor Society for students and faculty in the biological sciences), 2000-2004
Honorable Mention, Founders Day Poster Session, Animal Behavior Society, 1995

INVITED SEMINARS and SYMPOSIA

Invited Seminar, Mountain Yellow-legged frog workshop November 201.

Invited Oral Paper, Symposium: What is hindering the success of conservation translocations? International Congress for Conservation Biology, Cartegena Columbia, 2017

Invited Oral Paper, Earth Optimism Summit, Smithsonian, April 2017

Invited Seminar, International Management Conference, October 2014

Invited Seminar, San Onofre Foundation, August 2013

Invited Talk, Animal Behavior Society Conservation Workshop July, 2013

Invited Seminar, Point Loma University, October 2011

Invited Seminar, University of California, San Diego, March 2011

Invited Seminar, San Diego State University, November 2010

Invited Seminar, Oxford University, WildCru, Department of Zoology, January 2010

Invited Seminar, Sam Houston State University, Department of Biological Sciences, April 2009

Invited Seminar, University of California, Los Angeles, Department of Ecology and Evolutionary Biology, November 2008

Invited Seminar, Department of Biology University of Reno, Nevada, April 2008

Invited Seminar, University of California, Santa Barbara, Cheadle Center for Biodiversity and Ecological Restoration, March 2008

Invited Symposium Talk, *Conservation Behavior: From Implications to Applications*, Animal Behavior Society, July 2007

Invited Seminar, CRES, Zoological Society of San Diego September 2005

Invited Seminar, New Mexico State University, January 2005

Invited Talk, Student Plenary Session, American Society of Mammalogists, June 2004

Invited Lecture, University of California, Davis, October 2003

Invited Lecture, University of California, Los Angeles, April 2003

Invited Lecture, United States Air Force Academy, Colorado Springs, CO, April, 2002

Invited Talk, University of California, Davis, Stamps Symposium, Animal Behavior Graduate Group and Section of Evolution and Ecology, October 2007

SELECTED PRESENTATIONS AT SCIENTIFIC MEETINGS

Oral Paper, International Conference on Urban Wildlife, June 2017

Wildlife Management Society, October 2012

Oral Paper, Wildlife Management Society, October 2012

Oral Paper, Society for Conservation Biology, July 2009

Oral Paper, 1st International Reintroduction Conference, April, 2008

Oral Paper, Animal Behavior Society, August, 2006

Oral Paper, Animal Behavior Society, July, 2005

Oral Paper, Animal Behavior Society July 2003

Oral Paper, Animal Behavior Society, August, 2001

Oral Paper, San Francisco Bay Area Conservation Biology Symposium, January, 2001

Oral Paper, Communication Workshop, University of California Davis, June, 2000

Oral Paper, Animal Behavior Society, July, 1999

Oral Paper, International Society for Behavioral Ecology, July, 1997

Oral Paper, Animal Behavior Society, July, 1996

PRESENTATIONS TO GOVERNMENT AGENCIES

Presentation to the Reserve Management Committee, Riverside California, May 2014

Presentation to Riverside County Habitat Conservation Agency, April 2014

Presentation, Tasmanian Government, February 2014.

Presentation to Riverside County Habitat Conservation Agency, March, 2011

Presentation to Riverside County Habitat Conservation Agency, February, 2010

Presentation to the Reserve Management Committee, Riverside California, May/July 2009

Presentation to Riverside County Habitat Conservation Agency, November, May/September 2009

Presentation to Riverside County Habitat Conservation Agency, November, 2008

Presentation to Head, Environmental Security, Marine Corps Base Camp Pendleton, 2008

Presentation to Head, Environmental Security, Marine Corps Base Camp Pendleton, 2007

Presentation to S4 Command Edson Range, Marine Corps Base Camp Pendleton, 2007

SELECTED TEACHING EXPERIENCE

Title	Course	Terms Taught
Adjunct Assistant Professor	University of California, Los Angeles Practicum in Environmental Science	Winter/Spring 2016
Adjunct Assistant Professor	University of California, Los Angeles Field Conservation Biology	Winter 2011, 2013, 2015
Lecturer	University of California, Los Angeles Field Conservation Biology	Winter 2009
Teaching Assistant	University of California, Los Angeles Molecular Biology and Evolution	Spring 2004
Teaching Assistant	University of California, Los Angeles Field Behavioral Ecology	Spring 2003
Teaching Assistant/ Lab Instructor	University of California, Los Angeles Animal Behavior	Fall 2000-Winter 2002

RESEARCH MENTORING

42 undergraduates have gained research experience during my research projects at UC Berkeley, UC Davis, and at the San Diego Zoo.

Larry Rabin, Kevin Hornberger at UC Berkeley received research training on my master's project at the Captive Breeding facility for the Endangered Morro Bay Kangaroo Rat.

Whitney Steihler, Cory Unruh, Heidy Contreras, Tanya Silva received research training on my Ph.D. project at UC Davis.

Matt Petelle, Laura Albert, Christina Walker, Jessica Price, Amanda Lea, Megan Cromp, James Liu, Matthew Golembeski, Alicia Bird, Rachel Chock, Andrew Heath, Julianne Pekney, Melanie LaCava, Amaranta Kozuch, Jennifer Bradley received research training on my research projects at the San Diego Zoo.

Current Ph.D. student (coadviser)

Rachel Chock, University of California, Los Angeles

Ph.D. Students completed

Liv Baker, University of British Columbia

Outside Committee Member

Elina Rantanen, Oxford University
Emma Dunstun, Charles Sturt University, New South Wales, Australia

ACADEMIC AND OUTSIDE SERVICE

Consultant for Tasmanian Government, Tasmanian Devil Reintroduction Program, 2014
Editor, The Conservation Behaviorist, Animal Behavior Society 2012 – Present
IUCN Reintroduction Specialist Group, 2010-2018
Reviewer for Animal Behavior Society student grant awards, 2008-2009, 2012
Expert Consultant for Sun Power, Endangered Giant Kangaroo Rat translocation, 2010-2011
External Reviewer, Ph.D. Viva, Oxford University, 2010
USGS Pacific Pocket Mouse Monitoring Workshop, 2007
Consultant for The Nature Conservancy, Marmot Translocation, Reno Nevada, 2005-2006
Associate Editor, The Conservation Behaviorist, Animal Behavior Society, 2006-2012
Animal Behavior Society, Conservation Committee, 2000-2015
Morro Bay Kangaroo Rat Recovery Team, Independent Advisers to the U.S. Fish and Wildlife Service, 2000-2002
Animal Behavior Graduate Group, Executive Committee, Graduate Student Member, 1999-2000
Manuscript reviewer for: Conservation Biology, Biological Conservation, Animal Behaviour, Behaviour, Behavioral Ecology, Behavioral Ecology and Sociobiology, Acoustical Society of America; Journal of Mammalogy, Journal of Wildlife Management; Western Northamerican Naturalist

INTERVIEWS and DOCUMENTARIES

Orange County Register August 2013

National Public Radio, California Report January 2013

Boston Globe, November 2011

Science News, October 2011

North County Times, August 2010

Science for an article on the 1st International Reintroduction Conference, 2008

Hotspots documentary. 2008. Piece on pocket mouse research on Camp Pendleton. A dancing Star Foundations production in collaboration with Conservation International written and directed by Michael Tobias & Jane Morrison

OUTREACH

Invited talk to Chadwick High School, Palos Verdes California, Fall 2010, 2011.

Invited Speaker, Casa Romantica Cultural Center and Gardens, January 2009

Keynote address: Ardvark's Club, Zoological Society of San Diego, January 2009

Invited expert: Conservation and Behavior, Vassar College, April, 2009

Oral testimony on Impacts of Proposed Toll Road Project on the Critically Endangered Pacific Pocket Mouse (*Perognathus longimembris pacificus*) February/September, 2008.

Keynote address: President's Associates dinner. Zoological Society of San Diego. April 2008.

Invited talk to UCSD Extension Teacher Workshop, Oct. 2008

Invited talk to Hightech High students, San Marcos, CA, Potential impacts of the proposed Foothill South toll road on the critically endangered pacific pocket mouse, January 2007.

Keynote speaker: BEWISE (Better education for women in science and engineering) program at CRES, SD Zoo. Participated in conservation education roundtable for female students 11-14 years, April 2006.

Conservation education for Zoo student program, Conservation Corps, May 2006.

Invited talk to Kiwanis Club, Cimarron, New Mexico, The keystone role of black-tailed prairie dogs in the grassland ecosystem: benefits of reestablishing populations on the Vermejo Park Ranch, 2002.

Invited talk to Cimarron High School, Cimarron, New Mexico, The keystone role of black-tailed prairie dogs in the grassland ecosystem, July 2003

PROFESSIONAL MEMBERSHIPS

Wildlife Society	2010-present
American Society of Mammalogists	1996-present
Animal Behavior Society	1995-present
International Society for Behavioral Ecology	1998-present
Society for Conservation Biology	2000-present
Sigma Xi	2001-present

Bruce Orr, Ph.D.
Principal/Senior Ecologist

Dr. Bruce Orr (Ph.D., Entomology/Ecology) has over 25 years of experience leading complex projects involving natural resource inventories, integrated natural resource management plan development, and federal and state regulatory processes. He has led numerous multi-disciplinary restoration feasibility and planning studies that incorporate hydrologic and water resource management planning, instream flow needs, and groundwater inputs in major watersheds throughout California (San Joaquin, Merced, and Santa Clara rivers), and is currently leading restoration planning projects on the Virgin and Gila rivers (Nevada and Arizona). Dr. Orr provides senior strategic support on many of Stillwater's large-scale regulatory, watershed management, and restoration projects. Dr. Orr is frequently invited to speak about restoration ecology, and in recent years he has developed and taught various professional program short courses, including wetland delineation, wetland restoration ecology, ecological restoration of riparian habitats, and watershed management. He serves a variety of science advisory committees, including the Santa Clara Valley Water District's Science Hub and the City of Los Angeles Biodiversity Expert Panel, to provide expertise on riparian and aquatic ecology, restoration, and management. Dr. Orr has been a member of the California Native Plant Society's Vegetation Committee since 1993.

AREAS OF EXPERTISE

- Riparian and Wetland Ecology
- Restoration Ecology
- Integrated Natural Resource Analysis and Management Planning
- Watershed Analysis
- Benthic Macroinvertebrate and Stream Ecology
- TMDLs

YEARS OF EXPERIENCE

At Stillwater: 21 years
In Total: 38 years

EDUCATION

Ph.D., Entomology (Aquatic Entomology/Aquatic and Wetland Ecology), University of California at Berkeley, 1991

BA, Biological Sciences and Environmental Studies (High Honors), University of California at Santa Barbara, 1979

PROFESSIONAL AFFILIATIONS

- American Institute of Biological

SELECTED PROJECT EXPERIENCE

Restoration Feasibility Study and Riparian Vegetation Dynamics, Classification and Mapping Study, Santa Clara River Parkway, CA *(Client: California Coastal Conservancy)*: Dr. Orr led a team that sampled, classified, and mapped over 25,000 areas of riparian vegetation and floodplain habitats along the Santa Clara River in Ventura County. Additional studies explored the physical process drivers and human land and water use impacts on riparian-floodplain dynamics. The final Feasibility Report integrated these and other studies to present strategies for habitat conservation, levee setback and removal, passive and active native plant revegetation, non-native species removal, fish passage improvement, and water quality treatment to improve ecosystem functions and increase the resiliency of the lower Santa Clara River to climate change impacts. Dr. Orr is currently directing studies supporting riparian and aquatic invasive species control and river and riparian and floodplain restoration implementation and monitoring efforts being implemented by local stakeholders under Prop 84 funding.

Strategic Habitat Conservation Planning for Least Bell's Vireo on the Santa Clara River, CA (*Client: USFWS*). Dr. Orr is currently working with USFWS, USGS, UCSB, and the Western Foundation of Vertebrate Zoology to link vegetation, habitat structure, and river-riparian habitat dynamics to habitat suitability and population response of least Bell's vireo as part of a larger USFWS effort to develop a strategic habitat conservation plan for this species. Team members were recently awarded an ESA Section 6 grant to expand the effort Dr. Orr and Stillwater will be updating the vegetation classification and

Sciences
- California Native Plant Society
- Ecological Society of America
- Society for Freshwater Science
- Society for Ecological Restoration
- Society of Wetland Scientists
- California Native Plant Society Vegetation Committee

PERMITS

- U.S. Fish and Wildlife Service 10(a)1(A) recovery permit (#TE237086-0) for California freshwater shrimp (*Syncaris pacifica*)
- California Department of Fish and Wildlife Scientific Collecting Permit (SC #6032) for freshwater fishes, anadromous fishes, freshwater invertebrates, reptiles, amphibians.
- California Department of Fish and Wildlife California ESA Plant Voucher Collecting Permit No. 2081(a)-13-133-V

SELECTED CONFERENCE PRESENTATIONS AND PUBLICATIONS

Orr, B.K., A.M. Merrill, Z.E. Diggory, and J.C. Stella. 2017. **Use of the biophysical template concept for riparian restoration and revegetation in the Southwest.** In: B.E. Ralston and D.A. Sarr (eds.), *Case Studies of Riparian and Watershed Restoration Areas in the Southwestern United States—Principles, Challenges, and Successes.* U.S. Geological Open File Report 2017-1091, 116 p., https://doi.org/10.3133/ofr20171091.

Orr, B., M. Johnson, G. Leverich, , T. Dudley, J. Hatten, Z. Diggory, K. Hultine, D. Orr, and S. Stone. 2017. **Multi-scale riparian restoration planning and implementation on the Virgin and Gila Rivers.** In: B.E. Ralston and D.A. Sarr (eds.), *Case Studies of Riparian and Watershed Restoration Areas in the Southwestern United States—*

mapping along 65 miles of the Santa Clara River and developing detailed descriptions of riparian and floodplain habitat structure using LIDAR and field surveys to support development of habitat suitability models and decision support tools to guide restoration and management of southwestern willow flycatcher, and western yellow-billed cuckoo and their habitats in the river corridor.

Wetland and Riparian Assessment and Restoration Planning, San Joaquin River Restoration Plan, CA *(Client: Friant Water Users Authority and NRDC; U.S. Bureau of Reclamation)*: Dr. Orr co-managed a unique effort to develop a plan for restoring the San Joaquin River ecosystem in balance with beneficial uses of San Joaquin River water supplies. Stillwater developed restoration objectives and strategies pre-settlement agreement and SJRRP initiation to restore the San Joaquin River below Friant Dam to support self-sustaining, naturally reproducing populations of aquatic species, including Chinook salmon. Dr. Orr was the technical team lead for riparian and floodplain wetland assessment and restoration planning, as well as macroinvertebrate drift studies. He is currently a member of the consultant team hired by the U.S. Bureau of Reclamation to provide technical support to the multi-agency team charged with implementing the restoration along 150 miles of the San Joaquin River.

Ecohydrologic Assessment, Virgin River, UT, AZ, and NV *(Clients: Walton Family Foundation and The Nature Conservancy):* Dr. Orr is the project director for an ecohydrologic assessment to help identify and prioritize suitable riparian restoration locations along the flood prone, ecologically sensitive Virgin River—a major tributary to the Colorado River. The assessment supports the initial phases of the much greater Virgin River Restoration Framework involving numerous resource agencies, academic researchers, and local stakeholders all working towards the removal of the invasive tamarisk plant and restoration of critical habitat for listed species, including Southwestern Willow Flycatcher. Dr. Orr is leading the riparian vegetation analysis and modeling to identify hydrologically and ecologically suitable locations for restoration implementation.

Ecosystem Linkages and Ecological Flows Studies, Sacramento River, CA *(Clients: CALFED and The Nature Conservancy):* Dr. Orr led the Ecosystem Linkages Study and other studies as part of the Sacramento River Ecological Flows Study initiated by The Nature Conservancy in collaboration with ESSA Technologies, Stillwater Sciences, UC Davis, and UC Berkeley. The purpose of this study was to define how flow characteristics (e.g., the magnitude, timing, duration, and frequency) and associated management actions (such as gravel augmentation and changes in bank armoring) influence the creation and maintenance of

Principles, Challenges, and Successes. U.S. Geological Open File Report 2017-1091, 116 p., https://doi.org/10.3133/ofr20171091**.**

Rasmussen, C.G. and **B.K Orr.** 2017. **Restoration principles for riparian ecosystem resilience.** 2017. In: B.E. Ralston and D.A. Sarr (eds.), *Case Studies of Riparian and Watershed Restoration Areas in the Southwestern United States—Principles, Challenges, and Successes.* U.S. Geological Open File Report 2017-1091, 116 p., https://doi.org/10.3133/ofr20171091.

Orr, B, M. Keever, A. Merrill, N. Hume, J. Long, H. Green, and G. Darren**. 2016. Restoration Design in the Sacramento-San Joaquin Delta – Lessons from Case Studies.** Bay-Delta Science Conference 2016**.**

Beller, E.E., P. W. Downs, R.M. Grossinger, **B.K. Orr**, and M.N. Soloman. 2015**. From past patterns to future potential: using historical ecology to inform river restoration on an intermittent California rive**r. Landscape Ecology, DOI 10.1007/s10980-015-0264-7

Cui, Y., J. Wooster, C. Braudrick, and **B. Orr.** 2014. **Lessons learned from sediment transport model predictions and long-term postremoval monitoring: Marmot Dam Removal Project on the Sandy River in Oregon**. J. Hydraul. Eng. 140(9), 04014044

Real de Asua, R, E., E. Bell, **B. Orr**, P. Baker, and K. Faucher. 2012. **Use of BasinTemp to model stream summer temperatures in the south fork of Ten Mile River, CA.** Pages 141–150 *in* R. B. Standiford, T. J. Weller, D. D. Piirto, and J. D. Stuart, tech. coordinators. Proceedings of coast redwood forests in a changing California: A symposium for scientists and managers. Gen. Tech. Rep. PSW-GTR-238. Pacific Southwest

habitats for a number of native species that occur in the Sacramento River corridor. Dr. Orr was the technical lead for studies focused on riparian and floodplain habitats and ecosystem linkages between river processes and species of interest.

Regional Assessment of Geomorphic and Ecological Processes and Biological Responses, Napa River Basin, CA (*Clients: State Water Quality Control Board and California Coastal Conservancy; U.S. Army Corps of Engineers*): Dr. Orr managed a multi-year, phased project for the Regional Water Quality Control Board to provide technical support for the development of a sediment TMDL for the Napa River Basin. The first phase of the project focused on assessment of current in-channel and riparian habitat conditions to determine which factors are currently limiting production of Chinook salmon, steelhead trout, and California freshwater shrimp in the Napa River Basin. Later phases tested key hypotheses about limiting factors and causal linkages between land and water use activities and their effects on habitats and biological populations of interest.

Merced Alliance Biological Monitoring and Assessment Project, CA *(Clients: East Merced RCD and State Water Resources Control Board)*: As a component of the larger Merced River Alliance Project, this effort represents the first comprehensive assessment of fish, bird, and benthic macroinvertebrate (BMI) species composition and distribution along the upper and lower Merced River. The Merced Alliance Project was created to bring together two independent watershed management efforts and to support collaboration by conservation districts and stakeholder groups for the upper and lower Merced River on a variety of watershed-wide issues.

Cache Slough Complex Conservation Assessment, Sacramento-San Joaquin Delta, CA *(Client: Department of Water Resources [DWR])*: Dr. Orr is project director for the consultant team providing support to DWR in the implementation of the Fish Restoration Program (FRP) in order to fulfill requirements contained within Biological Opinions of the USFWS (2008) and NMFS (2009) for continued water export operations of the SWP and CVP. For the Cache Slough Complex Conservation Assessment, Dr. Orr is working with DWR and DFW staff to support DWR in identifying and prioritizing tidal marsh restoration opportunities in the northwestern portion of the Delta. The assessment relies upon existing conceptual models to synthesize historical ecology of the Delta, current landscape and waterscape patterns, and effects of climate change and other factors. The assessment integrates knowledge from recent and ongoing restoration projects (Liberty Island, lower Yolo Bypass, Prospect Island, Calhoun Cut), as well as broader planning efforts (2008 Delta Vision Strategic Plan; 2010 Ecosystem Restoration

Research Station, Forest Service, U.S. Department of Agriculture, Albany, California. http://www.nrs.fs.fed.us/pubs/18240

Downs, P. W., M. F. Singer, **B. K. Orr**, Z. E. Diggory, and T. N. Cosio. 2011. **Restoring ecological integrity in highly regulated rivers: the role of baseline data and analytical references.** Environmental Management. DOI 10.1007/s00267-011-9736-y.

Orr, B.K., and others. 2011. **Riparian vegetation classification and mapping: important tools for large-scale river corridor restoration in a semi-arid landscape**. *In* J. Willoughby, **B. Orr**, K. Schierenbeck, and N. Jensen [eds.], Proceedings of the CNPS Conservation Conference: Strategies and Solutions, 17-19 Jan 2009.

Orr, B. K., C. Riebe, and R. Peek. 2008. **Linking biological responses to river processes: implications for conservation and management of the Sacramento River—a focal species approach.** CALFED Science Conference.

Orr, K. E., J. T. King, **B. K. Orr**, and M. Singer. 2008. **Aquatic bioassessment as part of the Merced River Alliance Project.** CALFED Science Conference.

Stella, J. C., J. J. Battles, **B. K. Orr,** and J. R. McBride. 2006. **Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California.** Ecosystems 9: 1–15.

Orr, B. K. 2006. **Tools for riparian-floodplain restoration planning along large river corridors: examples from the San Joaquin River, CA.** CALFED Science Conference.

Stella, J. C., J. J. Battles, J. R. McBride, and **B. K. Orr**. 2010. **Riparian seedling mortality from simulated water table recession, and the design of**

Program Stage 2 Conservation Strategy; 2012 Bay Delta Conservation Plan).

Prospect Island Tidal Habitat Restoration Project, Sacramento-San Joaquin Delta, CA *(Client: Department of Water Resources [DWR])*: Dr. Orr is project director for the consultant team providing support to DWR in the restoration of 1,600 acres on Prospect Island in partial fulfillment of requirements for 8,000 acres of tidal habitat restoration contained within recent Biological Opinions of the USFWS (2008) and NMFS (2009) for continued water export operations of the SWP and CVP. This project involves a multidisciplinary team responsible for (1) developing and screening restoration alternatives, (2) evaluating the attainment of BiOp requirements and potential adverse effects of different design approaches, (3) developing preliminary restoration designs, and (4) development of EIR and permits for the Proposed Project to restore 1,600 acres of tidal habitat at Prospect Island.

Klamath Basin Wetlands, OR *(Client: Bureau of Indian Affairs)*: Dr. Orr was the technical lead for assessment of the effects of changes in water level and vegetation on wildlife habitat in Klamath Marsh. This effort linked the results of field and modeling studies of vegetation-hydroperiod relationships with habitat conditions using a variety of Habitat Suitability Index models. He also led initial studies of surface flow and vegetation and wildlife habitat associated with seeps and springs in the Upper Klamath Basin.

Big Lagoon Wetland and Creek Restoration and Redwood Creek Watershed Assessment, CA *(Client: National Park Service):* Dr. Orr led biological studies for the ecological restoration program for Big Lagoon, Redwood Creek. The program is based on anticipating and directing the seasonal and inter-annual patterns of flooding, sedimentation, erosion, wind-blown sand, wave action and saltwater mixing to minimize the need for future intervention. Dr. Orr also served as senior scientific advisor for an assessment of the Redwood Creek watershed conducted to assist the National Park Service in developing appropriate natural resource management plans.

Geomorphic and Ecological Evaluations of Removal of Marmot Dam, Sandy River, OR *(Client: Portland General Electric)*: The removal of Marmot Dam represented one of the first large-scale releases of dam-impounded sediment in the United States, and raised numerous ecological concerns. Prior to dam removal, Dr. Orr led Stillwater Sciences' effort to provide geomorphic, sediment transport, and ecological evaluations associated with the potential release of approximately 1 million cubic yards of sand and gravel stored behind the dam. The analyses permitted stakeholders to agree upon an

sustainable flow regimes on regulated rivers. Restoration Ecology 18, supplement S2: 284-294.

Orr, B. K., Z. Diggory, and T. Dudley. 2010. **Strategic planning for control of Arundo donax and riparian restoration in semi-arid landscapes**. California Invasive Plant Council Symposium.

Orr, B. K., N. P. Hume, and T. J. Ford. 2004. **Evaluating the effects of flow on aquatic invertebrate communities in the lower Tuolumne River, California.** CALFED Science Conference.

Stella, J., J. Vick, and **B. K. Orr.** 2003. **Riparian vegetation dynamics on the Merced River.** *In* P.M. Faber, editor. Proceedings of the Riparian Habitat and Floodplains Conference. The Western Section of the Wildlife Society and the Riparian Habitat Joint Venture, Sacramento, California. 12–15 March 2001.

Golet G.H.; Roberts, M.D.; Peterson, D.R.; Jukkola, D.E.; Crone, E.E.; Geupel, G.R.; Small, S.L.; Greco, S.E.; Holl, K.D.; Larsen, E.W.; Ligon, F.K.; **Orr, B.K.**; Vick, J.C.; Power, M.E.; Rainey, W.E.; Silveira, J.G.; Wilson, D.S. 2003. **Using science to evaluate restoration efforts and ecosystem health on the Sacramento River Project, California**. In: Faber, P.M., editor. Proceedings of the Riparian Habitat and Floodplains Conference. The Western Section of the Wildlife Society and the Riparian Habitat Joint Venture, March 12-15, 2001, Sacramento, CA.

Orr, B., C. Braudrick, A. Wilcox, J. Vick, S. Kramer, Y. Cui, and J. Keil. 2002. Evaluation of Geomorphic Effects of the Removal of Marmot Dam and Potential Impacts on Anadromous Salmonids. Presented at HydroVision

ecologically and economically acceptable dam removal alternative, based on a single season deconstruction schedule, followed by natural fluvial erosion of the formerly-impounded sediment. Removal of Marmot Dam occurred in 2007. Dr. Orr continues to participate in post-removal monitoring studies.

Sediment and Temperature TMDL Support, South Fork Eel River *(Client: U.S. Environmental Protection Agency)*: Dr. Orr directed sediment source assessment and stream network water temperature modeling studies, including scenario testing for various riparian vegetation management options, to support EPA's development of a sediment and temperature TMDL for the South Fork Eel River, California.

Environmental Impact Statement/Program Timberland Environmental Impact Report for Mendocino Redwood Company's Habitat Conservation Plan/Natural Community Conservation Plan, CA *(Client: Mendocino Redwood Company)*: Dr. Orr is project director and science team supervisor for a joint NEPA/CEQA impact analysis of MRC's multi-species HCP and NCCP in coastal Mendocino County, CA.

Habitat Conservation Plan/Sustained Yield Plan for Jackson Demonstration State Forest, CA *(Client: California Department of Forestry and Fire Protection)*: Dr. Orr managed the development of a draft multi-species Habitat Conservation Plan (HCP), Sustained Yield Plan (SYP) for timber management, and a joint draft EIS/EIR for the California Department of Forestry and Fire Protection's 50,000 acre Jackson Demonstration State Forest.

Steelhead Limiting Factors Analyses: Sonoma, Stevens and Upper Penitencia Creeks, CA *(Clients: SF Regional Water Quality Control Board, Santa Clara Valley Water District, Sonoma Ecology Center)*: Dr. Orr served as project director and technical advisor for several studies of critical factors limiting steelhead production in SF Bay Area streams, including Sonoma Creek (Sonoma County) and Stevens Creek and Upper Penitencia Creek (Santa Clara County).

Lagunitas Limiting Factors Analysis, Marin County, CA *(Client: Marin Resource Conservation District)*: Dr. Orr led a limiting factors analysis for Lagunitas Creek and its major tributaries that involved development of conceptual models for each species, tailored fish population modeling, and input from local experts and technical advisors. Key uncertainties were identified to develop focused studies for Phase II studies.

Willamette Falls/Sullivan, Oak Grove, North Fork, and Pelton-Round Butte Project Relicensing, Western OR *(Portland General Electric)*: Dr. Orr served as the project manager for technical studies of geomorphic and ecological effects of dam removal alternatives, the

2002, Portland OR. July.

Olson, C. and **B. Orr**. 1998. Combining tree growth, fish and wildlife habitat, mass wasting, sedimentation, and hydrologic models in decision analysis and long-term forest land planning. Forest Ecology and Management 110: 1-10.

Orr, B.K. 1997. Ecosystem health and salmon restoration: a broader perspective. Invited paper prepared for a special session on "The role of applied ecological research in the management of a regulated river: New Don Pedro Dam and the Tuolumne River," International Association for Hydraulic Research Conference, San Francisco, CA. August 11-15, 1997.

Lacey, L. and **B.K. Orr**. 1994. The role of biological control of mosquitoes in integrated vector control. American Journal of Tropical Medicine and Hygiene 50(6) Suppl: 97-115 (invited paper).

Orr, B.K. and V.H. Resh. 1992. Influence of *Myriophyllum aquaticum* cover on *Anopheles* mosquito abundance, oviposition, and larval microhabitat. Oecologia 90:474-482.

Orr, B.K., S. Morhardt, and R.D. Stone. 1991. Influence of drought on the distribution and abundance of montane riparian plants along a western Sierra Nevada stream. Paper presented at the California Riparian Systems Conference III: Progress in Protection and Restoration, Sacramento, California. 16 November.

Orr, B.K., W.W. Murdoch, and J.R. Bence. 1990. Population regulation, convergence, and cannibalism in *Notonecta* (Hemiptera). Ecology 71(1): 68-82.

Orr, B.K. and V.H. Resh. 1989.

aquatic resources component of an Environmental Assessment (EA), and preparation of biological assessments for hydroelectric projects on four rivers in Oregon.

Merced River Corridor Restoration Plan, Merced County, CA *(Clients: CALFED and USFWS AFRP; State Water Resources Control Board)*: Dr. Orr directed the riparian vegetation establishment and dynamics for the ongoing restoration of the lower Merced River. The overall plan identifies and guides restoration of critical geomorphic and ecological processes in the Merced River, continuing the long-term effectiveness of site-specific restoration projects. Dr. Orr also served as project director for a recently completed multi-year project involving baseline inventories of benthic macroinvertebrates, fish, and riparian birds in the upper and lower Merced River.

Habitat Conservation Plan and Sustained Yield Plans *(Clients: Louisiana-Pacific Corp. and Mendocino Redwood Company):* Dr. Orr served as project manager for Louisiana-Pacific's multi-species HCP and SYP project in northern California. This 3-year project involved conducting watershed, fisheries, and wildlife assessments and the development of SYPs and HCPs covering over 300,000 acres of industrial forestlands owned by Louisiana-Pacific, with a total watershed and wildlife assessment area exceeding one million acres. He is currently project director for the development of and EIS and Programmatic Timberland EIR as part of the development of a multispecies Habitat Conservation Plan and Natural Community Conservation Plan for the same forestlands, now owned and operated by Mendocino Redwood Company.

Benthic Macroinvertebrate and Fish Studies, Lower Tuolumne River *(Client: Turlock and Modesto Irrigation Districts)*: Dr. Orr served initially as project manager and later as senior technical advisor on multi-year studies of the effects of summer flow regimes on benthic macroinvertebrate and fish communities in the lower Tuolumne River.

South Feather River Botanical, Wetland and Riparian Studies *(South Feather Water and Power Authority):* Dr. Orr was the technical lead for studies of special-status plant species, noxious weeds, wetlands, riparian habitat dynamics, and vegetation mapping conducted for reclicensing of a hydroelectric project.

Botanical, Wetland and Riparian Studies on the McKenzie River, Oregon *(Eugene Water and Electic Board)*: Dr. Orr recently served as senior scientific advisor for studies of of special-status plant species, noxious weeds, aquatic weeds, wetlands, riparian habitats, and vegetation mappi conducted for reclicensing of the Carmen-Smith Hydroelectric Project. He

Experimental test of the influence of aquatic macrophyte cover on the survival of *Anopheles* larvae. Journal of the American Mosquito Control Assoc. 5:579-585.

Collins, J.N. and **B.K. Orr**. 1989. An ecological overview of the Coyote Hills wetlands, *in* Talk about Wetlands, Proceedings of the Coyote Hills Wetlands Workshop, February 1987, (J. Collins and K. Burger, eds.), pp. 34-42.

is now supervising implementation of multi-year botanical monitoring studies. He previously conducted

East Bay Watershed Inventory and Management Plan *(Client: EBMUD):* Dr. Orr managed a large, multidisciplinary project to conduct a comprehensive inventory of EBMUD watershed lands in the eastern SF Bay Area and drafted preliminary ecosystem management plan elements as part of EBMUD's Master Plan development process.

Restoration Framework for the Upper Gila River, AZ *(Clients: The Gila Watershed Partnership of Arizona and Walton Family Foundation)*: Restoration planning effort along the upper Gila River to restore wildlife habitat and native riparian corridor, which has become densely choked by an invasive tamarisk forest. The comprehensive effort involves generation of baseline ecological and hydro-geomorphological factors, followed by synthesis of these data with others, including wildlife potential, soils and groundwater, and land use, to ultimately identify and prioritize restoration sites best suited for sustainable, cost-effective treatment.

Sacramento River Bank Protection Project: Environmental Planning Support *(Client: USACE)*: Provided strategic guidance and senior review of revegetation plans and other botanical tasks as part of environmental permitting and mitigation at emergency levee repair sites within the Sacramento River Bank Protection Project area.

ADDITIONAL TRAINING

California Native Plant Society series classification/releve training, 1999
CDFG certification in California Wildlife Habitat Relationships (WHR) system, 1995
Applied Fluvial Geomorphology Course, taught by David Rosgen and Luna Leopold, 1993
National Wetlands Science Training Cooperative Certification in Jurisdictional Delineation of Wetlands, 1993
USFWS Habitat Evaluation Procedures (HEP), 1992

Christian Braudrick, Ph.D.
Fluvial Geomorphologist

Dr. Christian Braudrick (*Ph.D., Earth and Planetary Science*), has worked on rivers for nearly 20 years as an environmental consultant and researcher. Dr. Braudrick uses mechanistic understanding of river processes to better understand how rivers respond to environmental changes in order to inform land use decisions and stream restoration planning. Dr. Braudrick research interests focus on the controls on channel planform and how rivers respond to changes in sediment supply including from dam removal. His work often uses the results of numerical models and sediment budgets to assess morphological impacts to streams. As an environmental consultant, he has assessed the effects of dams on hydrology and geomorphology on the Merced and Tuolumne Rivers; the impacts of fine sediment mudflow on the channel morphology and ecology of the Sandy River, OR; the downstream effects of Soda Springs Dam on the morphology and ecology of the North Umpqua River, OR; and sediment loading and transport on American Fork Creek, UT. He has managed projects on Clear Creek, and was deputy project manager for a project to develop instream flow and channel design alternatives to improve salmonid habitat on the Chelan River, WA.

AREAS OF EXPERTISE

- Fluvial Geomorphology
- Hillslope Geomorphology
- Sediment Transport

YEARS OF EXPERIENCE

At Stillwater: 5 years
In Total: 20 years

EDUCATION

Ph.D., Earth and Planetary Science, University of California, Berkeley, 2013

M.S., Geology, Oregon State University, 1997

B.A., Earth Science, University of California, Santa Cruz, 1993

AWARDS

-Horton Research Grant, American Geophysical Union

-Outstanding Graduate Student Instructor UC Berkeley

-NSF Earth Science Postdoctoral Scholarship

SELECTED PROJECT AND RESEARCH EXPERIENCE

Slide Creek Bypass Reach Habitat Enhancement, North Umpqua River, Oregon *(Client: PacifiCorp)*: Dr. Braudrick helped design and monitor an on-the-ground restoration project for PacifiCorp's North Umpqua Hydroelectric Project. This enhancement project involved creating spawning habitat with gravel and boulder augmentation in a steep, confined mountain stream, as well as pre- and post-implementation surveys and monitoring. Monitoring included topographic surveys, low-altitude aerial photography, installation and monitoring of scour chains, and facies mapping.

Downstream effects of Soda Springs Dam, North Umpqua River, Oregon *(Client: PacifiCorp)*: Dr. Braudrick synthesized a sediment budget and other geomorphic, geologic, and hydrologic data to infer the effects of Soda Springs Dam on channel morphology and aquatic habitat as part of the relicensing of the North Umpqua Hydroelectric Project.

Pelton-Round Butte Hydroelectric Project Relicensing, Oregon *(Client: Portland General Electric)*: Dr. Braudrick helped design a gravel augmentation and sediment monitoring program for gravel transport downstream of the Pelton-Round Butte hydroelectric project and was the sediment transport lead during the relicensing negotiation.

Lake Chelan Project Relicensing, Utah *(Client: Chelan County Public Utilities District)*: Working with stakeholders, Dr. Braudrick helped evaluate potential habitat enhancement sites downstream of Lake Chelan Dam. This required integrating geomorphic analysis and habitat suitability criterion in a short reach downstream of the canyon mouth.

Marmot Dam Decomissioning, Sandy River, Oregon *(Client: Portland General Electric)*: On the Sandy River, OR, Dr. Braudrick analyzed

PROFESSIONAL AFFILIATIONS

-American Geophysical Union

SELECTED PUBLICATIONS

Braudrick, C.A., W.E. Dietrich, G.T. Leverich, and L.S. Sklar (2009), **Experimental evidence for the conditions necessary to maintain meandering in coarse-bedded rivers**, Proceedings of the National Academy of Science, 106, 16936-16941.

Cui, Y., J.K. Wooster, **C.A.** Braudrick, and B.K. Orr (2014). **Marmot Dam Removal Project, Sandy River, Oregon: Lessons Learned from Model Predictions and Long-term Post-Removal Monitoring.** *Journal of Hydraulic Engineering*, 140, 04014044.

Cui, Y., G. Parker, **C. A. Braudrick,** W. E. Dietrich, and B. Cluer (2006) **Dam Removal Express Assessment Models (DREAM). Part 1: Model development and validation**, *Journal of Hydraulic Research*, 44, 291-307.

Y. Cui, **C. A. Braudrick**, W. E. Dietrich, B. Cluer, G. Parker (2006) **Dam Removal Express Assessment Models (DREAM). Part 2: Sample runs/ sensitivity tests**, *Journal of Hydraulic Research*, 44, 308-323.

Braudrick, C. A. and G. E. Grant (2001) **Transport and deposition of large wood debris in streams: A flume experiment**. *Geomorphology*. 41: 263-283.

Braudrick, C. A. and G. E. Grant (2000) **When do logs move in rivers?** *Water Resources Research*. 36: 571-583

Braudrick, C. A., G. E. Grant, Y. Ishikawa, and H. Ikeda (1997) **Dynamics of Wood Transport in Streams: A Flume Experiment.** *Earth Surface Processes and Landforms*. 22: 669-683.

sediment transport modeling results to assess the geomorphic effects of different dam removal alternatives, and communicated these analyses to the stakeholders in the Decommissioning group. This led to a settlement and the eventual removal of the dam in 2007.

Fish Passage Monitoring Post Dam Removal, Sandy River, Oregon *(Client: Portland General Electric)*: In response to concerns by the stakeholder group, Dr. Braudrick helped develop a five-year monitoring plan following dam removal to determine the potential for fish passage impairment following dam removal. This monitoring plan used data from a suite of cross sections to determine changes to channel complexity.

Saeltzer Dam Removal Modeling and Monitoring, Clear Creek, California *(Clients: CALFED and UC Davis)*: Dr. Braudrick designed and implemented a study to evaluate the downstream effects of sediment following the removal of Saeltzer Dam on Clear Creek, CA. This study included collecting hydrology, sediment grain size, and cross section data before and after dam removal. This data was used to inform (prior to dam removal) and verify a sediment transport model in the first year following dam removal.

A preliminary evaluation of the potential downstream sediment deposition following the removal of Iron Gate, Copco, and JC Boyle Dams, Klamath River, CA *(Client: American Rivers)*: Dr. Braudrick helped conduct a preliminary evaluation of downstream sediment deposition following dam removal on the Klamath River using results from the Dam Removal Express Assessment Model and a site visit.

Arroyo Mocho Vegetation Monitoring (*Client: Zone 7*): Working collaboratively with plant ecologists, Dr. Braudrick mapped and described the channel dynamics of a 1-mile long reach of Arroyo Mocho, near Livermore, CA where native riparian vegetation was planted in 2014. Following the 2016-2017 floods, extensive bar growth and bank erosion created fresh surfaces to support recruitment of native willow and cottonwood seedlings. Dr. Braudrick helped to develop recommendations to maximize shading of the channel in this dynamic reach.

Channel network dynamics in headwater streams *(Client: NCASI)*: Dr. Braudrick helped map the geomorphic and hydrologic extent of steep headwater streams in the North Umpqua Basin, OR. This network extent was then compared to amphibian surveys to determine the degree to which amphibian presence was tied to summer low flow extent.

Dynamics of large woody debris in streams *(Oregon State University)*: As a Master's student, Dr. Braudrick developed and tested theories for the entrainment, transport, and deposition of wood in streams. This theory was tested in a laboratory flume experiments designed and conducted by Dr. Braudrick.

TEACHING EXPERIENCE

Lecturer–UC Berkeley
Geomorphology (Fall 2012)
The Water Planet (Summer 2002, Spring 2011, 2012, 2013, 2016)

Near-channel sediment source analysis for the Minnesota River Basin *(Utah State University)***:** As part of a large, cross-disciplinary team Dr. Braudrick used paired gauges coupled with sediment transport theory to predict the contribution of large bluff and gully erosion to sediment outflux for 15 large tributaries to the Minnesota River.

Meandering in gravel-bed rivers (*UC Berkeley*): Dr. Braudrick compiled an extensive field dataset of gravel bed meanders to determine the range of conditions that support meandering relative to gravel braided channels and sand-bed meanders. Dr. Braudrick also designed and conducted the first experiments to create a dynamic self-sustaining, single-thread meandering channel in a laboratory. These experiments used alfalfa sprouts as model vegetation and importantly included both coarse sediment (model gravel) and lightweight fine sediment (to simulate sand).

The effects of sediment supply on meandering channels (*UC Berkeley*): Dr. Braudrick conducted experiments using a meandering channel that was fixed in place to explore how sediment supply influences bar morphology. He found that rather than causing the bars to widen, which might increase the stress on the outer bank, the bars tended to lengthen transitioning from a single point bar to a series of point bars on the same side of the channel. These experiments implied that increased bar size due to increases in supply might be related to deposition of suspended load rather than bed load.

Wendy Katagi, C.E.P

Senior Manager, Watershed and Ecosystem Restoration Services

Wendy Katagi *(B.A., Social Ecology)* is a Certified Environmental Professional with over 28 years of experience in watershed planning, natural resource management, and regulatory compliance with emphasis in managing multi-benefit restoration projects from concept development to design/build, including environmental analyses, integrated design, facilitation, and monitoring. Ms. Katagi has supported SAWPA and Member Agencies with CEQA/NEPA compliance, Santa Ana Sucker Recovery, Arundo Removal Protocol, watershed-wide wetlands, trails, Burn Area Emergency Response, and other watershed resource management projects. She has an extensive background in successful grant funding, totaling over $240 million, and integrated planning to produce award-winning multi-benefit projects that integrate water resource management, restoration of ecosystem function and values, endangered species recovery, and sustainability—encouraging multiple partnerships.

AREAS OF EXPERTISE

Project Management Full Lifecycle
Watershed Planning and Design
Natural Resource Management
Ecosystem Restoration/Water Quality
CEQA/NEPA and Permitting

YEARS OF EXPERIENCE

28 years

EDUCATION

B.A., Social Ecology, Specialization in Environmental Health and Planning, UC Irvine, 1986.

Drucker School of Management, Claremont Graduate School, Claremont, CA, 1990

PUBLICATIONS

WEF Urban River Restoration Conference, Cambridge, MA, Conference Proceedings 2010. "Case Study: Central Arroyo Seco Stream Restoration Near Downtown Los Angeles"

EWRI World Water Congress, Honolulu, HI, Publication ASCE EWRI Conference Proceedings May 2008, "Steelhead Recovery in the San Juan and Trabuco Creeks Watershed"

EWRI World Water Congress, Honolulu, HI, Publication ASCE EWRI Conference Proceedings May 2008, "Central Arroyo Seco Stream Restoration Near Downtown Los

SELECTED PROJECT EXPERIENCE

Upper Santa Ana River Tributaries Restoration Project Environmental Impact Report (EIR) and Initial Study (IS), Riverside, CA *(Client: San Bernardino Valley Municipal Water District [SBVMWD])***:** Wendy is assisting in the preparation of the EIR for the Upper Santa Ana River Tributaries restoration project. This is an early implementation project of the Upper Santa Ana River HCP. Target species include the Santa Ana Sucker among other listed species. She is overseeing Stillwater's team in the delivery of key technical sections including aquatic resources, alternatives, utilities, population and housing, and recreation. Wendy managed the preparation of the Initial Study for the project as well.

Project Manager, Upper Santa Ana Wash Trails Master Plan *(Client: San Bernardino Valley Water Conservation District):* Ms. Katagi managed the integrated Trails Master Plan for the Upper Santa Ana Wash, in close coordination with District water facilities management and USFWS priorities for habitat conservation of the listed San Bernardino kangaroo rat, Santa Ana River Woolly Star, Slender-Horned Spineflower, Coastal California Gnatcatcher, and cactus wren. The approximate 5,000-acre ecological preserve provides opportunities for interpretive education, stewardship, sustainability, and trail connections to the Cities of Redlands, Highlands, and many communities along the Santa Ana River Trail. Preserve management mirrored National Park management approaches based on similar characteristics.

Project Manager, Santa Ana River Watershed User's Guide to Treatment Wetlands, Santa Ana Watershed, CA* *(Client: SAWPA):* Ms. Katagi managed the preparation of a "How to" book on wetlands restoration and treatment wetlands design and implementation, recipient of the State of California 2005 AEP Outstanding Environmental Resource Document Award. Regulatory requirements for different types of wetland projects are identified as well as next steps for prioritizing target sites for future wetland projects within the watershed.

Angeles"

"Watershed Economics", Business Life Magazine, July 2004, Authors: W. Katagi, A. Croissant and R. Thomas

California and World Ocean's Conference 2002, Santa Barbara, CA, Published by ASCE. Large-scale Watershed Planning in the Santa Ana Watershed, Oral Presentation and Proceedings, "From Opposite Sides of the Table to the Same Side of the Fence"

California and World Ocean's Conference 2002, Santa Barbara, CA, Published by ASCE. "Thinking Native in Southern California: Coastal Benefits of a Watershed Approach to Invasive Exotic Plant Removal." Authors: Christy Loper, Daniel Cozad, Wendy Katagi, and Jeffrey Beehler

PROFESSIONAL AFFILIATIONS

Certified Environmental Professional, Academy of Board Certified Environmental Professionals; American Fisheries Society

TRAINING/CERTIFICATIONS

Certified Project Management Associate (CDMU, Project Management Institute)

Fish Passage Training, Salmonid Restoration Federation, 2013

US Army Corps of Engineers, Planner Core Curriculum, Certificate of Completion for FY 2008 Planner Core Curriculum course: Introduction to Planning

ACWA Conference Fall 2002, Anaheim, CA, Oral Presentation, "Santa Ana Watershed Planning"

Great Valley Conference 2002, Sacramento, CA, Oral Presentation, "Santa Ana Watershed Planning"

American Planning Association Award for an Implementation Program, 2000, Ontario Sphere of Influence Parks, Open Space and Biological Resources Implementation Plan

Technical Advisor, Santa Ana Watershed Integrated Regional Water Management Proposition 84 Support Services, Santa Ana Watershed, CA* *(Client: SAWPA):* Ms. Katagi served in an advisory role to SAWPA in the development of project ranking criteria, prioritization of One Water One Watershed (OWOW) projects, and ranking of eligible projects for inclusion in a Proposition 84, Round 1 Implementation Grant. The process included ranking approximately 300 projects totaling $1.7 billion in funding requests. Inclusion in the SAWPA OWOW IRWMP allows project proponents to be eligible for future funding through multiple grant opportunities. Ms. Katagi has supported SAWPA and Member Agencies with CEQA/NEPA compliance, Santa Ana Sucker Recovery, Arundo Removal Protocol, watershed-wide wetlands, trails, post-fire assessments, and other watershed resource management projects.

Project Manager, Park Partnership and Mitigation Opportunities, Riverside, CA* *(Client: Chino Hills State Park):* Natural resource mitigation is often an essential requirement for project development throughout the southern California region. This document presents an alternative that can reduce the uncertainties associated with meeting mitigation obligations, while at the same time contributing to the enhancement of an outstanding existing public resource, the Chino Hills State Park.

Project Manager, Central Arroyo/Brookside Park BMP Design-Build Project, Pasadena, CA * *(Client: Arroyo Seco Foundation):* Ms. Katagi managed the multi-award winning Central Arroyo/Brookside Park BMP $1.8M grant funded Design-Build Project, including CEQA, design, permitting, and construction. Biological surveys/assessments were completed, particularly for native fish, including the arroyo chub. The design team utilized an integrated watershed management approach to address issues of water quality improvement, habitat restoration, flood management, equestrian/bike/pedestrian trails, pet waste, and interpretive signage in the Central Arroyo Seco Watershed. Rose Bowl Parking Lot I was improved with ten native plant islands which capture oil, grease, sediment, and trash, thereby improving water quality. Trash capture insert devices were installed citywide to comply with trash TMDL requirements. Ms. Katagi worked with CDFW to translocate 300 arroyo chub into the Arroyo Seco's restored reaches.

Project Manager, Arroyo Seco Native Fish Recovery Program *(Client: Arroyo Seco Foundation):* Ms. Katagi managed a post-Station fire stream assessment in the Central Arroyo Seco focused on assessing habitat quality for native fish and recommendations for future studies in the Arroyo Seco to address fish barriers, sediment management, and other limiting factors to native fish recovery.

** Denotes project completed prior to joining Stillwater Sciences.*

Project Manager, Steelhead Recovery San Juan and Trabuco Creeks, CA *(Client: Caltrout/Trout Unlimited):* Ms. Katagi managed the grant and preparation of Fish Passage Designs, Steelhead Recovery Plan, and Watershed Assessment for the San Juan and Trabuco Creeks Watershed used by CDFW as an example for other watershed management plans, resulted in the identification of approximately $28 million in restoration projects for the federally-endangered Southern California Steelhead Trout (*Oncoryhnchus mykiss irideus*) with benefits to other special status species. Key projects: Metrolink Fishway, Interstate 5 Fishway, Trabuco Creek Stream Restoration, and San Juan Creek Estuary Restoration

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