SEDIMENT TRANSPORT AND DEPOSITON ASSESSMENT OF FREEMAN DIVERSION CONVEYANCE SYSTEM

PHASE 2: EVALUATE ALTERNATIVES

FINAL REPORT

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DISCLAIMER

EXECUTIVE SUMMARY

This report presents the results of an alternatives evaluation study for improvement of the Vern Freeman Diversion conveyance and recharge system. The improvements are being developed to enable the system to convey higher flows, facilitate diversions when river flows and turbidity are higher than typical for current diversion practices, and improve sediment management in the conveyance and recharge system. Alternatives are developed and evaluated, and a recommended plan for improvement of the Freeman Diversion conveyance system is presented.

The study summarized in this report follows two prior studies of the system performance: (1) a 2005 study by Brown and Caldwell that identified physical and operational improvements to maximize water yield and developed strategies for integration of new gravel pits to enhance storage and recharge capacities; and, (2) a 2014 Phase 1 study by Northwest Hydraulic Consultants (NHC) which expanded on the 2005 study with emphasis on the sediment transport characteristics of the system. The Phase 1 study evaluated the physical and operational constraints of the existing facility related to sediment, and quantified the potential gains associated with modification of these existing constraints.

At the beginning of this Phase 2 study, conceptual improvement plans were screened and a selected set of alternatives were identified for further analysis. The selected alternatives included: (1) a minimal improvement plan that provides connection to all of the recently purchased recharge basins and enables system wide conveyance capacity up to the existing permitted diversion rate of 375 cfs; (2) an improved and expanded existing system that follows the current alignment of the main conveyance channel, connects to the newly added recharge basins, and increases system capacity to 750 cfs (identified as Alternative 1 in main body of the report); and, (3) a bifurcation plan that includes a new conveyance channel downstream of the existing desilting basin, which would allow direct connection of diverted flows to the Noble and Ferro Basins (identified as Alternative 3 in the report). The new conveyance channel of this third alternative was sized assuming design capacities of 375 cfs and 750 cfs, and with both concrete-lined and unlined channels. The selected alternatives were refined using hydraulic and sediment transport models, and evaluated considering construction cost, functionality and other criteria.

Options were developed for improvement of the individual components that make up the upstream portions of diversion system, including the fish screen, the headworks pipes, the desilting basin, the three-barrel culvert and the siphon crossing. Construction costs and functionality of these options were summarized and contrasted.

Similarly, construction costs and functionality for the two alternatives for conveyance system improvement downstream of the desilting basin were compared. Estimated construction costs for the conveyance system options varied from about $1.5M for the minimal improvement alternative to about $26M for an option with a lined 750 cfs diversion to the Ferro Basin. In general, costs for the alternative that follows the existing alignment are significantly less expensive than the alternative that provides a bifurcation and direct diversion to the Ferro Basin. However, the bifurcation provides additional operational flexibility and potential sediment management options.

Simulations of water yield and sediment capture within the improved Freeman diversion system were computed using UWCD's yield simulation model. Water yield increases as the maximum sediment concentration allowed during diversion operations increases. Increasing system capacity also increases water yield compared to existing conditions, with computed average annual increases varying from about 5,000 to 12,000 af/year depending on operating scenarios. The simulation results indicate that the maximum yield occurs when all diverted flows pass through the existing desilting basin (rather than bypassing the existing desilting basin and diverting high turbidity flows directly to the Ferro basin). This is due to the spreading opportunity lost with flows that are passed directly to the Ferro Basin. Those flows are available for infiltration in the Ferro Basin only, whereas flows that pass through the existing desilting basin may be directed to all of the downstream spreading facilities. Both alternatives could be operated with all flow passing through the desilting basin.

Under existing conditions, the maintenance requirements related to sediment are sensitive to inlet management. Inlet operations will continue to be an important component of sediment management with the alternatives presented in this report. Local features have been added to the inlet modifications proposed in this study that will encourage larger fractions of the river sediment load to bypass the recharge system and/or enable easier local clean-out of accumulations in the vicinity of the fish screen.

Sediments that make it past the fish screen area will be more efficiently conveyed to and through the headworks area with the any of the conveyance options proposed for modification of the existing pipe system, reducing sediment maintenance requirements within the Freeman Canal. The vast majority of the sediment load passing the head regulating gates at the entrance to the Freeman Canal are expected to pass to either the existing desilting basin or the Ferro Basin, depending on the operation scenario applied.

Approximately 13 to 18 af/year of sediment have accumulated in the existing desilting basin since construction in 1991. The yield model simulation results indicate that increasing the system capacity to 750 cfs and increasing the allowable turbidity limits will significantly increase the sediment load to be handled by the system. The quantity of sediment captured is very sensitive to the turbidity limit applied to the diversion operations. With an operation scenario that passes all flows through the existing desilting basin and with diversion capacities increased to 750 cfs, the yield model indicates that the average annual sediment passing through the system would total 33.5 af if the turbidity cap were set at 10,000 mg/l, 47.0 af with a cap at 20,000 mg/l, and 71.5 af with a cap at 40,000 mg/l. Average annual water yields under these three scenarios would be 69,300 af/yr, 70,400 af/yr, and 71,500 af/yr, respectively.

Sediment transport simulation results conducted for this study indicate that, without the addition of a flocculation agent, the existing desilting basin may not be an effective trap of the very fine sediments (clays) that make up a significant fraction of the sediment load in the Santa Clara River. The effectiveness of the flocculation program under variable turbidity conditions is to be the subject of a future study by UWCD. The ability of the desilting basin to effectively remove sediment at higher flow rates and increased turbidity levels is important to maintain recharge capacity in the downstream basins.

Incremental yield and cost analysis indicates that, with system capacities increased to 750 cfs, diversion at concentrations higher than 10,000 mg/l may not be economical for operations that direct high turbidity flows to the Ferro basin. Higher concentration limits of between 10,000 and 20,000 mg/l would remain economical for operations that route all diverted flows through the existing desilting basin. These conclusions are sensitive to assumptions regarding the ratio of water yield value to the cost for sediment management (removal and disposal).

UWCD reviewed preliminary findings of the alternatives evaluation, and selected a preferred plan for improvement of the system. The preferred plan is a slightly modified version of the bifurcation (Alternative 3) plan, and includes the following elements (from upstream to downstream):

- An expansion of the existing fish screen, providing a duplicate system in parallel
- An open channel to replace the headworks pipes
- An additional inlet and new partition within the existing desilting basin
- A new bridge to replace the crossing at the existing thee-barrel culvert
- A new bridge to replace the crossing at the existing siphon
- A new bifurcation structure to be located near the entrance to Pond B. The structure will connect to a new lined downstream channel with 375 cfs capacity that will parallel the northern perimeter of the Saticoy, Noble and Ferro Basins. New culvert crossings at both Los Angeles Avenue and Vineyard Avenue will be required.
- Partitions within the Ferro Basin to maximize basin capacity.

The estimated construction cost for the preferred improvements is $28.2 million at 2016 pricing levels. Upgrading the additional bifurcated channel to increase its capacity to 750 cfs would cost an additional $3.5 million.

Preliminary design plans of the preferred alternative will be developed in the next phase of the study.

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1 INTRODUCTION

1.1 Purpose

The purpose of this study is to develop and analyze alternatives for improvement of the Freeman Diversion conveyance and recharge system. The improvements are being investigated to enable the system to convey higher flows, facilitate diversions when river flows and turbidity are higher than typical for current diversion practices, and improve sediment management in the conveyance and recharge system. Alternatives are developed and compared, and a recommended plan for improvement of the Freeman Diversion conveyance system is presented.

1.2 Background

In 2005, United Water Conservation District (UWCD) retained Brown and Caldwell to assist in the evaluation of the capacity of the existing facilities and to investigate facility improvement strategies that would help to increase the annual water supply yield from United's operations. The general scope of that study was to identify physical and operational improvements to maximize water yield, and to develop strategies for integration of new gravel pits to enhance storage and recharge capacities.

Northwest Hydraulic Consultants (NHC) was retained by UWCD in 2014 to expand on the 2005 study with emphasis on the sediment transport characteristics of the system. NHC's Phase 1 study, completed in 2014, evaluated the physical and operational constraints of the existing facility related to sediment, and quantified the potential gains associated with modification of these existing constraints. The Phase 2 study, summarized in this report, assesses potential alternatives for improvement of sediment performance in the system.

1.3 Scope of Work

The following tasks were completed for this study:

Task 1 – Alternatives Development
Task 2 – Hydraulic and Sediment Assessment
Task 3 – Alternatives Evaluation
Task 4 – Reporting
Task 5 – Meetings and Coordination

The work performed for each task is described in the following paragraphs.

1.3.1 Task 1 – Alternatives Development

NHC had several teleconferences with United Water Conservation District (UWCD) to review preliminary alternatives identified in Phase 1. Additional potential concepts were discussed, and screening criteria relating to location, sizing, and configuration for the components of each alternative were identified. Preliminary concepts were screened, and two general concept and alignment alternatives (with options) were selected for further evaluation.

1.3.2 Task 2 – Hydraulic and Sediment Assessment

Preliminary layouts for the selected alternatives were used to develop hydraulic models of the system. The hydraulic models were used to refine component sizing and provide the basis for assessing sediment performance for each alternative. Hydraulic and sediment transport performance over a range of operation conditions was simulated.

1.3.3 Task 3 – Evaluate Alternatives

Alternatives were compared based upon expected functioning, costs, maintenance and operational considerations, and flexibility. Expected yield, sediment capture and maintenance and operation requirements associated with sediment for each alternative were assessed based on the sediment transport and yield model results. Construction costs were developed for each component of each alternative. Based on the evaluation, a preferred alternative was identified.

1.3.4 Meetings, Coordination and Reporting

Throughout the duration of the study, bi-weekly coordination calls/web meetings were held to review progress and receive interim direction from UWCD. This report was prepared to summarize the alternatives development and evaluation process, and to present the recommended alternative.

2 ALTERNATIVES DEVELOPMENT

2.1 Alignments

Initially, five alternative alignments were proposed for routing of flows and sediment load through the Freeman diversion and recharge system (including the recently acquired Rose and Ferro basins). The alternatives included four that had been presented in the Phase 1 study (Ref. 1), and an additional alternative (Alternative 5, described below), developed in the initial weeks of this Phase 2 study. Screening of these alternatives were conducted through discussions with UWCD, and two of the alternatives (Alternatives 2 and 4) were removed from further consideration. The alternatives that remained are described as follows:

Alternative 1 – This alternative improves the conveyance system along the existing alignment to enable 750 cfs capacity. It adds a connection from Noble Basin No. 3 to the Ferro Basin, and incorporate the Rose Basin as a percolation pond via connection to the Noble Basins. The alignment and major features of Alternative 1 are illustrated in **Figure 1**.

Alternative 3 – This alternative adds a new conveyance path, sized for 750 cfs, beginning at the downstream end of the existing desilting basin. The new conveyance follows an alignment that skirts the north boundary of the Saticoy, Noble and Ferro basins. The new conveyance channel will require a new crossing of L.A. Avenue and a crossing of Vineyard Avenue from the Noble Basin to the Ferro Basin. This alternative will maintain the existing conveyance path between the desilting basin and the Noble Basins at a capacity of 375 cfs, and incorporate the Rose Basin as a percolation pond via connection to the Noble Basins. The alignment and major features of Alternative 3 are illustrated in **Figure 2**.

Alternative 5 – This alternative increases the capacity of the existing system to 750 cfs, and adds a connection from Noble Basin No. 3 to the Ferro Basin. A new connection from the Grand Canal to the Rose Basin is provided, and the Rose Basin is reconfigured as a desilting basin, with downstream connection to Noble Basin No. 1. The alignment and major features of Alternative 5 are illustrated in **Figure 3**.

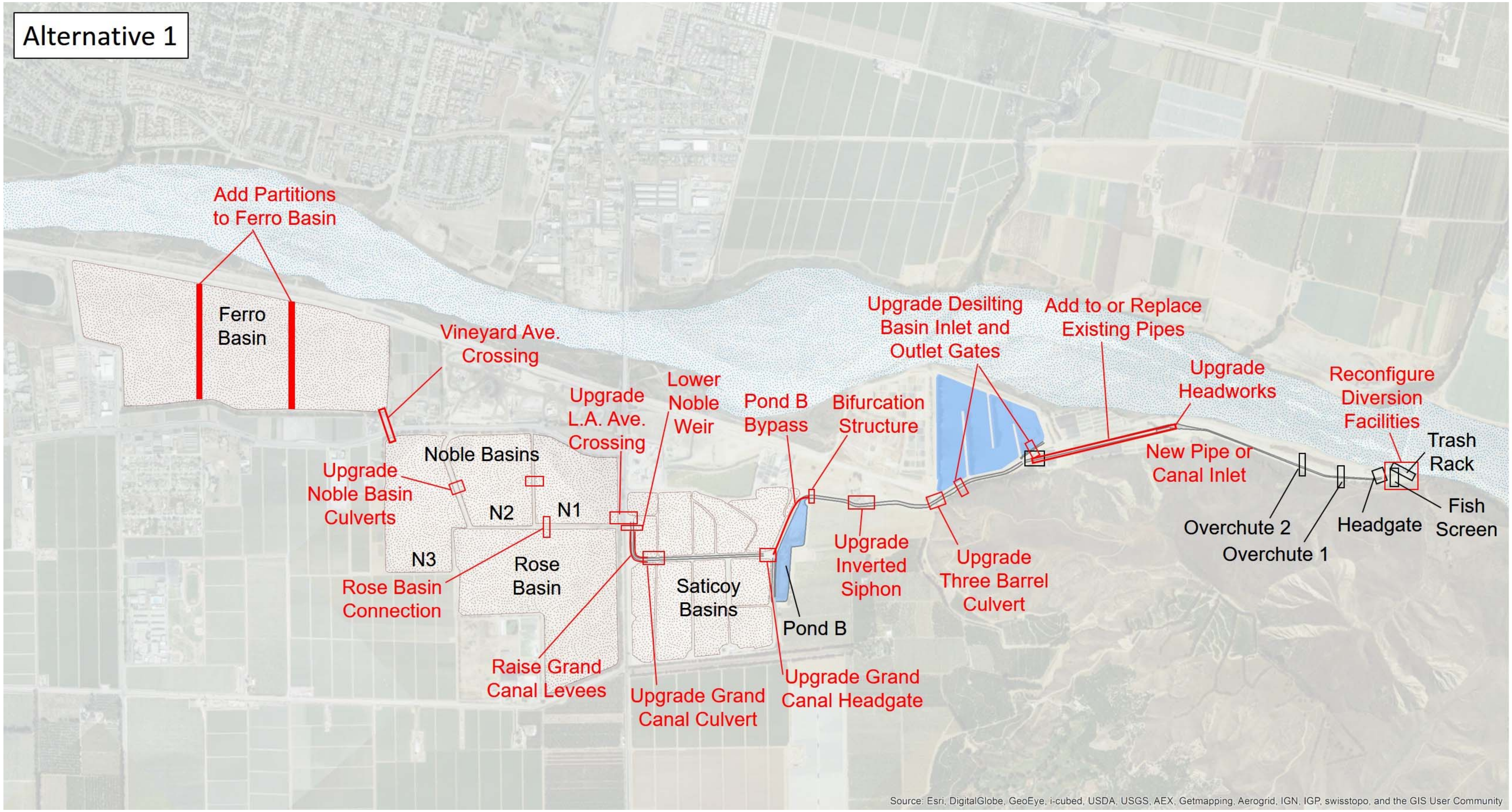

Figure 1 Plan view of Alternative 1

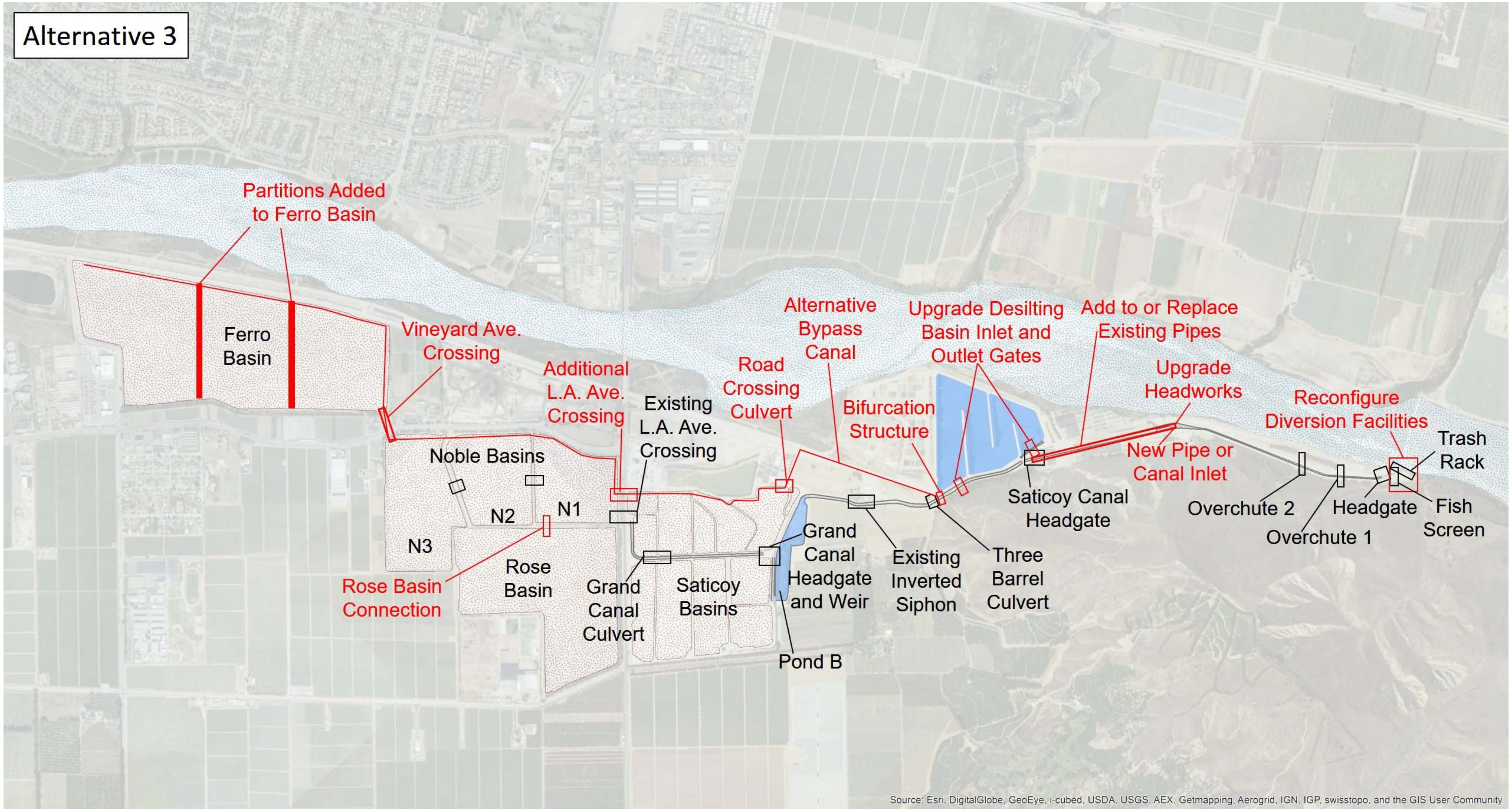

Figure 2 Plan view of Alternative 3

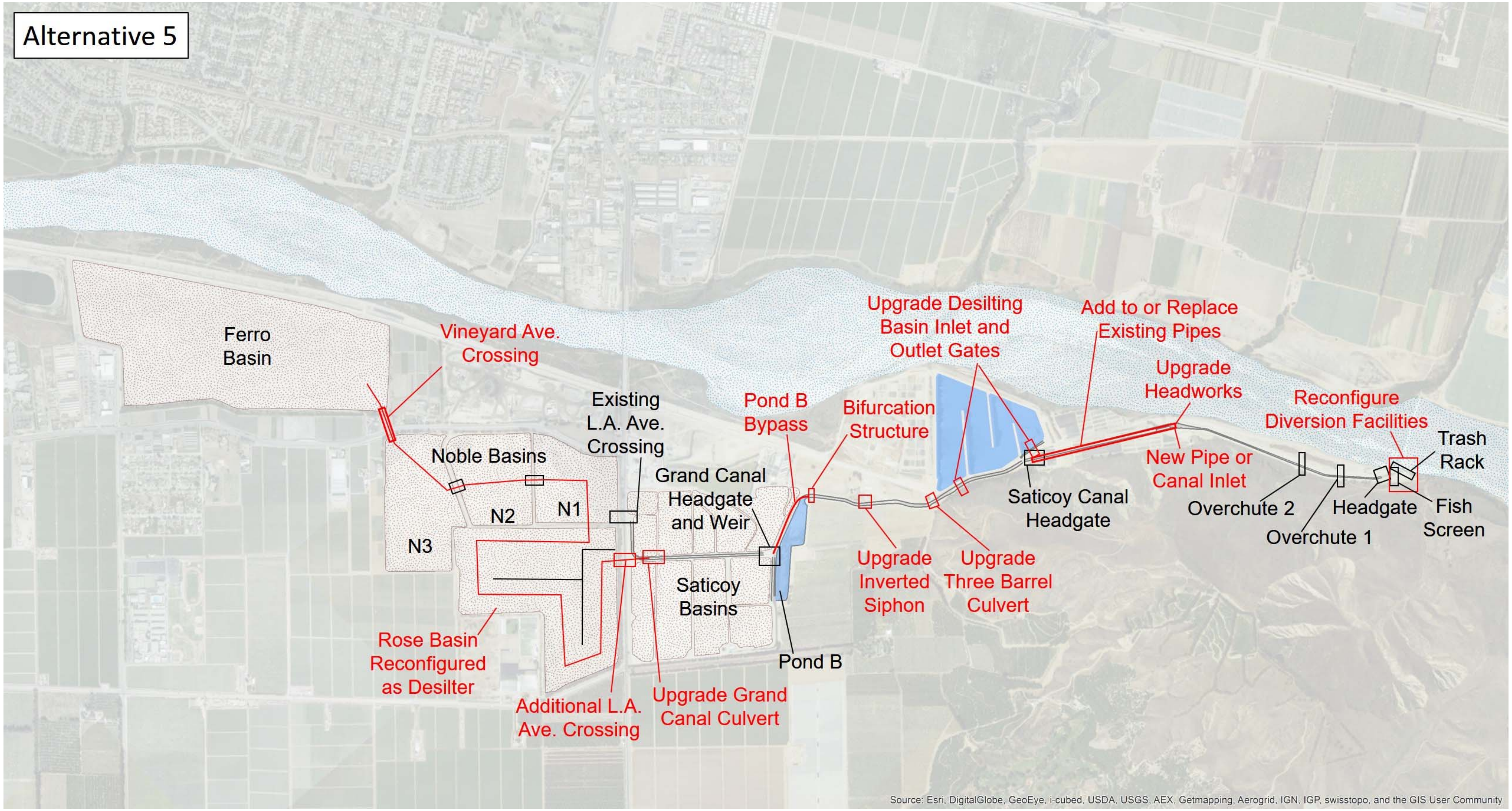

Figure 3 Plan view of Alternative 5

United had several concerns regarding Alternative 5. The Rose Basin is located furthest from the river, which makes it relatively more valuable as a percolation basin. United's preference is to protect the recharge capacity of the ponds more distant from the river in order to prevent loss of infiltration vi river return (as the aquifer mounds). This is also a potential (but lesser) disadvantage associated with Alternative 1, since an optional destination for high turbidity flows under this alternative would be the Noble Basins. United judged that Alternative 3 would provide the most flexibility in operations, but the costs to achieve this flexibility might be high.

After screening review by UWCD, Alternative 5 was removed from further consideration. UWCD directed NHC to focus on Alternatives 1 and 3 for further evaluation. In addition, NHC was directed to evaluate two capacity options for the new conveyance path associated with Alternative 3 – 375 cfs and 750 cfs. A 'minimal improvement' alternative, establishing a capacity of 375 cfs through the main conveyance line and providing connection to the newly acquired Ferro and Rose basins, was also to be included in the evaluation.

2.2 Cost Estimates

Construction costs for the facilities and alternatives in this report were estimated at a reconnaissance level based on pricing levels for January 2016. Unit costs were developed from previous project cost data, estimating guides, manufacturer's quotes, and professional judgment. Due to the conceptual nature of the alternatives, unit costs attempt to reflect ancillary items not specifically identified at this stage of the project. There is considerable uncertainty in the estimates due to the conceptual level of design development, unknowns related to geotechnical and utility conditions, and potential environmental and fisheries constraints. A 30 percent contingency has been included in the construction cost estimates. Costs for planning, design, environmental compliance, construction engineering, and contract administration are not included in the construction cost estimates. Unit costs assumed for this study are summarized in Appendix A.

2.3 Upstream Components

Each of alternatives selected for further evaluation include improvement to the inlet/fish screen area and improvement or replacement of the Headworks pipes. Options for improvement of operation and maintenance of the existing desilting basin have also been developed. The options may be matched with any of the alternatives for downstream improvement. The options for each of these upstream elements are presented and contrasted in the following paragraphs.

2.3.1 Inlet

Four preliminary inlet configurations were developed for the Freeman Diversion system. Each of these has been sized with a capacity of 750 cfs, and to be compatible with fish ramp modification proposals as currently envisioned. Three of the configurations maintain the existing off-channel location for the screens and focus on increasing screen area to accommodate the higher flow. Features are provided with these options for improving sediment management. The fourth configuration uses an on-channel screen. The design of a new or modified juvenile bypass system to meet fisheries criteria has not been specifically addressed in these configurations. All of the revised configurations would require more detailed design and analysis to meet hydraulic criteria for protection of fish, and would require review and approval by the fisheries agencies. The configurations and associated costs should therefore be considered subject to considerable uncertainty.

The most-straightforward inlet modification may be to replace the existing fish screen panels with taller elements, and raise the walls to contain the higher design flow rate. A profile view of the existing channel through the fish screen reach is presented in **Figure 4**. The modified fish screen will be required to meet maximum flow-through velocities of 0.4 feet per second, equivalent the conditions achieved under current flow conditions (375 cfs). To achieve 0.4 feet per second at 750 cfs without changing the existing fish screen width (approximately 173 feet, see **Figure 5**), the height of the fish screen will have to be increased to approximately 11 feet, and the head regulating gate and walls will have to enable development and containment of this flow depth. Head control for sediment management could move downstream to the canal inlet gate under this option.

Note that 11 feet added to the existing invert elevation at the existing fish screen (elev. 152.5 ft) would put the top of the existing screen at elevation 163.5 ft, which is higher than the existing Freeman diversion dam (elev. 162 ft). Therefore, this design option would require structural modification and lengthening of the existing screen bay to provide sufficient screen area for the 750 cfs diversion conditions at a water surface elevation below the dam crest. Keeping the top of the fish screen at an elevation of 162 ft, for example, would require a total screen length of approximately 200 feet. If the design flow is reduced, the existing screens could potentially be replaced without lengthening the bay.

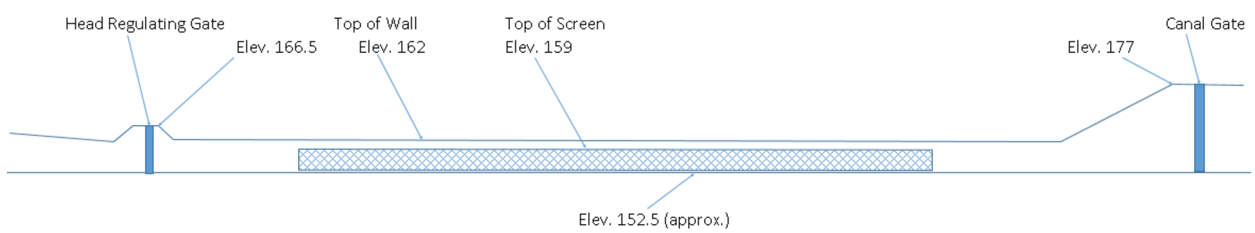

Figure 4 Profile view of the upstream end of the Freeman diversion channel

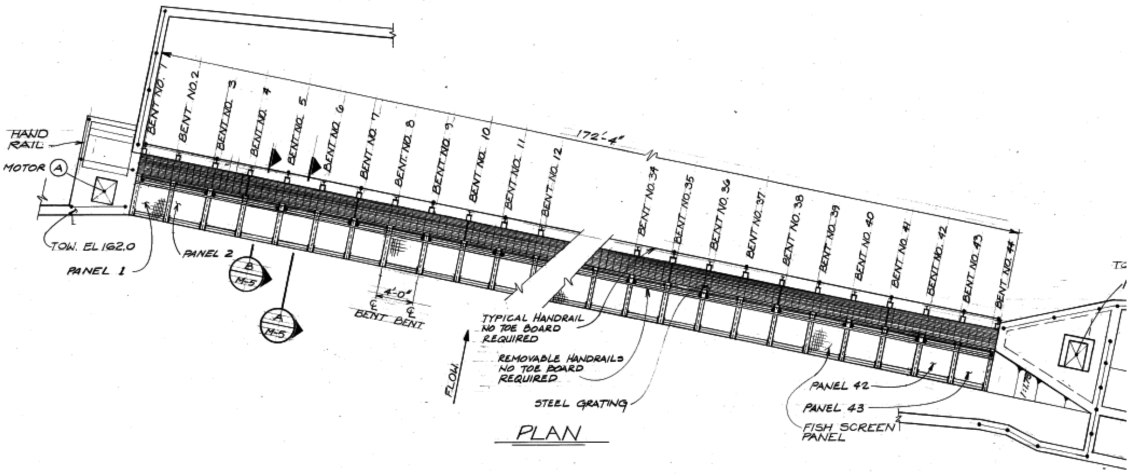

Figure 5 Existing fish screen configuration

Some features could also be added to this modified inlet to improve maintenance capability. A plan view showing the raised and extended fish screen with these potential improvement features is shown in **Figure 6**. Note that with the addition of the sluice way culverts for sediment cleanout, the fish trap feature of the existing screen would require modification (which has not been addressed at this time). A fish bypass may be required in place of the trap if the screens are modified, and the design of the bypass and operation of the sluicing features would require review with the fisheries agencies.

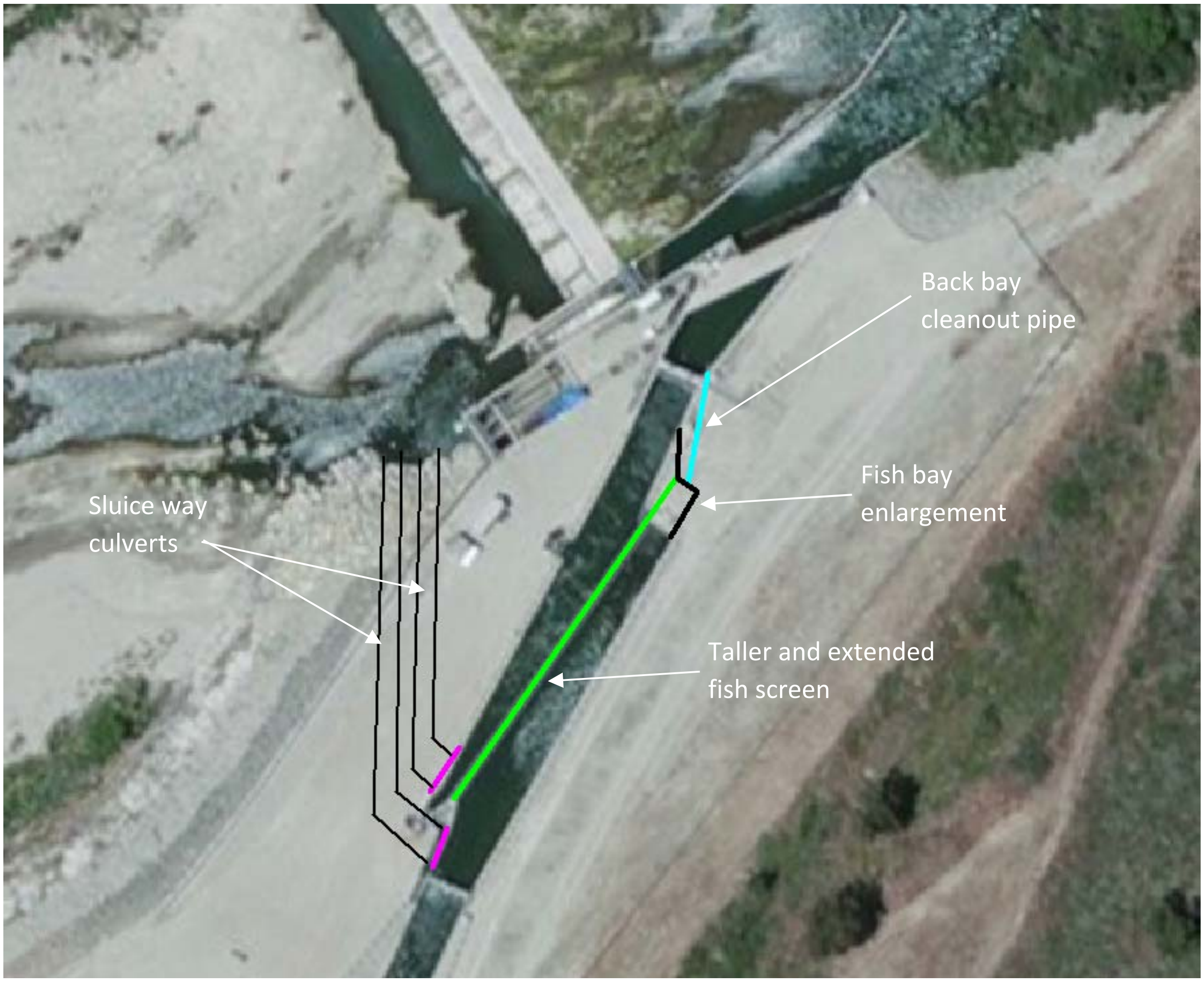

Figure 6 Plan view of existing fish screen at inlet, with Option 1 modifications

A second option for improvement of the fish screen would involve duplicating the existing structure, as shown in **Figure 7**. The potential improvements for aiding in local maintenance are also shown in this figure. This option would provide dual paths for inlet of flows, which would enable shut-down of one side at a time for maintenance purposes. Head control for sediment management would remain at the upstream canal gates, as under existing conditions, unless the second bay were constructed with taller screens and walls (as in the first option). As for the first option, a new fish bypass system (not shown) would likely be required.

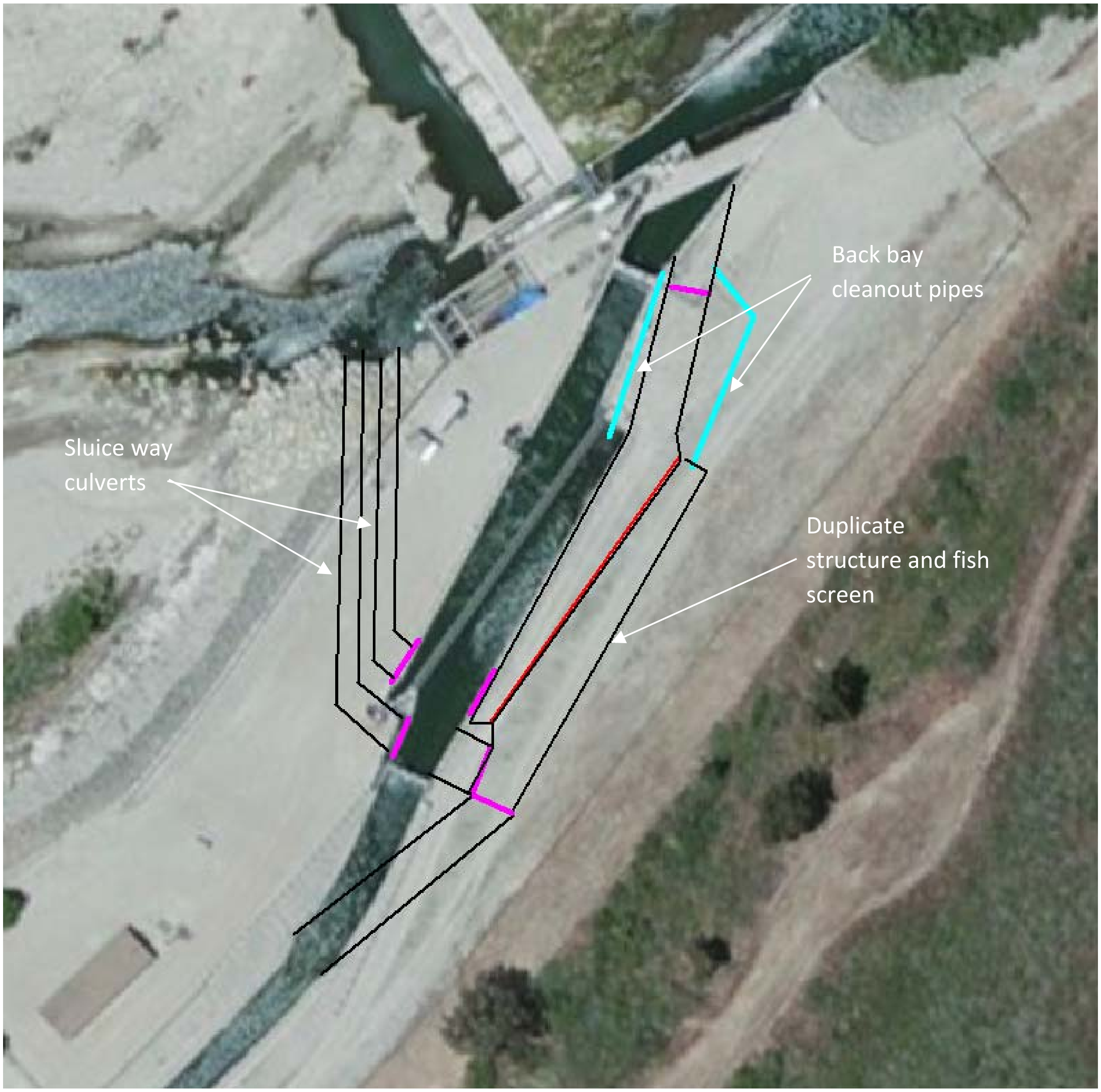

Figure 7 Plan view of duplicated fish screen option, with potential added features

A third configuration option of the fish screen is to completely remove the existing structure and replace it with a modified but similar arrangement as shown in **Figure 8**. This modified option would include sluice way culverts to allow local cleanout of the bays in front of each fish screen, and an added gate and shared back bay that would eliminate the need for an additional cleanout pipe. New fish bypasses (not shown) would be required.

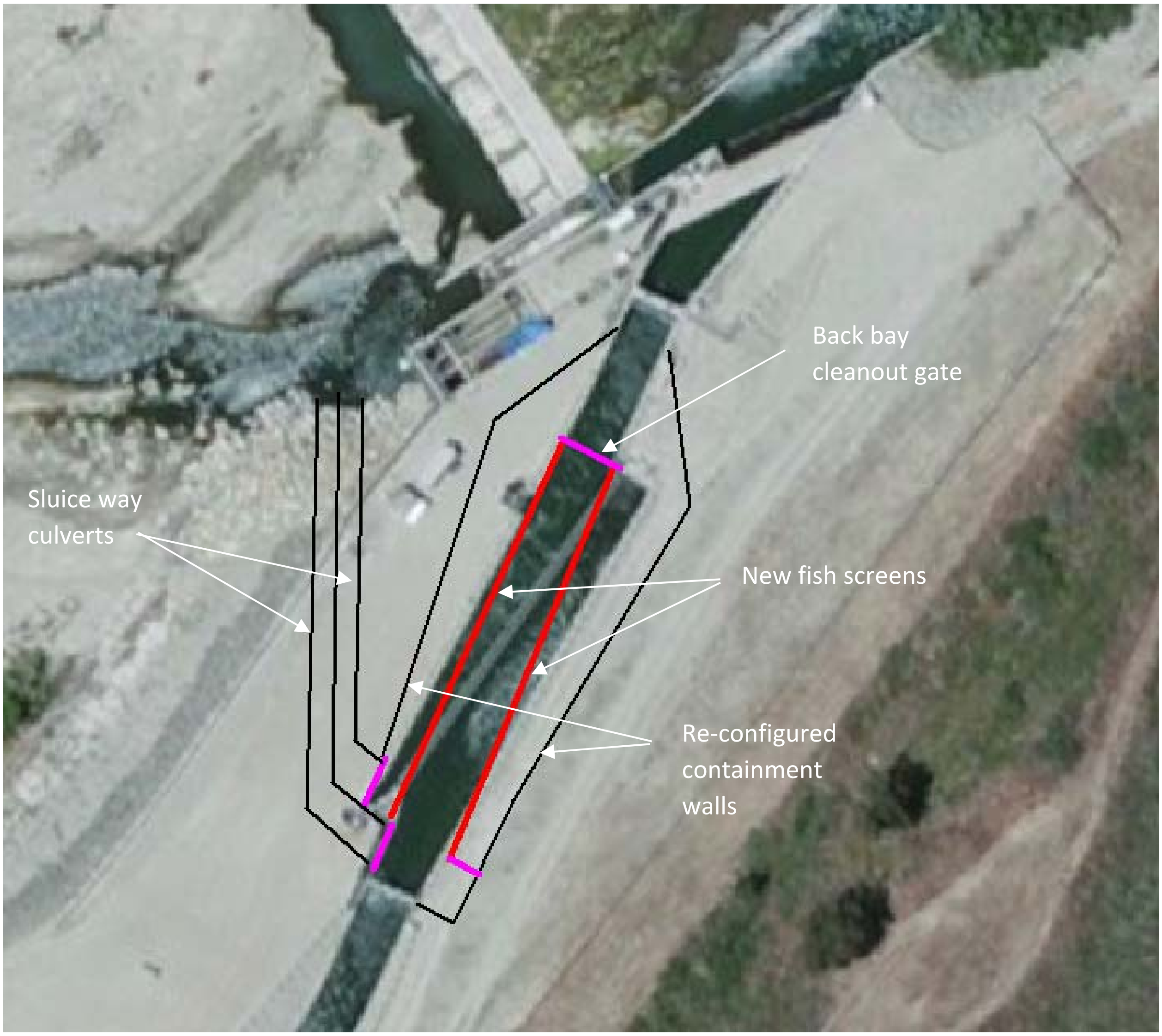

Figure 8 Plan view of a modified fish screen option

The fourth option considered at the inlet adds a Coanda screen along the bank of the river upstream of the existing inlet, as shown in **Figure 9**. This configuration would pull flow from the top of the water column rather than the bottom via an overflow weir with control gates. Flows overtopping the weir would pass over and through a Coanda screen (see **Figure 10**), with fish and debris separated from the captured flow and collected in a bypass channel. The screened flow could connect to the existing diversion system downstream of the existing fish screen, as shown in **Figure 9**. It should be noted that Coanda screens are considered experimental technology by the fisheries agencies and thus would require special review.

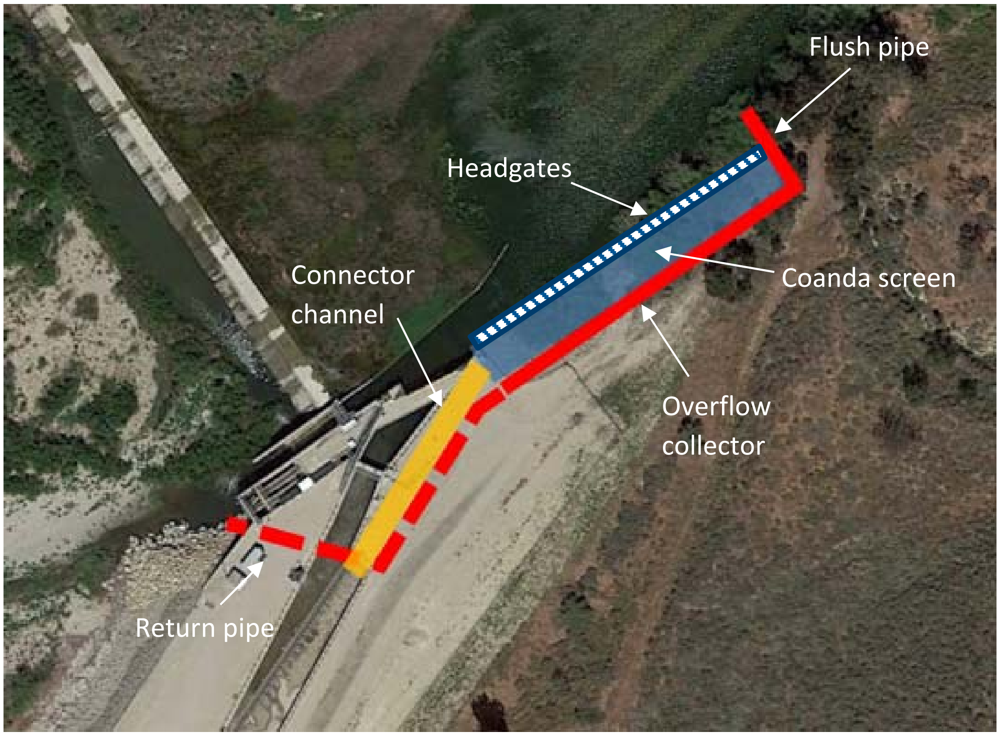

Figure 9 Plan view of a Coanda screen option

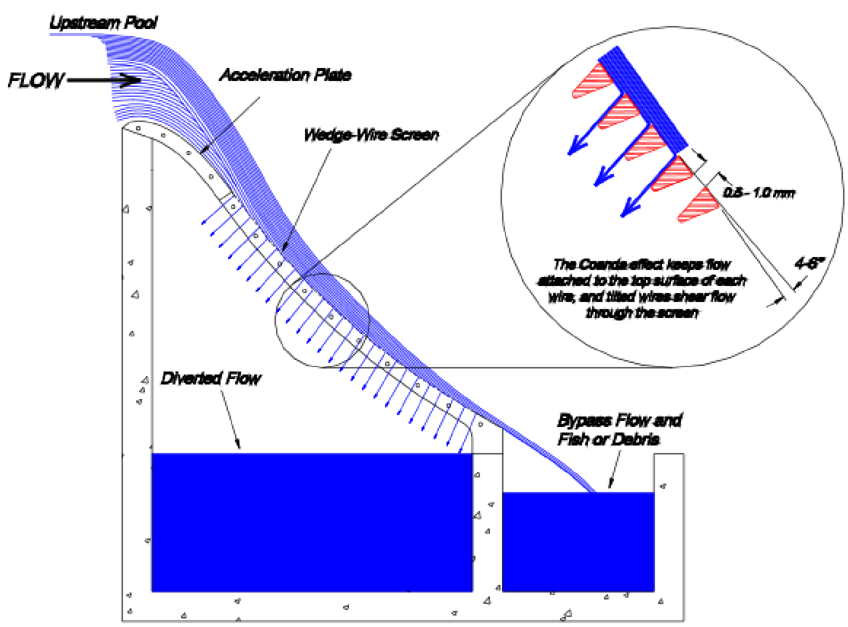

Figure 10 Section view of a Coanda screen diversion system

Preliminary construction costs estimates and the advantages and disadvantages of the four options for improvement of the Freeman Diversion inlet are summarized in Table 1.

Table 1 Comparison of inlet improvement options

Option	Construction Cost ($Millions)	Functionality and Flexibility	Reliability	Permitting
Raise and extend existing fish screen, modify walls of fish bay	$2.2	Allows downstream head control, which will improve fish screen operation	Less severe hydraulics, local cleanout capability	Improved version of the existing system
Duplicate the existing fish screen	$4.4	Upstream head control (same as existing), unless walls are raised as with the first option. Improved operational flexibility with two screen bays.	Similar hydraulics as the existing system, dual paths provide alternate paths during maintenance, local cleanout capability	Identical to the existing system
New inverted V configuration	$3.6	Allows downstream head control, which will improve fish screen operation. Improved operational flexibility with two screen bays.	Less severe hydraulics, local cleanout capability	Similar to the existing system
Coanda Screen	$6.3	Less sediment in the system, flexibility provided via multiple inlet gates, backup system provided by the existing fish screen	Potentially the best option for fish and sediment management, but locally untested	New technology, local agencies may not be familiar

All four options would improve sediment management at the inlet. Sediment accumulation will continue to occur in the fish screen bays with the first three options, as occurs under existing conditions, but with increased magnitude due to the increased diversion capacity. The local cleanout capabilities provided with these three options would enable more efficient management of these sediment accumulations. Design and operation of these facilities would be subject to review by the fisheries agencies.

Option 4, (the Coanda screen) is the only option that would significantly change the upstream sediment accumulation condition associated with the off-channel fish screen bay arrangement. Option 1 is the least costly to construct, with Options 2 and 3 expected to cost approximately twice as much, and Option 4 nearly three times as expensive.

An added measure that could be combined with any of the improvement options for the inlet would be the incorporation of a pre-inlet bay immediately upstream of the inlet gate (see Figure 11). The measure would create a local expansion upstream of the inlet that would force slowing of the diversion flows, encouraging depostion prior to passing though the canal gate. The expanded area would connect to the flushing channel to enable cleanout of the deposits. A sloping invert and/or the addition of low flow guidance groins within the channel bottom could be incorporated in the design to assist in sediment clearing of the entire pre-inlet bay during flushing operations. The design of such an inlet bay would need to be coordinated with the proposed fish passage improvements (fish ramp) at the dam because the ramp will extend upstream of the existing flushing channel and require modification of the inlet headworks.

Figure 11 Pre-inlet bay concept for sediment capture upstream of the inlet

2.3.2 Headworks Pipes

The existing headworks pipes do not have the capacity to convey the increased design discharge of 750 cfs without causing extensive backwater conditions extending all the way upstream to the Freeman diversion inlet. Three general options for improvement of this portion of the system were considered: (1) add a pipe to the existing set of pipes; (2) replace the existing pipes with a single, larger pipe or box culvert; and, (3) replace the existing pipes with an open channel.

The existing headworks pipes have invert elevations of approximately 149 ft at the upstream end, and outlet at elevation of about 145 ft near the inlet to the existing desilting basin. The headworks pipes consist of a single 2400-ft long 81-inch diameter pipe, and a parallel pipe combination with diameters of

60-inches and 48-inches at the upstream end, combining into a single 60-inch pipe approximately half-way to the outlet (three pipes at the inlet, two pipes at the outlet). The dimensions of the options for improving this reach of the system are summarized in Table 2. A plan view of the area for improvement is shown in Figure 12.

Figure 12. Aerial view of the headworks pipes are

Table 2 Dimensions of options for improving the Headworks pipes

Option	Dimensions
Add an additional pipe	96" diameter
Replace the existing pipes with a new single buried conveyance	Double 8' X 8' box culvert
Replace the existing pipes with an open channel	10' bottom width 1.5:1 side slopes 10' depth:

The three options for improvement of the pipes below the headworks area are contrasted in Table 3.

Table 3 Comparison of options for improvement of the conveyance through the Headworks pipes

Option	Construction Cost ($ Millions)	Functionality and Flexibility	Reliability	Right-of-way issues
Add a pipe	$4.1	Issues with the existing pipes will remain	Less easy to maintain multiple pipes.	Minimal change to the status quo
Replace existing pipes with a new closed conduit	$6.7	Improved	Improved, but closed, thus less accessible to maintenance.	Major short term disturbance, then similar to existing conditions
Replace existing pipes with a new open channel	$2.3	Improved	Improved, best option for maintenance access	Will remove some leased property from current use.

2.3.3 Desilting Basin

The existing desilting basin has been designed to handle peak flows of 375 cfs. Sediment deposits accumulate at the upstream end of the desilting basin, sometimes affecting hydraulic conditions at the desilting basin inlet and causing a backwater condition that extends up the headworks pipes. There currently are no means for isolating a portion of the desilting basin to allow local maintenance to occur, or for redirecting the inflow point to allow alternative distribution of the sediment deposits near the inlet. Modification or addition of inflow gates could enable the rotation of inflow points to the desilting basin, allowing for selection of the location of the initial deposition zone, and enabling partial desilting operations to occur concurrently with shut-down, drying, and maintenance of some portions of the basin.

The general layout of the existing desilting basin is shown in **Figure 12**. The inlet to the desilting basin is shown in **Figure 13**. The existing inlet consists of a double box culvert beneath the access road, with twin 6-ft by 8-ft gates on the upstream side. An additional box culvert cell and gate will be needed at the inlet and outlet of the existing desilting basin to increase capacities to 750 cfs. An additional gate will also be needed at the bypass channel outlet.

Figure 12 Aerial view of the existing desilting basin

Figure 13 Inlet to the existing desilting basin

The addition of a similar (upgraded) structure immediately downstream of the existing inlet, or modification of the (upgraded) structure downstream of the road crossing, would enable flow to enter the basin at more than one location. Illustration of two concepts for inlet modification are presented in **Figure 14**.

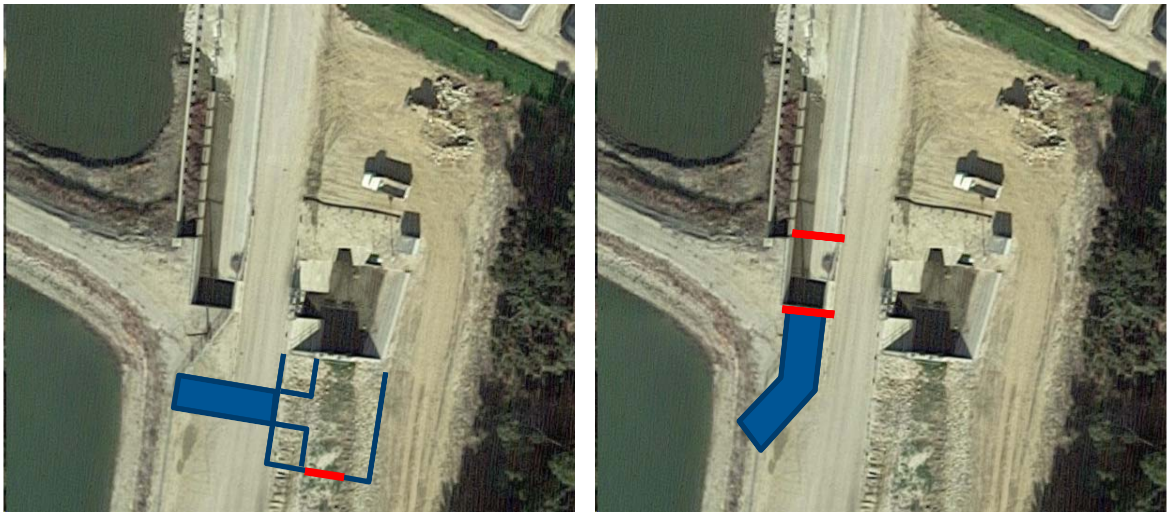

Figure 14 Options for adding an inlet to the existing desilting basin

The addition of gates and partitions within the existing desilting basin could be used to isolate individual bays for maintenance. The more gates and partitions added, the more flexibility is provided for isolation and circulation options. A relatively simple partition and gate modification plan is shown in **Figure 15**a. A more extensive partition and gate modification plan is shown in **Figure 15**b.

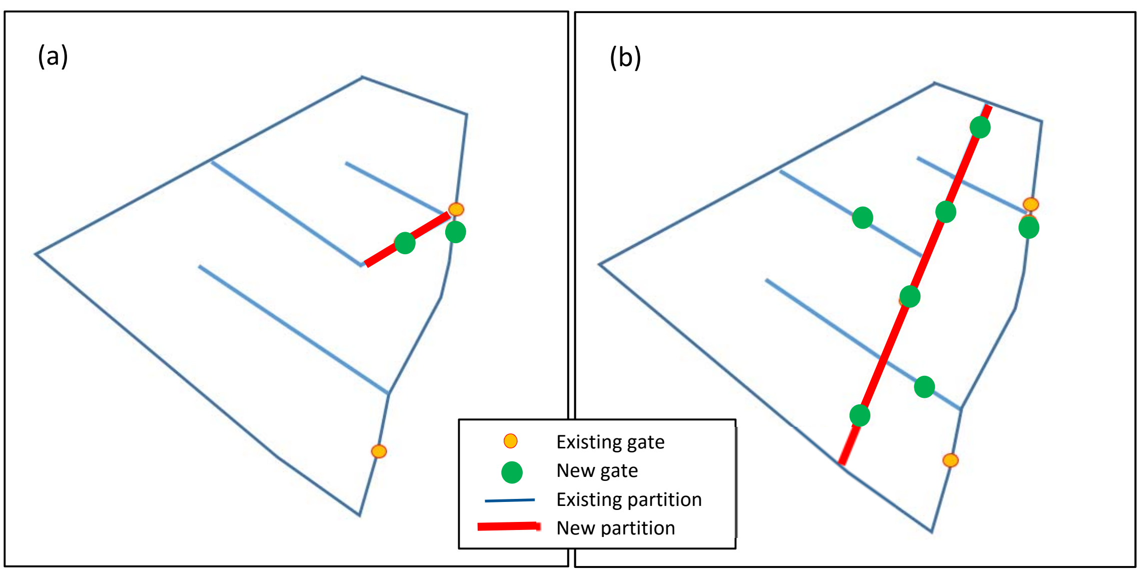

Figure 15 Options for addition of partitions and gates within the existing desilting basin

The simple partition plan illustrated in **Figure 15**a would be adequate to provide an alternate entry to the existing desilting basin and enable isolation of the main entry bay for maintenance purposes. The more extensive partition plan illustrated in **Figure 15**b would enable a range of isolation and circulation options, as illustrated in **Figure 16**. It is assumed that the additional partitions identified in **Figure 15** would be constructed to match the configuration of the existing interior berms. An as-built section drawing of the existing berm is shown in **Figure 17**.

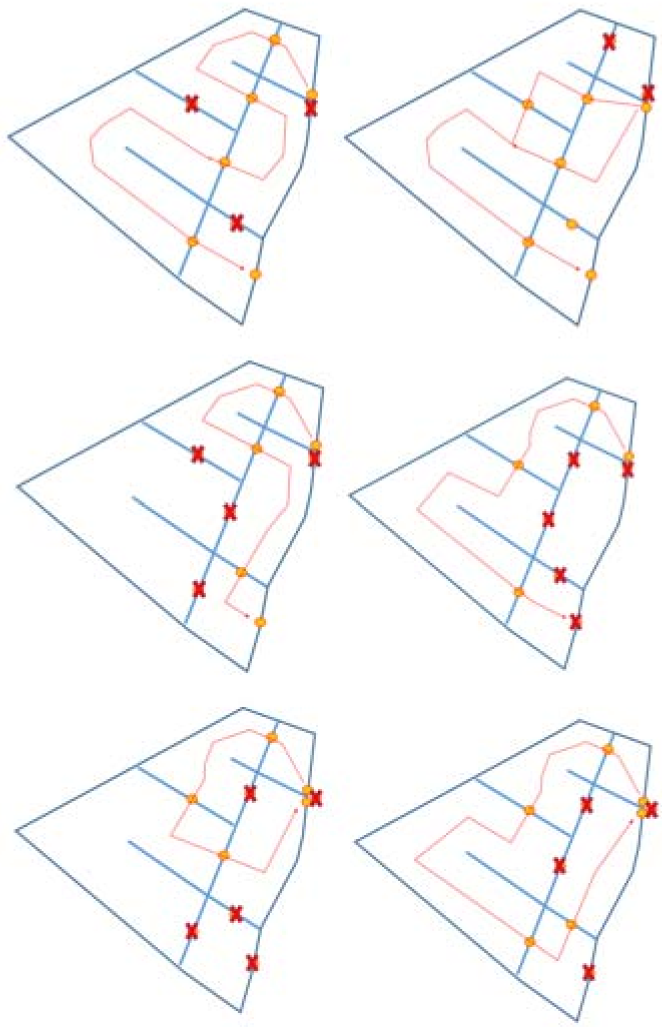

Figure 16 Potential circulation options in the modified desilting basin plan shown in Figure 15b

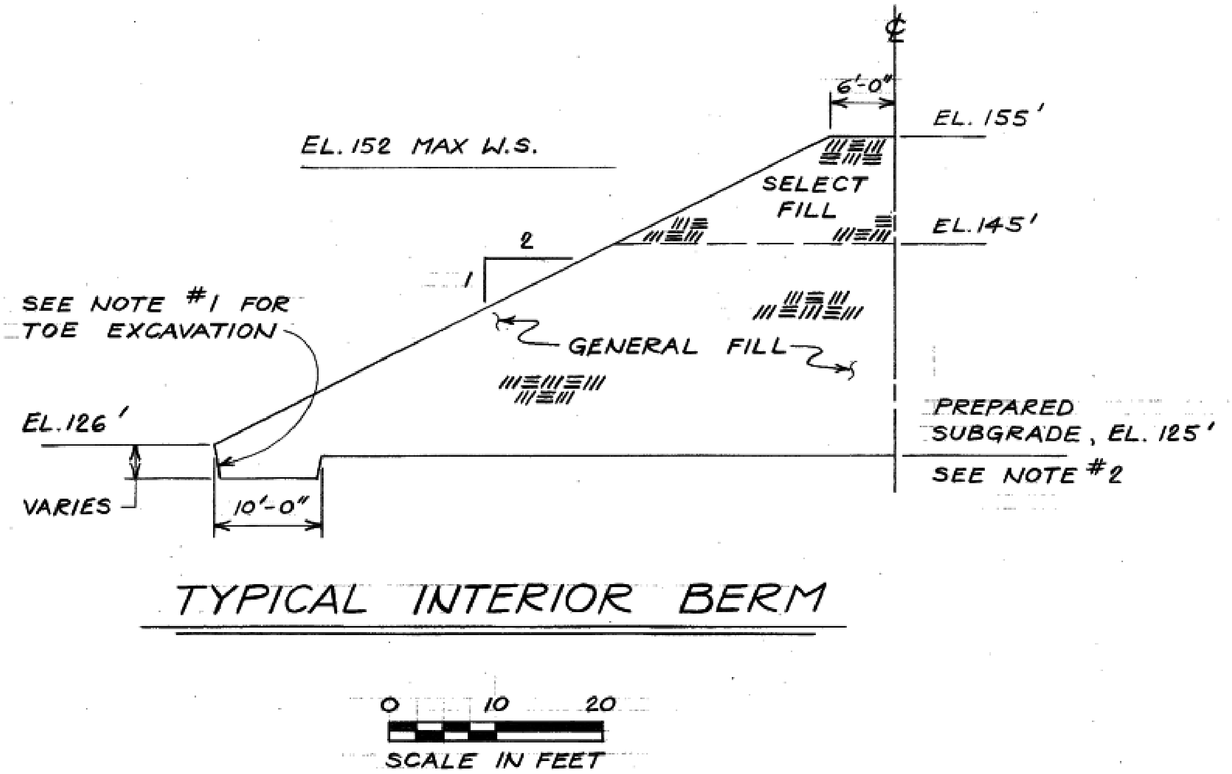

Figure 17 Interior berm section of existing desilting basin

Options for improvement of the inlet and partition scheme for the existing desilting basin are compared in Table 4.

Table 4 Comparison of options for improvement of the existing desilting basin

Option	Construction Cost ($ Millions)	Functionality and Flexibility	Reliability
Improve inlet through duplication	$1.1	Duplication of a tested system	Similar to the existing
Improve inlet through downstream bifurcation	$0.9	Multiple gates on each inlet path, may require increased maintenance	An additional bifurcation adds some hydraulic complexity
Add a single additional partition	$1.1	Flexibility in inlet flow location provided, allows inlet bay isolation for maintenance	Less moving parts, similar reliability as the existing basin
Add multiple additional partitions	$4.5	Flexibility in the entire circulation pattern and bay isolation is provided	Multiple gates adds some uncertainty, though redundancy is provided as well

2.4 Downstream Conveyance Paths

Alternatives 1 and 3 differ downstream of the existing desilting basin in the paths provided for conveying flows downstream to the Ferro Basin. In Alternative 1, the existing path (through the Saticoy Channel, Grand Canal, and Noble Basins) is followed, with a connection to the Ferro Basin via a new culvert under Vineyard Avenue at the downstream end of Noble Basin 3. An optional bypass of Pond B is included in Alternative 1. With Alternative 3, the existing conveyance path is maintained (and improved, where necessary), and an additional optional path is provided immediately downstream of the existing desilting basin, following a higher elevation, more direct path to the Ferro Basin. Under both alternatives, the Rose Basin is connected to Noble Basin 1 via a set of invert level pipes (as currently proposed by UCWD).

2.4.4 Alternative 1 Conveyance Path Improvements

Grand Canal Gates

The Grand Canal Gates are addressed first, due to their significant effect on the conveyance capacity of the upstream system. Hydraulic analysis of the existing structures indicate that an additional 48” pipe is required at this location to provide 375 cfs capacity through and upstream of the Grand Canal inlet (see

Section 3.2 of this report). To increase the capacity to 750 cfs, additional pipes are necessary. Three 5-ft diameter pipes with gates (in addition to the four 48” pipes) would provide the required capacity.

Three Barrel Culvert

With improvement of the Grand Canal Gates, the capacity of the channel in the vicinity of the three barrel culvert crossing is improved. The gates at the three barrel culvert crossing are operated by Ventura County Watershed Protection District, and information on the function of the gates has been requested from the District. Several options are available for increasing the capacity further to 750 cfs. These options include adding additional pipes, replacing the existing structure with larger culverts, or replacing the existing structure with a bridge. The bridge option would not be viable if gates are needed at the crossing. The options and sizes/dimensions and approximate costs are summarized in Table 5. With the exception of the gates, the functionality and reliability of each of these options are similar, and are not noted in this table.

Table 5 Comparison of options for improving the existing three-barrel culvert crossing

Option	Dimensions	Construction Cost
Add additional pipes	Add two 84” diameter pipes	$590,000
Replace entire structure with new culverts	Double 8’ W X 6’ H box culvert	$620,000
Replace entire crossing with a new bridge	50' bridge length with center pier (25' span) no pedestrian or public access, simple guardrail 24' bridge width	$390,000

Siphon

As with the three barrel culvert, options for improving the existing siphon include adding additional pipes, replacing the existing structure with larger culverts, or replacing the existing structure with a bridge. Construction cost for siphon improvements are presented in Table 6.

Table 6 Comparison of options for improving the existing siphon crossing

Option	Dimensions	Construction Cost
Add additional pipes	Add 2 84" pipes	$410,000
Replace entire structure with new culverts	Double 8ft W X 6ft H box culvert	$420,000
Replace entire crossing with a new bridge	50' bridge length with center pier (25' span) no pedestrian or public access, simple guardrail 24' bridge width	$390,000

Pond B Bypass

Under existing conditions, flows travel a somewhat circuitous path between the siphon and the Grand Canal inlet via Pond B, as shown in Figure 18. With the addition of a bifurcation structure and some local improvement to the existing channel that parallels Pond B, this original path can be maintained for normal operating conditions, but an optional shorter path (also shown in Figure 18) could be employed for streamlined conveyance of high turbidity flows to the Grand Canal and downstream. The shorter path would require some expansion of the cross-section of the existing channel that currently parallels Pond B west of the Grand Canal entrance.

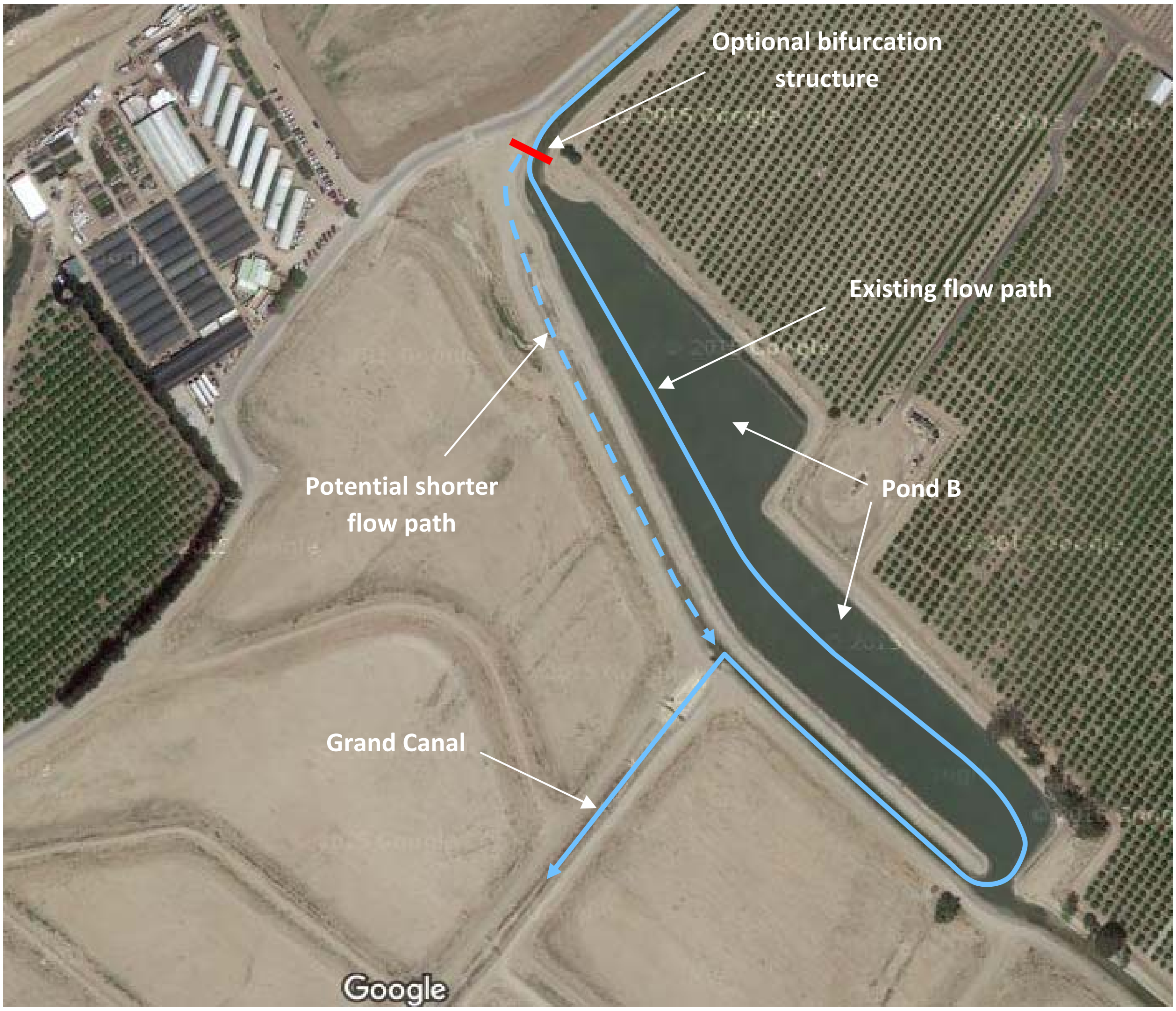

Figure 18 Flow paths near the Grand Canal inlet

Other Grand Canal Improvements

The culvert crossing of the Grand Canal and the downstream outlet to the Noble Basins will both require additional pipes to allow conveyance of 750 cfs. At both locations, the addition of two 5-ft diameter pipes will provide the required capacity. In addition, the channel capacity of the lower reach of the canal will need to be increased through modification of the Noble weir and local raising of the lower channel levees.

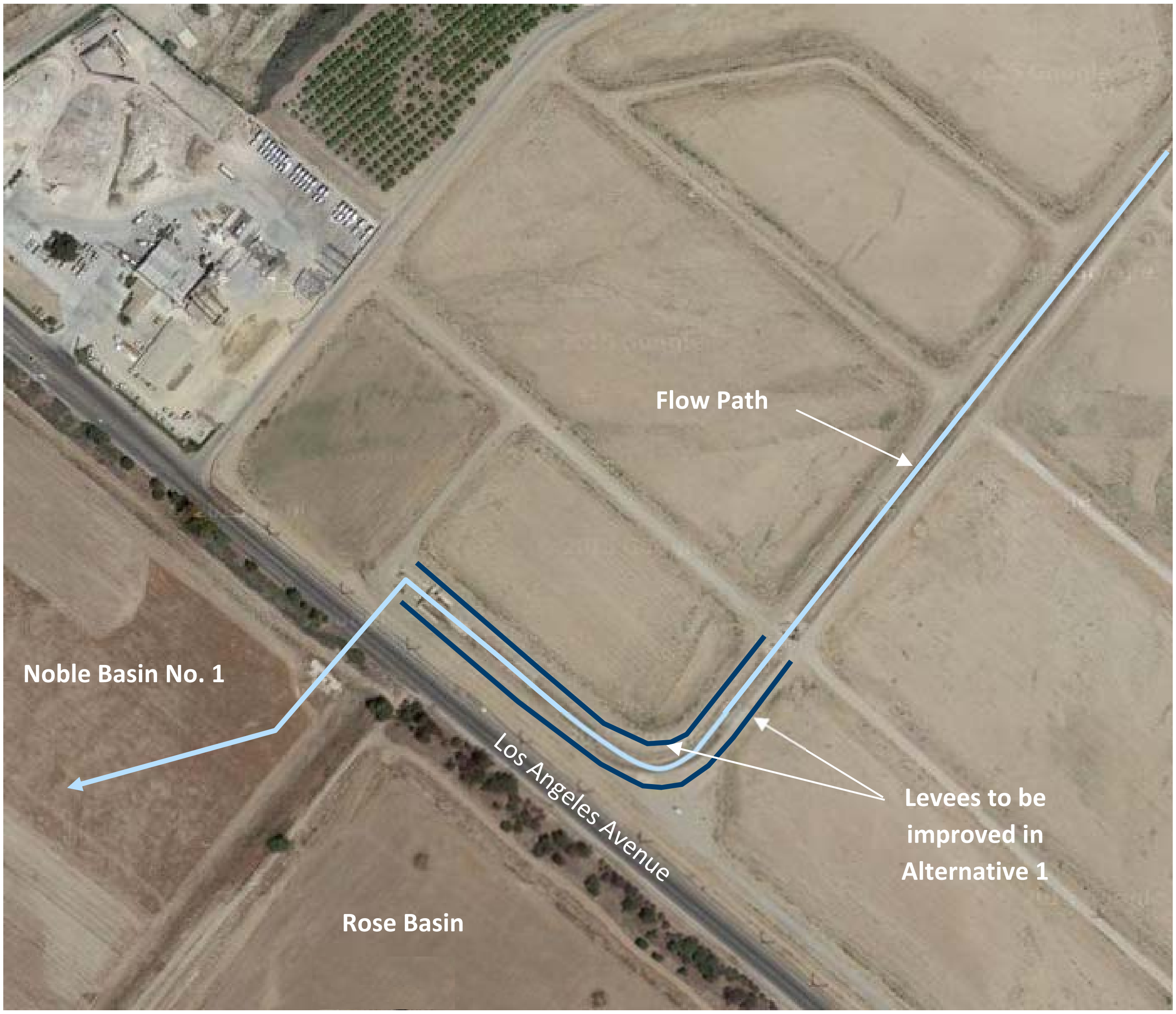

Figure 19 Lower end of the Grand Canal

Noble Basin Improvements

The partitions through the existing Noble Basins were originally sized for a maximum capacity of 375 cfs. To increase the capacity to 750 cfs additional pipes/gates through these partitions will be required.

Vineyard Crossing

To connect the lower end of Noble Basin No. 3 to the Ferro Basin, Vineyard Avenue will have to be crossed. A culvert crossing of four 6-ft diameter pipes will provide 750 cfs capacity with adequate freeboard. Under Alternative 1, the invert of this crossing is at the elevation of the bottom of the Ferro Basin at its northern end.

Ferro Basin Improvements

Without partitioning in the Ferro Basin, the capacity of the Ferro Basin is not fully utilized, due to the slope of the existing ground. Partitions with gated flow through culverts are required to maximize the available capacity.

2.4.5 Alternative 1 Minimum Improvement Plan

A minimal improvement plan along the Alternative 1 alignment would involve improving the capacity of the Grand Canal gates to ensure 375 cfs capacity, and connection of the lower Noble Basin to the Ferro Basin via a conduit beneath Vineyard Avenue. Combined with UWCD's plans for connection of the Rose Basin to upper Noble Basin, this minimal improvement plan would provide connection to all the recently acquired percolation basins and would provide conveyance capacity through the system up to the currently permitted rate.

2.4.6 Alternative 3 Conveyance Path Improvements

All alternative 3 conveyance path improvements have been sized considering two design capacities (375 cfs and 750 cfs), and two resistance scenarios (earthen channel and concrete lined channel).

Bifurcation Structure

Located just upstream of the three barrel culvert, this gated structure will include a culvert downstream of the gates to allow the road to cross. The existing gates at the three barrel culvert will also be used to control the bifurcated flow quantity.

New Channel Downstream to LA Avenue

The new channel will parallel the Santa Clara River, then cross the UWCD access road via a new culvert. Downstream of this culvert the new channel will be constructed along the north side of the existing Saticoy basins. Dimensions of the new channel under the four capacity/lining combinations assumed are summarized in Table 7 and Table 8. Lining of the channel allows higher slopes and smaller cross sectional area to be used because of higher allowable velocities.

Table 7 Dimensions of the Alternative 3 channel between the proposed bifurcation and the access road crossing

Option	Bottom Width ft	Side Slope (H:V)	Channel Height ft (includes 3 ft freeboard)	Invert slope (ft/ft)
Unlined, 375 cfs	17	2:1	7.0	0.0015
Unlined, 750 cfs	18	2:1	8.5	0.0015
Lined, 375 cfs	6	1.5:1	7.0	0.0028
Lined, 750 cfs	9	1.5:1	8.0	0.0015

Table 8 Dimensions of the Alternative 3 channel between the access road crossing and LA Avenue

Option	Bottom Width ft	Side Slope (H:V)	Channel Height ft (includes 3 ft freeboard)	Invert slope (ft/ft)
Unlined, 375 cfs	15	2:1	7.0	0.00188
Unlined, 750 cfs	20	2:1	8.0	0.0018
Lined, 375 cfs	9	1.5:1	6.0	0.00283
Lined, 750 cfs	10	1.5:1	7.0	0.0032

New LA Avenue Crossing

A new crossing at LA Avenue will be constructed to connect the Alternative 3 channel from the Saticoy Basin side to the Noble Basin side. This new channel will remain elevated on both sides of this crossing (in contrast to the existing LA Avenue crossing at the downstream end of the Grand Canal, which drops to the floor elevation of Noble Basin No. 1).

New Channel Paralleling the Noble Basins

The new channel will parallel the east and northern boundaries of the Noble Basins, requiring some fill of the existing side slopes. The channel will cut through the existing partitions which divide the basins. Channel dimensions are summarized in Table 9.

Table 9 Dimensions of the Alternative 3 channel paralleling the Noble Basins

Option	Bottom Width ft	Side Slope (H:V)	Channel Height ft (includes 3 ft freeboard)	Invert slope (ft/ft)
Unlined, 375 cfs	11	2:1	7.0	0.00263
Unlined, 750 cfs	21	2:1	8.0	0.00124
Lined, 375 cfs	7	1.5:1	6.0	0.00233
Lined, 750 cfs	8	1.5:1	7.0	0.00442

Vineyard Crossing

Under Alternative 3, a higher elevation crossing of Vineyard Avenue is proposed, connecting the new channel paralleling the perimeter of the Noble and Ferro basins.

Ferro Basin Improvements

Improvements to the Ferro Basin under Alternative 3 include the construction of a new brim channel paralleling the eastern and northern perimeter, and new partitions with nominal flow though capacity. The new brim channel will require some fill of the existing side slopes. Outlet gates with pipes from the new channel bottom to the basin invert in each partition of the basin will be required. The dimensions of the Ferro Basin channel are summarized in Table 10.

Table 10 Dimensions of the Alternative 3 channel paralleling the Ferro Basin

Option	Bottom Width ft	Side Slope (H:V)	Channel Height ft (includes 3 ft freeboard)	Invert slope (ft/ft)
Unlined, 375 cfs	13	2:1	7.0	0.00233
Unlined, 750 cfs	22	2:1	8.0	0.00169
Lined, 375 cfs	7	1.5:1	6.5	0.00233
Lined, 750 cfs	8	1.5:1	7.0	0.00241

3 HYDRAULIC, SEDIMENT TRANSPORT AND YIELD ASSESSMENT

3.1 Hydraulic Models

The US Army Corps of Engineers' HEC-RAS program was used for development of hydraulic models of the alternatives examined for this study. The existing hydraulic model of the Vern Freeman conveyance system developed in the Phase 1 study was used as a starting point for the sizing and evaluation analysis conducted for each alternative. The models were used to aid in preliminary sizing of the individual components under each alternative, and for evaluation of the hydraulic characteristics throughout the diversion system under optional routing scenarios (i.e. bypassing the existing desilting basin, bypassing Pond B, etc.). Schematic views of two of the hydraulic models developed for this study are shown in **Figure 20** and **Figure 21**.

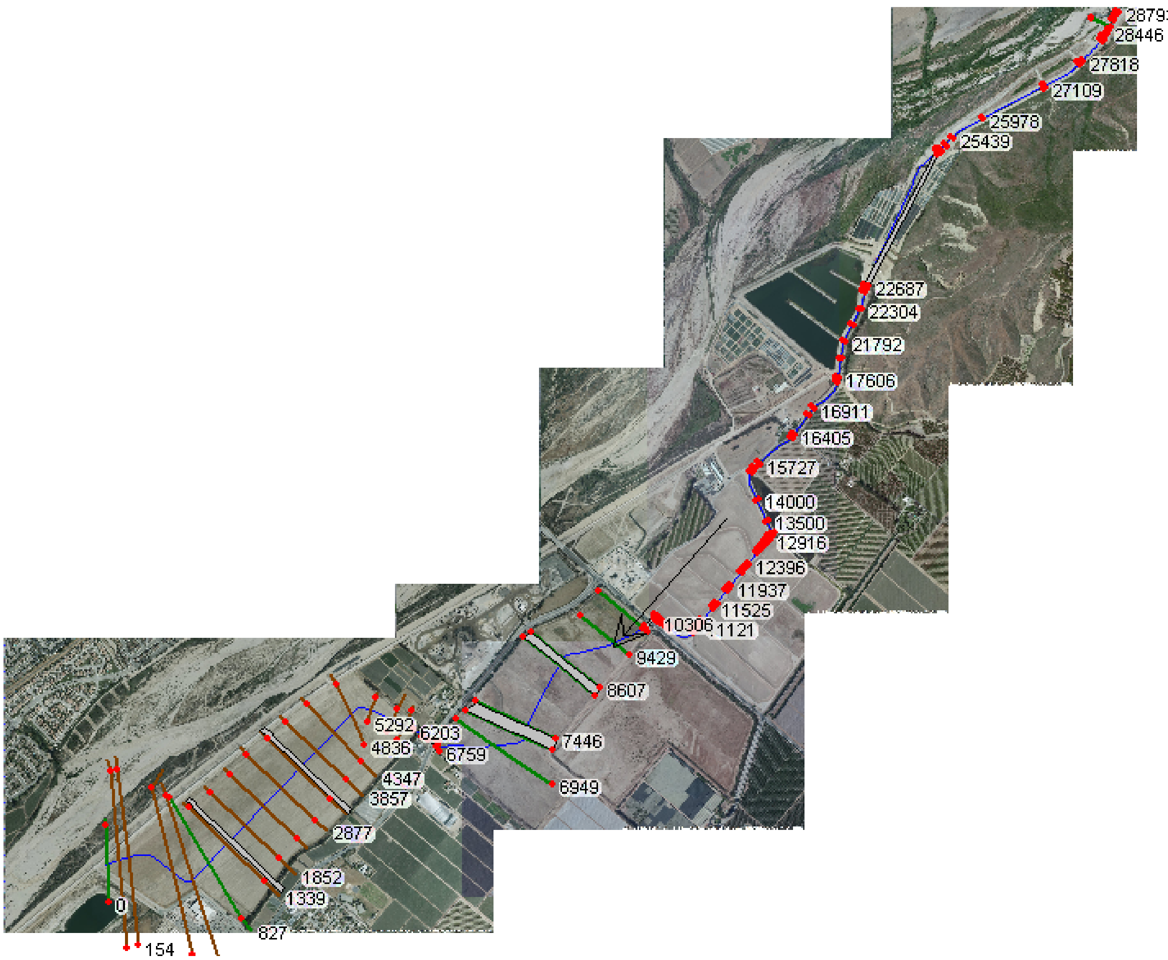

Figure 20 Alternative 1 cross-section layout schematic (Option: bypassing the existing desilter and Pond B, flowing through the Noble and Ferro Basins)

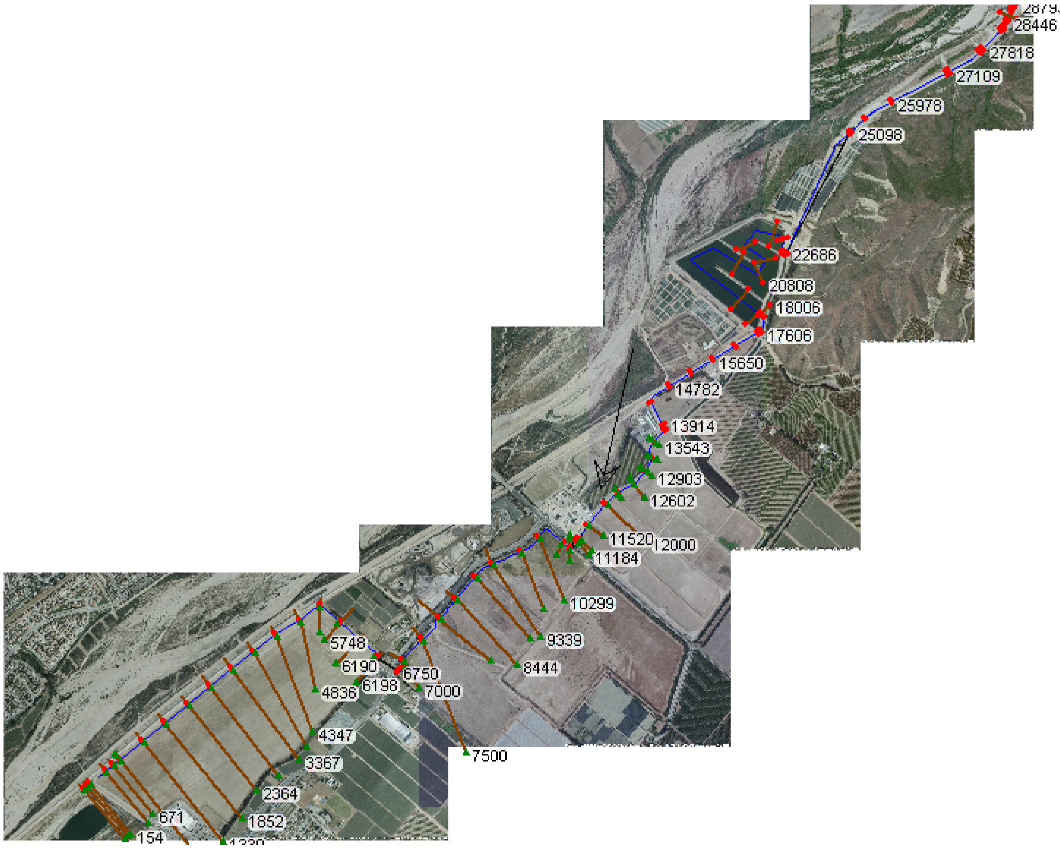

Figure 21 Alternative 3 cross-section layout schematic (Option: routed through the existing desilter and following the new direct flow path paralleling the Noble and Ferro Basins)

3.2 Hydraulic and Sediment Transport Analysis Results

The alternative component sizing and evaluation process began with examination of locations of conveyance deficiency within the existing conveyance system. Both Alternatives 1 and 3 include reaches of the existing conveyance system that will require modification. Components of each alternative were sized and evaluated in a progressive manner beginning at the downstream end of the system. For example, under existing conditions, some limitations in capacity are evident in the reach of the Saticoy Canal between the existing desilting basin and the Grand Canal. Hydraulic simulations indicate that significant improvement in conveyance capacity is achieved in this reach with improvement of the inlet gate at the upstream end of the Grand Canal. With local improvement at this inlet, some of the upstream deficiencies are alleviated, as shown in **Figure 22**.

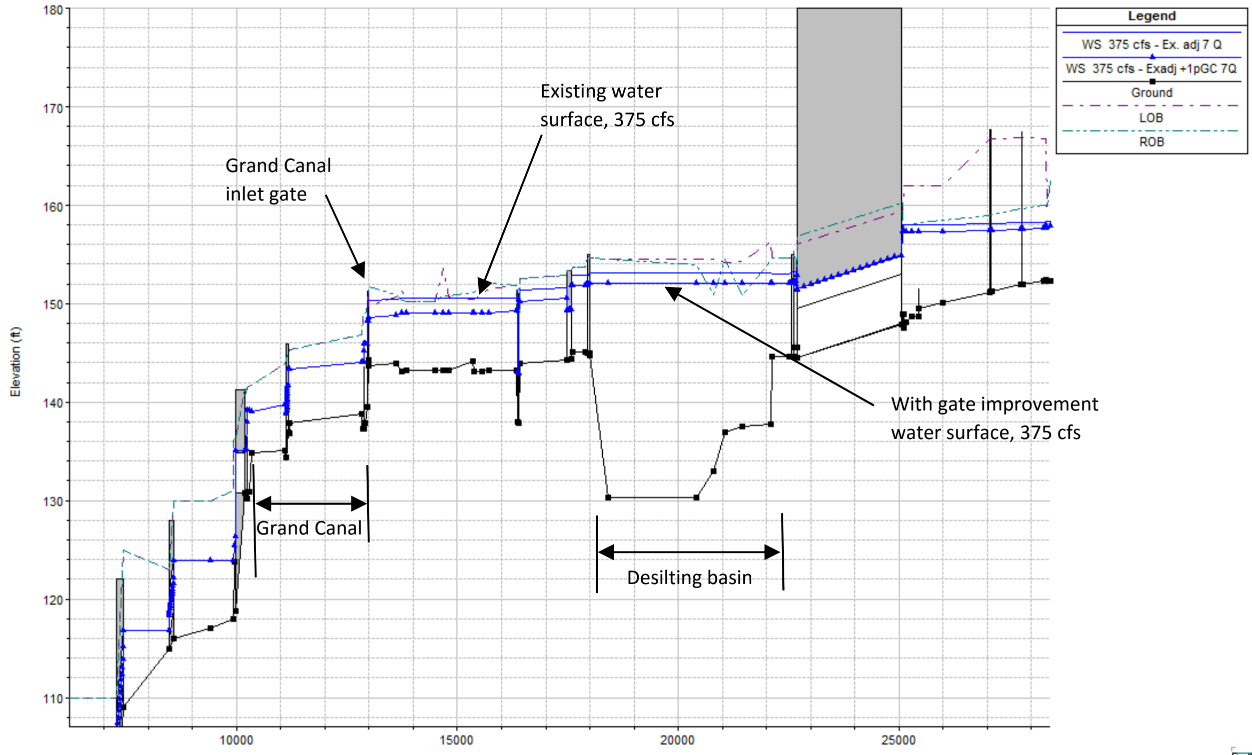

Figure 22 Water surface profiles, with and without improvement of the Grand Canal inlet gate

The hydraulic models developed for sizing the components of the alternatives were also used for evaluation of sediment transport capabilities of the proposed conveyance systems. Sediment transport simulations were conducted using the quasi-unsteady simulation routines available in the HEC-RAS model. The Yang sediment transport equations were applied in these simulations, and transport/deposition of the full range of available sediment sizes were approximated. Sediment transported in the Santa Clara River includes silts and clays – materials that are finer than the sizes used in development of the Yang transport equations. The erosion and deposition rates of these smaller particles are only approximated by extrapolation of the Yang relations, because the chemical and cohesive properties are not addressed. In addition, processes such as coagulation and flocculation in the desilting basin (due, for example, to the addition of flocculation agents) and re-suspension by wind are not addressed in the simulations. The extrapolation is considered reasonable for a first estimate of transport capacities under idealized natural (unassisted) conditions. Sediment loading rating curves matching those applied in the Phase 1 study simulation were applied at the top of the model, and steady flow simulations were run for several days to determine trends in expected sediment concentration variation down the length of each model.

Both hydraulic and sediment transport capacities were considered in the design of the alternative components. The final configurations were then examined under the variable routing scenarios that would be available with implementation of each alternative.

Representative hydraulic and sediment transport results for several alternative and routing scenarios are presented in **Figure 23** through **Figure 27**. These figures illustrate the invert and water surface profiles, the channel velocity variation, and the sediment concentration profiles computed for the specified alternative and routing combinations under a discharge of 750 cfs. Note that the channel profile, length, and hydraulic and sediment transport characteristics vary considerably between alternatives. A notable drop in flow velocity and sediment concentration is evident as flows pass through the fish screen at the upstream end of the model, and through the existing desilting basin and Pond B (when they are not bypassed). Other channel reaches have transport capacities that exceed that of the fish screen. Therefore, sediment which passes the fish screen can generally be conveyed by the other channel reaches.

The unlined options for the new flow path of Alternative B were designed to have average flow velocities of 5 ft/sec or less to avoid channel scour (see **Figure 26**, for example). This requirement results in a much flatter-sloped channel for the new unlined option as compared to the lined case (compare channel profiles in **Figure 26**and **Figure 27**).

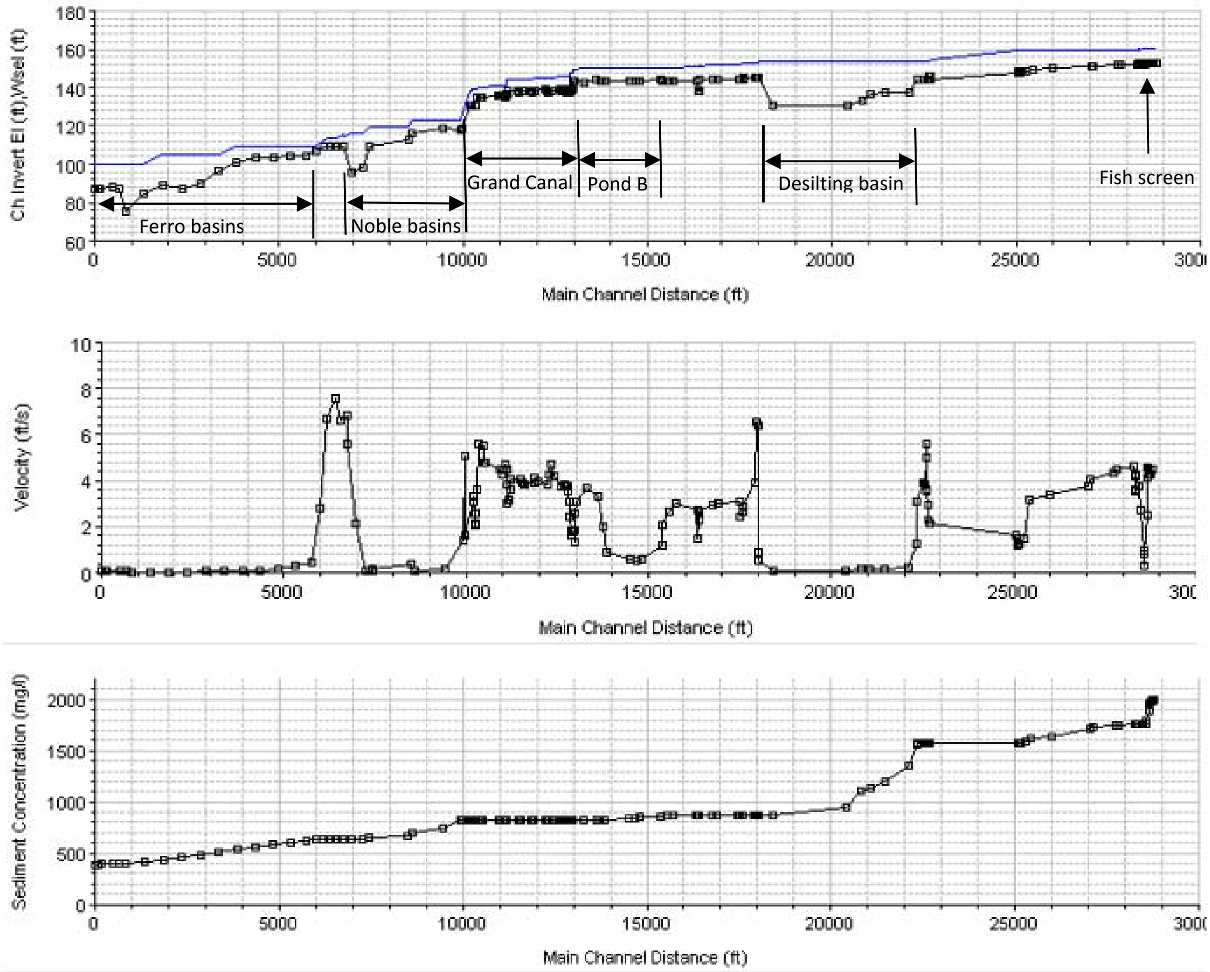

Figure 23 Alternative 1 routed through the existing desilting basin and through Pond B at 750 cfs. Top = invert and water surface profie; Middle = channel velocity plot; Bottom = sediment concentration plot.

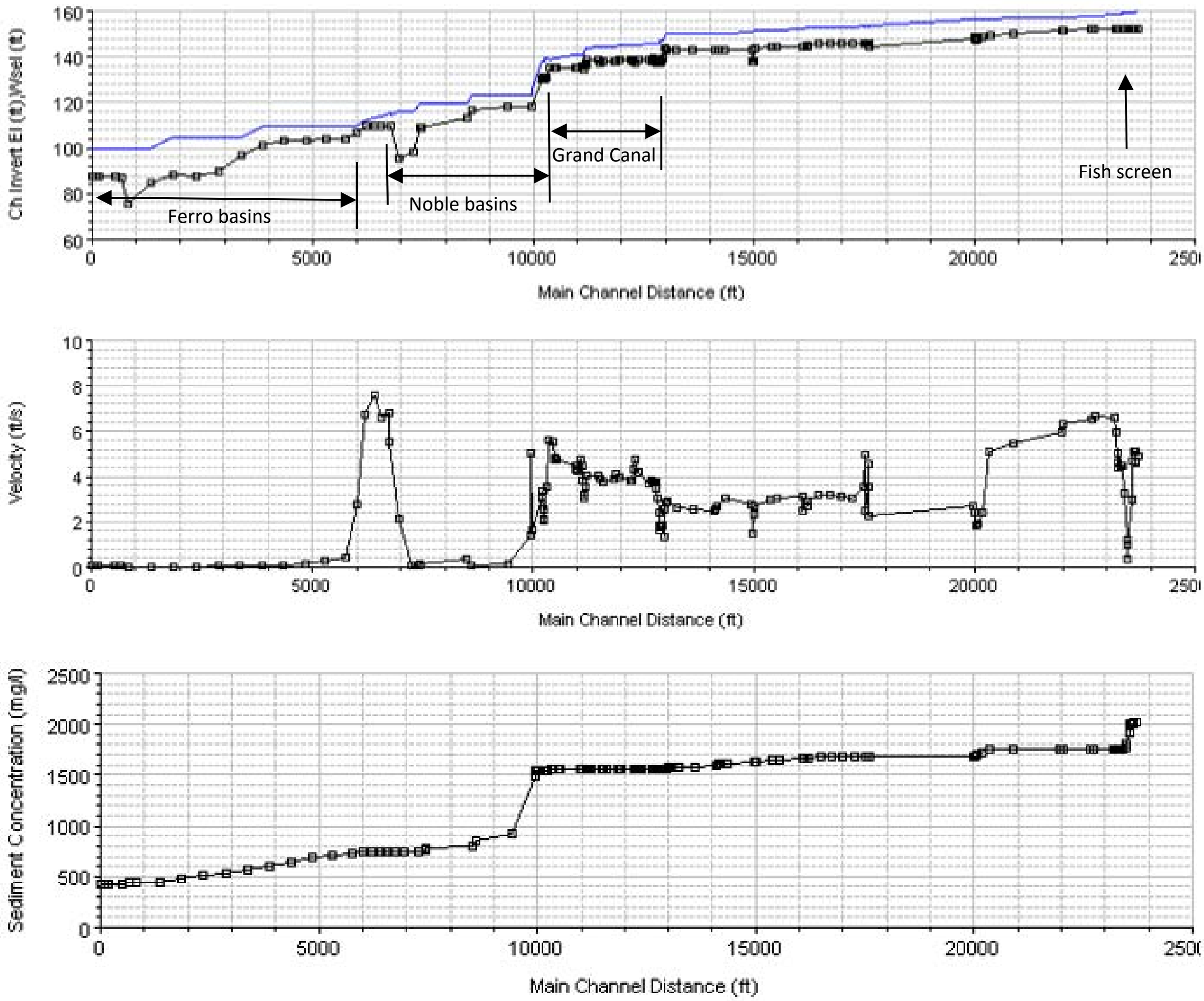

Figure 24 Alternative 1 bypassing the existing desilting basin and Pond B at 750 cfs. Top = invert and water surface profie; Middle = channel velocity plot; Bottom = sediment concentration plot.

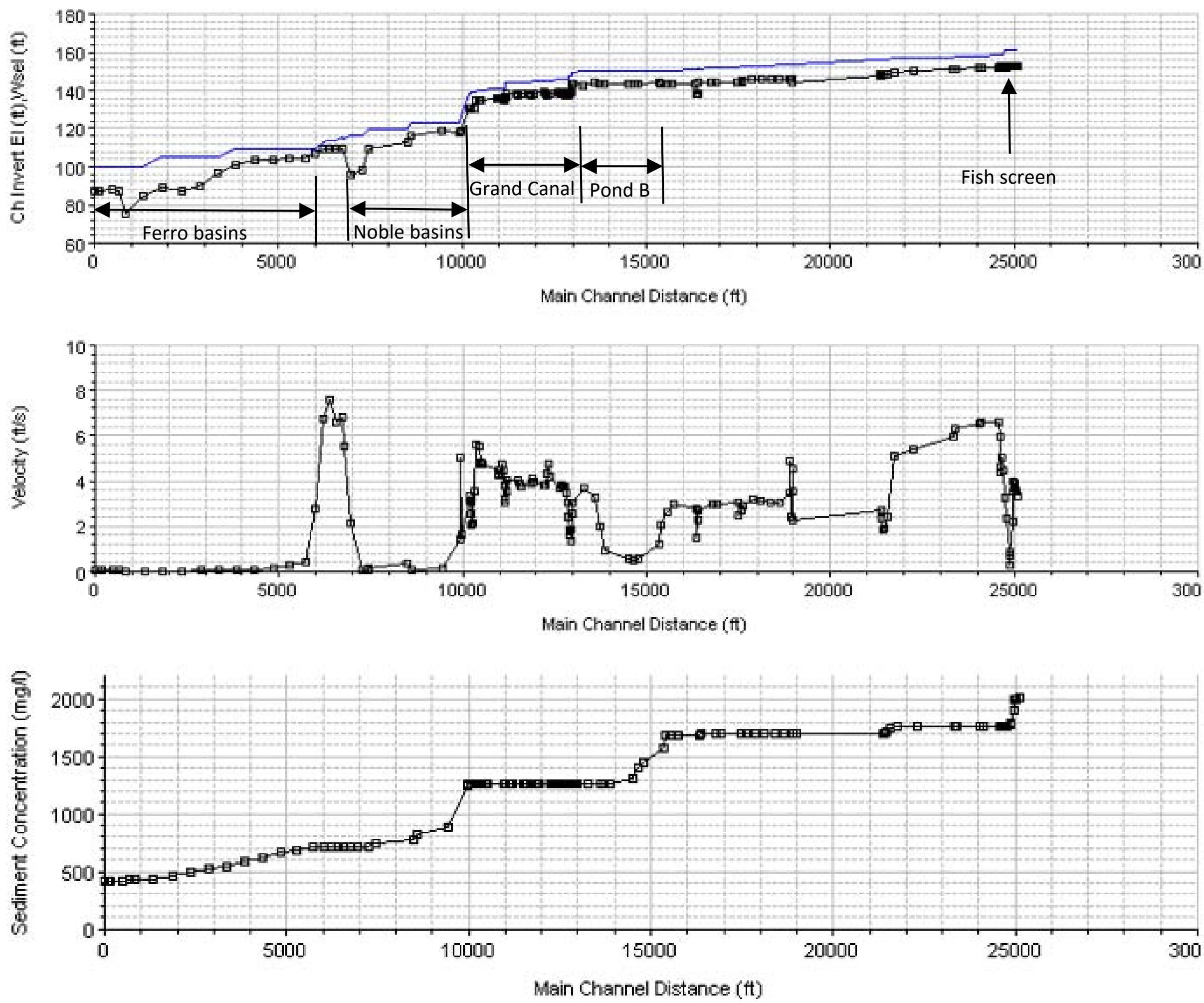

Figure 25 Alternative 1 bypassing the existing desilting basin and routed through Pond B at 750 cfs. Top = invert and water surface profie; Middle = channel velocity plot; Bottom = sediment concentration plot.

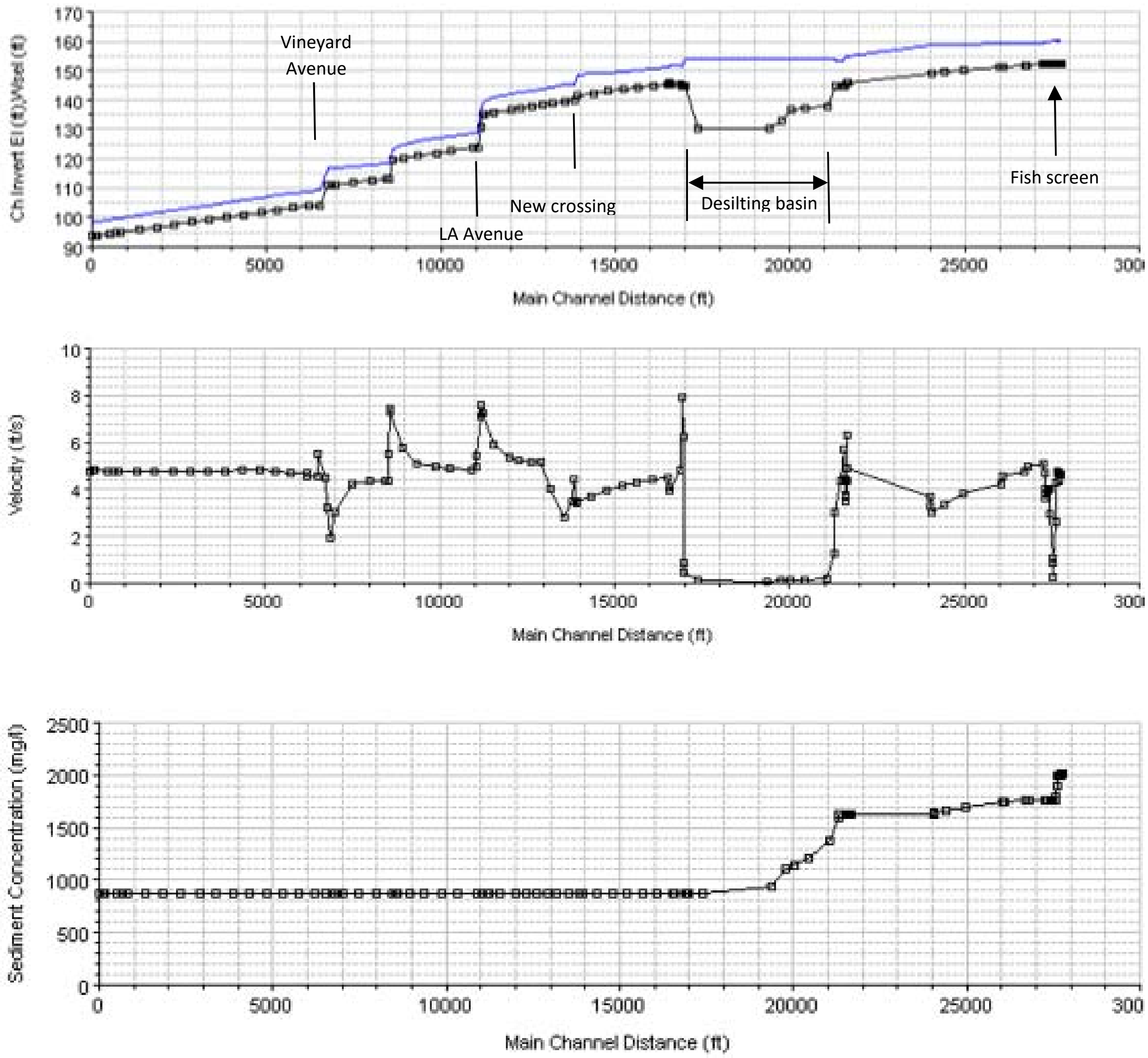

Figure 26 Alternative 3 routed through the existing desilting basin and following the new (unlined) channel paralleling the Noble and Ferro Basins at 750 cfs. Top = invert and water surface profile; Middle = channel velocity plot; Bottom = sediment concentration plot.

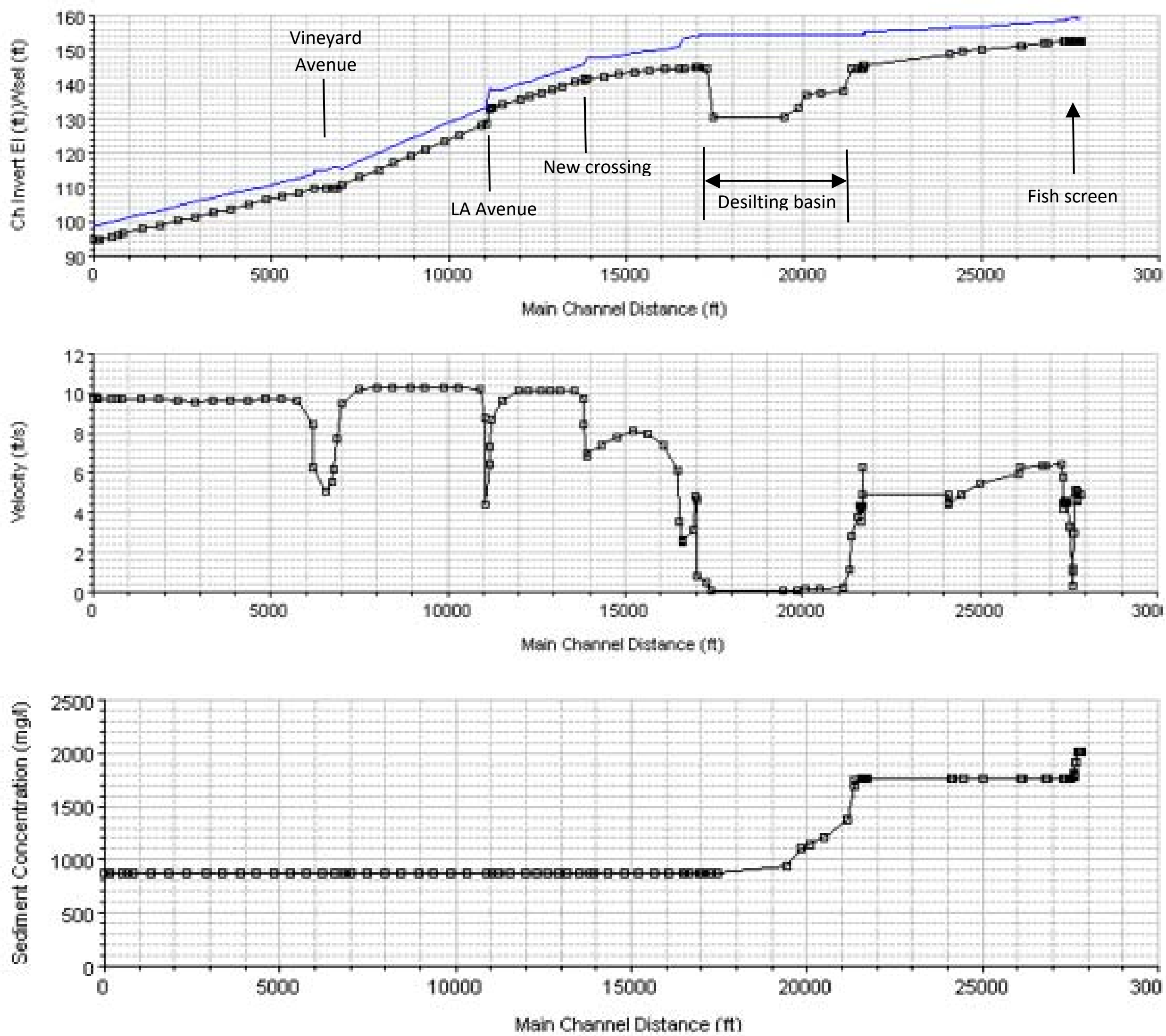

Figure 27 Alternative 3 routed through the existing desilting basin and following the new (lined) channel paralleling the Noble and Ferro Basins at 750 cfs. Top = invert and water surface profile; Middle = channel velocity plot; Bottom = sediment concentration plot.

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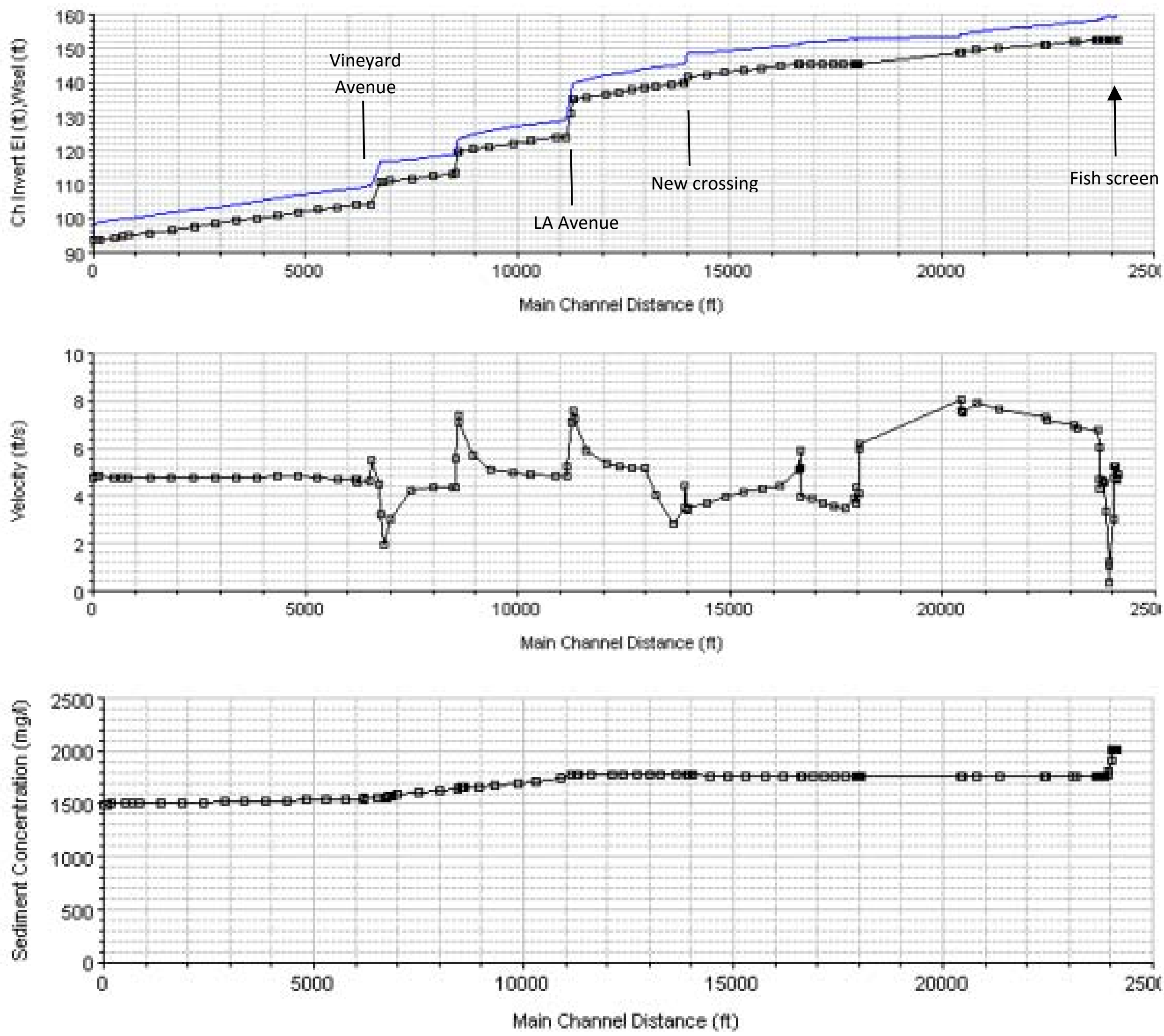

Figure 28 Alternative 3 bypassing the existing desilting basin and following the new (unlined) channel paralleling the Noble and Ferro Basins at 750 cfs. Top = invert and water surface profile; Middle = channel velocity plot; Bottom = sediment concentration

3.3 Yield

Version 3.8 of the Freeman Yield Model developed by UWCD was used to estimate the water yield and sediment capture of the improved diversion system under a range of operations conditions and assumptions. In each of these simulations, the system was assumed to have been improved to handle the flow and sediment discharge capacities indicated. Also, for the simulations examined, the additional containment and infiltration capacities provided by the (future) inclusion of the Rose and Ferro Basins were assumed available. Estimated flow and sediment concentration data for the Santa Clara River over the 1944 through 2014 period are contained in the model.

The simulations were conducted to evaluate the potential benefits associated with the use of the Ferro Basin as a direct destination of turbid flows, compared to operations which pass all flows through the existing desilting basin.

Low flows in the Santa Clara River tend to carry less sediment – they are in general less turbid – than flows of high magnitude. Flow availability for diversion from the Santa Clara River increases as higher turbidity flows become acceptable (or manageable) in the diversion system, as indicated in **Figure 29**.

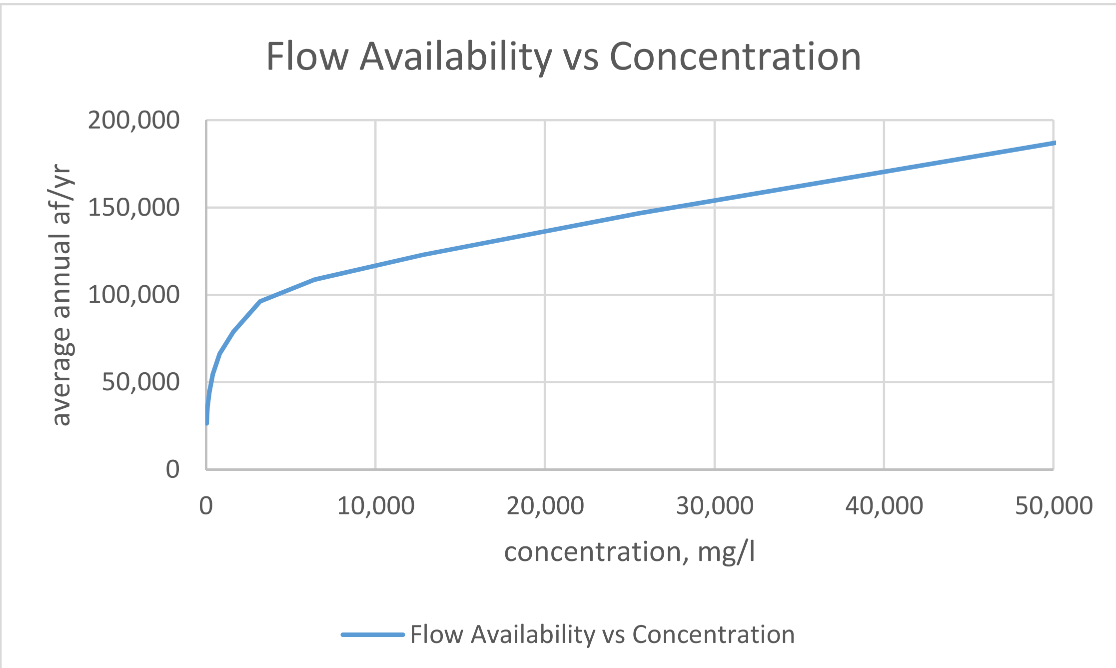

Figure 29 Average annual flow available from the Santa Clara River versus sediment concentration limit,1944-2014 water years

Higher concentration flows become less frequent as the concentraion level increases, as shown in **Figure 30**. Daily flows with average concentrations exceeding 2,000 mg/l are expected approximately 10 days per year on average, according to the model record, whereas concentrations of 20,000 mg/l or greater are approximately 10 times less frequent, occuring on average about 1 day per year.

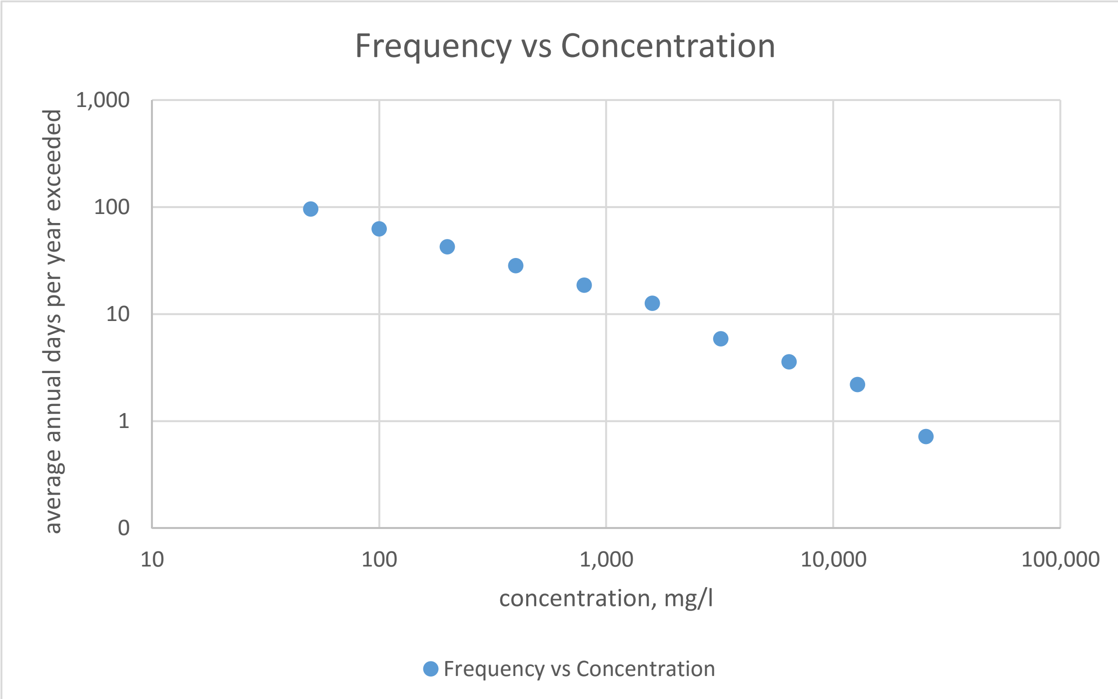

Figure 30 Average annual days of flow versus sediment concentration limit in the Santa Clara River, 1944-2014 water years

The estimated flow and sediment concentration record for Santa Clara River, together with system volume capacities and local infiltration rates, are used in UWCD's yield model to determine the amount of flow and sediment captured by the diversion system given user-supplied operations rules. UWCD's application of the yield model indicate that recent actual operations and turn-out record at the Freeman Diversion are reasonably matched by the yield model if the simulated diversions are halted when river flow concentrations reach 2,580 mg/l. Using this as a base, alternative simulations were run, varying maximum diversion rates and maximum concentration levels for higher turbidity flows to be captured (flows that would normally be bypassed). In these simulations, the system passes flows at normal turbidity levels through the existing desilting basin and on to the existing and proposed recharge facilities, as would occur under today's operations rules. However, in addition to these flows, some flows that would normally be bypassed due to higher turbidity levels are captured, when capacities allow, via direct transit to the Ferro Basin (bypassing the existing desilting basin). The yield model allows both the maximum diversion rate and the maximum allowable concentration of these 'extra' flows to be input by the user.

The average annual number of days that the Ferro Basin would receive flow under variable diversion rates and variable maximum concentrations are plotted in **Figure 31**. Note that this figure shows total days of flow received at the Ferro Basin, which includes flows received during both normal and higher turbidity days (i.e., through the expanded conveyance system ending at Ferro and through the direct diversion to Ferro). The simulations indicate that the number of days that the Ferro Basin would receive high turbidity flows is independent of the maximum diversion rate, and are a function of the maximum concentration level only. This relation is plotted in **Figure 32**. The model results indicate that Ferro Basin would receive high turbidity flows on a surprisingly few number of days (on an average annual basis), even with high maximum concentration limits allowed for the captured flows. This result reflects the relatively low frequency of flow events of high sediment concentration occuring at times when excess storage is simulated by the model to be available in the Ferro Basin.

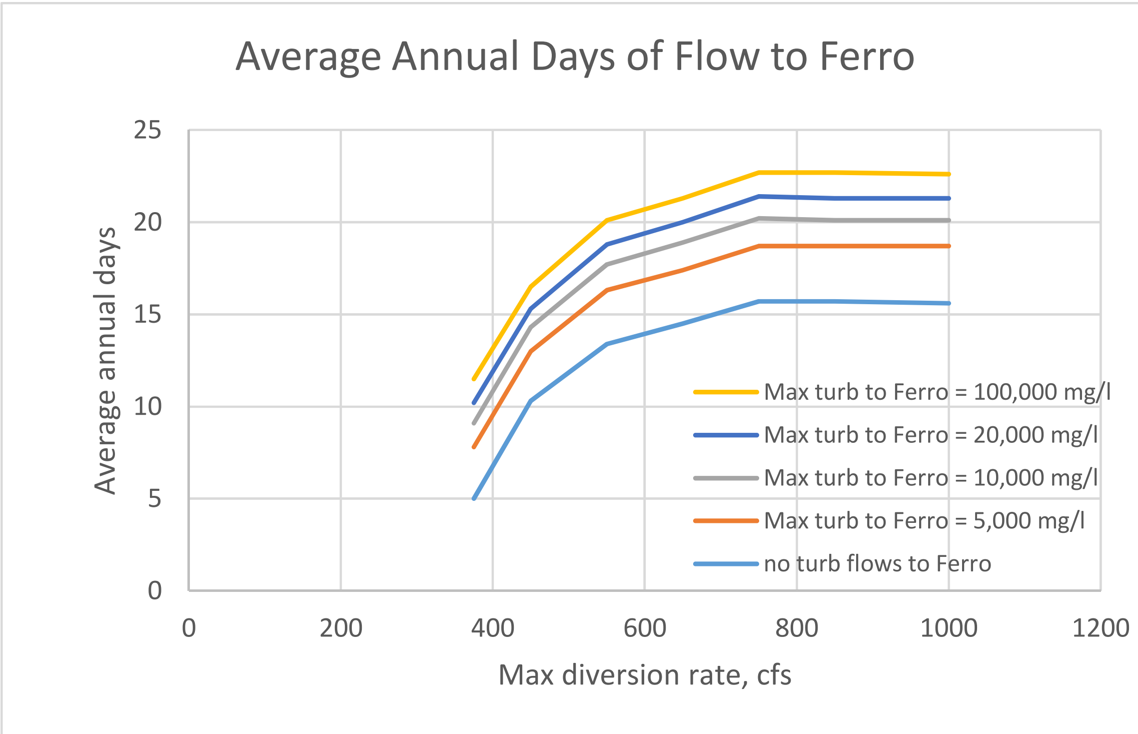

Figure 31 Average annual days of flow to the Ferro Basin versus maximum diversion rate, for a range of direct-to-Ferro turbidity (sediment concentration) limits and assuming the maximum sediment concentration passing to the existing desilting basin = 2,580 mg/l

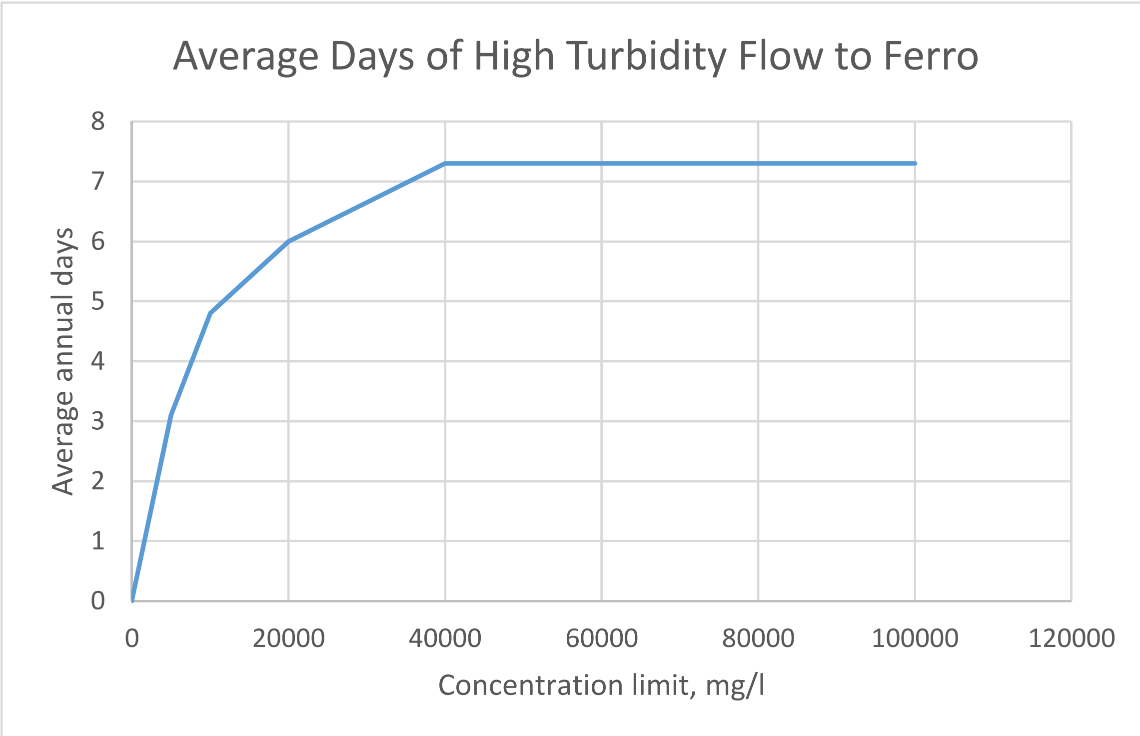

Figure 32 Average annual days of high turbidity flow to the Ferro Basin versus maximum concentration limit for direct-to-Ferro flows, assuming the maximum sediment concentration passing to the existing desilting basin = 2,580 mg/l

The total amount of flow captured in the system under variable diversion rates and maximum allowable concentrations is illustrated in **Figure 33**. The lowest line in **Figure 33** represents the flow yield without 'extra' diversions direct to the Ferro Basin, and the remaining lines represent the flow yielded under scenarios with varying maximum allowable concentrations for the direct-to-Ferro diversions. The amount of extra flow captured due to the addition of the direct diversions to the Ferro Basin under these same scenarios is illustrated in **Figure 34**. The additional yield captured due to increasing the maximim allowable concentration of the diverted flow tends to diminish with both increasing concentration rates and increasing diversion rates, as shown in **Figure 34**.

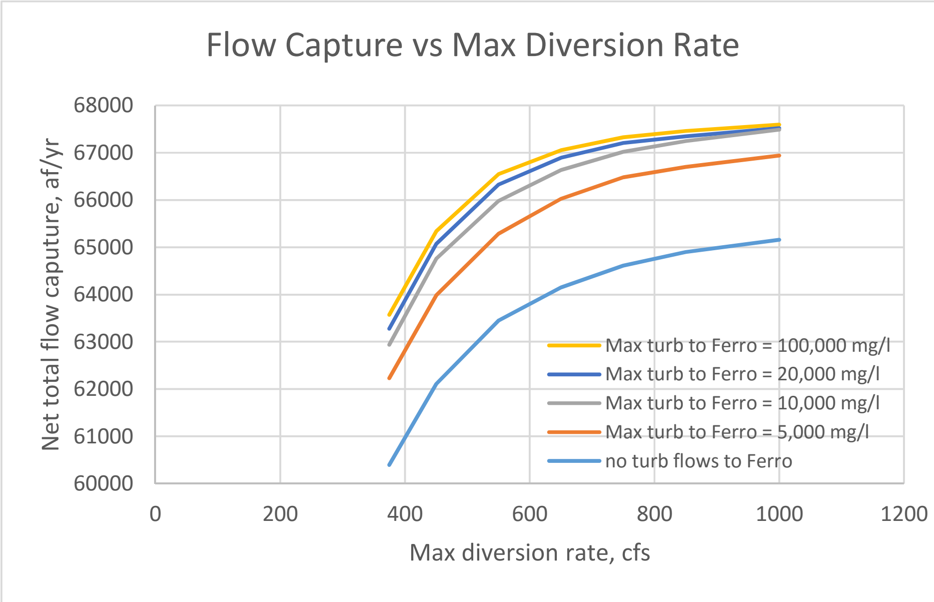

Figure 33 Average annual net flow capture versus maximum diversion rate, for a range of direct-to-Ferro turbidity (sediment concentration) limits and assuming the maximum sediment concentration passing to the existing desilting basin = 2,580 mg/l

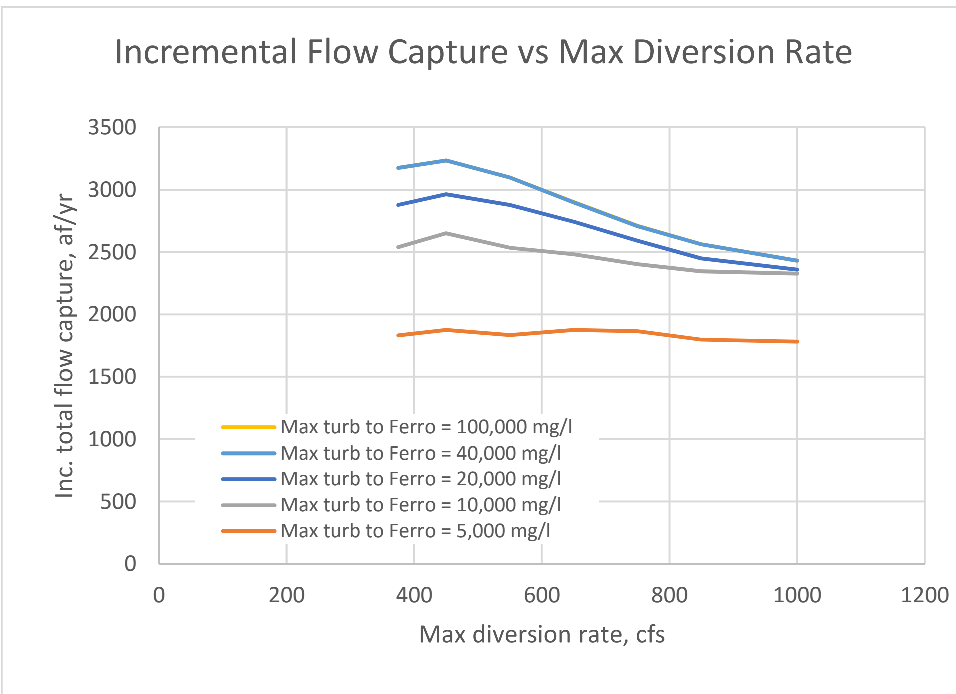

Figure 34 Average annual incremental flow capture versus maximum diversion rate, for a range of direct-to-Ferro turbidity (sediment concentration) limits and assuming the maximum sediment concentration passing to the existing desilting basin = 2,580 mg/l

The total amount of sediment captured in the existing desilting basin and the Ferro Basin under variable diversion rates and maximum allowable concentrations is illustrated in **Figure 35**, given the model assumption of 100% sediment capture in the basins. The lowest line in **Figure 35** represents the sediment captured in the existing desilting basin without 'extra' diversions direct to the Ferro Basin, and the remaining lines represent the total sediment capture (existing desilting basin plus Ferro Basin) under scenarios with varying maximum allowable concentrations for the 'extra' Ferro diversions. The amount of sediment captured in the Ferro Basin alone under these same scenarios is illustrated in **Figure 36**. The expected magnitude of sediment capture in the Ferro Basin is highly sensitive to the maximum concentration variable (up to about 40,000 mg/l), but very insensitive to the maximum diversion rate, as shown in **Figure 36**.

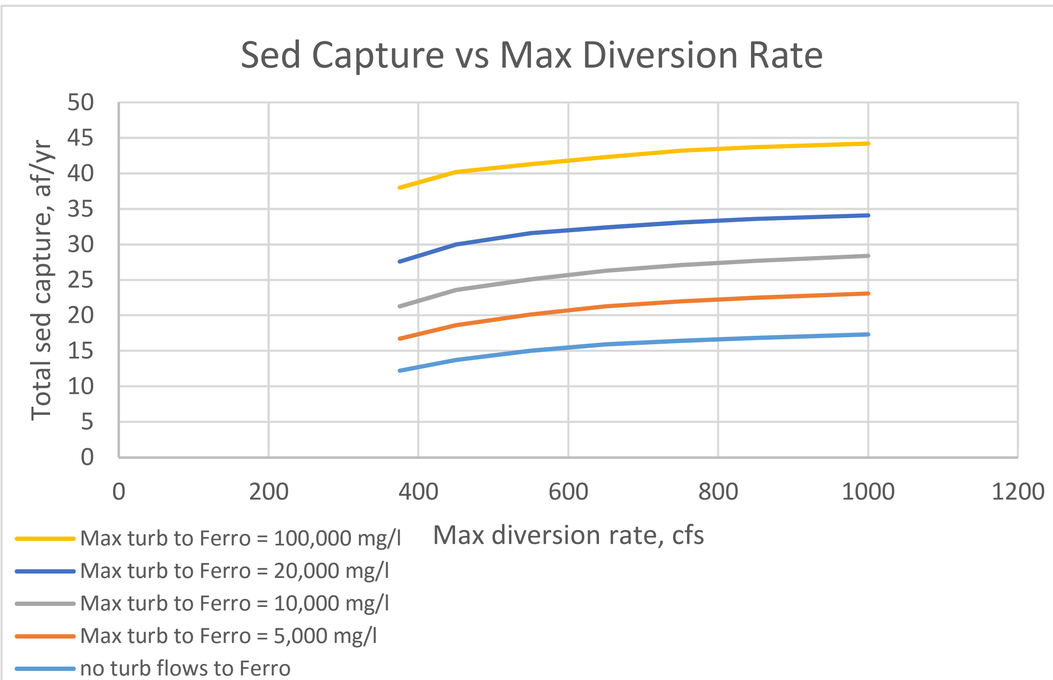

Figure 35 Average annual sediment capture versus maximum diversion rate, for a range of direct-to-Ferro turbidity (sediment concentration) limits and assuming the maximum sediment concentration passing to the existing desilting basin = 2,580 mg/l

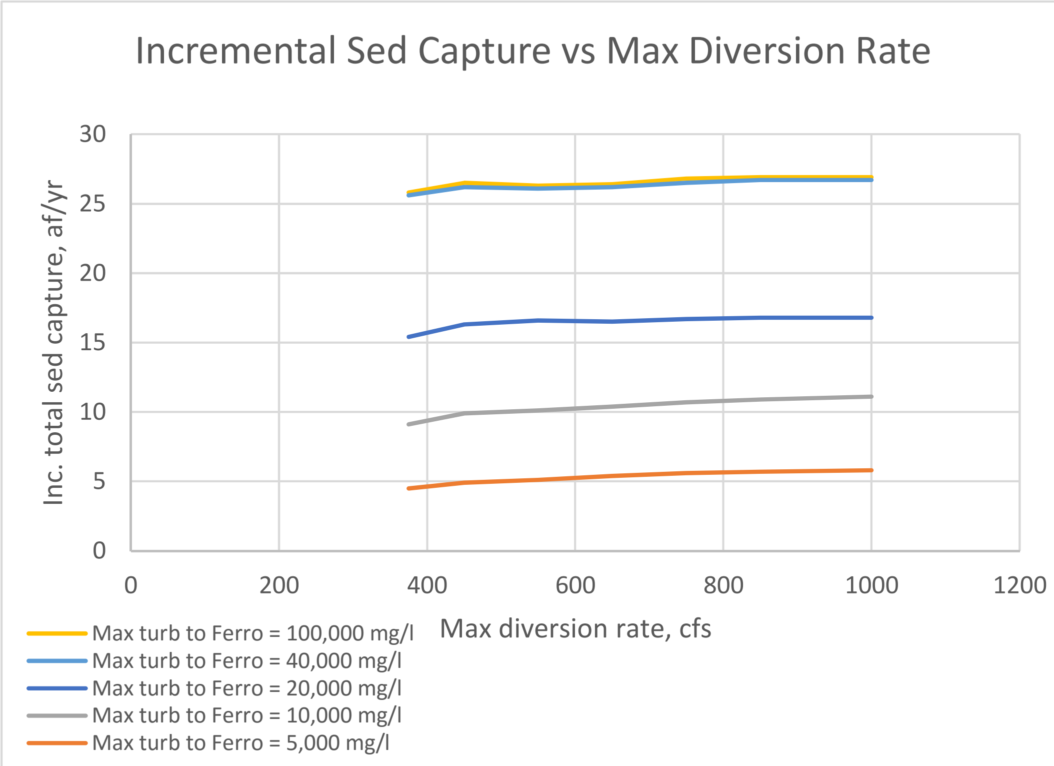

Figure 36 Average annual sediment capture in the Ferro Basin versus maximum diversion rate, for a range of direct-to-Ferro turbidity (sediment concentration) limits and assuming the maximum sediment concentration passing to the existing desilting basin = 2,580 mg/l

The diversion simulation results presented above all represent scenarios that assume normal operations (with flows passing through the existing desilting basin) when sediment concentrations in the Santa Clara River are 2,580 mg/l or less. Flows are directed to the Ferro Basin (bypassing the existing desilter) during diversions of flows at higher concentrations. To test the sensitivity of the results to the 2,580 mg/l constraint on normal operartions, this cap on diversions to the existing desilting basin was also varied. Initially, scenarios were run assuming two maximum concentration levels for flows directed to the Ferro Basin, 10,000 mg/l and 20,000 mg/l. The maximum concentration for flow passing through the existing desilting basin was increased incrementally. The results are shown in **Figure 37**.

The results illustrated in **Figure 37** indicate that the computed yield at any maximum diversion rate increases as the maximum concentration allowed to pass into the existing desilting basin increases. The maximum yield occurs when the cap on concentrations passing though the desilting basin equals the cap on concentrations passing directly to Ferro (that is, when all diverted flows pass through the existing desilting basin). And yield continues to increase as that cap is raised, up to about 40,000 mg/l, after which no appreciable gain in yield is achieved, as shown in **Figure 38** (likely due to the lack of available storage capacity and/or opportunities for diversions at these higher concentrations).

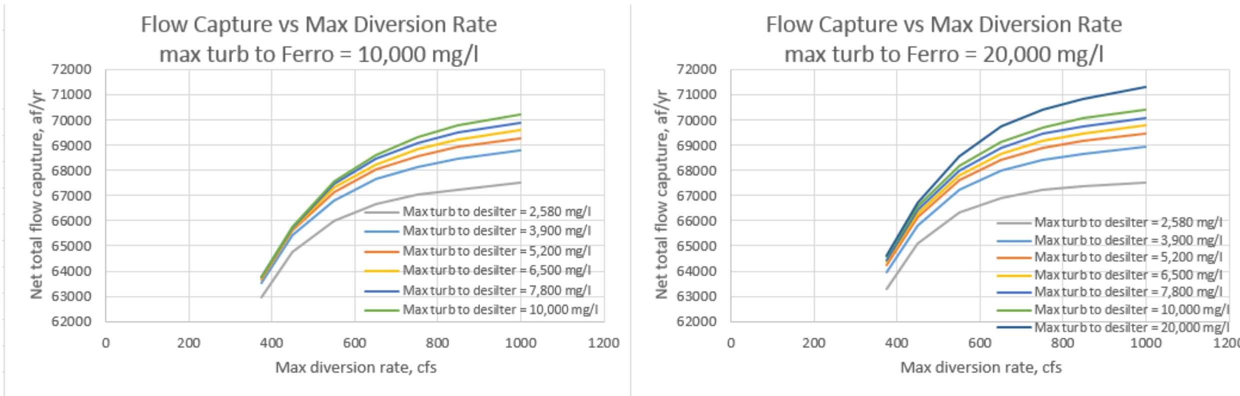

Figure 37 Average annual net flow capture versus maximum diversion rate, for a range of turbidity (sediment concentration) limits for flows passing to the existing desilting basin and assuming the maximum sediment concentration for the direct-to-Ferro diversions = 10,000 mg/l (left) and 20,000 mg/l (right)

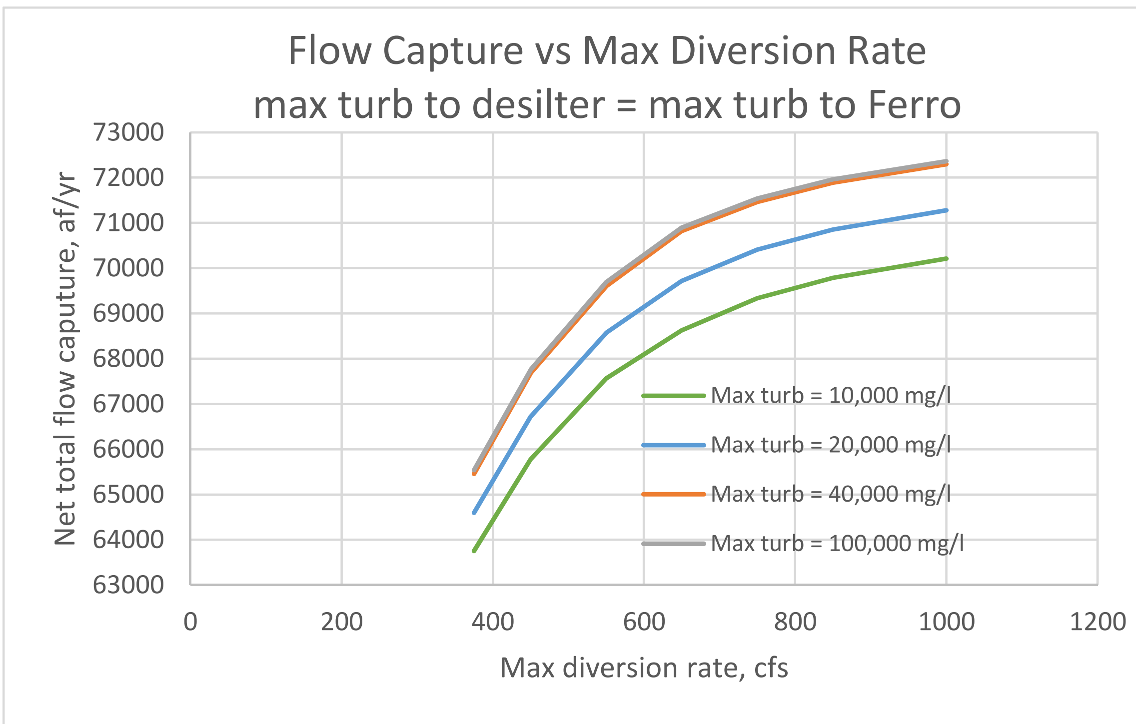

Figure 38 Average annual net flow capture versus maximum diversion rate, for a range of turbidity (sediment concentration) limits, all flows passing through the existing desilting basin

The additional yield associated with increasing the cap on concentrations delivered to the existing desilting basin (versus splitting off the high concentration flows for delivery directly to the Ferro Basin) is further illustrated in **Figure 39**. In this figure, expected yields considering maximum concentrations of 10,000, 20,000 and 40,000 mg/l are shown, with results for operations that split the high turbidity flows (with a cap of 2,580 mg/l for flows passing through the existing desilting basin) compared to those where that cap is lifted (all flows pass through the existing desilting basin). The difference in yield is significant for all diversion rates, with much greater yield associated with allowing all flows to pass through the existing desilting basin. This is due to the spreading opportunity lost with flows that are passed directly to the Ferro Basin. Those flows are available for infiltration in the Ferro Basin only, whereas flows that pass through the existing desilting basin may be directed to all of the downstream spreading facilities.

As noted above, the model assumes that sediment is entirely removed in the desilter. The ability of the desilter to remove sediment at higher flows and higher turbidities has not been tested, and the effectiveness of flocculation is under investigation. If additional sediment passes through the desilter and affects percolation rates in the downstream recharge basins, yield could be reduced.

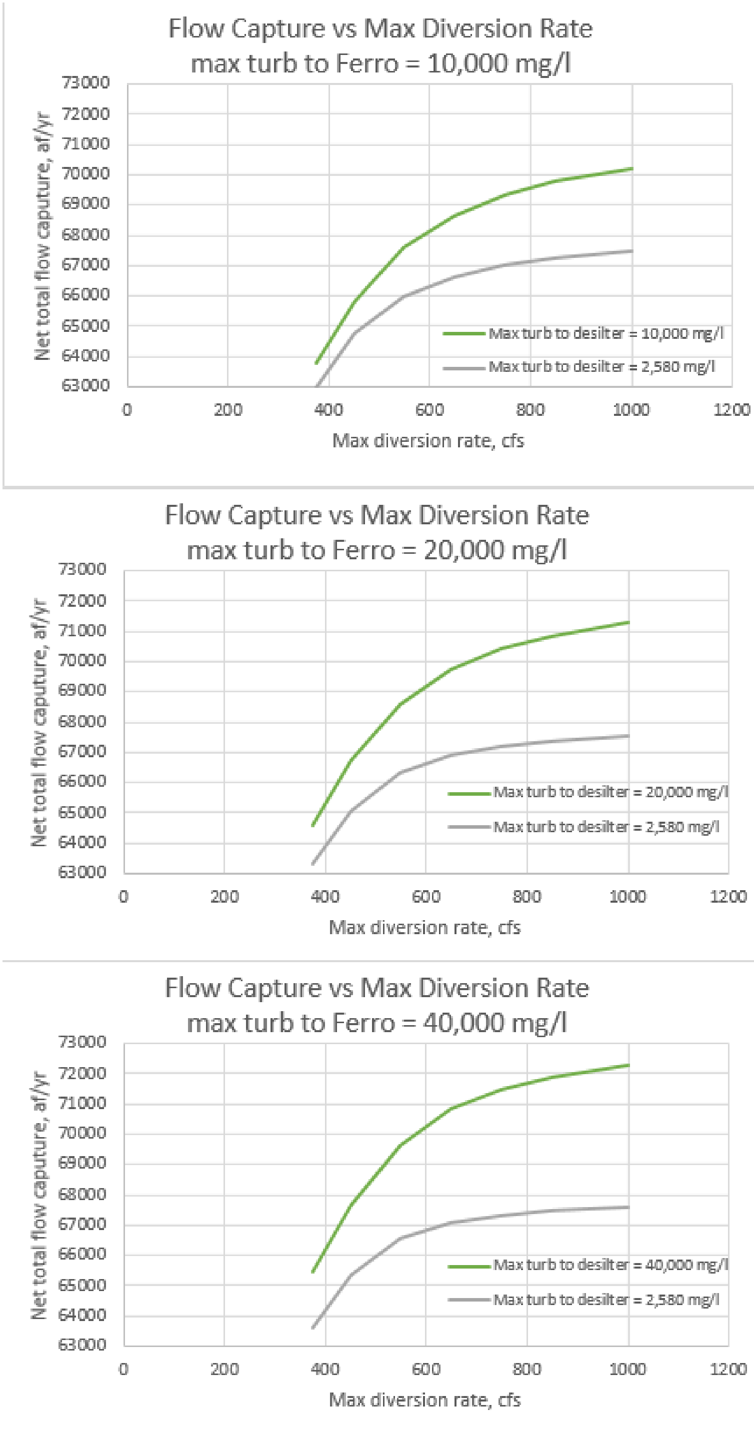

Figure 39 Average annual net flow capture versus maximum diversion rate, all flows passing through the existing desilting basin compared to flows to the existing desilting basin limited to maximum concentrations of 2,580 mg/l. Top: maximum concentration = 10,000 mg/l; Middle: maximum concentration = 20,000 mg/l; Bottom: maximum concentration = 40,000 mg/l.

The expected sediment load captured in the system under the same scenarios presented in **Figure 39** are shown in **Figure 40**. The sediment load is significantly increased as the cap is lifted on concentrations for flows passing through the existing desilting basin. However, the water yield-to-sediment capture ratio remains relatively high, even under the highest allowable concentration scenario examined, as shown in **Figure 41**.

Figure 40 Average annual sediment capture versus maximum diversion rate, all flows passing through the existing desilting basin compared to flows to the existing desilting basin limited to maximum concentrations of 2,580 mg/l. Top: maximum concentration = 10,000 mg/l; Middle: maximum concentration = 20,000 mg/l; Bottom: maximum concentration = 40,000 mg/l.

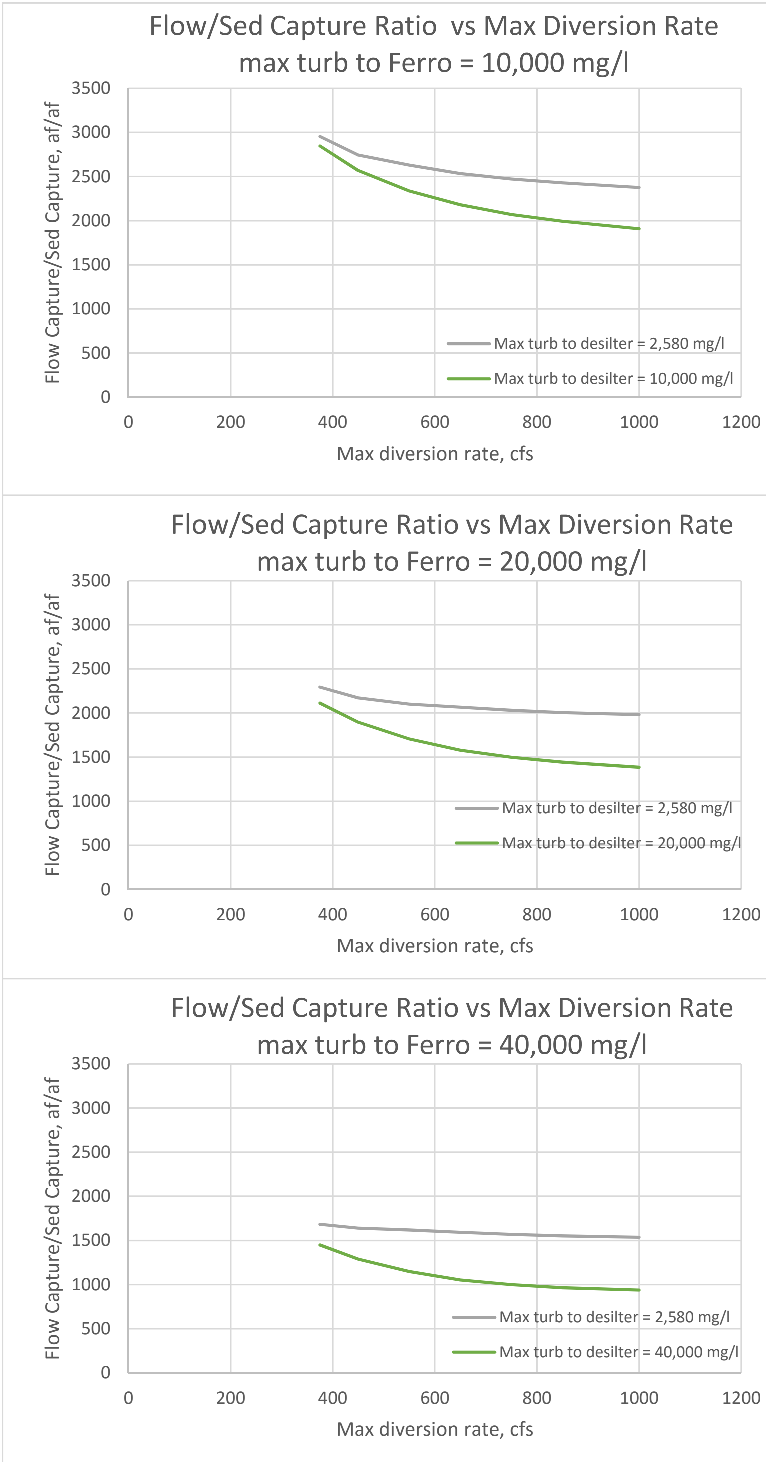

Figure 41 Flow-to-sediment capture ratio versus maximum diversion rate, all flows passing through the existing desilting basin compared to flows to the existing desilting basin limited to maximum concentrations of 2,580 mg/l. Top: maximum concentration = 10,000 mg/l; Middle: maximum concentration = 20,000 mg/l; Bottom: maximum concentration = 40,000 mg/l.

The expected average annual water yield versus maximum concentration limit for the diverted flows, with the system conveyance capacity increased to 750 cfs is shown in **Figure 42**. Two operation scenarios are contrasted in this figure: (1) all flows passing through the existing desilting basin, and (2) flows with concentrations higher than 2580 mg/l are diverted directly to the Ferro basin. Water yields progressively increase with increasing maximum concentration limit under scenario (1), while water yields plateau under scenario (2) above maximum concentration limits of about 10,000 mg/l.

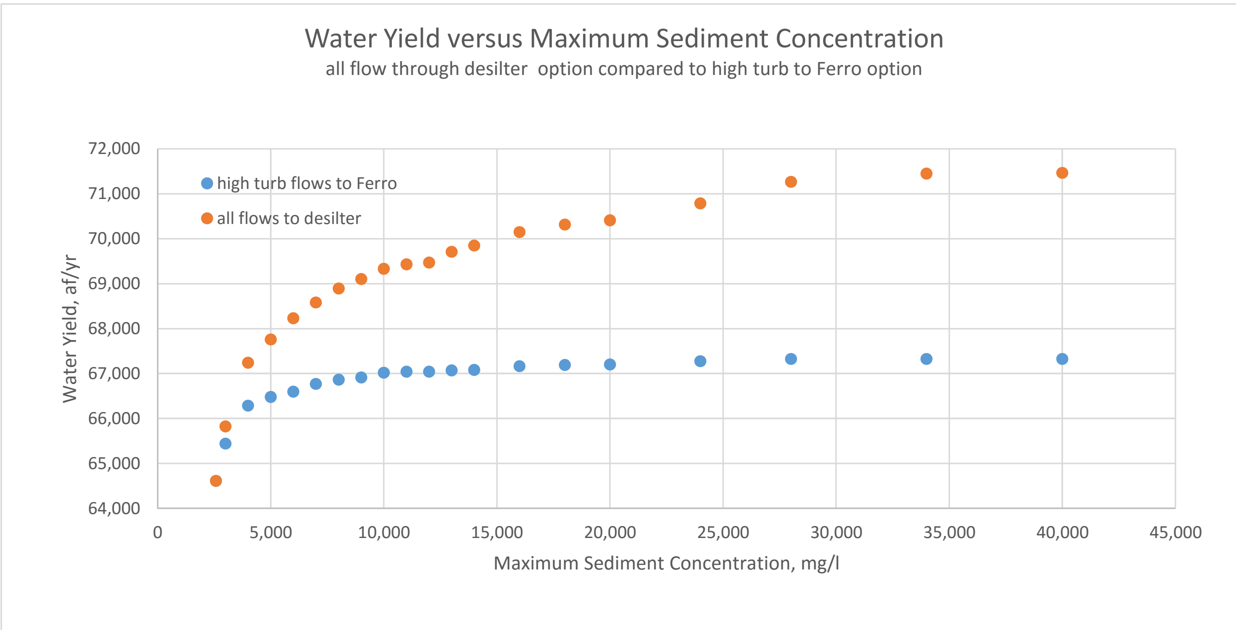

Figure 42 Water yield versus concentration limit for two operation scenarios, max diversion rate = 750 cfs

Expected sediment capture is contrasted with water yield in **Figure 43** for those same two operation scenarios, again with the system conveyance capacity increased to 750 cfs. Sediment capture quanties rapidly increase for water yield volumes above about 67,000 af/year under the 'direct to Ferro' operation plans. Sediment capture increases progressively (and less sharply) with increased water yield for operation with all flows passing through the existing desilting basin.

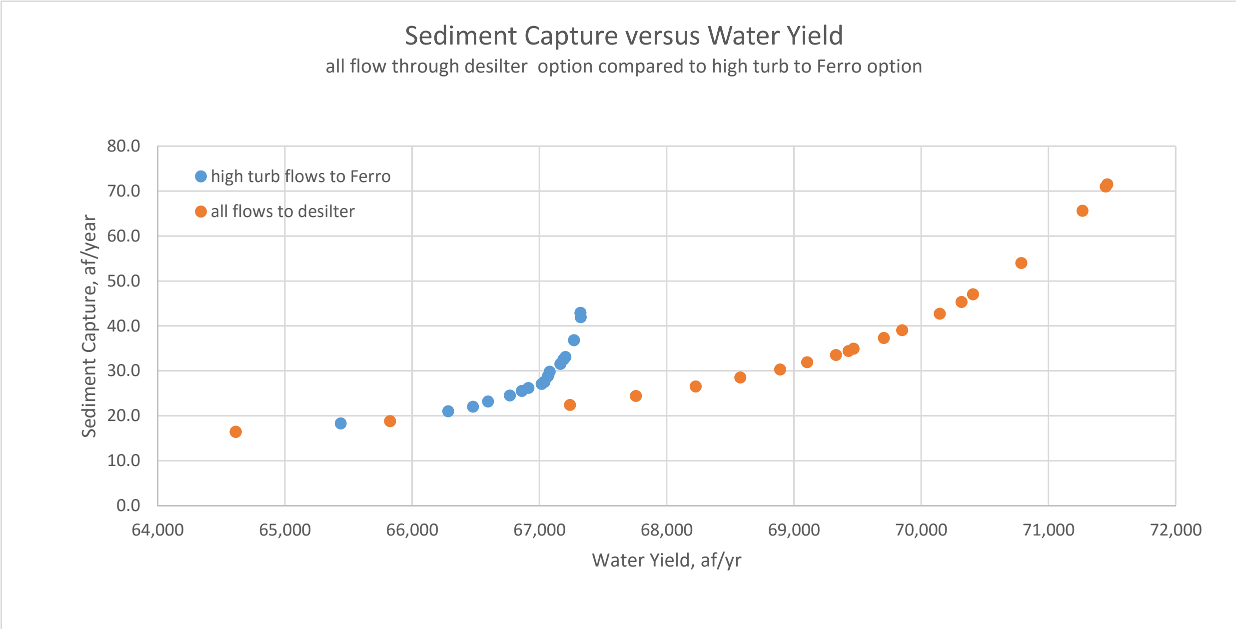

Figure 43 Sediment capture versus water yield for two operation scenarios, max diversion rate = 750 cfs

Incremental cost versus yield analysis was conducted using an assumed cost for sedment management of $25 per cubic yard and an assumed value for water yield of $500 per acre-foot. Cost versus yield ratios were determined on an incremental basis as the maximum concentration limit for the diverted flow was increased, assuming maximum diversion rates of 750 cfs. Ratios of incremental sediment cost to incremental water yield value are contrasted for the 'though the existing desilting basin' and 'direct to Ferro' operation plans in **Figure 44**. Incremental costs are higher than incremental yield value when the ratio of cost/value is greater than 1. As shown in **Figure 44**, this occurs for maximum concentration rates ofless than 10,000 mg/l under the 'direct to Ferro' scenario, and for maximum concentration rates between 10,000 and 20,000 mg/l under the 'through the existing desilting basin' scenario.

The sensitivity of this analysis to the unit cost for sediment and the value of water yeild is illustrated for the 'through the existing desilting basin' scenario in **Figure 45**. Diversion of flows with concentrations as high as 20,000 mg/l become economical under this scenario if the unit costs for sediment management decrease to $15/cubic yard. Withi unit costs increased to $30/cubic yard for sediment management, concentration limits are reduced to levels below about 12,000 mg/l or less.

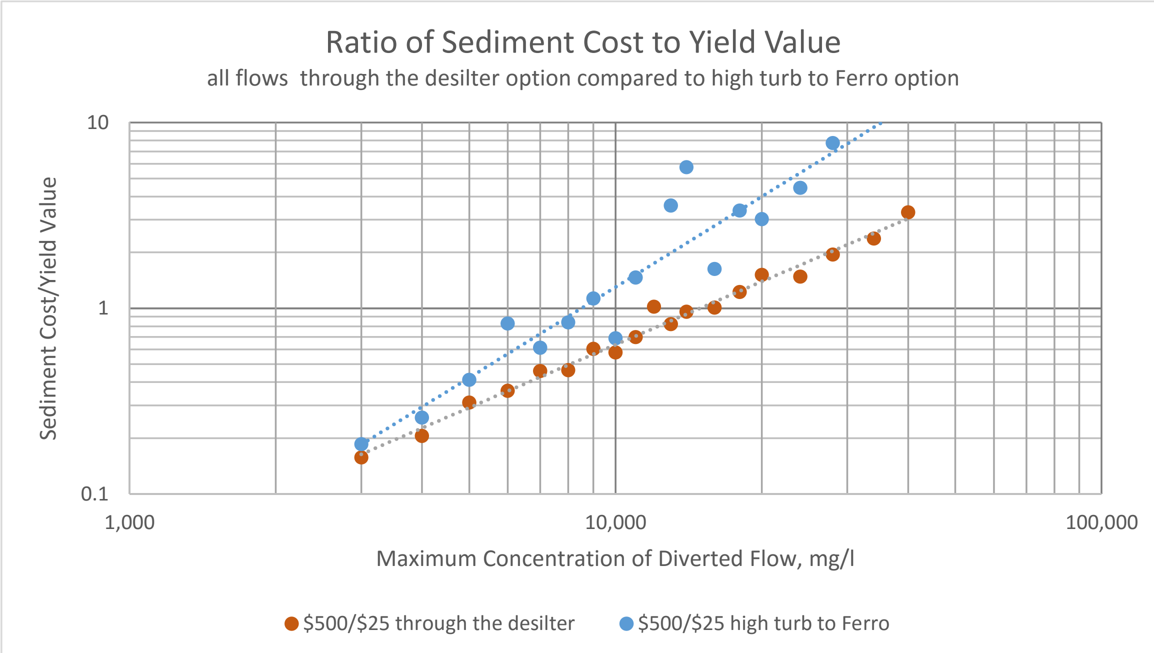

Figure 44 Ratio of incremental sediment cost to incremental water yield value, two operation scenarios, max diversion capacity = 750 cfs

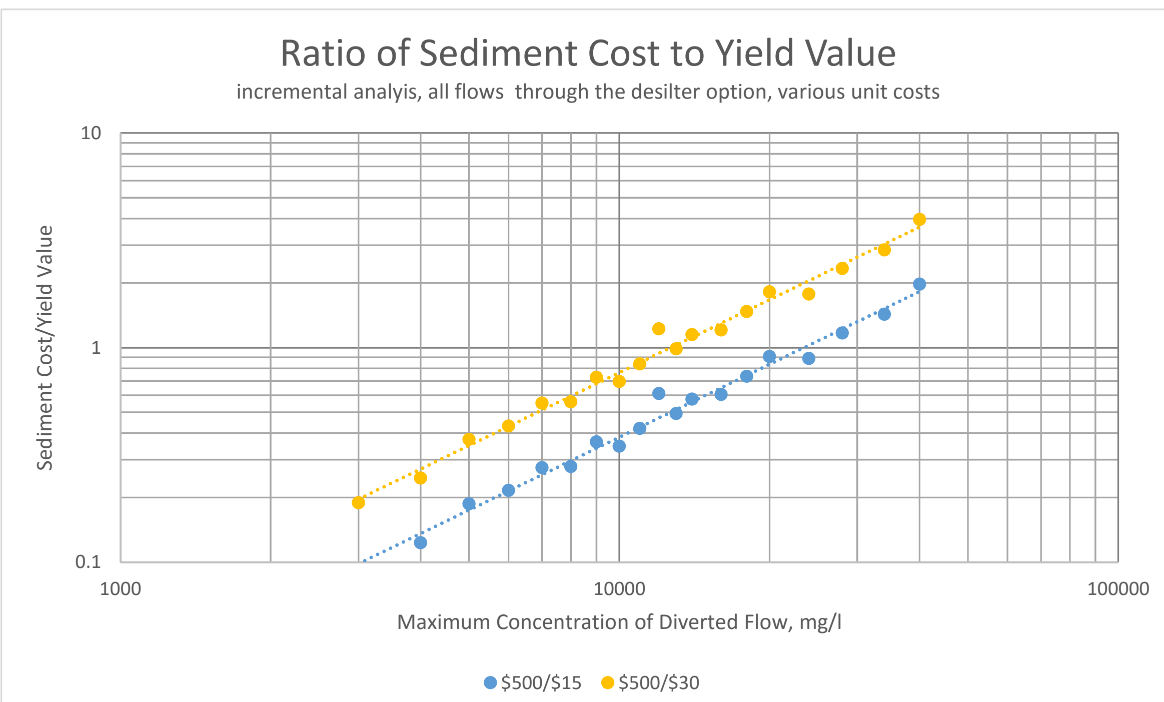

Figure 45 Ratio of incremental sediment cost to incremental water yield value, variable unit values and costs, all flows through the existing desilting basin, max diversion capacity = 750 cfs

The simulated variations in water yield for the 1944-2014 period for the 'through the existing desilting basin' operation scenario, maximum diversion rate of 750 cfs, under two maximum concentration limits are shown in **Figure 46**. The effect of increasing the maximum sediment concentration limit for the diverted flows has a small effect on total flow captured in any given year on a percentage basis. The effect on sediment capture is more significant, as shown in **Figure 47**.

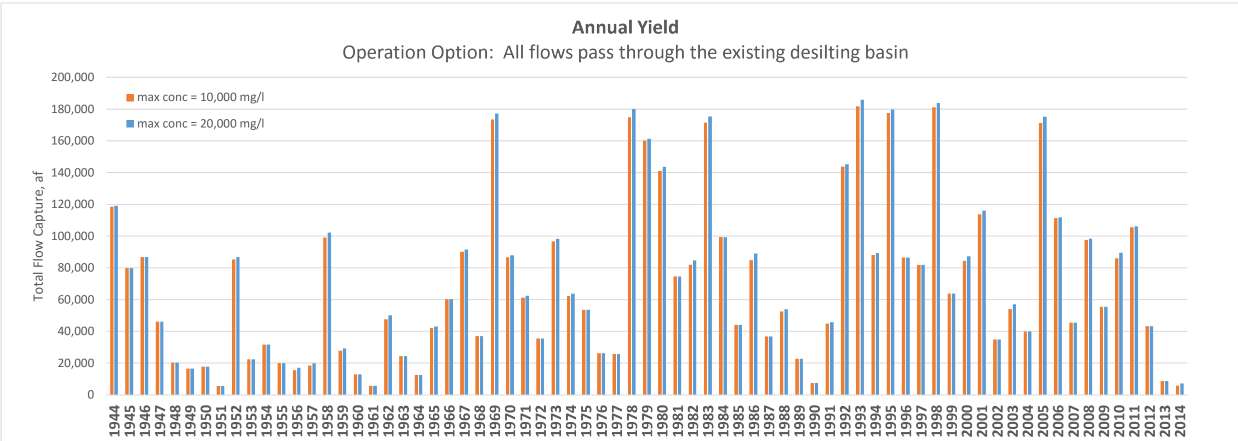

Figure 46 Simulated water yield, 1944-2014, all flows through the existing desilting basin, max diversion rate = 750 cfs, two max sediment concentration limits

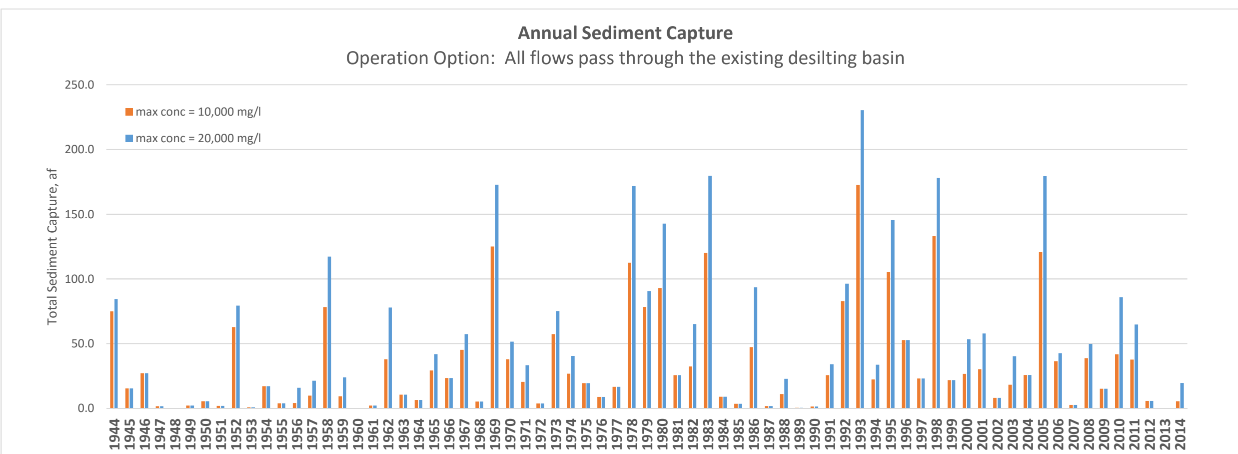

Figure 47 Simulated sediment capture, 1944-2014, all flows through the existing desilting basin, max diversion rate = 750 cfs, two max sediment concentration limits

As shown in Figure 48, maximum sediment capture for the scenario examined would have occurred in the 1993 water year. The variation of the simulated sediment capture over that water year is illustrated in **Figure 48** for two maximum concentration limits. The sediment capture quantities are epsodic, coinciding with the storm events of that year, and vary in intensity as the maximum concentration limits allow. Cumulative yields captured during the 1993 water year would fill approximately one-third of the design capacity of the existing desilting basin (capacity = 700 af) under the concentration limit of 20,000 mg/l – a manageable quantity of an extreme year, but underscoring the regular maintenance that would be requried under this operation scenario to ensure capacity for capture in future years.

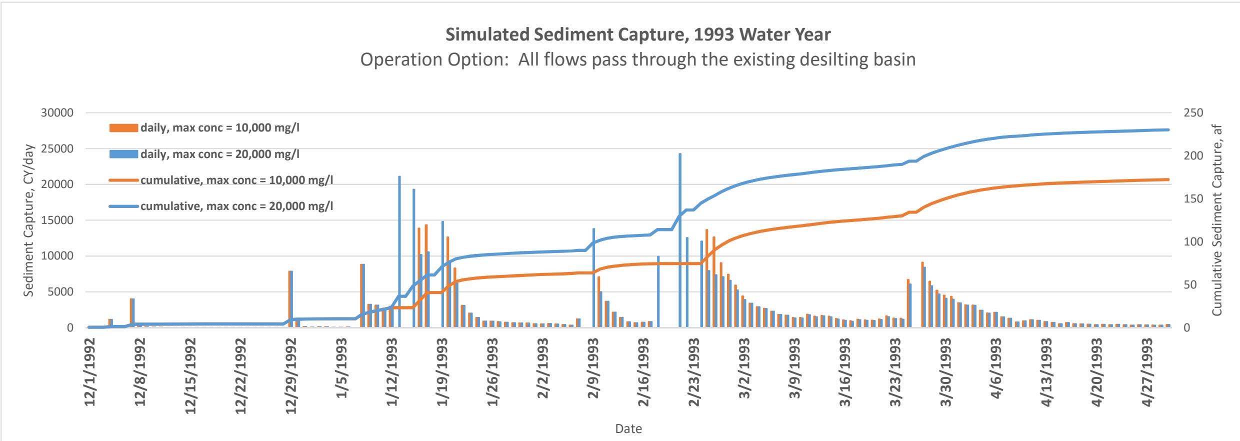

Figure 48 Simulated sediment capture, 1944-2014, all flows through the existing desilting basin, max diversion rate = 750 cfs, two max sediment concentration limits

The Freeman Yield Model is structured to allow simulation of flow and sediment capture under operation scenarios that pass flows either through the existing desilting basin or directly to the Ferro Basin. These scenarios cover the potential operations of Alternative 3 and normal operations of Alternative 1, but do not explicitly simulate the functioning of Alternative 1 under scenarios where the existing desilting basin is bypassed. Under these operations scenarios, flow and sediment loads would pass directly to the Noble basin (assuming Pond B is bypassed as well). Noble Basin No. 1 would be the primary accumulator of sediment under this operation condition. Water yields under these scenarios would be expected to be greater than the direct-to-Ferro scenarios (since the Noble and Rose basins would be available for recharge of the diverted flows), but less than the through-the-existing-desiling-basin scenaros (since the Saticoy basins would be bypassed, which would reduce the recharge capacity of the system).

4 ALTERNATIVE CONVEYANCE PATH EVALUATION

The Alternative 1 and Alternative 3 improvements of the Freeman Diversion System are compared in the paragraphs that follow. Construction cost, functionality, flexibility and reliability are first compared. Maintenance requirements and right-of-way issues are discussed in the sections that follow. It should be noted that the construction costs listed in the tables that follow are preliminary estimates with a contingency of 30% applied, and do not include planning, design, environmental documentation and permitting, or construction administration costs.

4.1 Cost and Functionality Comparison

The two main alternative flow paths downstream of the existing desilting basin, with their respective main options, are contrasted in Table 11. Alternative 1 allows an increase in maximum diversion rate to 750 cfs, except for the Alternative 1 minimum improvement plan, which was sized for 375 cfs capacity. Alternative 3 was also sized for a system capacity of 750 cfs, with options for the Ferro diversion capacity of 375 cfs and 750 cfs. As discussed in Section 4 of this report, the flow and sediment capture (and destination of that capture) of each option is controlled by the operation plan applied to each alternative, not the alternative configuration itself. The alternatives and main options vary significantly in cost and functionality, as noted in Table 11.

Table 11 Comparison of Alternative 1 and Alternative 3 (with options)

Alternative and Main Option	Construction Cost[1] ($Millions)	Functionality and Flexibility	Conveyance System Maintenance
Alternative 1, no bypass of Pond B	$9.5	Similar to the existing system, higher capacity	Increased Pond B sediment capture and maintenance
Alternative 1, with bypass of Pond B	$10.3	Adds option for diversion of high turbidity flows around Pond B. Additional routing path allows some maintenance flexibility	Maintenance flexibility increases reliability, adds a new gate to manage
Alternative 1 minimum improvement plan	$1.5	Similar to the existing system	Similar to the existing system
Alternative 3, new 750 cfs unlined channel bifurcation	$19.6	Adds option for diversion of normal or high turbidity flows to downstream destinations, at the new design capacity	Will require more channel maintenance than the lined option
Alternative 3, new 750 cfs lined channel bifurcation	$25.9	Adds option for diversion of normal or high turbidity flows to downstream destinations, at the new design capacity	Less channel maintenance than the unlined option, but more than Alternative 1 (multiple channels to maintain)
Alternative 3, new 375 cfs unlined channel bifurcation	$17.0	Adds option for diversion of normal or high turbidity flows to downstream destinations, at the original design capacity	Will require more channel maintenance than the lined option
Alternative 3, new 375 cfs lined channel bifurcation	$21.3	Adds option for diversion of normal or high turbidity flows to downstream destinations, at the original design capacity	Less channel maintenance than the unlined option, but more than Alternative 1 (multiple channels to maintain)

[1] Costs shown are for conveyance system improvement downstream of the desilting basin only

Either Alternative 1 or Alternative 3 could be operated with all flows passing though the existing desilting basin prior to distribution to the available basins downstream. The water yield and sediment capture for existing and improved systems under variable maximum concentration rates, computed using the District's yield model, are compared in Table 12.

Table 12 Water and sediment capture, existing and improved systems, variable max concentrations

Option	Annual Flow Yield/Captured Sediment (af/af)			
	Max concentration to existing desilting basin (no direct-to-Ferro high turbidity flows)			
	2,580 mg/l	10,000 mg/l	20,000 mg/l	40,000 mg/l
375 cfs system, no Rose or Ferro Basin (i.e. existing)	59,439/11.6	62,439/21.2	63,188/28.9	63,960/42.9
375 cfs system with Rose and Ferro Basins online	60,396/12.2	63,756/22.4	64,597/30.6	65,453/45.2
750 cfs system with Rose and Ferro Basins online	64,614/16.4	69,331/33.5	70,409/47.0	71,464/71.5

Alternative 3 provides flexibility in destination of captured flows and sediment, and provides a path for the diversion of flows of high turbidity directly to the Ferro Basin (and potentially, beyond to former mining pits that exist downstream of the Ferro Basin). Were operations to continue similar to those of the recent past (maximum concentration to the existing desilting basin = 2,580 mg/l), but with the Ferro and Rose Basins online, and with the option for diverting higher turbidity flows directly to the Ferro Basin added via Alternative 3, water yield and sediment capture would increase, as shown for variable maximum turbidities in Table 13.

Table 13 Water and sediment capture, existing and improved systems, variable max concentrations

Option	Annual Flow Yield/Captured Sediment (af/af)			
	Max concentration for direct-to-Ferro flows			
	No high turbidity flow to Ferro	10,000 mg/l	20,000 mg/l	40,000 mg/l
375 cfs system, max 375 cfs capacity to Ferro Basin	60,396/12.2	62,936/21.3	63,275/27.6	63,572/37.8
750 cfs system, max 750 cfs capacity to Ferro Basin	64,614/16.4	67,018/27.1	67,205/33.1	67,323/42.9

While the yield volumes captured using the Ferro Basin as a dedicated destination for high turbidity flows are not as high as when flows of similar turbidity are allowed to pass though the existing desilting basin, benefits associated with this secondary destination for sediment may be realized that may not be achieved with Alternative 1. The sediment trapping capacity of the existing desilting basin has not been tested for the higher flow rates proposed for the improved system – the dependability of the flocculation program at these higher flow rates is unknown. The Ferro Basin is considered a less valuable location for percolation than the Rose and Noble basins, due to its proximity to the Santa Clara River, so keeping it as an alternate destination for sediment may prove beneficial should the existing desilting basin not function as desired. Additionally, due to its capacity and the relatively rare expected use, the

Ferro Basin as a high turbidity destination may require less frequent maintenance, and will definitely reduce maintenance requirements in the existing desilting basin.

Note that the existing desilting basin could also by bypassed under high turbidity conditions under Alternative 1. However, the initial destination of the sediment in this case would be the Noble Basins (or Pond B, if it wasn't bypassed). Yields would be less than those listed in Table 8 (due to bypassing the Saticoy basins), but higher than those listed in Table 9 (due to the percolation capacity of the Rose and Noble Basins). United's yield model does not have the option for simulation of this operation scheme. Delivery of increased sediment to the percolation basins could reduce recharge effectiveness or increase maintenance requirements in the basins.

4.2 Right-of-Way

The improvements discussed above are, for the most part, located within properties owned by UWCD. There are three exceptions, however: at the upstream end of the Alternative 3 channel bifurcation, at the proposed new or improved crossing of LA Avenue, and at the proposed crossing of Vineyard Avenue.

A local map of parcel ownership near the downstream end of the existing desilting basin is shown in **Figure 49**. The proposed alignment of the new channel downstream of the Alternative 3 bifurcation is shown in this figure. The alignment as originally proposed will require easement or outright purchase from Ventura County Flood Control at the upstream end of the new channel, and the alignment parallels the flood control levee in this area. Should this prove difficult, the alignment could be modified, with the bifurcation repositioned to a point downstream of the existing three barrel culvert. This alternative alignment would require improvement of the three barrel culvert, however, as it would be required to convey the full 750 cfs with the bifurcation located downstream. The three barrel culvert is at the upstream end of the flood protection levee and is operated by Ventura County. Any modification would likely require coordination and permitting with the US Army Corps of Engineers and Ventura County.

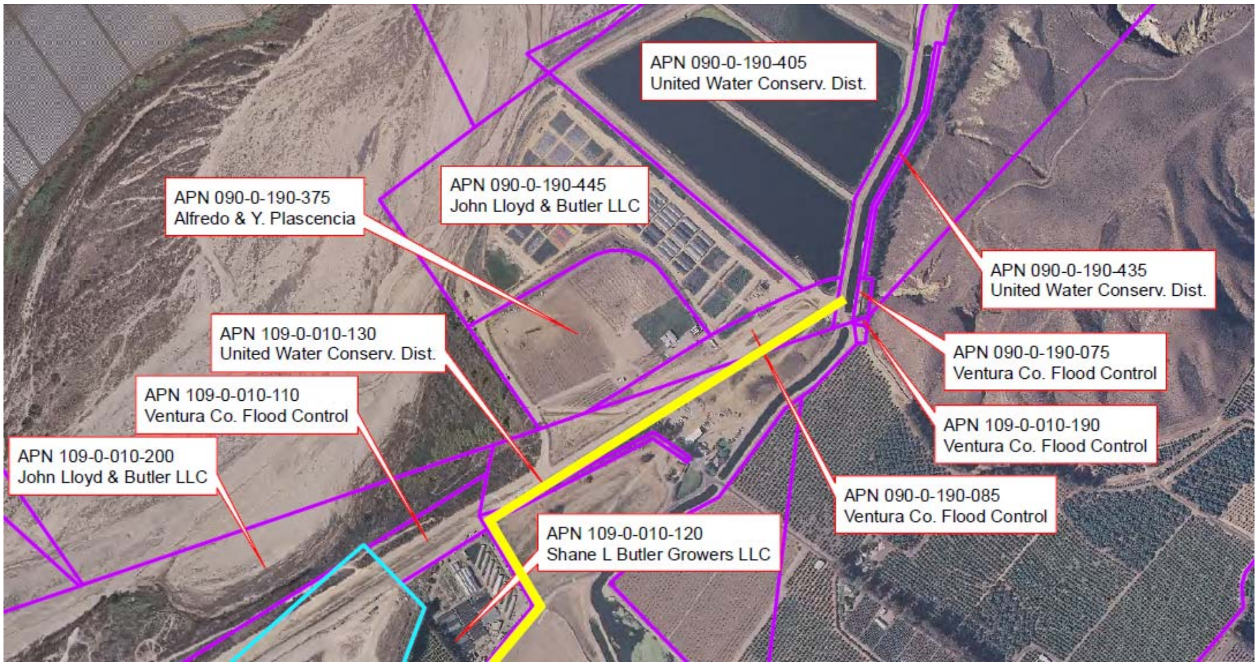

Figure 49 Parcel boundaries and ownership and proposed alignment of the Alternative 3 bifurcated channel (yellow) downstream of the existing desilting basin

Properties on both sides of the new and existing Los Angeles Avenue crossings are owned by UWCD. The proposed improvements would be additons to or enlarged duplication of the existing crossing at the downstream end of the Grand Canal, which connects the Grand Canal to Noble Basin No. 1. Alternative 1 would enlarge this existing crossing to enable conveyance of 750 cfs. Alternative 3 would create a new crossing north of the existing crossing location. Both crossings are assumed to be constructed by jack and bore or micro-tunneling methods. An encroachment permit will be required to pass through County and State right-of-way, and utility relocation may be required. Potential conflicts with utilities are minimized in Alternative 1 by approximetely following the existing pipe profile.

At the new crossing of Vineyard Avenue (to connect Noble Basin No. 3 to the Ferro Basin), properties on both sides of the crossing are also owned by UWCD. The crossing is assumed to be constructed by jack and bore or micro-tunneling methods. Similar to the Los Angeles Avenue crossing, encroachment permits will be required and utility relocation may be required.

4.3 Maintenance

With the current diversion system and operations, the maintenance requirements related to sediment are sensitive to inlet management. Inlet management activities affecting the magnitude of sediment load taken into the system include turn-out timing, frequency of flushing operations (used to clear the inlet channel and the reach of the Santa Clara River immediately upstream of the inlet), and gate control (which forces a dead pool upstream of the inlet to encourage upstream deposition). Inlet operations could be significantly altered with the fish ramp alternatives currently being proposed at the diversion dam, however the extent of the modifications are not known at this time.

Inlet operations will continue to be an important component of sediment management with the alternatives presented in this report. Local features have been added to the inlet modifications discussed in Section 2 of this report that will encourage a larger fractions of the river sediment load to bypass the recharge system (with the Coanda screen option) or enable easier local clean-out of accumulations in the vicinity of the fish screen.

Sediments that make it past the fish screen area will be more efficiently conveyed to and through the headworks area with the any of the conveyance options selected for modification of the existing pipe system, reducing sediment maintenance requirements within the Freeman Canal. The vast majority of the sediment load passing the head regulating gates at the entrance to the Freeman Canal are expected to pass to either the existing desilting basin or the Ferro Basin, depending on the operation scenario applied.

Under split diversion operation conditions, (flows with normal turbidity passing through the existing desilting basin, flows with high turbidity passing directly to the Ferro Basin), and with diversion capacities increased to 750 cfs, the UWCD yield model indicates that the average annual total sediment passing through the system would total 27.1 af if the turbidity cap were set at 10,000 mg/l, 33.1 af with a cap at 20,000 mg/l, and 42.9 af with a cap at 40,000 mg/l. The annual volume of sediment diverted directly to the Ferro basin would average 11.6 af, 17.7 af, and 27.6 af, respectively, under these scenarios, with 15.5 af, 15.4 af, and 15.3 af delivered to the existing desilting basin. Water yield and sediment capture quantities for these scenarios (and at a range of other maximum diversion rates) are summarized in Table 14 through Table 16.

With an operation scenario that passes all flows through the existing desilting basin and with diversion capacities increased to 750 cfs, the UWCD yield model indicates that the average annual total sediment passing through the system would total 33.5 af if the turbidity cap were set at 10,000 mg/l, 47.0 af with a cap at 20,000 mg/l, and 71.5 af with a cap at 40,000 mg/l. The majority of this sediment would be trapped in the desilting basin. No sediment would be diverted directly to the Ferro basin under this operation scenario.

Table 14 Yield model simulation results, maximum sediment concentration = 10,000 mg/l

Max turb to Ferro = 10,000 mg/l, max sed to desilter = 10000 mg/l						
Qmax	Net Vol desilter	Sed to desilter	Sed to Ferro	to Ferro days	to Ferro Sed days	total Sed
	af/yr	af/yr	af/yr	days	days	af/yr
375	63756	22.4	0	7.3	0	22.4
450	65777	25.6	0	14.6	0	25.6
550	67567	28.9	0	18.2	0	28.9
650	68621	31.5	0	19.4	0	31.5
750	69331	33.5	0	21.1	0	33.5
850	69788	35	0	21	0	35
1000	70213	36.8	0	21	0	36.8

Max turb to Ferro = 10,000 mg/l, max sed to desilter = 2580 mg/l						
Qmax	Net Vol desilter	Sed to desilter	Sed to Ferro	to Ferro days	to Ferro Sed days	total Sed
	af/yr	af/yr	af/yr	days	days	af/yr
375	62936	12.2	9.1	9.1	4.8	21.3
450	64758	13.6	10	14.3	4.8	23.6
550	65982	14.6	10.5	17.7	4.8	25.1
650	66632	15.2	11.1	18.9	4.8	26.3
750	67018	15.5	11.6	20.2	4.8	27.1
850	67244	15.7	12	20.1	4.8	27.7
1000	67489	15.8	12.6	20.1	4.8	28.4

Table 15 Yield model simulation results, maximum sediment concentration = 20,000 mg/l

Max turb to Ferro = 20,000 mg/l, max sed to desilter = 20,000 mg/l						
Qmax	Net Vol desilter	Sed to desilter	Sed to Ferro	to Ferro days	to Ferro Sed days	total Sed
	af/yr	af/yr	af/yr	days	days	af/yr
375	64597	30.6	0	7.9	0	30.6
450	66722	35.2	0	16	0	35.2
550	68572	40.2	0	19.5	0	40.2
650	69718	44.2	0	20.7	0	44.2
750	70409	47	0	22.3	0	47
850	70849	49.1	0	22.3	0	49.1
1000	71279	51.5	0	22.2	0	51.5

Max turb to Ferro = 20,000 mg/l, max sed to desilter = 2580 mg/l						
Qmax	Net Vol desilter	Sed to desilter	Sed to Ferro	to Ferro days	to Ferro Sed days	total Sed
	af/yr	af/yr	af/yr	days	days	af/yr
375	63275	12.2	15.4	10.2	6	27.6
450	65071	13.5	16.5	15.3	6	30
550	66326	14.6	17	18.8	6	31.6
650	66893	15.1	17.3	20	6	32.4
750	67205	15.4	17.7	21.4	6	33.1
850	67347	15.6	18	21.3	6	33.6
1000	67519	15.6	18.5	21.3	6	34.1

Table 16 Yield model simulation results, maximum sediment concentration = 40,000 mg/l

Max turb to Ferro = 40,000 mg/l, max sed to desilter = 40,000 mg/l						
Qmax	Net Vol desilter	Sed to desilter	Sed to Ferro	to Ferro days	to Ferro Sed days	total Sed
	af/yr	af/yr	af/yr	days	days	af/yr
375	65453	45.2	0	8.4	0	45.2
450	67683	52.5	0	17.3	0	52.5
550	69604	60.6	0	20.7	0	60.6
650	70818	67.3	0	22	0	67.3
750	71464	71.5	0	23.6	0	71.5
850	71885	74.6	0	23.6	0	74.6
1000	72292	77.1	0	23.5	0	77.1

Max turb to Ferro = 40,000 mg/l, max sed to desilter = 2,580 mg/l						
Qmax	Net Vol desilter	Sed to desilter	Sed to Ferro	to Ferro days	to Ferro Sed days	total Sed
	af/yr	af/yr	af/yr	days	days	af/yr
375	63572	12.2	25.6	11.4	7.3	37.8
450	65340	13.5	26.4	16.4	7.3	39.9
550	66546	14.6	26.5	20	7.3	41.1
650	67050	15.1	27	21.2	7.3	42.1
750	67323	15.3	27.6	22.6	7.3	42.9
850	67461	15.5	28	22.6	7.3	43.5
1000	67592	15.5	28.5	22.5	7.3	44

In the Phase 1 study, it was estimated that 13 to 18 af/year had accumulated in the existing desilting basin since construction in 1991 (including estimated historical cleanouts of 71 af, and 23 years of capacity loss of 230-350 af). The yield model simulation results indicate that increasing the system capacity to 750 cfs and increasing the allowable turbidity limits will significantly increase the sediment load to be handled by the system. With the split diversion scenario, average annual sediment accumulation in the existing desilting basin would be comparable to what has been historically observed, but accumulations in the Ferro Basin would represent an additional quantity approximately equal to and as much as double that accumulation rate (depending on the concentration applied for the direct-to-

Ferro diversions). With the non-split operation scenario, sediment accumulation in the existing desilting basin would increase by a factor of 2 to 5 (again, depending on the maximum cap on turbidity allowed during diversion operations). It should be noted that UWCD yield model results assume that the existing desilting basin has 100% trapping efficiency but the ability of the desilter to effectively remove sediment at higher flow rates and turbidities, in order to protect downstream recharge capacity, needs to be verified. Sediment transport simulation results conducted in this study indicate that the trapping efficiency of the existing basin would likely be significantly less without the addition of flocculation agent. The effectiveness of the flocculation program under variable turbidity conditions is to be the subject of a future study by UWCD.

5 THE PREFERRED ALTERNATIVE

UWCD reviewed preliminary findings of the alternatives evaluation, and selected a preferred plan for improvement of the system. The preferred plan is a slightly modified version of Alternative 3, which was selected for the operational flexibility that it provides in managing flows and sediment. The preferred plan includes the following elements (from upstream to downstream):

- An expansion of the existing fish screen, providing a duplicate system in parallel. The fish screen bay would be modified to allow head control at the gates downstream of the fish screen, rather than at the upstream canal inlet gates.
- An open channel to replace the headworks pipes
- An additional inlet and new partition within the existing desilting basin
- A new bridge to replace the crossing at the existing three-barrel culvert
- A new bridge to replace the crossing at the existing siphon
- A new bifurcation structure to be located near the entrance to Pond B. The structure will connect to a new lined downstream channel that will parallel the northern perimeter of the Saticoy, Noble and Ferro basins. New culverts at both LA Avenue and Vineyard Avenue will be required.
- Partitions within the Ferro Basin to maximize basin capacity.

The alignment of the preferred alternative is illustrated in Figure 50.

The estimated construction costs for the preferred improvements are summarized in Table 17, which also identifies the fraction each component cost contributes to the total. Costs listed assume the new bifurcated channel has been sized for 375 cfs. Upgrading the new bifurcated channel to enable diversion of flows up to 750 cfs would cost an additional $3,500,000.

Table 17 Preliminary Construction Cost Estimate, Preferred Improvement Plan

Element	Construction Cost	Fraction of Total
Modify Fish Screen (parallel option)	$ 4,400,000	15%
Open Channel at Headworks	$ 2,300,000	8%
Bifurcated Inlet at Desilter	$ 900,000	3%
New Partition at Desilter	$ 1,100,000	4%
Three Barrel Culvert Bridge	$ 400,000	1%
Inverted Siphon Bridge	$ 400,000	1%
Bifurcation	$ 600,000	2%
New Canal Along Saticoy Basins	$ 1,600,000	6%
Highway 118 Crossing	$ 1,200,000	4%
New Canal Along Noble Basins	$ 3,700,000	13%
Vineyard Avenue Crossing	$ 1,400,000	5%
New Canal Along Ferro Basin	$ 7,100,000	25%
Ferro Partitions	$ 3,100,000	11%
Total	**$ 28,200,000**	**100%**

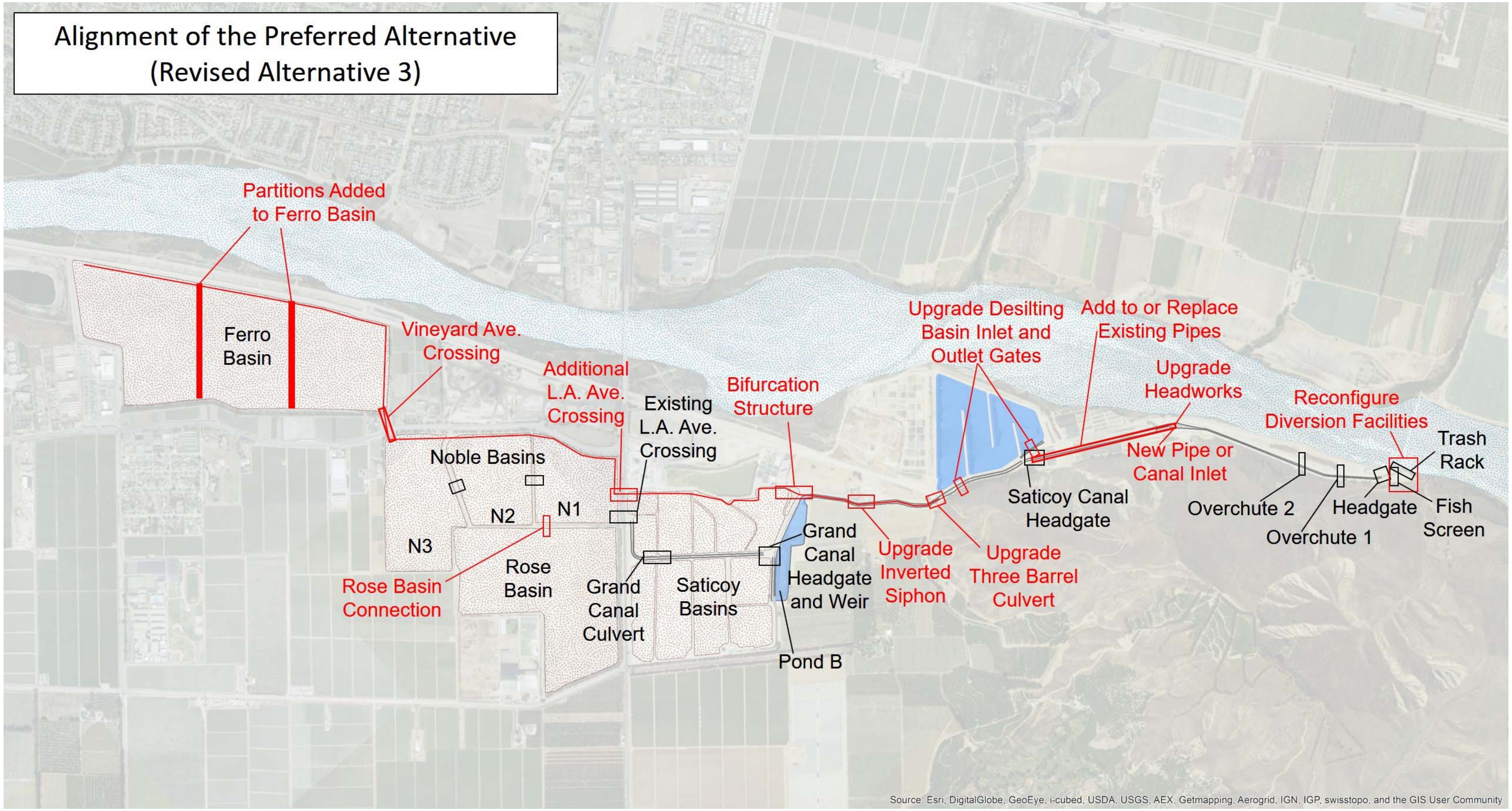

Figure 50 Alignment of the preferred alternative

6 REFERENCES

1.) Sediment Transport and Deposition Assessment of the Freeman Diversion Conveyance System; Phase 1 – Existing System Performance, 2015. Prepared by Northwest Hydraulic Consultants for United Water Conservation District.
2.) Preliminary Engineering Report; Oxnard Plain Groundwater Recharge Project, 2005. Prepared by Brown and Caldwell for United Water Conservation District.

Appendix A

Unit Costs

Unit costs are summarized in the table below:

No.	Item	Unit Cost		Unit
1	Mobilization/Demobilization	~8%		LS
2	Site Preparation & BMPs	By Element		
3	Site Restoration	By Element		
4	48" Diam. RCP	$	250	LF
5	60" Diam. RCP	$	350	LF
6	60" Diam. RCP (Tunnel/Bore)	$	1,700	LF
8	72" Diam. RCP	$	520	LF
9	72" Diam. RCP(Tunnel/Bore)	$	2,100	LF
10	84" Diam. RCP	$	780	LF
11	96" Diam RCP	$	1,100	LF
14	Riprap Bank Protection 1T	$	135	ton
15	Embankment Construction	$	9	CY
16a	Box Culvert (10' W x5' H)	$	900	LF
16b		$	800	
18a	Box culvert (8' W x 6' H)	$	770	LF
18b		$	650	
19a	Box Culvert, three (6'W X 5'H)	$	1,750	LF
19b				
22	Channel Excavation	$	7	CY
23a	Clearing and Grubbing (trees)	$	7,500	AC
23b	Clearing and Grubbing (No trees)	$	2,500	AC
25	Concrete Floor (9"-15"thick)	$	500	CY
26	Concrete Channel Lining (6")	$	130	SY
27	Concrete Wall (12-18" thick, 4-10' high,)	$	800	CY
28	Concrete Wall Raising (12-18"thick, 12-36" high)	$	800	CY
29	Concrete Columns, Elevated Slabs, Beams	$	1,500	CY
30	Inlet/Outlet Structure (2-10x5 RCB)	$	25,000	EA
31	Inlet/Outlet Structure (3-6x5 RCB)	$	25,000	EA
33	Inlet Outlet Structures (96" RCP)	$	16,000	EA
38a	Inlet Outlet Structures (3-60" RCP)	$	21,000	EA
38b		$	25,000	EA
40	Inlet Outlet Structures (3-72" RCP)	$	25,000	EA
41a	Inlet Outlet Structures (6'X8' Gate)	$	28,000	EA
41b	Inlet Outlet Structures (2-6'X8' Gate)	$	42,000	EA
42	Inlet Outlet Structures (4-72" RCP)	$	34,000	EA
47	Flow Control Gate (10'Wx10'H)	$	123,000	EA
48	Flow Control Gate (12'Wx10'H)	$	140,000	EA
49	Flow Control Gate (60")	$	50,000	EA
50	Flow Control Gate (72")	$	60,000	EA
51	Flow Control Gate (8'Wx8'H)	$	70,000	EA
52	Flow Control Gate (6'Wx8'H)	$	60,000	EA
53	Flow Control Gate Structure	$	-	0
58	Import material	$	13	CY
59	Dispose Excess Material	$	12	CY
65	Paving Restoration	$	65	SY
71	Revegetation (Seeding and Mulching)	$	10,000	AC
86	Structural Excavation	$	25	CY
87	Structural Fill	$	30	CY