June 11, 2015

Orange County Water District
Attn: Mr. Greg Woodside, P.G., C.HG
Executive Director of Planning and Natural Resources
18700 Ward Street
Fountain Valley, CA 92708

Subject: Prado Dam Planned Deviation
Santa Ana River - Upstream Effects Due to Water Conservation (Final)

Mr. Woodside:

This technical memo provides an assessment of how increasing the allowable water surface elevation (WSE) during the flood season (October through February) from 498.0 ft National Geodetic Vertical Datum of 1929 (NGVD29) to 505.0 ft NGVD29 may affect sediment deposition and habitat types in Prado Basin and along the Santa Ana River (SAR). The following analysis will focus on an area along the SAR from Prado Dam (Dam) and the Prado Flood Control Basin (Basin) extending upstream between River Road Bridge and the Hamner Avenue/SAR crossing, referred to as the "Dam to Hamner Reach" for the purposes of this report. This information may be used to estimate the effect on sediment deposition and on various habitat types along the SAR should the allowable water conservation WSE be increased during the flood season. Historical topographic surveys, aerial imagery, recent sediment transport models, historical data, and reports have been used to estimate how additional water conservation may contribute to any long-term changes in river morphology along the SAR immediately upstream of the Dam.

Background

The primary purpose of the Dam is to provide flood risk management benefits. A secondary beneficial use of the Dam and Basin is water conservation. Water conservation benefits provided by the Dam are possible by using the Dam structure and Basin area to capture, and hold, storm flows. The captured water is released at rates conducive to downstream groundwater recharge operations. The water conservation volume afforded by the Dam is controlled by the allowable WSE during the flood season and non-flood season (March through September). Currently, the maximum water conservation elevation is 498.0 ft NGVD29 during the flood season and 505.0 ft NGVD29 during the non-flood season.

In an effort to improve water conservation in the region, an increase to the water conservation WSE in the Basin during the flood season is being evaluated. The proposed change would increase the flood season water conservation WSE from 498.0 ft NGVD29

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to 505.0 ft NGVD29. It is important to note that flood risk management operations take precedence over any water conservation objectives afforded by the Dam. An elevation of 490.0 ft NGVD29 is typically the minimum flood season WSE that is held during the early stages of a storm event. This WSE is referred to as the “Debris Pool”. The Debris Pool is necessary to help limit the amount of floating debris that enters the Dam outlet gates, which in turn helps ensure the gates can function properly during a storm event.

Once the Basin has been drained after the last storm event of the season the WSE is typically very near the streambed elevation at the Dam, or elevation 470.0 to 474.0 ft NGVD29, with the Dam outflow equal to the Basin inflow. The range of flow rates where inflow is equal to outflow are considered to be the “base flow” condition, with flows ranging between 50 cubic feet per second (CFS) to 200 cfs.

History of Prado Dam and Water Conservation

To better understand the potential future effects of increased water conservation at Prado a thorough understanding of past decisions and operations is relevant. As previously stated, the primary purpose of the Dam is flood risk management with a secondary beneficial use of water conservation. Water conservation was established as a design consideration in the mid 1930’s as the Flood Control Act of 1936 was approved. Below is a timeline (Table 1) of events that are relevant to Prado Dam, water conservation at Prado Dam and significant storm events that have affected the Dam to Hamner Reach of the SAR. A number of the events in the following timeline will be referenced later in this report.

Table 1: Prado Dam Timeline

Timeline (Year)	Events
1936	Prado Dam Authorized by Flood Control Act of 1936: Elevation 507.5 was set as the safe water conservation elevation.
1937	
1938	Flood of 1938: Flow approx. 100,000 cfs through Santa Ana Canyon
1939	
1940	
1941	Prado Dam Completed: 6 gated outlets and 2 ungated outlets.
1942	
1943	
1944	
1945	
1946	First ungated outlet was gated for water conservation purposes with new water conservation elevation set at elevation 514.0 before the remaining gates would be opened for flood control releases.
1947	
1948	
1949	
1950	
1951	
1952	
1953	
1954	
1955	
1956	
1957	
1958	
1959	
1960	
1961	
1962	
1963	
1964	Santa Ana River Mainstem Project was initiated
1965	
1966	
1967	
1968	
1969	USACE revised the design flood criteria for Prado Dam: Debris pool Elevation set at 490, 1969 Flood revealed downstream channel deficiencies, 2nd ungated outlet was gated, Water con elevation was reduced to elevation 490.0, efforts made to limit release flows to 5,000 cfs
1970	
1971	
1972	
1973	
1974	
1975	USACE completed survey for the Santa Ana River Mainstem Project
1976	
1977	
1978	USACE submitted the survey for the Santa Ana River Mainstem Project to Congress
1979	
1980	USACE completed the Phase I Mainstem General Design Memorandum
1981	
1982	
1983	
1984	
1985	
1986	Santa Ana River Mainstem Project construction was authorized
1987	
1988	
1989	Santa Ana River Mainstem Project construction started
1990	USACE reduced targeted maximum release rates to 2,500 cfs, Water conservation elevation set to 494.0 feet during "favorable hydrological and reservoir conditions". Above 494 releases are determined by runoff and weather forecasts.
1991	USACE and OCWD start to formalize water conservation Memorandums of Agreement (MOA)
1992	
1993	MOA Signed: Flood season (elevation 494) and non-flood season (elevation 505) with release rate conditions.
1994	
1995	
1996	USACE prepared a Water Conservation Reconnaissance Report recommending feasibility study to increase water conservation.
1997	
1998	
1999	
2000	
2001	
2002	
2003	
2004	
2005	2005 Storm delivered flood flows, debris and sediment that turned the SAR in the Basin into OCWD Wetlands. Feasibility Study recommended flood season water conservation elevation be increased to 498.0 feet and keep non-flood season elevation at 505.0 feet.
2006	
2007	
2008	
2009	
2010	2010 Storm delivered flood flows, debris and sediment that turned the SAR into OCWD wetlands. Flow > 38,000 cfs, and 50+ acres of debris.
2011	
2012	Prado Basin Feasibility Study Started: Focus on ecosystem restoration, increased water con to 505 year-round and sediment management.
2013	
2014	
2015	

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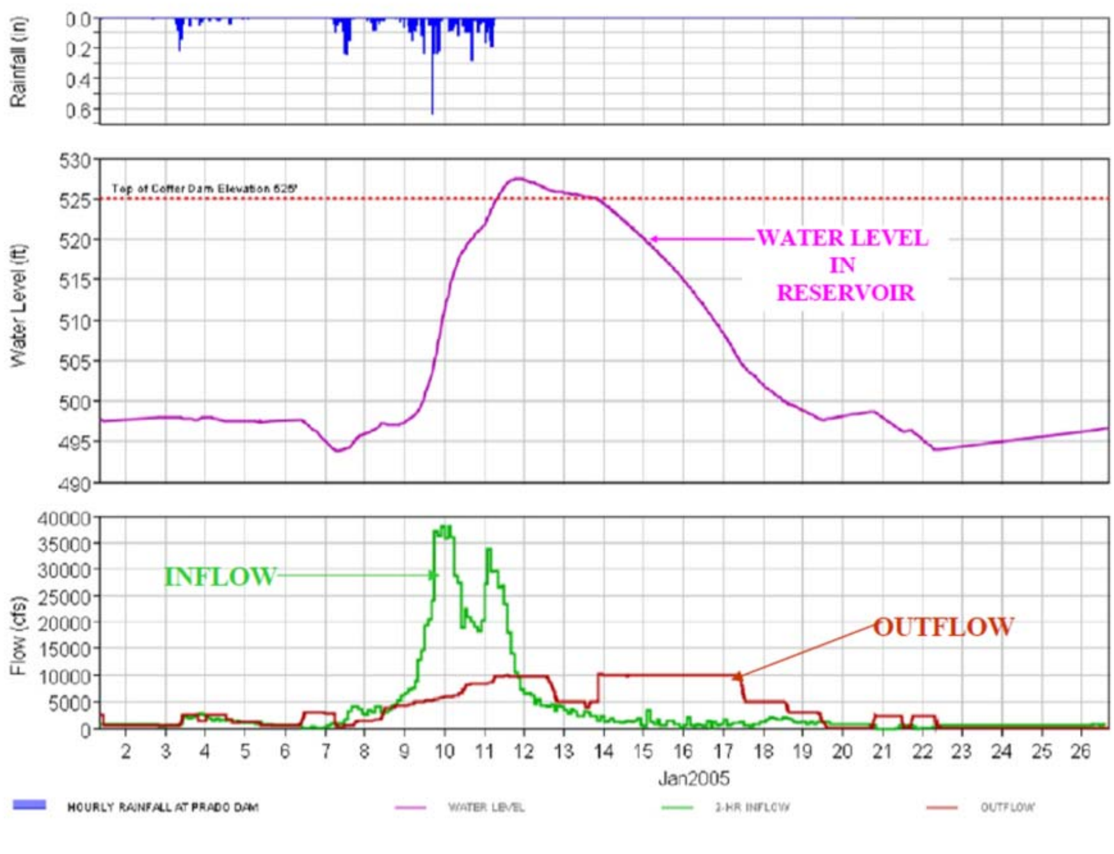
Nearly all of the sediment that enters the Basin will be deposited in the Basin regardless of water conservation WSEs. The sediment removal efficiency of the Basin has been estimated to be greater than 95% (Warrick and Rubin 2007, Brownlie and Taylor 1981).

One of the variables that affects the sediment deposition along the upstream SAR within the first 13,000 feet (2.5 miles) of the Dam is the WSE during significant storm events. High flow events transport the majority of the sediment into the Basin. In 2007 the USGS reported that it was estimated that over 90% of fine grain (silt and clay) sediment is transported in less than 1% (4 days or less) of each year in southern California coastal watersheds, including the SAR watershed (USGS 2007 Report). High WSE's in the Basin coincide with the most significant storm events in any given year. A well-documented storm event in January of 2005 highlights this phenomena. The January 2005 storm resulted in seepage through a portion of Prado Dam under construction and also resulted in large debris flows and sediment deposition in the SAR adjacent to the OCWD wetlands. A section of the SAR 75 feet wide by 4,080 feet long was plugged with Arundo up to 20 feet deep (OCWD Report to Board of Directors in 2006). This event caused massive sediment deposition in the SAR, and the SAR turned and flowed into the OCWD wetlands. The WSE prior to the storm event was approximately 497 ft NGVD29 (Figure 1).

Figure 1: January 2005 Prado Data



Source: U.S. Army Corps of Engineers; Design, Construction and Seepage at Prado Dam Presentation, 2005; USACE.

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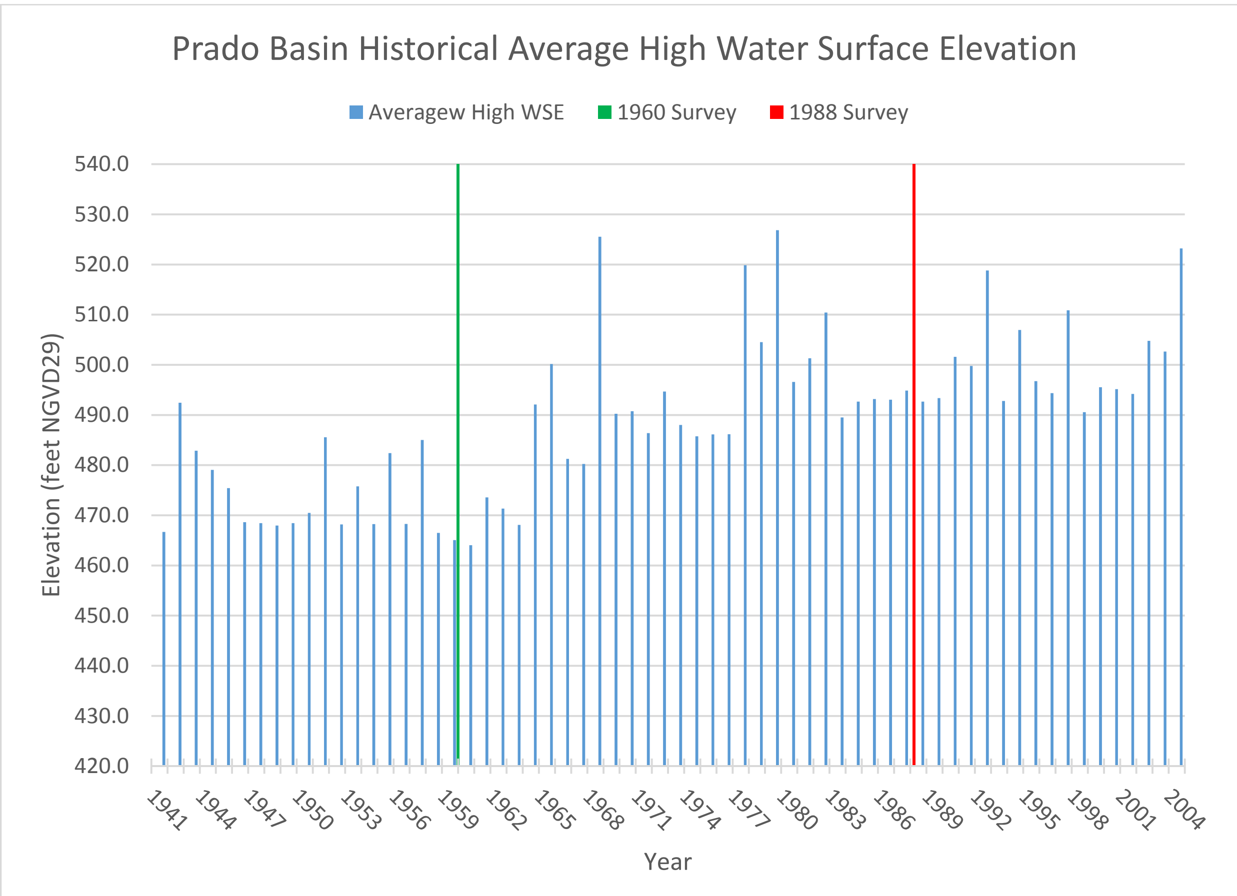
An analysis was performed to compare the trends in the annual average high WSE in the Basin from 1941 to 2005. The 5 days (corresponding with the 1% highest inflow events) with the highest WSE of each year were averaged for that year to determine long term WSE trends (Figure 2). When comparing this data to the timeline in Table 1 the most significant change occurs in 1969. This year coincides with the gating of the last uncontrolled Dam outlet and the start of operations of the Debris Pool at elevation 490 ft NGVD29. An additional factor that has contributed to an increase in the Basin WSE was the historical increase in peak flows due to the addition of impervious surfaces resulting from urbanization in the upper watershed.

Figure 2: Prado Basin Historical High WSE



Data Source: U.S. Army Corps of Engineers; Online Resource Link No Longer Active, Daily Values for WY 1941-1990, 2005; USACE.

Upper Watershed Considerations

A wide variety of variables affect the habitat types along the Dam to Hamner Reach of the SAR. It is important to note that changes in the upper SAR watershed affect how the habitat types in the Dam to Hamner Reach will change over time. Below is a listing and

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brief discussion of several variables that have affected, and will continue to affect, the habitat changes in the Dam to Hamner Reach of the SAR. These conditions have not been fully evaluated in this report but are listed here to help provide a comprehensive view of variables affecting habitat alterations.

1) Prado Inflow – Prado Dam is situated below 2,255 square miles of the SAR watershed. The construction of upstream dams, debris basins, flood control basins and groundwater recharge facilities attenuate, flows in the Dam to Hamner Reach of the SAR (1967 USACE Sediment Report).
   a. Seven Oaks Dam – Controls flow from 177 square miles
   b. San Antonio Reservoir – Controls flow from 27 square miles
   c. Big Bear Lake – Controls flow from 38 square miles
   d. Lake Elsinore – Controls flow from 792 square miles
   e. Small Basins (estimated) – Controls flow from an estimated approximately 500 square miles (235 square miles in 1967).
   f. Prado Dam – Controls unregulated flow from approximately 721 square miles.

   A recent study performed by Wildermuth Environmental, Inc predicts that future storm flows into the Basin will increase slightly (by as much as 7,969 af/year) due to future land development in the upper watershed, but that total future inflow to the Basin will be reduced by as much 19% (41,356 af/year) due to recycled water re-use (Wildermuth Environmental 2013). The reduction in total inflow will reduce the SAR's ability to transport sediment into the Dam to Hamner Reach.

2) Sediment Transport Interruption – The development of upstream dams, debris basins, flood control basins and groundwater recharge facilities (as described above) remove nearly 100% of all very coarse riverbed material (gravel and cobbles). Depending upon the upstream channel and basin configurations a portion of the sands, silts and clays may make it into the Dam to Hamner Reach. The impervious ground surface area in the unregulated 721 square mile Prado Basin catchment area, as well as the rip-rap and concrete lined flood control channels and river side slopes, eliminate sources of gravel and cobble which would otherwise be available for transport into the Dam to Hamner Reach of the SAR. The reduction of available gravel and cobble for transport downstream will continue to shift the gradation of the riverbed towards predominately sand in the Dam to Hamner Reach of the SAR.

   Over time as the unregulated areas and existing river bed/bank sands are transported downstream and depleted, there may be a trend reversal, and the Dam to Hamner Reach may start to coarsen. To-date, no detailed analysis has been performed in an attempt to quantify this, but basic sediment transport principles tell us that as the incoming sand, silt and clay sediment load decreases the riverbed will begin to coarsen. Due to the uncertainty of this potential future condition, and the likely lengthy time period it would take for this condition to develop, it should

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not be relied upon as a means to mitigate current sediment transport issues in the upper watershed. Additional analysis would be required to fully address this issue.

3) Non-Native Aquatic and Vegetation Species – The introduction and spread of non-native species in the upper watershed results in altered habitat types in those areas as well as in the Dam to Hamner Reach.
    a. Non-Native Vegetation – The growth of non-native vegetation in the riverbed and along the river banks has the ability to restrict the transport of all sediment types into, and through, the Dam to Hamner Reach. High flows which are capable of removing some of the vegetation create large debris flows that can create jams at various locations along the SAR, thereby forcing excessive deposition of sand, silt and clay in the riverbed and surrounding flood plains. Debris jams and excessive sediment deposition in Prado Basin have destroyed the OCWD wetlands in the recent past. Debris jams were also partially the cause of excessive sediment deposition upstream of the previous River Road Bridge.
    b. Non-Native Aquatic Species – As the upstream SAR slope flattens, peak flows decrease and sand, silt and clay become the dominate riverbed material, backwater and marsh habitats can expand. Areas of standing pools of water within backwatered floodplains along the Dam to Hamner Reach will expand under the current sediment transport and hydrological conditions. This habitat type encourages non-native predatory fish to flourish and negatively impact native fish populations.

Sediment Transport

The primary downstream boundary condition that controls sediment transport in the Dam to Hamner Reach of the SAR is the WSE in the Basin during storm events. The current slope in the Dam to Hamner Reach of the SAR is primarily controlled by the Debris Pool elevation (elevation 490 ft NGVD29), and the WSE during high intensity storm events (up to elevation 527 ft NGVD29). Water conservation elevations of 498.0 and 505.0 ft NGVD29 have a small effect on the overall long term deposition in the Basin and SAR. In 2008, the available volume between elevations 498.0 and 505.0 ft NGVD29 was approximately 10,500 acre-feet (af). An average inflow of 5,300 cfs fills this volume in approximately 24 hours. The presence of a Debris Pool, irrespective of water conservation, results in nearly all sand size particles (and larger particles) to deposit within the Basin.

It is important to note that a fundamental water conservation operational objective is to drain the water conservation pool as quickly as possible in order to make storage volume available for subsequent storm flows. Storm conditions do occur that fill the water conservation pools back-to-back; these storm events also produce flows that exceed the water conservation operating rules, and produce WSE's much higher than the 498.0 or 505.0 ft NGVD29 levels. These types of storms result in sediment deposition at much higher elevations in the Basin.

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When evaluating the slope of the Dam to Hamner Reach (channel slope is a main factor in sediment transport) the Debris Pool elevation was used as the controlling elevation after 1969. The original SAR streambed elevation in 1938 (at the location of the Dam prior to the construction of the Dam) was approximately 460.0 ft NGVD29. In 1941, the river slope in the vicinity of the Dam upstream to the Hamner Avenue crossing was fairly consistent at approximately 0.0030. The SAR streambed elevation in 2008, at the location of the Debris Pool 1,000 feet upstream from the Dam, was approximately 490.0 ft NGVD29. The overall river slope from the Debris pool upstream to the Hamner Avenue crossing in 2008 was approximately 0.0025. Historical SAR profiles (Figure 3) show us that the Dam to Hamner Reach of the SAR attempts to achieve a stable slope of approximately 0.003.

The overall 2008 SAR slope is somewhat misleading as there is a 10,000 linear foot section of the SAR between elevations 515 to 527 ft NGVD29 where the slope is much flatter than the overall average slope. Approximately 4,000 feet of the SAR in this area had a slope of 0.0004 as of 2008 (Figure 3). Based on debris removal operations, wetland reconstruction operations and SAR channel sediment removal following 2010 storm events, the extent of flattened slope had propagated further upstream. The next Basin survey will provide valuable insight as to the changes in the Basin since 2008.

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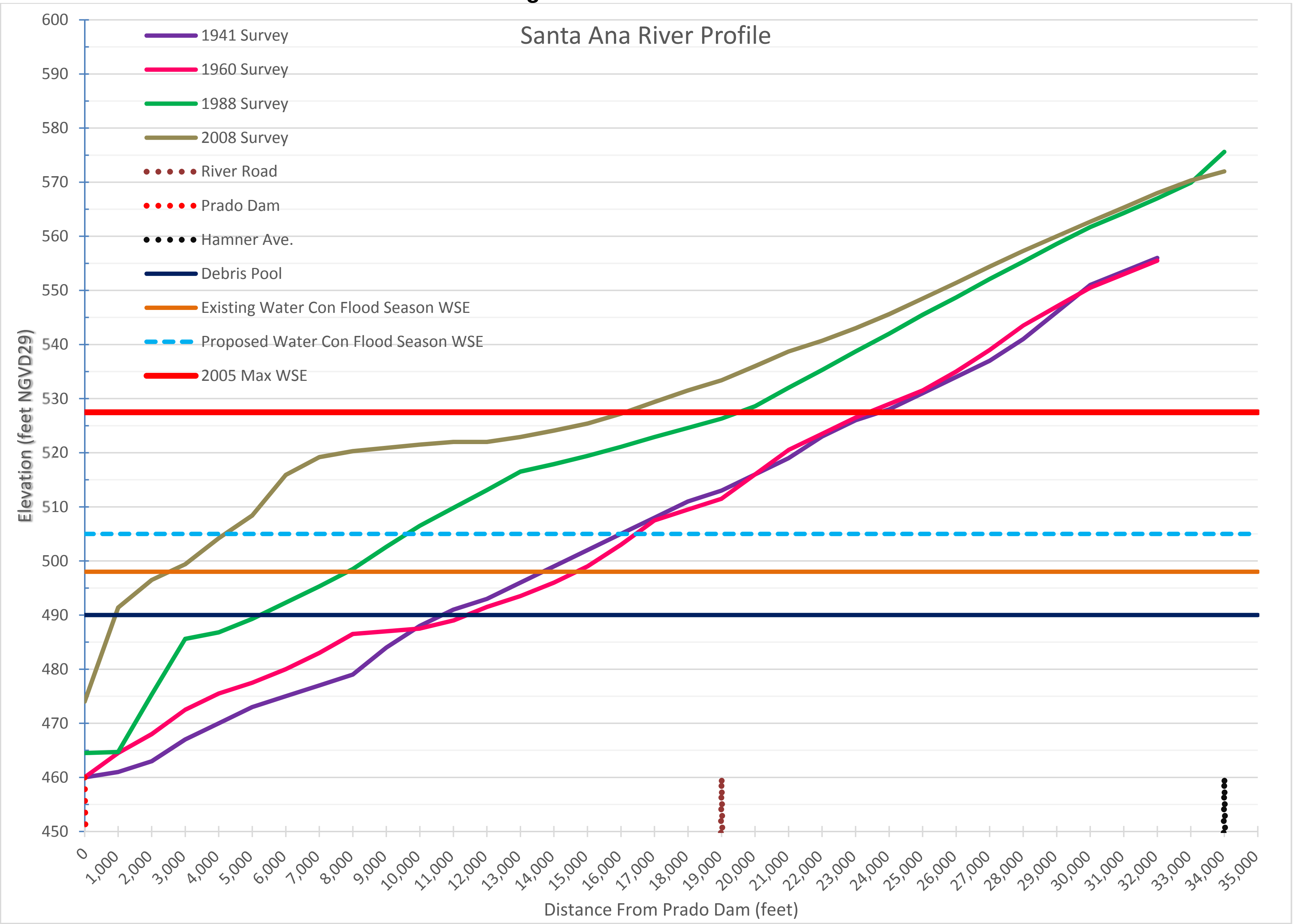
Figure 3: SAR Profiles



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As shown in Figure 3, the rate of aggradation between 1941 and 1960 was much less than after the 1960 survey. Recall that operation of a Debris Pool was established in 1969. The lower sedimentation rates prior to 1960 is likely due to the lower pool elevations during this time (Figure 2), and the operation of ungated outlets which allowed for higher rates of sediment transport through the Dam. Another factor that affected the overall deposition in the Basin during this time period was the generally dryer conditions in the watershed (SAR Watermaster Report, 2008) resulting in overall less run-off.

It can be argued that a much higher rate of sediment transport potential existed in the early years of Prado Dam. The potential was higher because the 1941 to 1960 period was during a time when available source material from the upper watershed would have been more plentiful due to fewer impervious surfaces, and many fewer debris and flood control basins would have existed than what is present today in the upper watershed.

In order to more completely assess the potential effect of increased water conservation a sediment transport model was developed to predict how the riverbed may react to increasing the downstream WSE by 7 feet during the flood season. Under the direction of the U.S. Army Corps of Engineers (USACE) and the Orange County Water District (OCWD), Wildermuth Environmental, Inc. (WEI) developed a 50-year daily inflow hydrograph for Prado Basin for the projected 2021 and 2071 conditions. The hydrograph is based on historical rainfall records, future land use conditions, expected flood control operations, projected recycled water discharges, and water conservation practices in the watershed tributary to the Prado Basin. A representative 10-year time period was selected from the 50-year daily inflow hydrograph (1975-1985) for detailed WSE analysis and detailed sediment transport modeling. A 10-year time period was determined to provide the most reliable model results at the best economy.

The projected Basin hydrograph was then used as input data to OCWD's groundwater recharge operations model. The operations model takes into account the downstream groundwater recharge capacities, operations and the optimal release rates from Prado Dam to maximize storm water capture and groundwater recharge. The OCWD operations model was then run under the existing condition (elevation 498.0 ft NGVD29 flood season storage level) and under the proposed future condition (elevation 505.0 ft NGVD29 flood season level). These modeling efforts provided an estimate of the maximum WSE elevation in the Basin, the duration of an increased WSE condition and the frequency of which these conditions may occur (Figure 4). Please note that the date range (x-axis) in the following figures relates to the dates of the historical data used to develop the future projections, the data presented in this report is for the projected future conditions.

The representative 10-year time period was selected as input to a HEC-RAS sediment transport model, in-part, to reduce the model run time to less than 1 week. For a complete discussion on the modeling assumptions, inputs and results please refer to the Golder Associates, Inc. technical memo, dated March 26, 2015; Prado Feasibility Study Project – Prado Water Level Analysis Sediment Transport Modeling Results.

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It should be noted that the storage and duration projections do not account for the incremental filling of the water conservation pool with sediment. Under current sedimentation rates nearly all storage volume below elevation 505 ft NGVD29 will be lost by 2071. As the Basin fills with sediment it will take much less time to drain the water conservation pool, and impacts from additional water conservation will decrease over time.

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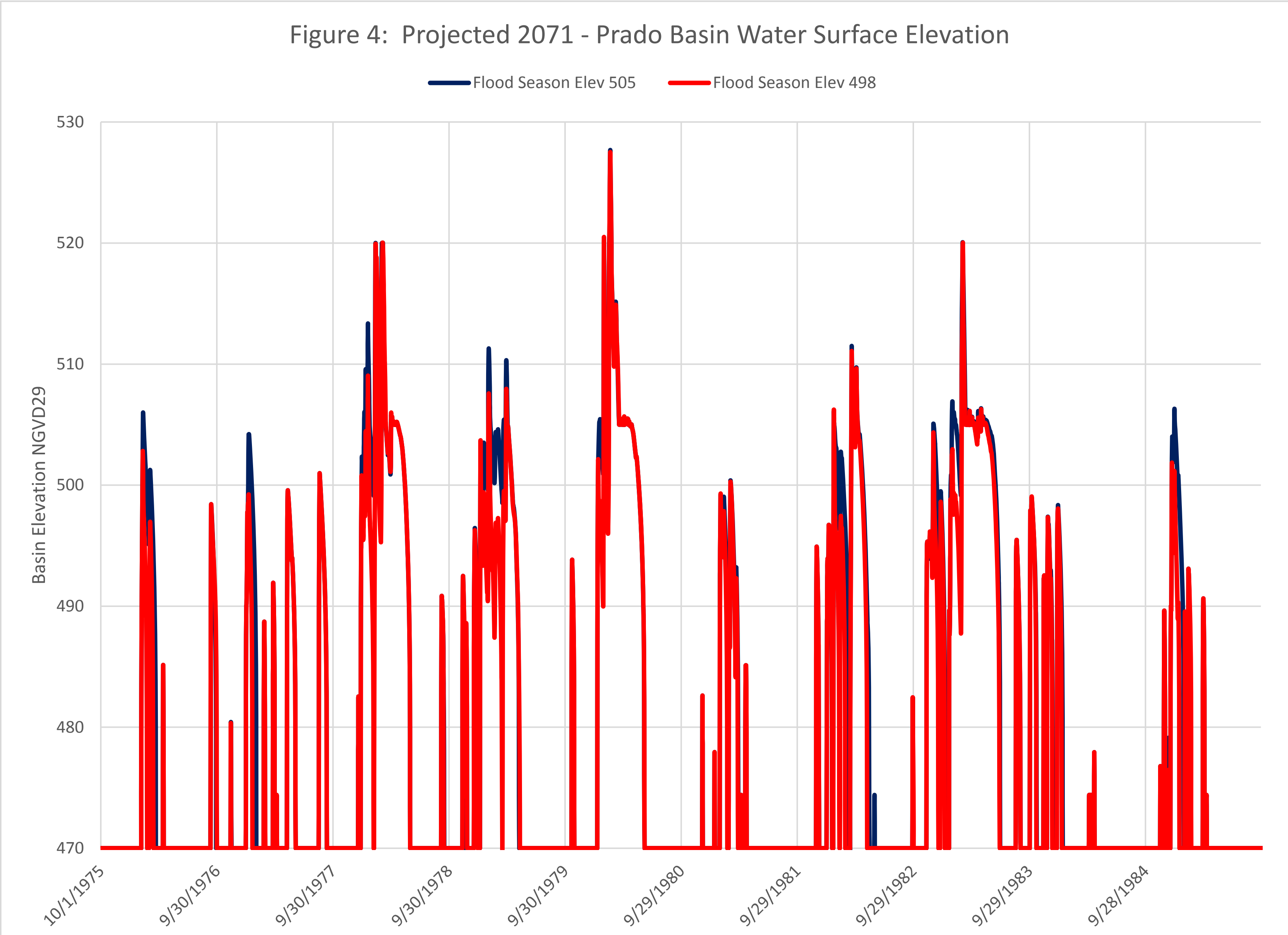

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The blue trend line in Figure 4 shows the anticipated, heightened, WSEs due to water conservation efforts resulting from the proposed flood season WSE increase. On average there is a 3 to 5 foot WSE increase once per year due the proposed deviation. This WSE data was then used as an input to a HEC-RAS sediment transport model to predict the impacts on the upstream SAR.

The results of the sediment transport model for the existing condition (flood season WSE of 498.0 ft NGVD29, Base 2) indicate that there will be a general trend of aggradation from above the I-15 Freeway crossing, extending downstream into Prado Basin. Aggradation over a 10 year time period is expected to range from 1 to 9 feet in depth. Based on the model results, the river bed around River Road Bridge is expected to experience the most aggradation which is consistent with what has been observed historically (Golder Associates, March 2015 Technical Memo).

The sediment transport model for the increased WSE scenario (flood season WSE of 505.0 ft NGVD29, Base 3) exhibits nearly identical aggradation trends as the existing conditions model. The only expected difference in the sedimentation trends between the two scenarios is a slight increase in deposition within Prado Basin between the 498 ft and 505 ft NGVD29 elevation contours. Based on historical topographic surveys there is approximately 1,000 linear feet between the 498 and 505 contours. If the flood season WSE is increased to elevation 505.0 ft NGVD29, then transient periods of increased aggradation may occur (between elevation 498.0 and 505.0 ft NGVD29) as high flow events coincide with periods of increased WSE. During periods where high flow events coincide with relatively low WSE, the aggradation trends will tend to revert back to historically observed conditions. A portion of the sediment deposited between elevations 498 and 505 ft NGVD29 will be transported below elevation 498 ft NGVD29 when high flow events coincide with relatively low WSE. As mentioned previously, it is important to note that once the water conservation pool is filled to the maximum WSE it is then drained as quickly as possible to create storage volume for subsequent storm flows. This mode of operation reduces the frequency of occurrence when the maximum water conservation WSE coincides with high flow events.

The sediment transport model results also show that there will be no appreciable change to the river bed gradation due to the increased WSE. The general trend for both scenarios is that there will be deposition of primarily fine to medium sand from above the I-15 Freeway crossing, extending downstream into Prado Basin. The overall quantity of sediment and sediment particle size distribution entering Prado Basin will be the same for both WSE scenarios. The alteration to the SAR morphology caused by the proposed flood season increase to the WSE will likely be limited to the spatial distribution of sediments between elevations 498 and 505 ft NGVD29 (Figure 5 and Figure 6).

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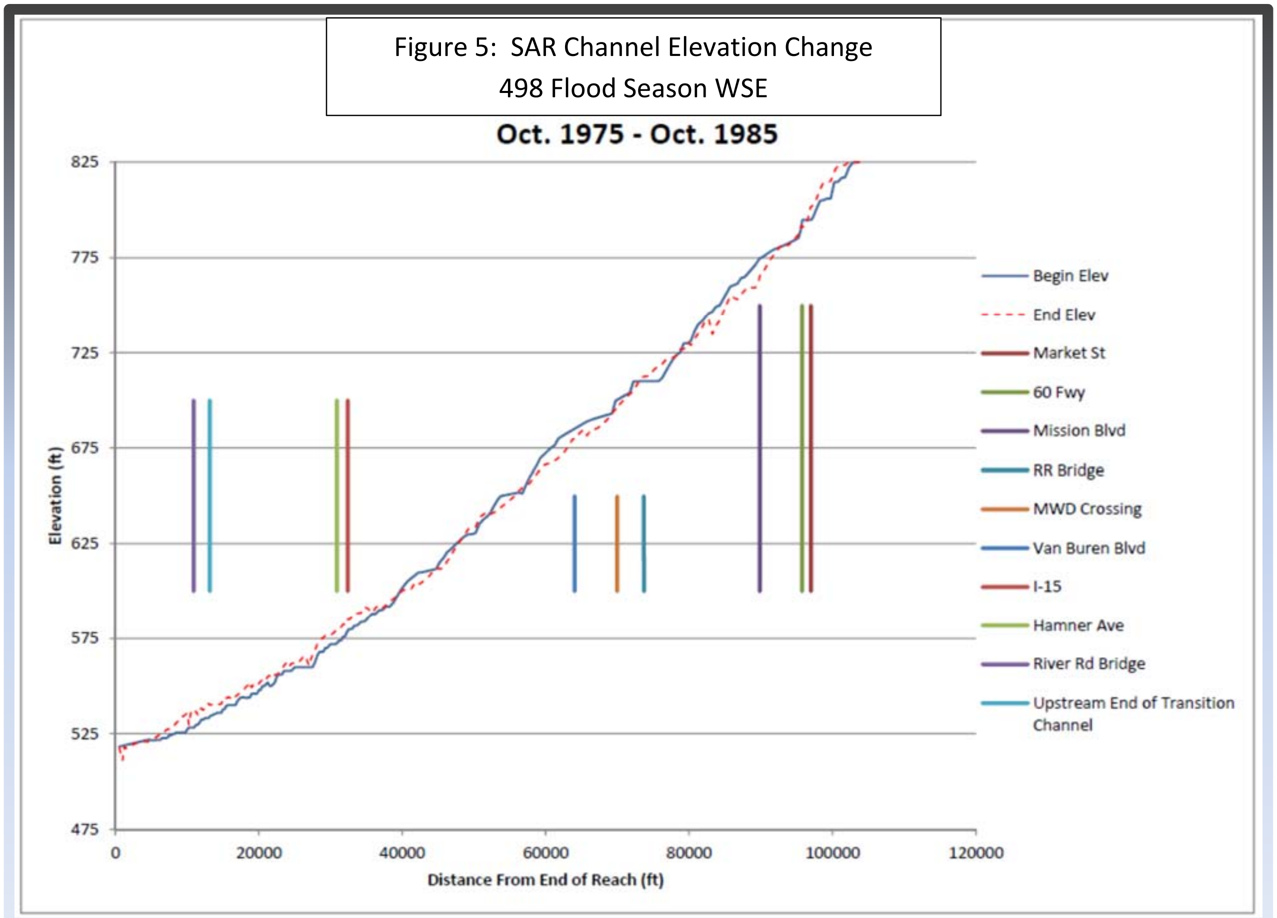
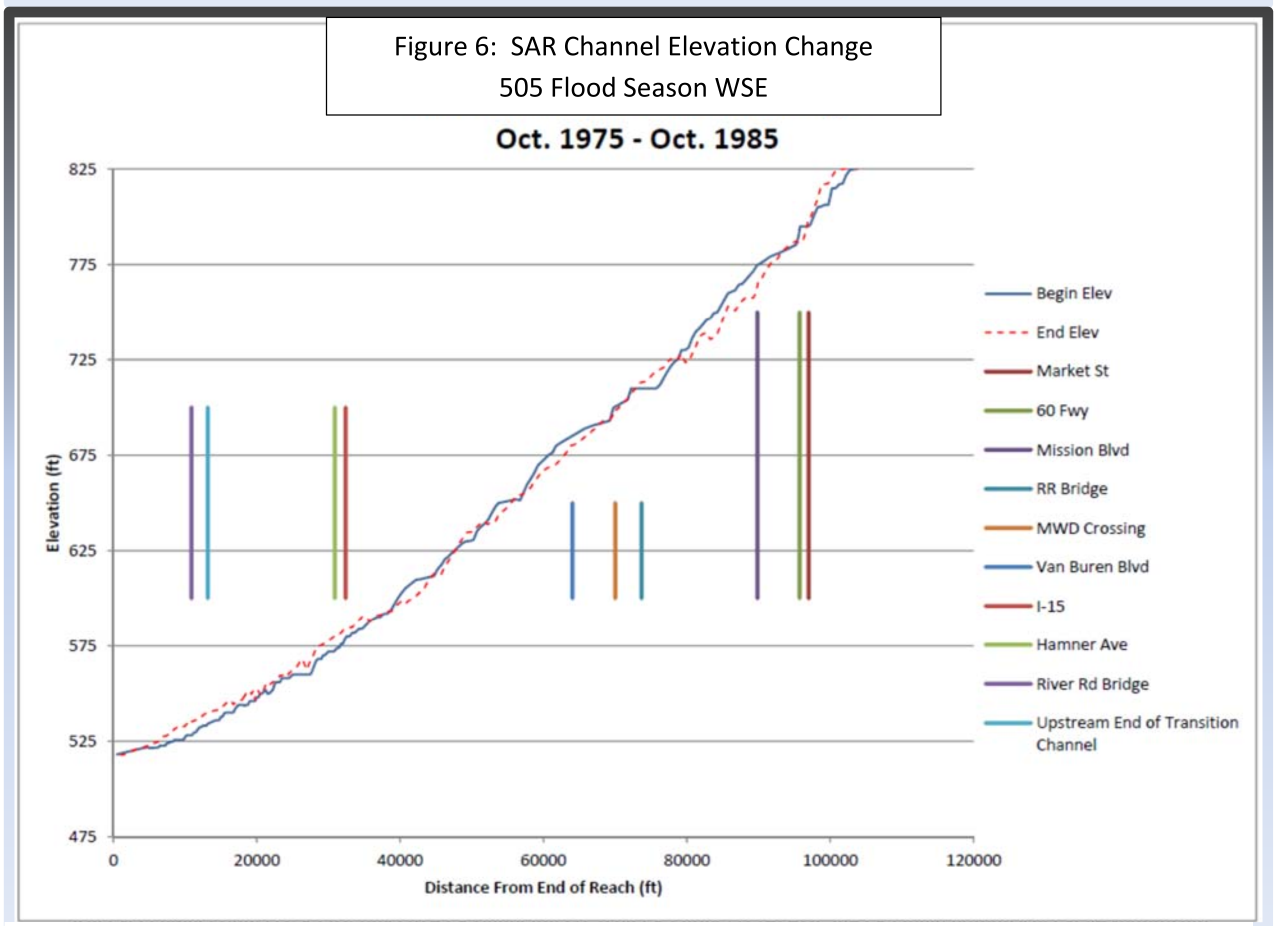


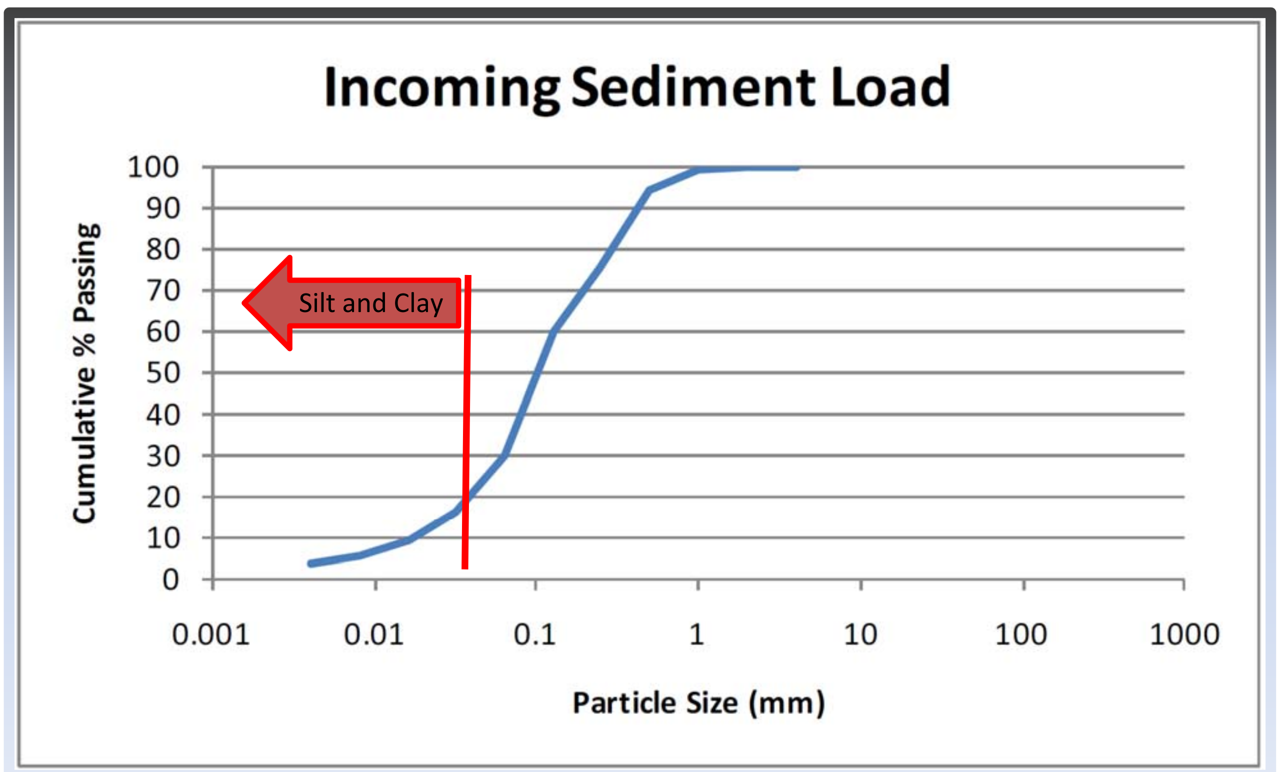


Source: Golder Associates Inc; Prado Feasibility Study Project – Prado Water Level Analysis Sediment Transport Modeling Results, March 26, 2015; Golder Associates Inc.

As discussed previously, nearly all of the sand that enters the Basin will be deposited in the Basin regardless of water conservation WSEs. The sediment removal efficiency of the Basin is estimated to be greater than 95% (Warrick and Rubin 2007, Brownlie and Taylor 1981). This means that the existing residence time of water in the Basin allows for nearly all of the sediment to settle out of the water column. Additional quantities of silt and clay will be deposited in the Basin due to the storage of the increased water volume (for the proposed planned deviation) held for longer durations.

Several soil borings have been performed in the Basin along the SAR to better understand the sediment gradations being introduced and deposited in the Basin. These borings revealed that, on average, approximately 20 percent of the sediment deposited in the Basin is silt and clay (Figure 7). The results of the Golder sediment transport model support this data as well, revealing that approximately 23% of the sediment transported past River Road Bridge is silt and clay.

Figure 7: Average Existing Sediment Gradation in Prado Basin



Source: Orange County Water District; Prado Basin Sediment Management Demonstration Project 100% Engineering Analysis Draft, November 2014; Appendix B HEC-RAS Sediment Transport Modeling Santa Ana River; Golder Associates Inc.

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The following assumptions were used to quantify the additional sedimentation in the Basin due to the proposed planned deviation.

1) All sand size particles would deposit in the Basin irrespective of the proposed 7 foot increase to the flood season WSE, leaving a portion of the silt and clay fraction of the incoming sediment for deposition as a potential impact from the proposed planned deviation.
2) The additional 10,500 af of water in the Basin is held for a duration that allows all of the silt and clay particles to settle out of the water column. (Conservative Assumption)
3) The TSS of the Prado storm water inflow is 2,000 mg/L. Historical data shows average Prado storm water inflow TSS to range between 500 to 2,000 mg/L. (Conservative Assumption)
4) Based on soil borings and based on results from sediment transport modeling, the silt and clay portion of the historical sedimentation in the Basin is 20%.
5) The silt and clay deposits across a 1,890 acre area, or the 2008 area of the 505 ft NGVD29 pool.

Calculation of fine grain (silt and clay) deposition volume due to planned deviation:

10,500 af = 12,951,600,000 L

2,000 mg/L = 0.00441 lbs/L

(12,951,600,000 L/af) x (0.00441 lbs/L) = 57,116,556 lbs/10,500 af
(57,116,556 lbs) / (120 lbs/feet^3) = 475,971 feet^3
(475,971 feet^3) / (27 feet^3/yard^3) = 17,629 yard^3

17,629 yard^3 x 20% silt & clay = 3,526 yard^3 silt & clay per 10,500 af water

17,629 yard^3 – 3,526 yard^3 silt & clay = 14,103 yard^3 sand per 10,500 af water

3,526 yard^3 silt & clay per 10,500 af water $\approx$ 3,500 yard^3 silt & clay per 10,500 af water

On average it is expected that the Basin WSE will reach, or exceed, 505 ft NGVD one time per year (Figure 3). Therefore a volume of 10,500 af has been used as the additional water impounded due to the planned deviaion. The existing sediment removal efficiency of the Basin already removes a portion of the silt and clay that is being attributed to the planned deviation, but in order to be conservative it has been assumed that the entire volume of silt and clay in the10,500 af is deposited due to the planned deviation.

The above set of assumptions result in an additional 3,500 cubic yards of deposition of fine grain (silt and clay) sediments annually in Prado Basin due to the proposed planned deviation (Table 2). The fine grain (silt and clay) sediments disperse over large areas in the Basin due to their ability to stay suspended more easily than coarse (sand) and very

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coarse sediment (gravel and cobbles). The approximate surface area of the Basin below the 505 ft NGVD29 Basin contour is 1,890 acres (2008 Survey).

Table 2: Annual Prado Basin Sedimentation

Scenario	Flood Season Water Conservation WSE (ft NGVD29)	Total Annual Basin Sedimentation (yards^3/year)	Additional Annual Basin Sedimentation (yards^3/year)	Percent Change in Annual Sedimentation (%)
Existing Condition	498.0	1,200,000	0	0
Planned Deviation	505.0	1,203,500	3,500	0.30
Alternative*	503.9	1,202,900	2,900	0.24

*See page 27 for analysis.

Silt and clay remain suspended relatively easily in flowing water, especially in the high intensity storm flows considered in this analysis. Due to turbulence in the Basin created by wind action and tributary inflow it has been assumed that suspended fine sediments will be distributed somewhat evenly over the pool area in the Basin. If the silt and clay is distributed somewhat evenly across the 1,890 acres, then there would be an average of 0.001 feet per year of deposition. Over 50 years this would equate to 0.05 feet of additional sedimentation. Under existing conditions there is approximately 0.5 to 0.7 feet of sedimentation along the SAR in the Basin. After 50 years nearly all storage below elevation 505 ft NGVD29 would be filled with sediment and the proposed water conservation planned deviation will no longer be a factor in the operation of the Dam.

This calculation suggests that there is approximately 14,000 cubic yards of sand transported into the Basin with each 10,500 af of water. This is not the case as there is a very high volume of sediment transported into the Basin as bed load which is not captured in the above calculation. A fundamental assumption is that all suspended sand and all sediment transported into the Basin as bed load material is heavy enough to be deposited in the Basin regardless of any water conservation operations. Once bed load sediments enter a relatively tranquil body of water the bed load material deposits quickly and relatively close to the high energy stream system which delivered it. This sediment transport process is captured in Basin surveys taken in 1988 and 2008 (Figure 8). The areas of the greatest deposition in the Basin occur where the SAR encounters the 505.0 ft to 524.0 ft NGVD29 WSEs (Figure 8).

The historical annual average volume of sediment deposited in the basin is 1,200,000 cubic yards. The predicted additional sediment deposition in the Basin due to the planned deviation is negligible (3,500 cubic yard per year), representing a 0.3% increase in the annual sedimentation volume.

Topography and Mapping

The change in the SAR slope affects how easily the adjacent flood plain can drain into the low flow channel following a storm event. It is natural and healthy for a river to over-top its banks during a storm event and deposit sediments in the adjacent flood plain. Isolated areas of backwater and marsh habitat should be expected to develop as well under these conditions. The Dam to Hamner Reach of the SAR is no exception to this natural process, however, as the riverbed slope flattens, the backwater areas drain less quickly and completely, and areas of marsh habitat may expand beyond what is typically expected in an un-altered natural riverine system. Backwater pools (some deep at times) create habitat for non-native aquatic species that prey on native fish populations. Historical topographic maps and imagery have been examined to help determine the historical habitat types.

The U.S. Army Corps of Engineers (USACE) constructed Prado Dam 1941, and since that time an average of 770 acre feet per year (afy) (1,200,000 cubic yards (cu yds)) of sediment has deposited within Prado Basin annually (2008 USACE Basin Survey). The most recent Basin survey completed in 2008 revealed that a total of more than 50,000 acre feet (af) (80,600,000 cu yds) of sediment has been deposited in the Basin since 1941 (Table 3).

Surveys of the Basin conducted by the USACE in 1941, 1960, 1988 and 2008 have been used to predict the future sedimentation rates in the Basin (Table 3). The two most recent surveys (1988 and 2008) have been used to graphically demonstrate the topographic change in the Basin during that time period (Figure 8). Basin surveys were also conducted in 1969 and 1980 but GIS data from these two surveys have yet to be located for further analysis. The 1969 and 1980 storage capacity data is presented below in Table 2 along with the aforementioned survey years.

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Table 3: Prado Dam Historical Surveys

Prado Dam Storage Capacity											
Elevation	2008 Survey	1988 Survey	Storage Loss since 1988		Storage Loss since 1941		1980 Survey	1969 Survey	1960 Survey	1941 Survey	
	ac-ft	ac-ft	ac-ft	%	ac-ft	%	ac-ft	ac-ft	ac-ft	ac-ft	
470	0	7	7	100%	310	100%	8	5	58	310	
471	1	14	13	93%	404	100%	10	6	87	405	
472	5	22	17	77%	525	99%	14	9	128	530	
473	10	34	24	71%	670	99%	18	12	184	680	
474	17	48	31	65%	853	98%	25	18	259	870	
475	24	71	47	66%	1,096	98%	34	25	359	1,120	
476	31	103	72	70%	1,329	98%	46	36	500	1,360	
477	93	147	54	37%	1,587	94%	67	54	687	1,680	
478	121	208	87	42%	1,919	94%	103	99	931	2,040	
479	155	295	140	47%	2,305	94%	159	191	1,245	2,460	
480	196	414	218	53%	2,704	93%	239	305	1,645	2,900	
481	251	573	322	56%	3,349	93%	348	445	2,052	3,600	
482	330	779	449	58%	3,670	92%	488	659	2,540	4,000	
483	442	1,032	590	57%	3,958	90%	664	965	3,119	4,400	
484	581	1,333	752	56%	4,919	89%	883	1,311	3,802	5,500	
485	750	1,705	955	56%	5,750	88%	1,188	1,770	4,604	6,500	
486	954	2,155	1,201	56%	6,746	88%	1,627	2,303	5,435	7,700	
487	1,228	2,674	1,446	54%	6,972	85%	2,183	2,979	6,382	8,200	
488	1,569	3,268	1,699	52%	8,431	84%	2,843	3,753	7,458	10,000	
489	1,988	3,940	1,952	50%	8,512	81%	3,606	4,590	8,674	10,500	
490	2,500	4,688	2,188	47%	10,100	80%	4,474	5,471	10,045	12,600	Top of Debris Pool, Btm. of Buffer Pool
491	3,086	5,508	2,422	44%	10,714	78%	5,442	6,456	11,395	13,800	
492	3,753	6,404	2,651	41%	12,047	76%	6,507	7,565	12,881	15,800	
493	4,498	7,379	2,881	39%	13,502	75%	7,666	8,803	14,514	18,000	
494	5,310	8,435	3,125	37%	13,690	72%	8,915	10,144	16,303	19,000	Flood Season Top Buffer Pool
495	6,194	9,562	3,368	35%	14,806	71%	10,257	11,542	18,259	21,000	
496	7,149	10,758	3,609	34%	15,251	68%	11,693	12,972	20,146	22,400	
497	8,177	12,055	3,878	32%	16,423	67%	13,226	14,490	22,175	24,600	
498	9,278	13,460	4,182	31%	17,722	66%	14,857	16,130	24,353	27,000	Flood Season Water Con. Elev.
499	10,479	14,951	4,472	30%	19,021	64%	16,577	17,923	26,688	29,500	
500	11,760	16,522	4,762	29%	19,240	62%	18,376	19,856	29,187	31,000	
501	13,219	18,185	4,966	27%	20,781	61%	20,281	21,876	31,624	34,000	
502	14,722	19,944	5,222	26%	21,778	60%	22,323	24,061	34,206	36,500	
503	16,302	21,783	5,481	25%	22,898	58%	24,480	26,400	36,937	39,200	
504	18,016	23,712	5,696	24%	23,984	57%	26,732	28,849	39,823	42,000	
505	19,826	25,754	5,928	23%	25,174	56%	29,083	31,410	42,870	45,000	Non-Flood Season Water Con. Elev.
506	21,746	27,910	6,164	22%	26,054	55%	31,536	34,064	45,791	47,800	
507	23,762	30,185	6,423	21%	27,238	53%	34,088	36,808	48,849	51,000	
508	25,878	32,579	6,701	21%	28,122	52%	36,731	39,641	52,047	54,000	
509	28,111	35,084	6,973	20%	28,889	51%	39,466	42,572	55,389	57,000	
510	30,419	37,706	7,287	19%	30,181	50%	42,289	45,564	58,878	60,600	
511	32,818	40,442	7,624	19%	31,182	49%	45,218	48,683	62,229	64,000	
512	35,306	43,290	7,984	18%	32,694	48%	48,270	51,906	65,706	68,000	
513	37,897	46,253	8,356	18%	33,303	47%	51,434	55,194	69,311	71,200	
514	40,611	49,338	8,727	18%	34,389	46%	54,697	58,543	73,048	75,000	
515	43,445	52,534	9,089	17%	35,555	45%	58,067	62,004	76,918	79,000	
516	46,392	55,841	9,449	17%	35,908	44%	61,553	65,543	80,627	82,300	
517	49,505	59,247	9,742	16%	36,995	43%	65,149	69,147	84,451	86,500	
518	52,694	62,750	10,056	16%	37,306	41%	68,852	72,806	88,390	90,000	
519	55,984	66,375	10,391	16%	38,616	41%	72,653	76,514	92,446	94,600	
520	59,568	70,121	10,553	15%	39,432	40%	76,546	80,289	96,622	99,000	
521	63,100	73,966	10,866	15%	40,400	39%	80,535	84,187	100,779	103,500	
522	66,744	77,903	11,159	14%	41,256	38%	84,625	88,239	105,049	108,000	
523	70,516	81,941	11,425	14%	41,484	37%	88,812	92,380	109,432	112,000	
524	74,410	86,084	11,674	14%	42,590	36%	93,092	96,604	113,930	117,000	
525	78,394	90,334	11,940	13%	42,606	35%	97,470	100,905	118,544	121,000	
526	82,501	94,694	12,193	13%	43,699	35%	101,952	105,314	123,070	126,200	
527	86,769	99,162	12,393	12%	42,231	33%	106,534	109,850	127,701	129,000	
528	91,175	103,735	12,560	12%	44,825	33%	111,216	114,493	132,439	136,000	
529	95,722	108,440	12,718	12%	45,278	32%	116,000	119,221	137,285	141,000	
530	100,411	113,291	12,880	11%	45,589	31%	120,888	124,091	142,240	146,000	
531	105,307	118,271	12,964	11%	45,193	30%	125,898	129,107	147,347	150,500	
532	110,289	123,380	13,091	11%	45,711	29%	131,048	134,247	152,568	156,000	
533	115,396	128,607	13,211	10%	45,604	28%	136,330	139,502	157,902	161,000	
534	120,627	133,954	13,327	10%	46,373	28%	141,736	144,867	163,352	167,000	
535	125,976	139,432	13,456	10%	47,024	27%	147,270	150,362	168,917	173,000	
536	131,534	145,038	13,504	9%	46,466	26%	152,936	155,981	174,533	178,000	
537	137,252	150,757	13,505	9%	46,748	25%	158,732	161,706	180,264	184,000	
538	143,062	156,589	13,527	9%	46,938	25%	164,653	167,509	186,110	190,000	
539	149,037	162,549	13,512	8%	47,963	24%	170,698	173,386	192,071	197,000	
540	155,135	168,639	13,504	8%	47,865	24%	176,865	179,376	198,150	203,000	
541	161,458	174,856	13,398	8%	46,842	22%	183,157	185,501	204,364	208,300	
542	167,788	181,201	13,413	7%	48,212	22%	189,578	191,775	210,697	216,000	
543	174,312	187,681	13,369	7%	47,688	21%	196,135	198,222	217,150	222,000	Existing Spillway
544	180,935	194,304	13,369	7%	49,065	21%	202,838	204,820	223,725	230,000	
545	187,735	201,066	13,331	7%	48,265	20%	209,685	211,557	230,422	236,000	
546	194,632	207,968	13,336	6%	48,368	20%	216,678	218,430	237,299	243,000	
547	201,773	215,019	13,246	6%	48,227	19%	223,824	225,426	244,303	250,000	
548	208,981	222,225	13,244	6%	49,019	19%	231,132	232,548	251,435	258,000	
549	216,317	229,595	13,278	6%	49,683	19%	238,598	239,799	258,695	266,000	
550	223,808	237,139	13,331	6%	49,192	18%	246,215	247,176	266,084	273,000	
551	231,480	244,824	13,344	5%	50,520	18%	253,994	254,685	273,542	282,000	
552	239,593	252,656	13,063	5%	50,407	17%	261,946	262,312	281,129	290,000	
553	247,619	260,663	13,044	5%	50,381	17%	270,065	270,037	288,845	298,000	
554	255,744	268,836	13,092	5%	51,256	17%	278,345	277,875	296,691	307,000	
555	264,085	277,196	13,111	5%	48,915	16%	286,810	285,824		313,000	
556	272,513	285,757	13,244	5%	51,487	16%	295,481			324,000	
557	281,164	294,527	13,363	5%	50,836	15%	304,349			332,000	
558	290,025	303,506	13,481	4%	50,975	15%	313,409			341,000	
559	300,555	312,693	12,138	4%	49,445	14%	322,665			350,000	
560	309,784	322,080	12,296	4%	49,216	14%	332,120			359,000	
561	319,214	331,710	12,496	4%	49,786	13%	341,785			369,000	
562	328,855	341,603	12,748	4%	50,145	13%	351,670			379,000	
563	338,676	351,735	13,059	4%	50,324	13%	361,795			389,000	Future Spillway
			avg per year 1988-2008 =	622	avg per year 1941-1988=	776					
594.4											Top of Dam

Data Source: U.S. Army Corps of Engineers; 2008 Survey Data Spread Sheet, Prado Dam Storage Capacity Spread Sheet Disturbed via Email, 2009; USACE, Annotations added by Scheevel Engineering, LLC 2014.

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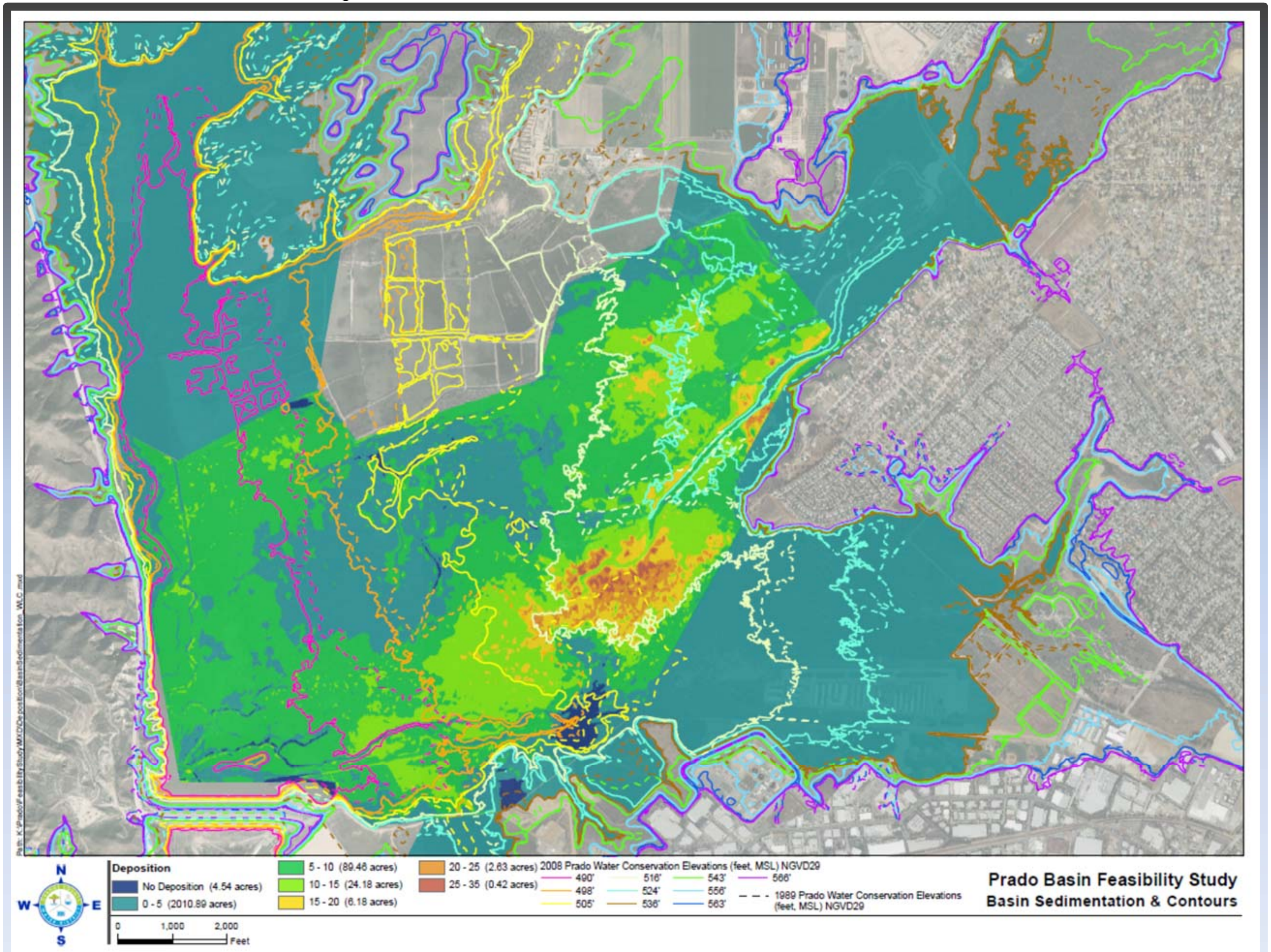
Figure 8: Basin Contours & Sedimentation 1988 - 2008



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Sedimentation is expected to continue at a rate equal to, or slightly less than, those experienced between 1988 and 2008. The potential for reduced sedimentation may result from;

1) Less total Basin inflow due to upstream water conservation and recycled water re-use,
2) Lower than historical peak inflows due to upstream storm water capture and recharge,
3) Lower sediment inflow due to urbanization in the upper watershed; and
4) Lower sediment load in the Santa Ana River due to;
    a. Seven Oaks Dam – Controls flow from 177 square miles
    b. San Antonio Reservoir – Controls flow from 27 square miles
    c. Big Bear Lake – Controls flow from 38 square miles
    d. Lake Elsinore – Controls flow from 792 square miles
    e. Small Basins (estimated) – Controls flow from approximately 500 square miles (235 square miles in 1967).

Historical aerial imagery was used to evaluate the historical habitat types along the Dam to Hamner Reach of the SAR. Historical imagery from 1929 (Figure 9) through 1967 (Figure 13) indicates that the Dam to Hamner Reach of the SAR riverbed has always been composed of a large percentage of sand. The resolution of the imagery does not adequately display the likely present gravel and cobble beds, but based on the gradation of sediment in the upper watershed, and the ability of the watershed to produce high flow events, it is very likely that transient areas of gravel and cobble beds were historically present in the Dam to Hamner Reach of the Santa Ana River.

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Figure 9: 1929 Prado Dam Area Aerial Imagery

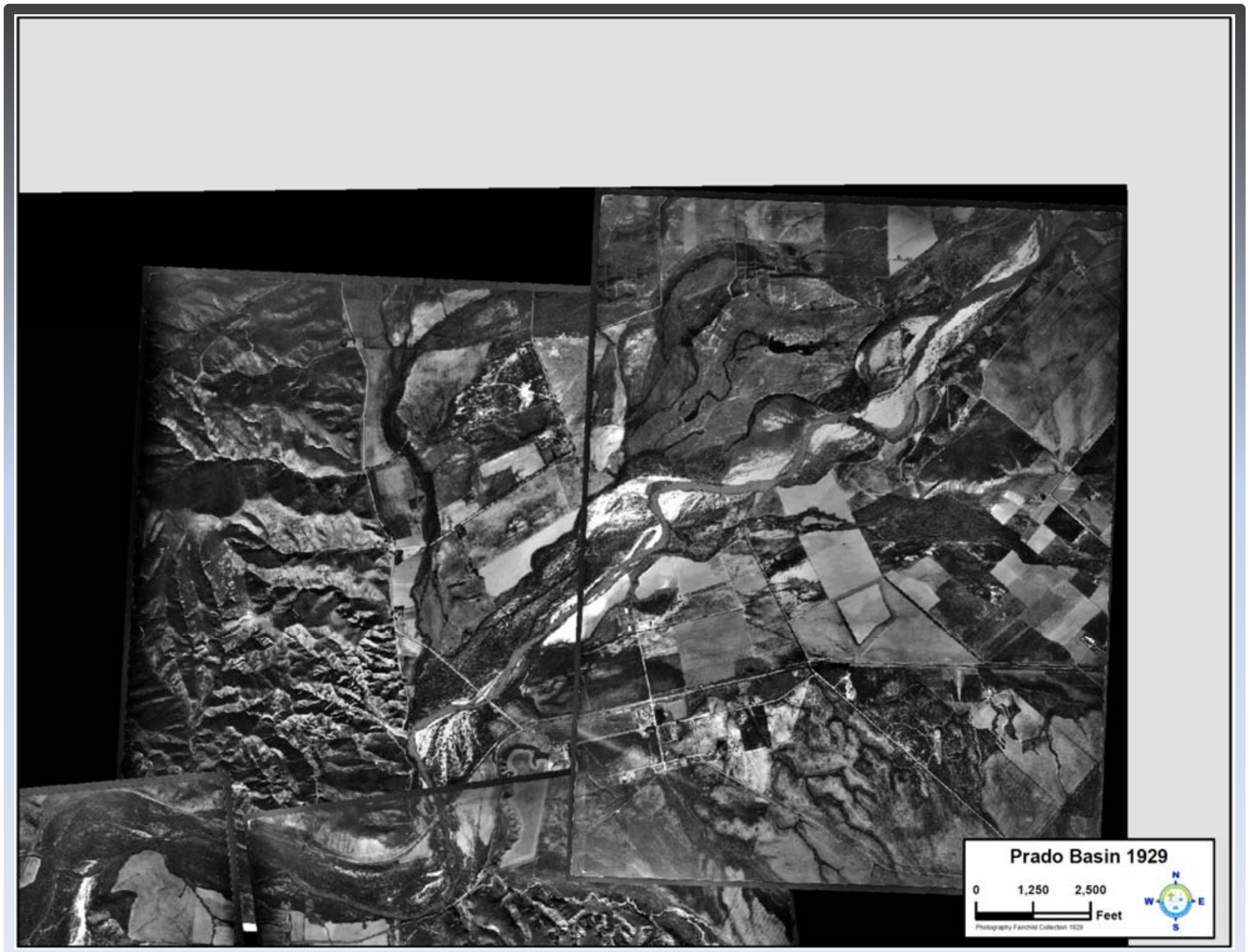

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Figure 10: 1938 Prado Dam Area Aerial Imagery

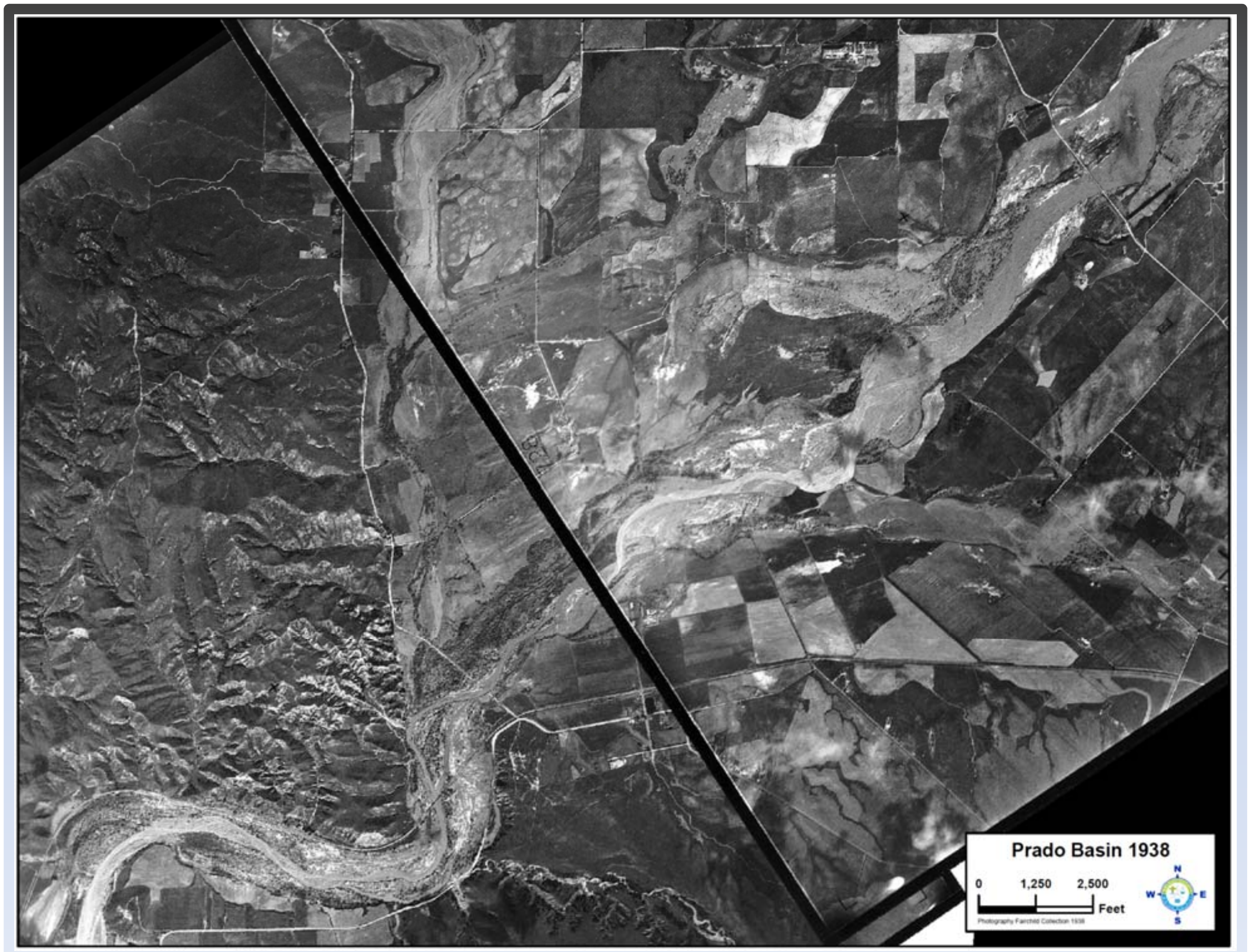

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Figure 11: 1947 Prado Dam Area Aerial Imagery

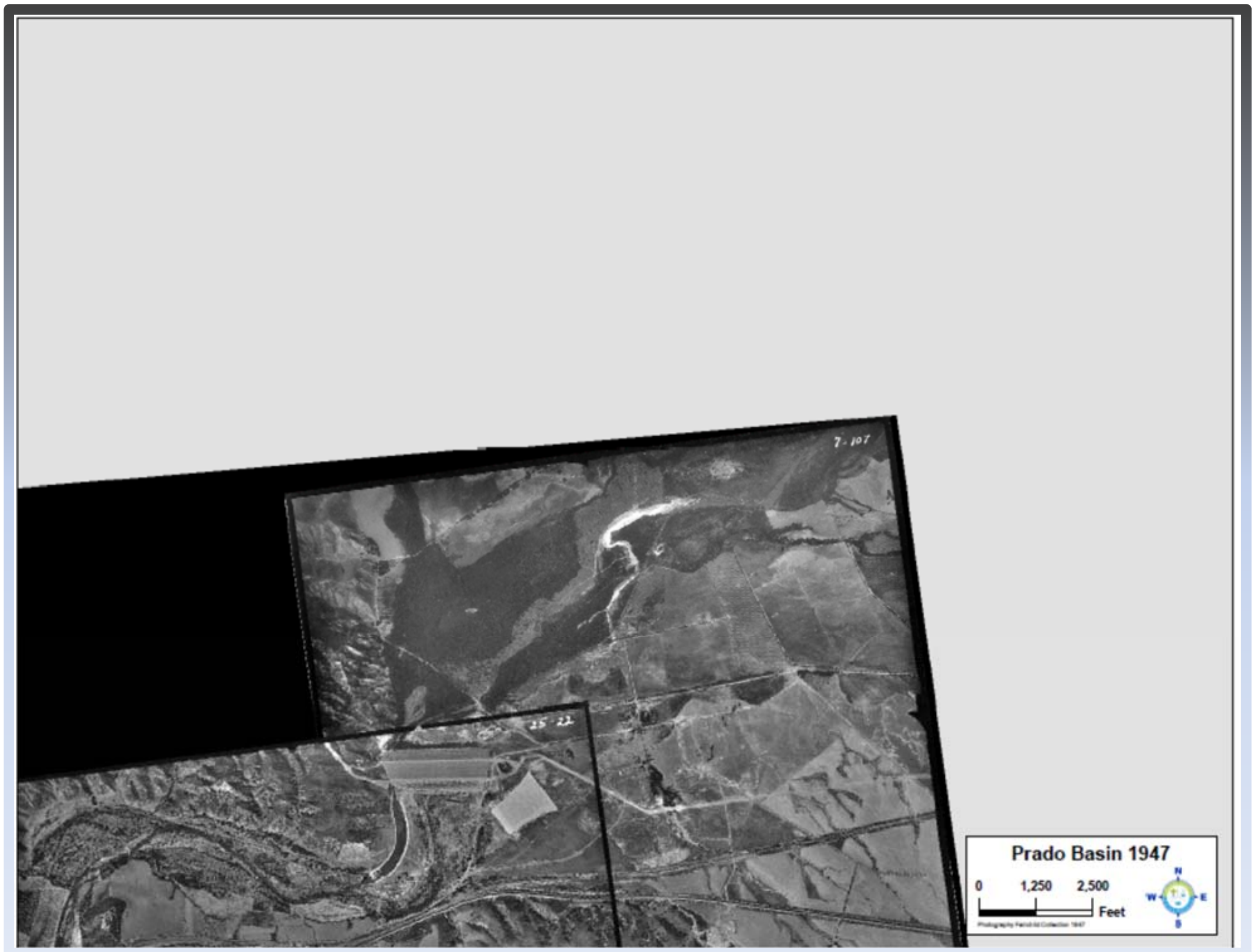

Figure 12: 1950's Prado Dam Area Aerial Imagery

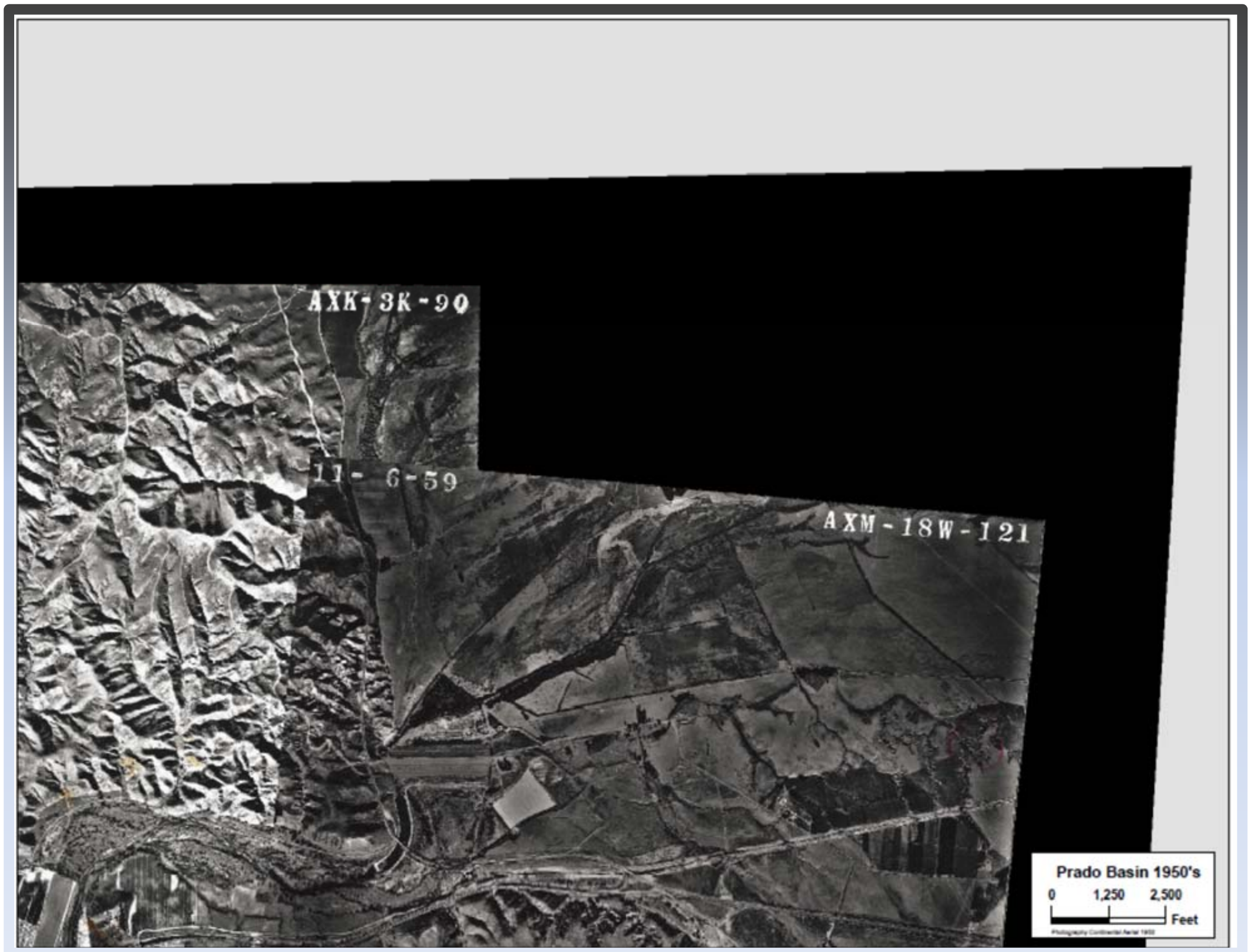

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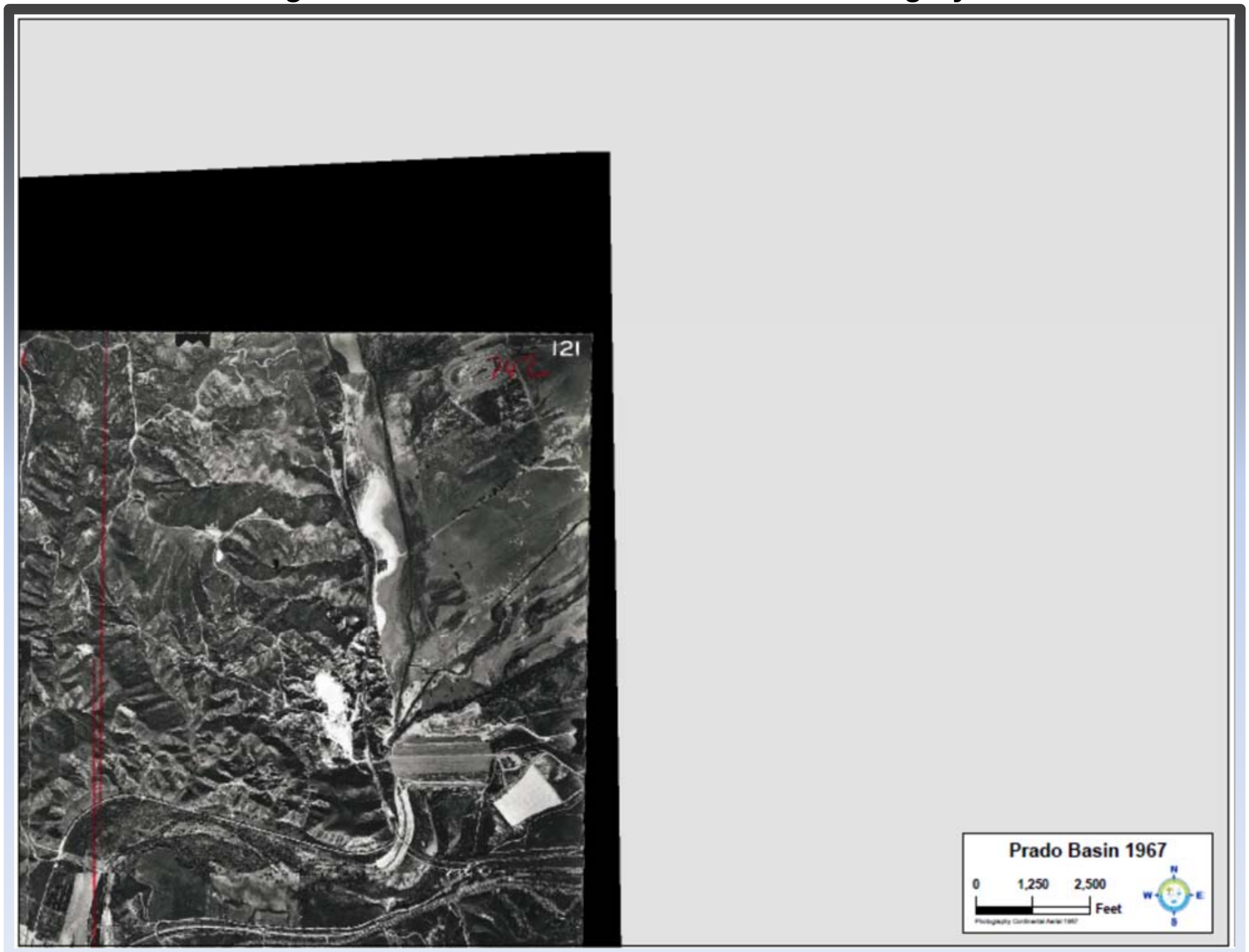
Figure 13: 1967 Prado Dam Area Aerial Imagery



The analysis presented earlier in this report predicts that the planned deviation will have no measurable effect on the SAR habitat types upstream of River Road Bridge and only negligible impacts to the rate of sedimentation in the Basin below elevation 505. Historical data, fundamental sediment transport principles, future water surface elevation predictions and the sediment transport model show that the vast majority of deposition in the Basin will occur irrespective of the planned deviation. Furthermore, the additional sedimentation due to the planned deviation (3,500 cubic yards or a 0.30% increase) is negligible when compared to the overall deposition already occurring (1,200,000 cubic yards annually). The average depth of new sedimentation will be approximately 0.001 feet per year which is expected to have no impact on native riparian habitat below elevation 505 ft NGVD29. The primary grain size of the additional sedimentation will be fine grain (silt and clay), which will disperse over large areas, thereby causing no measurable increase to backwater or marsh habitat along the SAR or in areas where native fish habitat is likely to exist.

Alternative Water Conservation Elevation

An alternative to the proposed flood season water conservation elevation of 505.0 ft NGVD29 would be to increase the elevation to a level between 498.0 ft and 505.0 ft NGVD29. For comparison purposes a flood season water conservation elevation of 503.9 ft NGVD29 has been evaluated.

The same discussion and analysis will apply to the 503.9 ft NGVD29 elevation as was used previously in this report for the 505.0 ft NGVD29 evaluation. The results of the alternative analyzed is summarized below;

1) The flood season water conservation WSE would be 503.9 ft NGVD29
2) The volume of additional captured water would be 8,700 af per year;
3) The additional sediment deposited in the Basin due to the 8,700 af per year of water would be approximately 2,900 cubic yards of sediment (primarily silt and clay);
4) The approximate area of the Basin below elevation 503.9 ft NGVD29 as of 2008 was 1,787 acres;
5) The additional annual average depth of sediment deposition over the 1,787 acres will be approximately 0.001 feet;
6) The 2,900 cubic yards of additional sedimentation represents an increase of 0.24% over the current condition; and
7) The additional deposition over fifty years is expected to be approximately 0.05 feet.

The above alternative will have the same negligible impacts on the SAR channel slope and surrounding habitat as was described for the planned deviation elevation of 505.0 ft NGVD29.

Conclusions

The existing sedimentation rate in the Basin is approximately 1,200,000 cubic yards per year. The estimated additional sediment deposition in the Basin due to the planned deviation is approximately 3,500 cubic yards per year. A volume of 3,500 cubic yards equates to an additional 0.001 feet of sedimentation annually in areas below elevation 505.0 ft NGVD29 (Basin wide) if the planned deviation is implemented. Historically there has been between 0.50 to 0.70 feet of deposition per year (due to TSS and bed load) since 1960 along the SAR in the Basin. The planned deviation represents an annual increase of 0.3 percent in total sediment deposition over the next 50 years, after which time the majority of the storage volume below elevation 505.0 ft NGVD29 will be filled with sediment (due to existing sedimentation conditions) and the proposed planned deviation will no longer be relevant.

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The potential impact to habitat along the SAR is limited to a 4,000 foot long stretch of the SAR below elevation 505.0 ft NGVD29. There is currently no clearly defined river channel or native fish habitat at this location in the Basin. This area is primarily braided streams with riparian habitat consisting of cottonwood trees with native understory and some non-native vegetation. The relatively small amount of additional fine grain (silt and clay) sedimentation from the planned deviation will have little or no effect on the current habitat type in this area as the increased rate of aggradation is approximately 0.001 feet per year. This rate of aggradation is considered negligible as the baseline sedimentation rate in this area ranges between 0.5 and 0.7 feet per year.

Sedimentation between elevations 498.0 ft and 505.0 ft NGVD29 will be transient as storm events occur at times when the WSE is higher or lower than the planned deviation. Sediments get deposited at higher elevations in the Basin during periods when high inflow coincide with a high WSE (this typically occurs when there is a storm that lasts several days or longer, or when significant storms occur back-to-back). As subsequent storms occur during periods when the WSE is much lower, portions of the sediment previously deposited high in the Basin will be transport to elevations below the WSE at the time of the inflow.

The propagation of sedimentation and flattening of upstream channel slopes are primarily controlled by the maximum WSE during high inflow events which have historically been as high as elevation 527 ft NGVD29 (22 feet higher than the planned deviation). The storms with the highest intensities and longest durations result in the highest WSE. These same storms transport the highest volumes of sediment (up to 90% of the annual average sediment inflow volume). As these storm events occur there are large volumes of sediment that deposit high in the Basin which then define a new SAR slope for areas above elevation 527 ft NGVD (refer to the 2008 profile plot in Figure 3).

The primary cause of habitat modifications in the Dam to Hamner Reach of the SAR is due to:

1) Reduced gravel and cobble sediment inflow from upstream, due to upstream basins and lower flows in the SAR;
2) Vegetation, debris and non-native habitat restrict sediment transport and cause excessive sedimentation along the Dam to Hamner Reach; and
3) Reduced SAR slopes along the Dam to Hamner Reach are a result of the flood attenuation effects of Prado Dam.

The proposed planned deviation to allow an increase in the flood season WSE will have negligible effects on habitat types along the SAR between the Dam and the Hamner Avenue crossing. The planned deviation will have no effect on habitat types upstream of the Hamner Avenue crossing.

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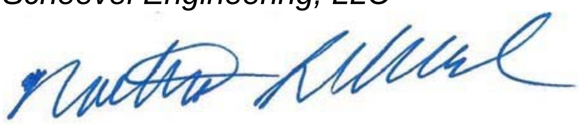
Scheevel Engineering greatly appreciates the opportunity to provide consulting services to OCWD and looks forward to working with OCWD on the next phase of this project. Please don’t hesitate to contact me with any questions you might have.

Sincerely,
Scheevel Engineering, LLC



Nate Scheevel, P.E.
Owner/Principal

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