

Palo Alto Flood Basin Tide Gate Structure Replacement Project

Planning Study Report

Project No. 10394001



August 2020

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VALLEY WATER

PALO ALTO FLOOD BASIN TIDE GATE STRUCTURE REPLACEMENT PROJECT

Project No. 10394001

PLANNING STUDY REPORT

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August 2020

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SIGNATURES

PALO ALTO FLOOD BASIN TIDE GATE STRUCTURE REPLACEMENT

Project No.: 10394001

PLANNING STUDY REPORT

Approved by:

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Executive Summary

Refined Project Objectives

The original Project Objectives have been refined based on information discovered during the problem definition phase. The original Project Objectives were developed and refined in 2016, and are refined again per the Problem Definition Report included in Appendix A.

Project Objectives are presented as follows:

1. Replace existing tide gate structure to protect property and infrastructure from coastal flooding which could result if existing structure fails.
2. Maximize gravity drainage opportunities to practicably address impacts to flood protection facilities due to future Sea Level Rise (SLR) and the 100-year fluvial flood in cooperation with local planning efforts.
3. Limit impacts to existing habitat areas within the Palo Alto Flood Basin (PAFB).

Next Steps

The project team recommends the existing tide gate structure to be replaced, and for the new tide gate structure to include additional hydraulic capacity to mitigate SLR. This would ensure continued coastal flood protection to inland areas, fluvial flood protection to Adobe, Barron, and Matadero Creeks, and would also maintain existing habitat areas within the PAFB. Next steps would include data collection and preliminary design of a new structure in coordination with long-term collaborative flood protection projects (SAFER Bay, Shoreline).

Preliminary Recommended Project

The Project team recommends that the Planning Study Report consider alternatives to replace the tide gate structure. To maintain the existing functionality of the tide gates with anticipated SLR, the following design elements are required:

1. Construct a replacement tide gate structure to maintain similar hydraulic function to the existing condition. This would reduce the risk of potential impacts to existing biological habitat, hydraulic function, and public recreation.
2. The capacity of the new tide gate structure will practicably maximize gravity drainage and practicably mitigate SLR impacts.

- 3. The top elevation of the new tide gate structure will be coordinated and consistent with planned future levee construction projects.
- 4. The new tide gate structure will include a motor-driven sluice gate to ensure appropriate water circulation conditions similar to the existing structure.

The total project cost to design and replace the tide gate structure is estimated to be \$32.8 million dollars.

Community Outreach

The project team has met with the City of Palo Alto, City of Mountain View, the SFCJPA, and other stakeholders on numerous occasions to develop the project and to coordinate upcoming public and stakeholder outreach events.

Project Implementation

If the Project Owner elects to authorize staff to continue the Project work, the following target scheduled is expected as the next steps for Project implementation of the staff recommended alternative:

- | | |
|--|-------------|
| • Complete planning, proceed the design phase and CEQA | Summer 2020 |
| • Complete design | Summer 2021 |
| • Complete permit acquisition | Summer 2021 |
| • Construct trail surface improvements | Fall 2021 |
| • Begin replacement structure construction | Fall 2022 |
| • Complete construction | Fall 2025 |

Chapter 1: Introduction

This Planning Study Report has been prepared as part of the Palo Alto Flood Basin Tide Gate Structure Replacement Project, Planning Phase. This Report gives a brief overview of the project background and objectives, goes over the alternatives considered, and the staff recommended alternative. A more detailed introduction of project background, history, problem definition, and conceptual alternative analysis has already been discussed in the Problem Definition/Refined Objectives Report in Appendix A (December 2019) and the Problem Definition/Refined Objectives Report in Appendix C (March 2016).

Chapter 2: Study Background

Please refer to the Palo Alto Flood Basin Tide Gate Structure Improvements Project – Problem Definition/ Refined Objectives Report in Appendix A for the study background.

Chapter 3: Problem Definition

Please refer to the Palo Alto Flood Basin Tide Gate Structure Improvements Project – Problem Definition/ Refined Objectives Report in Appendix A for the problem definition.

Chapter 4: Alternatives

This chapter provides an overview of conceptual alternatives considered and reasoning why the alternative was chosen or not. Additional development and details of some conceptual alternatives can be found in the Palo Alto Flood Basin Tide Gate Structure Improvements Project – Problem Definition/Refined Objectives Report in Appendix C (March 2016).

Development and details of the staff-recommended alternative are provided in Chapter 5 of this report.

4.1 Conceptual Alternatives

Six conceptual alternatives are discussed and explained below:

4.1.1 Conceptual Alternative A, “No Action” (Alt-A)

Under Alt-A where the existing tide gate would not be replaced, Valley Water would continue routine maintenance of the tide gate structure consistent with current practice. For the immediately foreseeable future, the tide gate structure would remain in its present condition but would be subject to continued deterioration and eventual failure.

Public works structures built during the 1950’s were typically designed for a 50-year useful period of service. The existing tide gate structure has functioned for 63-years and now suffers from regular aging. Due to the daily opening and closing of the gates and corrosive marine environment aging effects on the reinforced concrete structure and steel components, the structure now operates marginally with leaking tide gates seals, spalled concrete, and exposed corroded steel reinforcement. Additional problems include a weak structural foundation with respect to potential earthquake forces and declining tide gate hydraulic efficiency due to SLR impacts.

A large earthquake could damage the connection between the structure and the timber pile foundation, causing displacement and/or settlement which could prevent the tide gates from opening and closing as required.

If the tide gates were stuck open and the basin was completely open to the bay, annual high tide water levels could flood approximately 400 to 700 parcels and U.S. Highway 101, resulting in large economic loss. In addition to coastal flooding in low elevation areas, flooding from Matadero, Barron, and Adobe Creeks could worsen during high tide events when tidal water pushes into narrow creek channels and backs up creek flows. The PAFB would experience increased tidal action and the entire island on the interior of the basin would be inundated more frequently, reducing or removing breeding, roosting, and wintering habitat for birds and potentially salt marsh harvest mouse.

If earthquake damages caused the tide gates to be stuck closed and block water from leaving the PAFB, similar flood damages to those described above could result from PAFB overflowing and creek flooding.

The tide gate structure is also used as a bridge and is part of the San Francisco Bay Trail's Adobe Creek Loop Trail. Significant structural damage to the existing tide gate structure would require a closure of this segment of the trail.

Even without a major earthquake event, the existing structure conditions allow bay water to infiltrate into the basin through leaky tide gate seals. This is an ongoing issue for vector control. The conditions will worsen with further degradation of the structure and tide gate seals, as well as SLR.

If the existing deteriorated tide gate were to be retained, a future project such as the USACE's Shoreline Project would need to address the increased flood risks associated with failure of the tide gate structure. However, this project is in the early planning process and construction is not anticipated to be completed within the expected remaining functional lifespan of the existing tide gate structure. Therefore, it was determined that the tide gate structure must be replaced to maintain current levels of flood protection, as well as address SLR. An Emergency Action Plan has been prepared for this facility in case the existing structure fails during the planning, design, or construction phase of this replacement project.

4.1.2 Conceptual Alternative B, "Replace Tide Gate Structure in Existing Location" (Alt-B)

Alt-B, replacement of the tide gate structure in-kind in its current location was considered as a means of avoiding and minimizing impacts on the environment. Emergency repairs carried out in 2012 involved pumping underwater concrete beneath the structure to arrest underflow. While the underwater concrete was successful in temporarily repairing the underflow, it has contributed to uncertainty in the constructability of a replacement structure in its present location, specifically with respect to the installation of sheet pile walls (for both dewatering and the tide gate structure itself), drilling of CIDH piles, and ground settlement. Furthermore, control of flows into and out of the PAFB would need to be maintained during construction, requiring installation of a temporary tide gate structure. The temporary tide gate structure or a

large pump station would need to be constructed on the levee to the east of the existing structure, maintaining the same flow capacity of the existing structure throughout construction. The footprint of the temporary tide gate structure or temporary pump station would be of similar size/capacity to the existing tide gate structure. These dual structures would slow the pace of construction activities, requiring up to 6 years to complete the work. The temporary tide gate structure would be removed once the new tide gate structure is operational, and the area would be restored to levee. This methodology would greatly complicate the construction process, lengthen the construction duration, introduce flood protection risks, and increase costs, while not providing material reduction in environmental impacts. For these reasons, this option was rejected.

4.1.3 Conceptual Alternative C, “Replace Tide Gate Structure Adjacent to Existing Structure on Levee” (Alt-C)

Alt-C would involve replacing the tide gate structure adjacent to the east side of the existing tide gate structure along the existing levee alignment. While this option would provide many of the same benefits as the proposed Project, replacing the tide gate in this location would require excavation of a large pilot channel adjacent to Hook’s Island to connect the flow from the new tide gate structure to the existing tidal channel. Furthermore, relocating the tide gate structure to this location could cause erosion and loss of the sensitive salt marsh habitat on Hook’s Island near the existing structure, as flood flows from the new structure would be directed towards the island. Due to these risks, this alternative was rejected.

4.1.4 Conceptual Alternative D, “Replace Tide Gate Structure in New Location further East Along Existing Levee” (Alt-D)

Alt-D would involve constructing the replacement tide gate structure along the same PAFB levee but approximately 0.5 mile southeast of the existing structure in the northeast corner of the basin near Charleston Slough. Moving the tide gate structure to this location would change the hydraulics of the PAFB and surrounding areas. The existing ground elevation on both sides of the levee would need to be lowered by excavating or dredging in order to facilitate flows through the new tide gate structure. Furthermore, power and fiber optic lines would need to be installed within the existing levee and extended to this location. This option raises new concerns and would require more extensive data gathering and modeling without offering any meaningful benefits compared to the proposed project alternative. For these reasons, this alternative was rejected.

4.1.5 Conceptual Alternative E, “Remove Tide Gate Structure and Build-up Inner Levee & Flood Walls Along Matadero, Barron, and Adobe Creeks” (Alt-E)

Rather than replacing the tide gate to provide flood protection on Adobe, Barron, and Matadero Creeks, existing floodwalls along Matadero, Barron, and Adobe Creeks and PAFB inner-levees could be reconstructed higher to protect from coastal and fluvial flooding. This would involve

removing the tide gate structure and allowing unregulated tidal action into the PAFB. The northern segment of the Adobe Creek Loop Trail would be permanently closed with removal of the existing levee. This could result in restoration of the PAFB to tidal salt marsh and provide the opportunity to create a transition zone for tidal marsh to migrate in response to sea level rise. However, in order to maintain current levels of flood protection, floodwalls would be constructed or raised along each creek more than 1 mile upstream of US-101. Bridges at Matadero Creek, Adobe Creek, and Barron Creek would also require retrofitting (replacing bridge barriers with traffic rated flood walls, potential structural and seismic retrofits, and closing of gaps between adjacent bridges and/or flood walls between bridge gaps) to prevent coastal flooding and reconstruction and raising of inner-ring levees would be needed to protect the City of Palo Alto corporate yard. The Matadero Creek Pump Station and Coast Casey Pump Station would also require upgrades due to greater pumping requirements.

Construction of the floodwalls, levees, and other improvements would potentially result in significant impacts on aesthetics, biological resources (riparian habitat), noise, recreation, traffic, and other resources. Due to a lack of available land, land would also need to be acquired to construct the new floodwalls. The planning, environmental review, and permitting of such an action would likely extend well beyond the anticipated remaining functional lifespan of the tide gate structure, and temporary solutions to address this gap may be needed. The island on the interior of the PAFB would also be fully submerged by daily tide cycles. For these reasons, this option was rejected.

4.1.6 Conceptual Alternative F, “Replace Tide Gate Structure Nearby on New Alignment” (ALT-F)

Considering the construction feasibility and environmental impacts associated with Alternatives A through E above, Alt-F was selected as the proposed Project. Alt-F would construct a new tide gate structure upstream and slightly southeast of the existing tide gate in the interior of the PAFB. This alternative would first construct the new tide gate structure and put it in service, and then remove the existing tide gate structure. The new tide gate structure would be of similar size to the existing structure but would accommodate up to 2 feet of additional SLR. Further increased SLR adaptation can be made in the future by constructing higher levees and an addition of a pump station. This alternative allows for the existing tide gates to continue to function during construction of the new tide gates, preventing impacts associated with installation of temporary tide gates and lengthening of the construction schedule. Alt-F includes the installation of a smaller pilot channel than that proposed in Alt-C, and the tide gate structure would be angled towards the existing channel, avoiding potential risks of erosion impact to Hook’s Island. Additionally, because Alt-F relocates the tide gate minimally into the PAFB, this alternative could result in the formation of additional Bay habitat. Once completed, this alternative would preserve the existing conditions of the Adobe Creek Loop Trail and provide necessary improvements to flood protection and public safety. Alt-F is the proposed project alternative. Alt-F replaces the tide gate structure and meets all the project objectives.

4.2 Overview Map of Alternatives Evaluated

An overview map of alternatives evaluated was prepared to show the approximate physical locations of each alternative discussed (Figure 1).

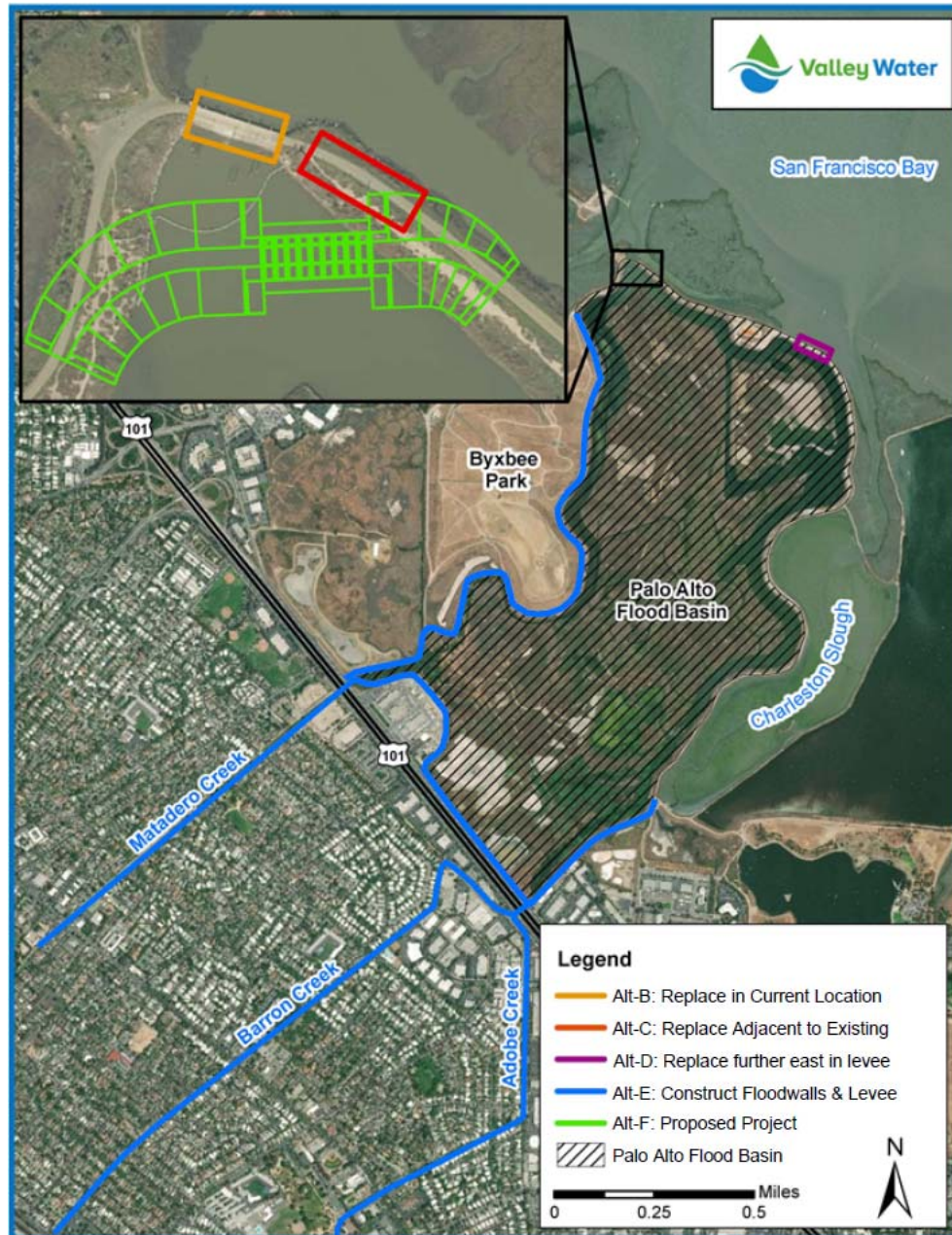


Figure 1: Overview Map of Alternatives Evaluated

4.3 *Conceptual Alternatives Matrix*

A conceptual alternative matrix was prepared on the following page to compare alternative characteristics (Table 1).

Table 1: Conceptual Alternatives Matrix

Alternative Element	Alternative A No Action	Alternative B Replace Tide Gate Structure in Existing Location	Alternative C Replace Tide Gate Structure Adjacent to Existing Structure on Levee	Alternative D Replace Tide Gate Structure in New Location further East Along Existing Levee	Alternative E Remove Tide Gate Structure and Build-up Inner Levee & Flood Walls Along Matadero, Barron, and Adobe Creeks	Alternative F Replace Tide Gate Structure Nearby on New Alignment
Estimated Years of Construction	N/A	Construction not feasible	4	4	5+	4
Environmental Impact	* Frequent tidal inundation of existing basin habitat * Annual high tidal water levels could regular flood parcels and U.S. Highway 101	N/A	* Temporary impacts during the construction work windows for 4 seasons. * Potential erosion impact to Hook's Island * Potential impact to channel used by Palo Alto boat dock/launch	* Temporary impacts during the construction work windows for 4 seasons. * Potential impact to channel used by Palo Alto boat dock/launch * Potential impacts affecting the existing hydraulics of the PAFB and surrounding areas	* Temporary impacts during the construction work windows for 5 or more seasons. * Anticipate significant impacts on aesthetics, biological resources (riparian habitat), noise, recreation, traffic, etc. * Basin would disappear thus reducing or removing breeding, roosting, and wintering habitat for birds and potentially salt marsh harvest mouse. * Restoration of the PAFB to tidal salt marsh and opportunity to create a transition zone for tidal marsh to migrate in response to sea level rise	* Temporary impacts during the construction work windows for 4 seasons. * Current brackish marsh habitat will be maintained.
Impact to Trail Users	Trail is expected to be lost if the tide gate structure fails.	N/A	The trail is expected to be closed at the limits of the construction area for 35 months.	The trail is expected to be closed at the limits of the construction area for 35 months.	Existing northern segment of Adobe Creek Loop Trail would be permanently closed with removal of existing levee.	The trail is expected to be closed at the limits of the construction area for 35 months.
Construction Uncertainties	N/A	Construction not feasible due to unknown extents of underwater concrete placed during 2012 repair work.	Lower risk of construction complications. Dewatering and poor soil conditions will be challenging for all construction activities.	Geotechnical exploratory borings would be needed to confirm the underlying soils in this project location.	There are many construction uncertainties due to the large scope of this alternative. Right of way for constructing taller retaining walls along all 3 creeks, retrofits to bridges, etc. Additional large scale data gathering and modeling would be required to verify details required for construction.	Lower risk of construction complications. Dewatering and poor soil conditions will be challenging for all construction activities.
Ease of Permitting	N/A	N/A	Permitting anticipated to be more difficult due to erosion impact concerns to Hook's Island.	Permitting anticipated to be more difficult due to potential impacts on existing hydraulics of the PAFB and surrounding areas.	Permitting this alternative would be very difficult due to the complexity and large scale impact included in this project scope. Large environmental impacts and right of way issues.	Permitting will be comparatively easier compared to other alternatives.
Mitigates Against future SLR	No	N/A	2-feet of future SLR	2-feet of future SLR	Can mitigate against future SLR.	2-feet of future SLR
Construction Cost	\$ -	\$ -	\$ 28,673,000	\$ 28,673,000	\$ -	\$ 28,673,000
Planning & Design Cost	\$ -	\$ -	\$ 3,006,000	\$ 3,006,000	\$ -	\$ 3,006,000
Permitting Cost	\$ -	\$ -	\$ 1,093,000	\$ 1,093,000	\$ -	\$ 1,093,000
Total Cost	N/A	N/A	\$ 32,772,000	\$ 32,772,000	\$200,000,000 ~ \$250,000,000	\$ 32,772,000

NOTE: A detailed cost estimate was not performed for Alternatives C & D as these alternatives were rejected for other said reasons. In general the costs for these alternatives would be similar to Alternative F. \$1.4M of estimated future long-term maintenance costs has been provided to Operations & Maintenance for their 5-year plan and is not included in the costs above.

Chapter 5: Recommended Alternative

The Staff Recommended Alternative F was determined by comparing the elements of each alternative listed in Table 1 and discussed in Chapter 4, Section 4.1. Alternative F is recommended because:

1. The Alternative F project satisfies all of the Project Objectives stated in the Executive Summary section of this report (Page 1).
2. The Alternative F project has fewer potential environmental impacts compared to other alternatives.
3. The Alternative F project has fewer construction uncertainties compared to other alternatives, and thus carries a lower risk for schedule and cost overruns.
4. The Alternative F project is anticipated to be easier to permit compared to other alternatives.
5. The Alternative F project duration is tied for the shortest overall construction duration at 4 years. This would minimize the amount of Adobe Loop Trail detour time to an anticipated 35 months.

The project team recommends that Alternative F be advanced to the design and construction phases.

5.1 Land Ownership

The Staff Recommended Alternative F is located within City of Palo Alto right of way; however, Valley Water holds a maintenance easement for the existing tide gate structure and the levees adjacent to the structure. The proposed tide gate replacement structure and new levees are within the existing maintenance easement.

Although the proposed levee and replacement tide gate structure will be covered within the existing maintenance easement, a temporary construction easement will be needed to incorporate the work area in the bay which is encompassed by the dewatering system.

5.2 Anticipated Construction Schedule

The proposed project includes a new tide gate structure that would be constructed in the water upstream (basin side) of the existing structure. The structure would be offset enough from the existing structure in order to construct the full length of the structure. The new structure will be larger in size than the existing structure with increased hydraulic capacity to practicably mitigate against SLR impacts. The Staff Recommended Alternative F project anticipates 3 months of trail surface improvements in “Year 0” followed by 4 years of construction as shown below:

“Year 0” (September 2021 - November 2021)

“Year 0” is trail surface improvement work which is anticipated to be performed by Valley Water Operations & Maintenance staff between September and November 2021. This trail surface improvement work is anticipated to consist of placing geotextile fabric on the existing trail surface, followed by Class 2 aggregate base. This work would increase the structural integrity of the trail surface and better distribute the anticipated loading that will occur once the structure replacement work starts. This work would occur within the limits of the existing trail and is anticipated to take 3 months. The trail would be temporarily closed for 3 months while this work is completed, and then opened back up.

Year 1 (September 2022 - January 2023)

Year 1 begins with installing a temporary sheet pile cofferdam dewatering system C-1 around the area where the new structure would be constructed (Figure 2). The next step would include dewatering and constructing the reinforced concrete pile foundation. The final step of Year 1 would include levee excavation within the work area enclosed by dewatering system C-1.

Year 2 (September 2023 - January 2024)

Year 2 would complete construction of the new structure, ground improvements, east approach levee, and construct an outlet channel (Figure 2). Ground improvements would be implemented to mitigate against excessive levee settlement and are anticipated to consist of deep soil mixing (DSM) method of ground improvements.

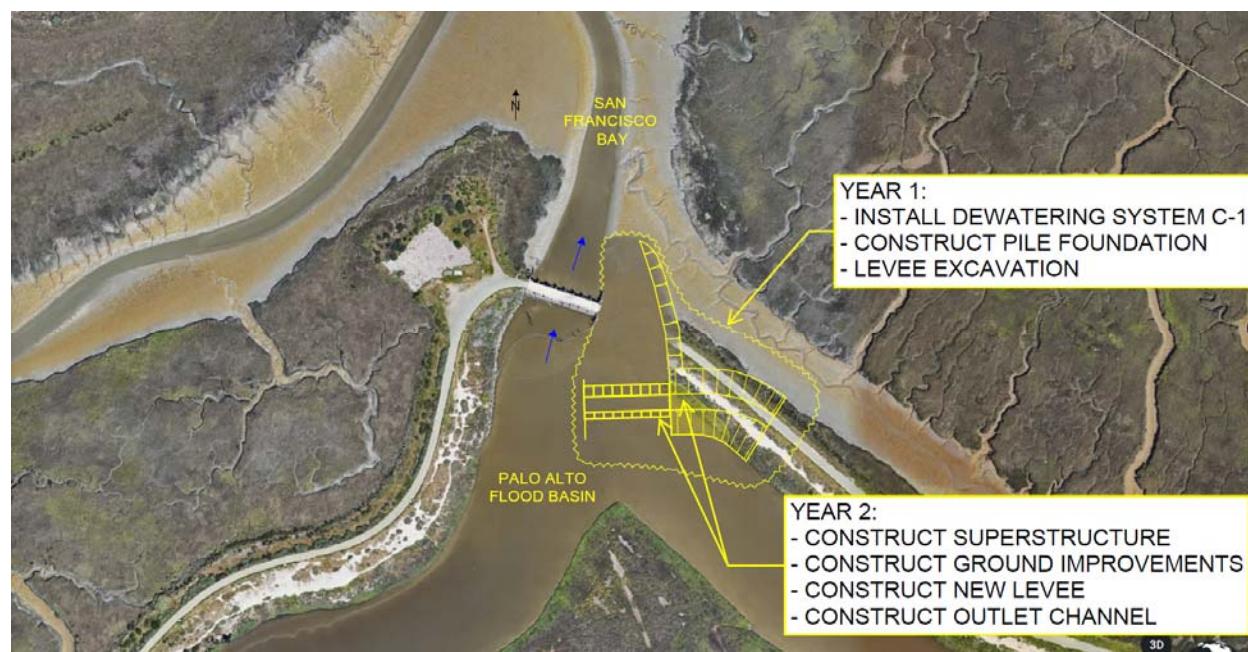


Figure 2: Alternative F Construction (Year 1 and Year 2)

Year 3 (September 2024 - January 2025)

Year 3 would start by constructing part of dewatering system C-2 and removing dewatering system C-1 and making the new structure operational (Figure 3). The remaining portion of dewatering system C-2 would then be constructed around the existing structure and work area for the new west approach levee. Ground improvements would be implemented to mitigate against excessive levee settlement and are anticipated to consist of deep soil mixing (DSM) method ground improvements. Year 3 would finish by completing the west approach levee and opening up the trail for recreational use over the new structure during the non-construction season.

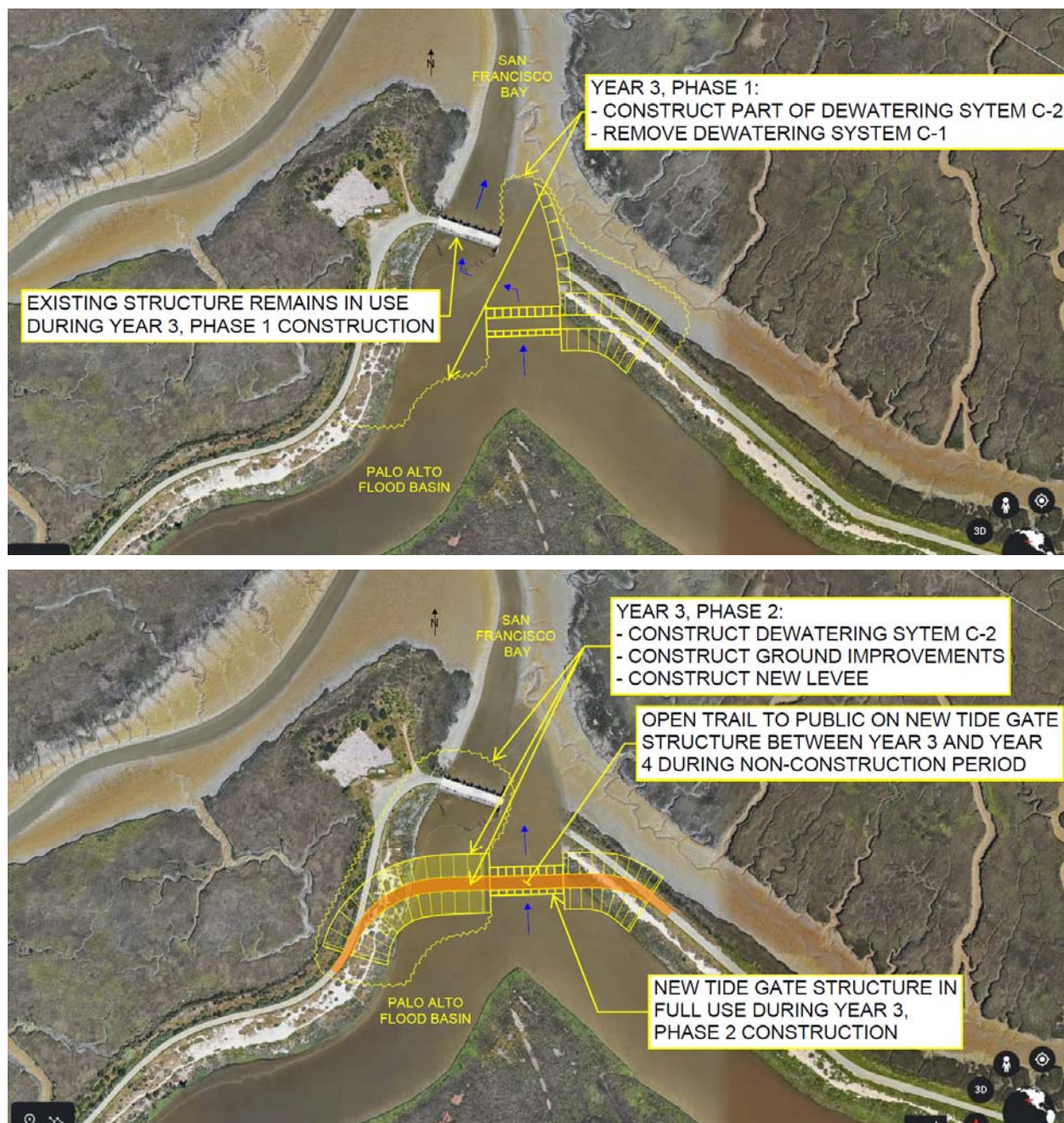


Figure 3: Alternative F Construction (Year 3)

Year 4 (September 2025 - November 2025)

Year 4 would remove the existing tide gate structure, any miscellaneous fixes, and remove dewatering system C-2 (Figure 4). Year 4 is anticipated to only take 3 months, and complete by the end of November 2025.

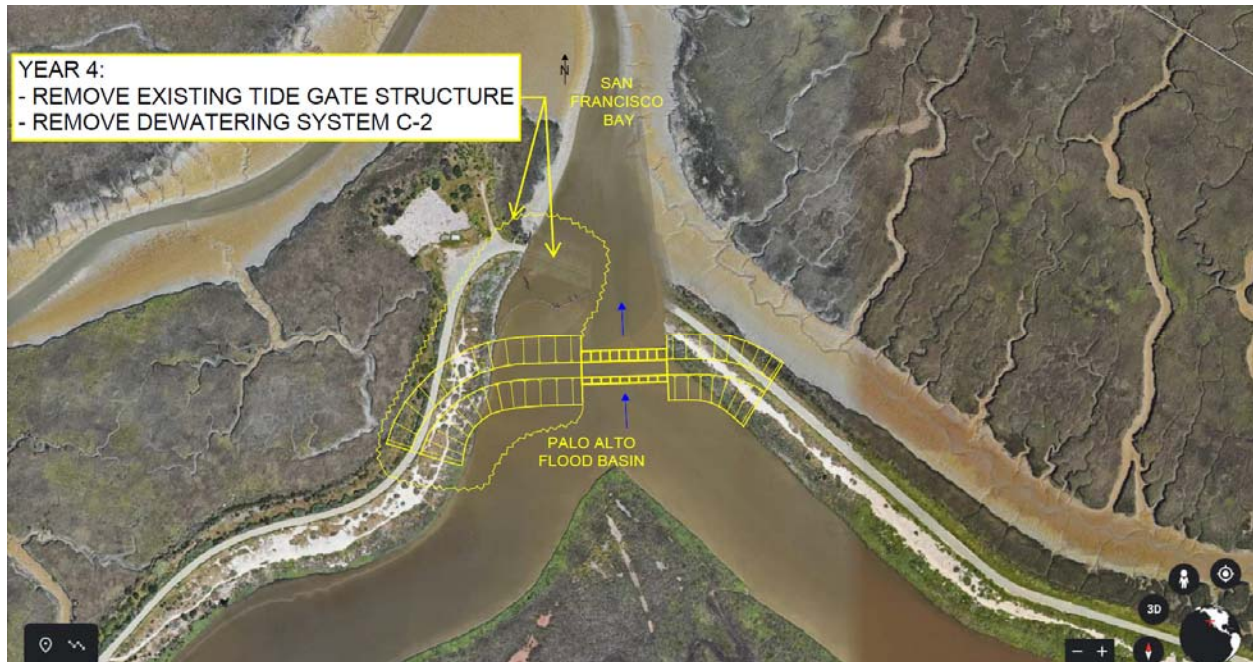


Figure 4: Alternative F Construction (Year 4)

Alternative F Cost Estimate

Cost estimates are in 2020 dollars. A detailed cost estimate can be found in Appendix B.

Construction:	\$ 28,673,000
CEQA/permits:	\$ 1,093,000
Land Acquisition:	\$ 0
Planning & Design:	\$ 3,006,000
Total Lifetime Cost:	\$ 32,772,000

5.3 Site Mobilization, Staging Areas, and Access

The Adobe Creek Loop Trail which extends along the top of the existing levee and tide gate structure is anticipated to be closed for a total of 35 months and includes initial trail surface improvement work. The levee and trail will be excavated during Year 1 construction making this portion of the trail inaccessible until the end of Year 3 construction. A temporary trail bypass bridge could be used in order to keep the trail open during the two 7-month non-construction periods between Construction Year 1 & 2 and Construction Year 2 & 3. However, a temporary

trail bypass bridge would need to be over 700 feet long in order to avoid the dewatering system work area. A temporary trail bypass bridge would likely take two years to construct due to environmental restrictions, would be challenging to obtain environmental permits, would be costly, and presumably might only reduce total trail closure by 4 months since the construction of the bypass bridge itself would require temporary trail closures. The main trail closure would occur from approximately 300 feet to the west and 2,300 feet to the east of the existing tide gate structure (Figure 5). Pedestrian and bicycle access to the trail would be restricted by installing a chain link fence, swing gates, and signage. A detour route along the south side of the flood basin would be marked with signs to direct pedestrians and cyclists around the closed section of the Adobe Creek Loop Trail.

The anticipated 35 months of trail closure target schedule is as follows:

- 9/1/21 – 11/30/21 – 3 months trail closure for initial trail improvement work.
- 9/1/22 – 1/31/25 – 29 months trail closure for Years 1, 2, and 3 scheduled work.
- 9/1/25 – 11/30/25 – 3 months trail closure for Year 4.

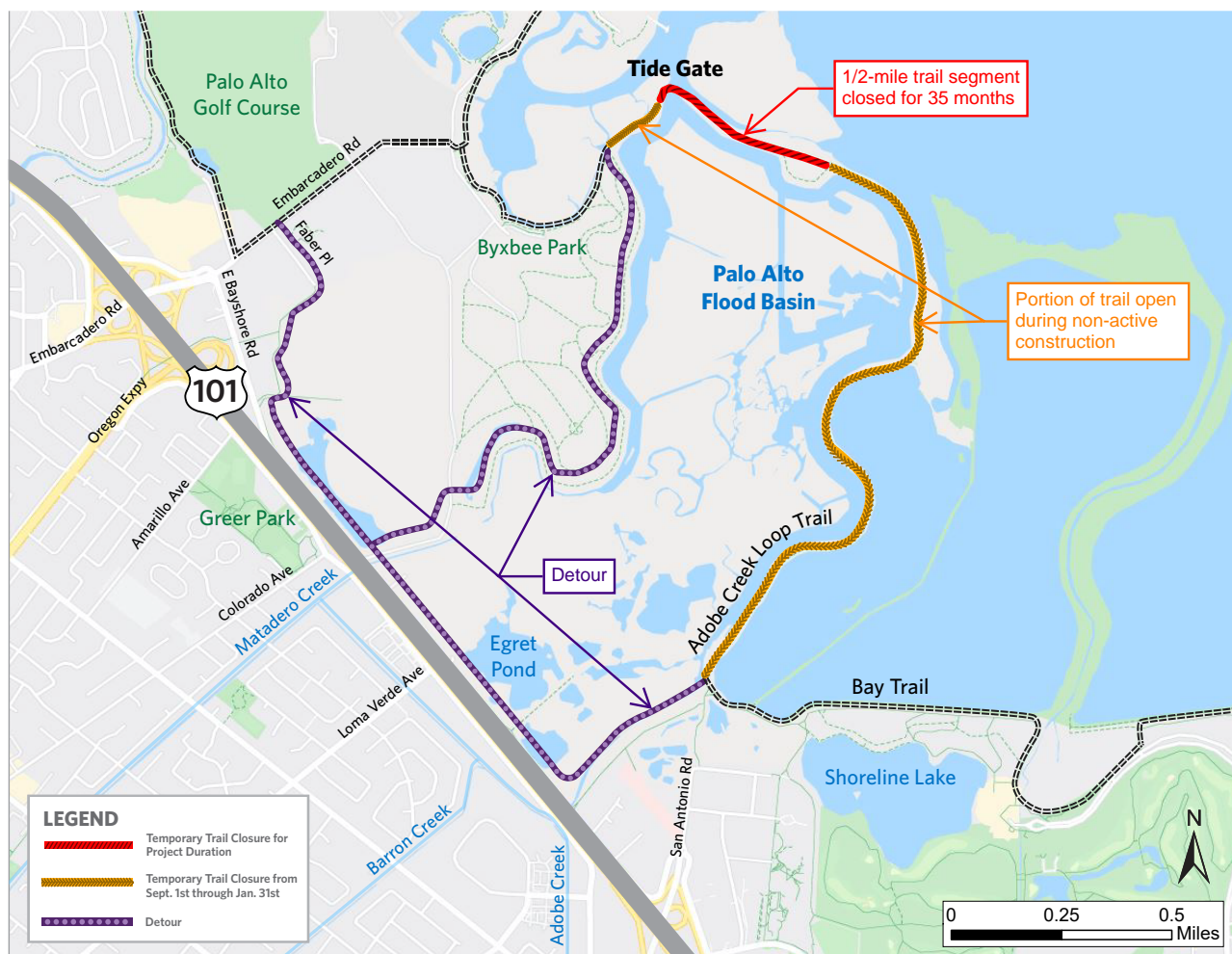


Figure 5: Trail Closure and Detour Limits

Two staging areas would be established to support construction activities. The first staging area would be approximately 0.4 acre and located just west of the existing tide gate in a previously disturbed area northwest of the Adobe Creek Trail. The second staging area would be approximately 6.2 acres and would be located starting approximately 260 feet east of the existing tide gate structure and extending an additional approximately 2,100 feet, extending into an area where a small pond is circled by the levee (creating a large turnaround area) (Figure 6). The staging areas would be enclosed with chain link fence.

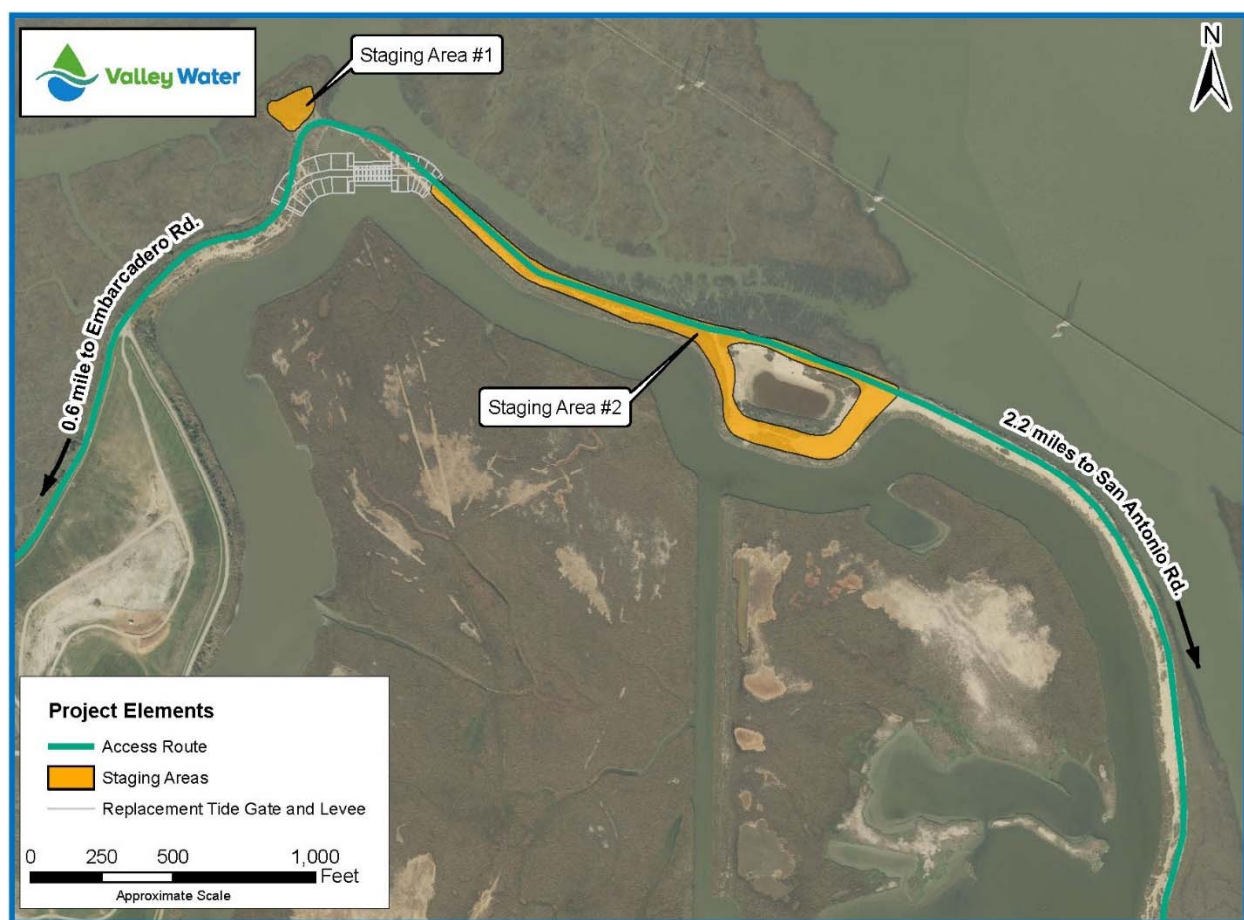


Figure 6: Staging Areas

Construction vehicle and equipment access would occur from both directions along the levee (Adobe Creek Trail), including from Embarcadero Road to the west (0.6 mile to work area) and from San Antonio Road to the south and east (approximately 2.2 miles to work area).

Chapter 6: Operations and Maintenance Program

Under existing conditions, regular maintenance is limited by the poor structural condition of the existing structure and inability to easily dewater the cells to perform repairs. In addition to regular inspections performed by Valley Water, the City of Palo Alto also monitors the condition of the tide gate structure as the City operates and maintains the existing motor driven sluice gate and water level instrumentation Supervisory Control and Data Acquisition (SCADA) system.

Long term maintenance activities for the new tide gate structure would include clearing debris from trash racks or floating booms, replacing leaking gate seals, and inspecting the structure for any deterioration. Maintenance of the new structure will be the shared responsibility of Valley Water and City of Palo Alto.

The existing tide gate structure has one motor driven sluice gate for water circulation during non-flood threat conditions. The new structure will include a similar motor driven sluice gate and SCADA water level measurement instrumentation that can be operated from a remote location. Operation and maintenance of the new motor driven sluice gate, power supply, water surface measuring instruments, and the SCADA system will be the responsibility of the City of Palo Alto. Prior to construction, a formal agreement between the two agencies will be executed to establish this arrangement.

Chapter 7: Project Cost, Funding, and Schedule

7.1 Capital Cost

The planning level capital cost for the staff recommended project including planning, design, permitting, construction, and contingencies (15%) is \$32,772,000 (2020 dollars). Cost details are provided in Appendix B.

7.2 Operations and Maintenance Cost

An assumed average annual maintenance cost for the staff recommended project would be \$28,000 per year. The total maintenance cost for the 50-year life of the staff recommended project would be approximately \$1,400,000. The operations and maintenance costs are not included in the total project costs, as these operations and maintenance costs are already accounted for in Valley Water's Operations and Maintenance budget plan.

7.3 Project Funding

Planning, design, and construction elements of the recommended alternative would be paid for by Valley Water's Watersheds and Stream Stewardship Fund 12. The project team is pursuing Proposition 68 grant funding and cost sharing with the City of Palo Alto.

7.4 Target Project Schedule

Project design work for the Project began in FY 2020. The design phase is expected to be completed in FY 2022. Pending permit approval, construction of the project is expected to begin in FY 2023 and complete in FY 2026.

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Appendix A
Problem Definition/Refined Objectives Report
(December 2019)

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Palo Alto Flood Basin Tide Gate Structure Improvement Project

DRAFT Problem Definition Report

Project No. 10394001



December 2019



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SANTA CLARA VALLEY WATER DISTRICT

PALO ALTO FLOOD BASIN TIDE GATE
STRUCTURE IMPROVEMENTS PROJECT

PLANNING STUDY

Project No. 10394001

DRAFT
PROBLEM DEFINITION /
REFINED OBJECTIVES REPORT

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Executive Summary

Background

The Palo Alto Flood Basin (PAFB) Tide Gate Structure Improvements Project (Project), funded by Valley Water's Watershed Stream Stewardship Fund 12, is located within the City of Palo Alto and the North Western portion of Santa Clara County. The Project study area includes the PAFB and the lower reaches of Adobe, Barron, and Matadero creeks.

This project was initiated by emergency repair work to the Palo Alto tide gate structure in September 2012. The original tide gate structure was constructed in 1957 and is now structurally compromised due to aging after 60+ years of service. Repair work was performed in 2012 to arrest significant water flow beneath the tide gate structure; however, structural repairs to the tide gate structure were not performed.

In 2014, Mark Thomas & Company, Inc (MTCO) completed a site inspection and structural investigation report assessing the condition of the tide gate structure. The report determined the structure to be in "generally good condition" and recommended \$180,000 in maintenance work to replace leaking tide gate seals and repair concrete spalling. In 2017, construction to perform this work was stopped due to leaking within the structure during dewatering. A consequent inspection of the structure resulted in a second structural assessment by MTCO (2017) and a letter recommending that "the structure be replaced rather than trying to repair the damage".

To address the aging tide gate structure, seismic vulnerabilities, and future sea level rise, Valley Water staff recommend the existing tide gate structure be replaced rather than repaired. The new tide gate structure will reduce flood risks in areas surrounding the PAFB and in the lower reaches of Matadero, Adobe, and Barron creeks and protect wildlife and aquatic habitats in the flood basin.

Tide Gate Structure Challenges

The primary problem is a risk of flooding due to physical failure of the tide gate structure.

A secondary problem facing the PAFB is the risk of flooding due to low levee elevations. A topographic survey completed in 2019 shows relatively low PAFB levee elevations along East Bayshore Road and between the PAFB and Renzel Marsh. If the tide gate structure fails, Bay water could flow unchecked into the PAFB and these levees could be overtopped by annual high tide events (8.6+ feet NAVD 88) resulting in flood damages that include temporary closure of Hwy 101 and tidal inundation of approximately 400 to 700 parcels.

Another concern is the potential for Sea Level Rise (SLR) to impact FEMA certification of existing flood facilities. Some of the floodwalls on Matadero Creek were constructed based on the Mean Higher High Water (MHHW) value of the Bay. At some point, the Mean Higher High Water (MHHW) value that was used for FEMA certification of the floodwalls may be revised upward due to SLR. For Matadero Creek a greater than 0.1 foot increase to MHHW could affect FEMA certification for existing flood improvements.

Refined Project Objectives

The original Project Objectives have been refined based on information discovered during the problem definition phase. The original Project Objectives were developed and refined in 2016, and are refined again per this Problem Definition Report.

Project Objectives are presented as follows:

1. Replace the existing tide gate structure to improve the functionality of the flood barrier system.
2. Maximize gravity drainage opportunities to practicably address impacts to flood protection facilities due to future SLR and the 100-year fluvial flood in cooperation with local planning efforts.
3. Limit impacts to habitat areas within the Palo Alto Flood Basin (PAFB).

Next Steps

The project team recommends the existing tide gate structure to be replaced, and for the new tide gate structure to include additional tide gates to mitigate SLR. This will ensure continued flood protection to Adobe, Barron, and Matadero Creeks and will also maintain habitat areas within the PAFB. Next steps will include data collection and preliminary design of a new structure in coordination with long-term collaborative flood protection projects (SAFER Bay, Shoreline).

Preliminary Recommended Project

The Project team recommends that the Planning Study Report consider alternatives to replace the tide gate structure. To maintain the existing functionality of the tide gates with anticipated SLR, the following design elements are required:

1. Construct a new tide gate structure next to the existing one to avoid construction challenges caused by known and unknown subsurface conditions. This will reduce cost escalation, schedule over-runs, and additional impacts to biological habitat and public recreation.
2. The capacity of the new tide gate structure will practicably maximize gravity drainage and practicably mitigate SLR impacts.
3. The top elevation of the new tide gate structure will match existing and potential future levee construction projects.
4. The new tide gate structure will include motor-driven gates to ensure appropriate water circulation conditions.

The total cost to replace the tide gate structure is estimated to be approximately \$26 million but will be further refined in the Planning Study Report. Long term maintenance costs have not been determined at the time of this report.

Community Outreach

The project team has met with the City of Palo Alto, the City of Mountain View, and the SFCJPA on numerous occasions to develop the project and to coordinate upcoming public and stakeholder outreach events.

Project Implementation

If the Project Owner elects to authorize staff to continue the Project work the following milestones are expected as the next steps for Project implementation:

- | | |
|---|----------------|
| • Complete planning phase, begin design phase, and begin CEQA | Spring 2020 |
| • Begin plans and specifications | Spring 2020 |
| • Complete design | Winter 2020/21 |
| • Complete permit acquisition and plans and specifications | Spring 2021 |
| • Begin construction | Summer 2021 |
| • Complete construction | Winter 2024/25 |

Chapter 1: Introduction

This report has been prepared as part of the PAFB Project planning study to describe existing site conditions and facilities, identify potential problems within the Project area, define opportunities and constraints, refine project objectives, and present preliminary conceptual alternatives.

Chapter one introduces the Project's background and objectives and reviews previous and ongoing engineering projects and other studies that contribute to the Project planning study.

Chapter two details existing conditions within the Project Area and briefly describes the Project's watershed and creeks that flow into the Project Area. Existing condition characterization includes: the outlet structure and tide gates, levees, geology, groundwater, habitat area, water quality, regular maintenance, public access, cultural resources, hazardous materials, and right of way.

Chapter three describes findings and defines problems identified during initial investigations including: levee settlement, ageing infrastructure, SLR impact to: flood protection facilities, biological resources, and levees forming the PAFB. The chapter concludes with a discussion of the problems, constraints, and opportunities that have thus far been identified for the Project.

Chapter four summarizes input received from community outreach with stakeholders.

Chapter five discusses opportunities and constraints to the Project.

Chapter six discusses potential changes to the project objectives based on Project team findings and stakeholder input. This chapter includes a general description of next steps to complete planning formulation.

Chapter 7 includes approval signatures for findings and recommendations in the Problem Definition Report.

1.1 Background and Origin of Study

This Project initiated from emergency repair work on the Palo Alto tide gates which was completed in September 2012. The repair work addressed unwanted water flow occurring beneath the tide gate structure which was originally constructed in 1957. A map delineating the PAFB and indicating the location of the tide gate structure is included as Figure 1.



Figure 1: Map of PAFB Surrounding Areas

The temporary repair arrested significant under flow; however, Santa Clara Valley Water District (District) staff are concerned that replacement of the existing tide gate structure is required to avoid future loss in level of service which could result in fluvial flooding in the lower reaches of Matadero, Adobe, and Barron creeks and impacts to wildlife and aquatic habitats in the flood basin.

The original purpose of the tide gate structure was to control the downstream water surface elevation for Matadero, Adobe, and Barron Creek, which all drain to the PAFB. The PAFB controls the downstream boundary condition (starting water surface elevation) for these creeks by keeping the high tide out and allowing the PAFB to empty during the low tides which occur twice daily.

Of the current 16 tide gates, 15 are operated by the District and one is operated by the City of Palo Alto. The latter is operated to allow some tidal inflow to the PAFB, subject to an elevation limit to protect PAFB flood capacity and limit saltwater inundation of freshwater habitats. Since San Francisco Bay (Bay) waters have limited access to the PAFB, it has developed a brackish habitat, different from adjacent tidal saltmarsh. This habitat would be changed if the tide gates become ineffective.

Because the PAFB levees and tide gate structure do not meet current FEMA freeboard requirements, the PAFB and surrounding areas are mapped by FEMA as AE Zone with a 100-year tide elevation of 11.0 feet NGVD'29 (13.75 NAVD'88). It should be noted that this is the current flood elevation and does not account for anticipated future SLR.

The PAFB and tide gate structures provide significant flood protection benefits during lesser tidal events and protect significant brackish marsh habitat. The tide gate structure has outlived its 50-year structural life and now exhibit signs of aging such as spalling concrete and exposed reinforcement steel. Without replacement, the tide gate structure is expected to fail in the next few years.

1.2 Goals and Objectives of the Study

The Project is funded by the District's Watershed and Stream Stewardship Fund 12. The mission of the District is to provide Silicon Valley with safe, clean water for a healthy life, environment, and economy.

The following Board Ends Policies are applicable to this Project:

- Board Ends Policy E-3, Article 3.1: "Provide natural flood protection for residents, businesses, and visitors."
- Board Ends Policy E-4, Article 4.1: "Protect and restore creek, bay and other aquatic organisms"
- Board Ends Policy E-4, Article 4.2: "Improved quality of life in Santa Clara County through appropriate public access to trails, open space, and District facilities."

The original Project Objectives have been refined based on information discovered during the problem definition phase. The original Project Objectives, in strikethrough text, and proposed revised Project Objectives are as follows:

- ~~1. Replace or repair the existing structure to improve the functionality of the flood barrier system.~~
1. Replace the existing structure to improve the functionality of the flood barrier system.
- ~~2. Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks.~~
- ~~Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail.~~
- ~~3. Prevent impacts to flood protection due to future SLR and the 100-year fluvial flood.~~
2. Maximize gravity drainage opportunities to practicably address impacts to flood protection facilities due to future SLR and the 100-year fluvial flood in cooperation with local planning efforts.
3. Limit impacts to habitat areas within the PAFB

1.3 Previous and Current Engineering Studies and Improvement Projects

Multiple watershed studies and capital improvement flood protection projects have been completed at the PAFB and on creeks tributary to the PAFB. A brief review and chronological listing of these projects follows.

- *Letter and Professional Opinion regarding structural assessment of the Palo Alto Flood Basin Floodgates Structure* - prepared by Mark Thomas & Company, Inc. for the District, October 2017.

This letter summarizes the state of the PAFB tide gate structure and concludes that the existing tide gate structure "should be able to function for another couple of years".

- *Palo Alto Flood Basin Hydrology* - prepared by Schaaf & Wheeler for the District, July 2016.

This report documents a re-evaluation of watershed hydrology and hydraulic performance for the PAFB. The report improves prior hydrology and hydraulic work that was prepared in detail for the District's Matadero and Barron Creeks Long-Term Remediation Project in 2002. The report forms a basis to examine the impact of SLR on flood basin performance and the efficacy of potential tide gates modifications with respect to reducing flood risks within the lower reaches of Adobe, Barron, and Matadero Creeks and impacts due to submergence of sensitive biological habitats.

- *Inspection Report of the Palo Alto Flood Basin Floodgates Structure* - prepared by Mark Thomas & Company, Inc. for the District, July 2016 and April 2014.

This report summarizes findings resulting from inspection of the PAFB Floodgates Structure conducted February 25, 2014. The investigation was made to determine the effectiveness of emergency repairs to arrest seepage beneath the tide gate structure which were implemented by the District in September 2012. The report concludes that the tide gate structure is generally in good condition, with most of the deterioration located inside the cells and on top of the concrete deck. The trash racks, steel sheet pile wing walls, and tide gates were all found to be in good condition. The report recommends minor improvements to extend the structure's expected years of service.

- *SAFER Bay Project* –presently ongoing San Francisco Creek Joint Powers Authority project.

The SFCJPA has retained consultant services to plan, design, and construct new flood protection facilities that consider the current tidal floodplain and projected SLR over a 50-year period to satisfy FEMA requirements. The project also seeks to explore cost-effective and innovative designs that can adapt to changing climate, enable enhancement of historic marshlands, including those that are part of the South Bay Salt Pond Restoration Project, and expand opportunities for recreation and community connectivity provided by the San Francisco Bay Trail.

- *Baylands & Creeks of South San Francisco Bay* -prepared by San Francisco Estuary Institute for the District, 2005.

The San Francisco Estuary Institute prepared a map for the Oakland Museum which presents both the historical and modern landscape of the South Bay. One side shows the salt marshes as they were prior to the gold rush. The other side presents the modern-day salt ponds and the lower reaches of the creeks in the area south of the Dumbarton Bridge.

- *Final Environmental Impact Report on Matadero/Barron Creeks Long-Term Remediation Project* - prepared by Schaaf & Wheeler for the District, October 2002.

This document, along with the Draft Environmental Impact Report (DEIR), constitutes the Final Environmental Impact Report (FEIR) for the Matadero and Barron Creeks Long-Term Remediation Project. The FEIR provides objective information regarding the environmental consequences of the proposed project. The FEIR also examines mitigation measures and alternatives to the project intended to reduce or eliminate significant environmental impacts.

The completed project includes a combination of bypass construction, channel modifications (including work within the PAFB), and floodwall modifications. The project allowed the District to cease emergency operation of the Barron Creek diversion facility and provide 100-year riverine flood protection along both Matadero Creek and Barron Creek from Foothill Expressway to San

Francisco Bay. Tidal flooding, which affects areas from the Bay to approximately Middlefield Road, is not addressed by the project.

- *Final Engineer's Report on Matadero/Barron Creeks Long-Term Remediation Project* - prepared by Schaaf & Wheeler for the District, October 2002.

In 1997, the District completed a series of flood protection improvements on Matadero and Barron Creeks. While these improvements were intended to provide flood protection meeting National Flood Insurance Program standards, subsequent analyses and system performance during the February 1998 El Nino flood demonstrated that the completed improvements did not provide flood protection meeting national standards.

This report provides an understanding of flood protection problems within the Matadero and Barron Creek Watersheds, shows how the recommended remediation plan was selected from a number of alternatives, and provides the District's Board of Directors and the public with information necessary to make informed choices regarding the proposed remediation plan and its alternatives.

- *Physical Model Studies of Barron Creek/Matadero Creek Flood Control Structures* – prepared by CH2M Hill for the District, December 1991.

The District prepared preliminary designs of diversion works and conveyance structures for improvements described in the 1988 Engineer's Report. Hydraulics for these features were sufficiently complex to make accurate water surface predictions difficult using only analytical means i.e., HEC-2 and standard head loss equations. Therefore, the District authorized CH2M Hill to conduct a more detailed hydraulic analysis to study these structures using physical modeling combined with refined calculations. This report includes the results of the model study and the preliminary design layouts needed by the District to prepare final design documents for construction of the modeled facilities.

- *Engineer's Report and Final Negative Declaration on Matadero and Barron Creeks Planning Study (Palo Alto Flood Basin to Foothill Expressway)* – prepared by District, April 1988.

The report is the final planning study report on the Matadero Creek and Barron Creeks proposed flood control project. The project consisted of replacing nine bridges and 2,500 feet of concrete channel, additional floodwalls along 8,000 feet of lower Matadero Creek, construction of a one-mile long underground high flow bypass channel and a 2,000 foot long underground diversion channel, and miscellaneous erosion repairs and access ramps in the upper reaches of Matadero Creek near Foothill Expressway.

- *Hydrologic Analysis of the Palo Alto Flood Basin* – prepared by Linsley, Kraeger Associates for the City of Palo Alto, March 1984.

In the early 1980s the District again proposed to raise the levees surrounding the PAFB. This proposal was made in anticipation of improvements to Adobe, Matadero, and Barron Creeks. The analysis in this report determined that the existing levees in the PAFB provided adequate flood protection.

- *Engineer's Report and Final Impact Report on Proposed Flood Control Measures On The Palo Alto Flood Basin* – prepared by District, September 1976.

The report discusses the potentials of the Project for reduction of flooding southwesterly of Bayshore Freeway. The report assesses the potential for damage from flooding in the community, considers the beneficial and adverse impacts which would arise from a flood protection project and alternatives to it and concludes that flood protection should be provided in the area.

The report recommends a combination of levees and floodwalls along a portion of Matadero Creek, around the Municipal Service Center, and along the northeast side of the East Bayshore Road.

- *Mathematical Model Study of the Palo Alto Flood Basin and Yacht Harbor* – prepared by Water Resources Engineers for the City of Palo Alto, March 1975.

This study used computer models to examine whether reintroducing a tidal marsh environment to the PAFB would affect the basins ability to store 100-year flood flows. The study also modeled the addition of tide gates facing the Palo Alto Yacht Harbor to improve circulation and release sediment from the PAFB.

- *Storage Capacity of the Palo Alto Flood Basin* – prepared by District, March 1974.

The objective of the study was to determine if the PAFB would provide flood control protection to existing residential, commercial and industrial development if the entire +/- 600-acre basin were converted to flood storage. The study recommended that portions of the levees be raised to a minimum elevation of 7.0 NGVD'29 (9.8 NAVD'88) including 2.4 feet of freeboard to account for wave action and future subsidence.

Chapter 2: Project Area

The PAFB is in the City of Palo Alto and near the northern limit of the District's jurisdiction. The PAFB collects floodwater runoffs from Adobe, Barron, and Matadero Creeks. These creeks originate in the foothills of the Santa Cruz Mountains in Santa Clara County and generally flow northeastward into San Francisco Bay through the PAFB. The total tributary drainage area of the PAFB is approximately 31.5 square miles (excluding 585 acres of the basin itself and including the Coast Casey Pump Station)¹. As the creeks flow in well-defined² channels of the valley floors, they pass through highly urbanized areas of the City of Palo Alto, and the Towns of Los Altos, and Los Altos Hills, thereby furnishing outfalls for the city storm drains systems.

These creeks historically discharged directly into the Bay through Mayfield and Charleston Sloughs. As floodwaters combined with Bay waters, flooding of the lowlands occurred during times of high tide. The flooding was intensified due to ground subsidence, which averaged approximately 5.5 feet over the years. To prevent flooding, levees were constructed in 1956 together with the flood gate structure which includes 16 tide gates. The levees and the tide gates were constructed by the District to create a flood basin, later named the PAFB. The PAFB, as it exists today, contains approximately 600 acres and is shown on Figure 2.

¹ Drainage area provided by Schaaf & Wheeler, 2016.

² Several sections of Adobe, Matadero and Barron Creeks have been constructed with concrete trapezoidal and u-frame channels.



Figure 2: Map of PAFB

The floodwaters stored in the PAFB are released to the Bay through sixteen tide gates. The purpose of the tide gate structure is to regulate flows through the basin. When the water surface elevation in the basin is higher than the tidal elevation of the Bay, the tide gates are pushed open by water pressure and discharge from the basin to the Bay. The tide gates are otherwise held shut by gravity and water pressure from the Bay.

The City of Palo Alto opens one of the sixteen tide gates during summer months to circulate Bay water within the PAFB in the vicinity of the outlet structure.

2.1 *Description of Tributary Creek Watersheds*

There are three major creek watersheds which drain in to the PAFB. They are: Adobe Creek, Barron creek and Matadero Creek.

The elevations of the watersheds range from slightly above mean sea level in the valley floor to about 2,000 feet above mean sea level in the mountainous regions. The total drainage area of the watersheds is 31.5 square miles. Of this area, approximately 9 square miles are hill lands and the balance is in the relatively flat valley floor³.

All three watersheds are in Santa Clara County. They are bounded by the San Francisquito Creek basin on the west side, the Santa Cruz Mountains on the south side, the Permanente Creek basin on the east side and the San Francisco Bay on the north side. Figure 3 shows a map of the combined creek watersheds and illustrates the general topography and land use of the areas. Most of the hill lands are characteristically brushy woodland; however, there is some development consisting of streets and private residential homes. The gentle sloping valley floors of the watersheds are highly developed into residential, commercial and industrial uses.

³ Land use area provided by District, 1976.

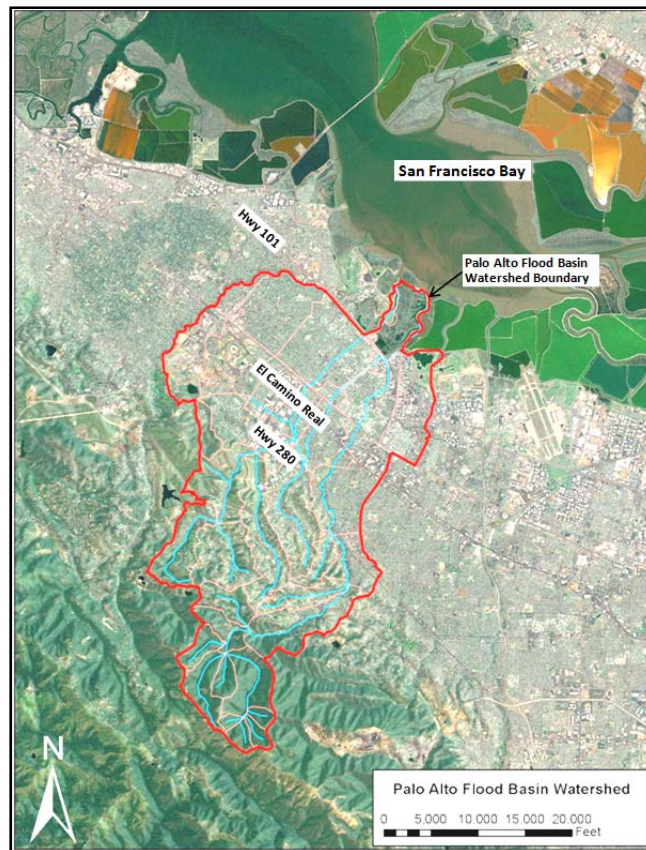


Figure 3: Map of PAFB Watershed Area

The watershed areas have a relatively mild climate. Temperatures range from an average high of about 80 degrees during July to an average low of about 40 degrees in January. The hill lands of the watershed areas have a mean annual precipitation of approximately 30 inches and the valley floor about 19-inches⁴. The area receives approximately 90 percent of this rainfall from November through March and January is usually the month with the most rainfall. The steep nature of the upper portions of the watershed results in short duration, high intensity runoffs for most of the major storms. After each major runoff, low flow continues in the creeks for several weeks as water temporarily stored in the natural storages of the watersheds is returned to the creeks. Although the stream is usually dry during the summer months thereby reducing the fish life, they support various animal life that can find water elsewhere during the dry months. The lower reaches of these creeks were reconstructed to minimize bank erosion and to provide needed flow carrying capacity during high flow events.

2.1.1 Adobe Creek

Adobe Creek runs primarily in a natural channel from its tributary sources in the hills above Interstate 280, downstream to Foothill Expressway. The Adobe Creek Watershed drains 11 square miles, of which

⁴ Mean annual precipitation values based on Appendix B of Schaaf & Wheeler, 2016.

7 square miles are mountainous, and 4 square miles are gently sloping valley floor. The creek's course runs 11 miles.

Adobe Creek's upper tributaries are, in order, the Middle Fork Adobe Creek, then immediately the West Fork Adobe Creek. Next the North Fork Adobe Creek, originating on Page Mill Road, joins Adobe Creek by the Duveneck's main house at Hidden Villa. The North Fork Adobe Creek is also known locally as Bunny Creek. The upper watershed of Adobe Creek is completely protected by Hidden Villa and the Mid-Peninsula Regional Open Space District.

Below the confluences of the "three forks", Adobe Creek is joined by three seasonal creeks in Los Altos Hills. The first is 1.3-mile-long Moody Creek. Next comes 2.0-mile-long Purissima Creek and then Robleda Creek in Los Altos Hills. From that point, Adobe Creek departs mountainous and hilly terrain and enters the valley floor to descend through the cities of Los Altos, Mountain View and Palo Alto.

From 2003 to 2009, the Upper Reach 5 of Adobe Creek (between Foothill Expressway and West Edith Avenue) was restored in an innovative partnership called the Adobe Creek Watershed Group with representatives from the District, local residents and representatives of the City of Los Altos and the Town of Los Altos Hills. The 7.2 million dollar project improved flood conveyance capacity in Reach 5, and also enhanced the creek ecosystem by removing the existing concrete banks and bottom, repairing and stabilizing the eroded banks using minimal hardscape, removing many non-native trees, and establishing a riparian area along 700 feet of bank using mostly shrubs and trees native to the Adobe Creek watershed.

Several sections of Adobe Creek have been re-aligned, including the trapezoidal concrete drainage channel between El Camino Real and U.S. Highway 101 (the portion between Alma Street and El Camino Real was constructed by the District in 1959).

Before passing under Highway 101 and entering the PAFB, Adobe Creek is joined by Barron Creek just upstream of Highway 101. The 100-year flows for Adobe Creek are included in Table 1.

Table 1: 100-year Flows Adobe Creek⁵

Location	100-year Peak (cfs)
At Francemont Avenue	1,800
At Bypass Channel Entrance	2,000
At Bypass Channel Confluence	1,100
Adobe Creek u/s Purissima Creek Confluence	2,000
Adobe Creek at Foothill Expressway	2,700
Adobe Creek at El Camino Real	2,900
Adobe Creek u/s Barron Creek	3,080

2.1.2 Barron Creek

Barron Creek begins in the hills above Interstate 280 in the Town of Los Altos Hills, and flows as a natural stream to Gunn High School, just downstream of Foothill Expressway. Barron Creek runs primarily in a

⁵ Flows determined from Adobe Creek Engineer's Report, 1999.

modified creek with 67% of its course classified as hardened between Foothill Expressway and its confluence with Adobe Creek. The Barron Creek watershed is about 3 square miles, of which 2 miles are mountainous and 1 square mile is gently sloping valley floor. The creek's course runs 5.8 miles long.

The Baron Sediment Basin and Barron Diversion Structure have been built to divert high flood flows from the Barron Creek watershed into the Matadero Creek Watershed. Low flows leaving the diversion structure are conveyed to Barron Creek in a storm drain pipe underneath the Gunn High School playing fields.

From Gunn High School to Laguna Avenue, Barron Creek flows in a natural stream channel adjacent to residential properties. Between Laguna Avenue and El Camino Real (a distance of 3,000 feet), creek discharge is conveyed in a buried 60-inch diameter pipe. Between El Camino Real and about 1,000 feet above the confluence with Adobe Creek, Barron Creek is concrete-lined and trapezoidal in section. Concrete floodwalls have been built downstream of Louis Road. In the lower reaches of Barron Creek, the channel is concrete lined. Downstream of Highway 101, Adobe Creek flows through a riparian corridor until it reaches the PAFB. The 100-year flows for Barron Creek are included in Table 2.

Table 2: 100-year Flows Barron Creek⁶

Location	100-year Peak (cfs)
At Foothill Expressway	740
At Laguna Avenue	160
At SPRR	250
At Adobe Creek	250

2.1.3 Matadero Creek

Matadero Creek runs primarily in a natural channel from its tributary sources in the hills above Interstate 280, downstream to El Camino Real. The Matadero Watershed drains 14 square miles, of which 11 square miles are mountainous, and 3 square miles are gently sloping valley floor. The creek's course runs 8 miles.

The creek drains the foothills through a relatively narrow canyon that stretches from the confluence with Arastradero Creek alongside Old Page Mill Road, downstream to the intersection of Old Page Mill Road with Page Mill Road near Foothill Expressway. Valuable riparian habitat is located along these creek reaches, although horse pastures located between Deer Creek Road and Foothill Expressway have degraded the quality of adjacent stream habitats. Scattered rural residents are also located close to the creek throughout the canyon and upstream watershed.

Construction of the Matadero Bypass Channel has reduced flood damage potential while maintaining the natural riparian corridor from Foothill Expressway to El Camino Real. The only disruption to the natural creek through this reach is an 800-foot long underground culvert beneath the Stanford management Group Tibco Campus near Hillview Avenue. In 1988, the bypass channel alternative was

⁶ Flows determined from Matadero and Barron Creeks Remediation Project Final Engineer's Report, Schaaf & Wheeler, 1999.

selected for this reach since it was the least costly plan and received strong support from the community (District, 1988).

Downstream from El Camino Real, Matadero Creek is contained within a concrete-lined channel of rectangular u-frame section to the Union Pacific Railroad. The vertical concrete walls of the u-frame section have been extended above the natural channel bank as necessary to contain water and/or provide freeboard.

Below Alma Street, which is immediately downstream of the railroad, Matadero Creek is conveyed in a concrete-lined trapezoidal channel. Concrete floodwalls have been built to contain floodwater and/or provide freeboard. Closer to the Bay, the concrete-lining ends at Greer Road and the creek channel transitions to a sacked concrete-lined slope with an earthen bottom. Emergent wetland vegetation has established itself within this reach, which is prone to the accumulation of sediments, particularly bed load.

The Matadero Pump Station, owned and operated by the City of Palo Alto, discharges to Matadero Creek nearly half-way between West Bayshore Road (frontage to Highway 101) and Greer Road. In addition to inflow from the pump station's tributary local storm drain system, runoff that exceeds the capacities of storm drain systems tributary to San Francisquito Creek (typically equal to the 10-year return period) naturally flows downhill toward Matadero Creek and to the extent of available storm drain system and pump station capacity (266 cfs), is discharged into Matadero Creek.

Downstream of Highway 101, Matadero Creek flows through a riparian corridor before it enters the PAFB. The 100-year flows for Barron Creek are included in Table 3.

Table 3: 100-year Flows Matadero Creek⁷

Location	100-year Peak (cfs)
At Foothill Expressway	1,900
At El Camino Real	2,700
At SPRR	2,800
At Middlefield Road	2,800
At Louis Road	2,800
At Highway 101	3,100

2.1.4 Coast Casey Pump Station

The Coast Casey Pump Station is a sub-basin tributary to the PAFB with a maximum pumping discharge of 150 cfs (Figure 4). The Coast Casey Pump Station discharges flood water from the City of Mountain View directly into the PAFB through three steel discharge pipes with tide gates at their outfall. The Coast Casey pump station drains approximately 1.6 square miles of mixed residential and business park area in the City of Mountain View.

⁷ Flows determined from Matadero and Barron Creeks Remediation Project Final Engineer's Report, Schaaf & Wheeler, 1999.



Figure 4: Coast Casey Pump Station Inlet

2.2 *Description of PAFB*

The PAFB was constructed by the District in 1956 and 1957 and is in the City of Palo Alto in the County of Santa Clara. The PAFB is bounded on the north by the City of Palo Alto refuse disposal area, on the east by the San Francisco Bay, on the south by Charleston Slough, on the west by a light industrial complex and Highway 101.

Matadero Creek, Adobe Creek, and Barron Creek receive surface water runoffs from outfalls for city storm drain systems. These creeks historically discharged directly into San Francisco Bay through Mayfield Slough and Charleston Slough. As subsidence occurred, a levee system was constructed to prevent saltwater flooding from the Bay. The PAFB was constructed with levees surrounding a 600-acre portion of the Palo Alto Baylands.

The PAFB was constructed to prevent a repeat of the floods of 1955, when a high tide prevented the escape runoff from Matadero, Adobe, and Barron Creeks into the San Francisco Bay. The trapped runoff waters overflowed upstream creek banks and caused severe flooding in Palo Alto. In order to control the flow of water into the flood basin, a tide gate structure was placed at the confluence of Adobe Creek, Matadero Creek, and the San Francisco Bay, so that the flood basin could be maintained at approximately 2 feet below sea level, creating room to detain floodwaters. The flood basin is relatively flat and mostly 0.6 feet below mean sea level with levees varying in elevation from a low of about one foot to a high of about 11.3 feet above mean sea level.

The PAFB is one of the few remaining wetlands in the San Francisco Bay area that is relatively undisturbed. Its 600-acre area provides a permanent habitat and nesting area for several species of fish, birds and mammals. It also provides a wintering ground for numerous migratory birds which complement the adjoining tidal marsh plant community.

2.2.1 *Historical Ecology*

Prior to Spanish colonization in the late 1700s, the South Bay landscape reflected a combination of natural processes and the influences of indigenous peoples. The native Ohlone used the Bay and its marshlands extensively, to hunt fish and waterfowl, harvest salt, and collect shellfish.

Spanish colonization included land reclamation to convert wetland, marsh, and willow groves typically found in the lowlands between the mountains and the Bay into sheep and cattle grazing areas. Following the defeat of Mexico in 1848, American reclamation projects included routing the outlet of San Francisquito Creek away from Mayfield Slough to its current location and concentrating and extending lowland drainages via constructed channels. As a result, Matadero Creek, Barron Creek, and Adobe Creek were each extended in 1877-1898⁸. Matadero Creek and Barron Creek were hydraulically connected to the Mayfield Slough and Adobe creek was similarly connected to the Charleston Slough. The area between these two sloughs was a complex tidal marshland including intricate small channels and panes (shallow tidally filled ponds). This area supported remarkable waterfowl, shorebirds, fish, and other native species that were reported in early accounts.

The Bay's tidal marshes played an early and lasting role in the development of local infrastructure. Prior to railroads and automobiles, the Bay was the primary means of transport, with the tidal sloughs providing links between land and deep water. Tidal flows into and out of the marshes maintained natural deep-water channels extending through the tidal flats. Where the channels came close to land, entrepreneurs established landings. From these landings, grain, fruit, vegetables, animal products, redwood timber, and other materials were shipped to San Francisco and beyond. San Francisquito Creek included Soto's Landing and Wilson's/Clark's Landing while Matadero Creek included Clarke's Landing.

2.2.2 *Outlet Structure and Tide Gates*

The tide gate structure is a 113' long concrete structure with eight concrete cells to house the tide gates (Figure 5). The top of the structure consists of a 14' wide concrete deck with chain link fences on both sides that is used for maintenance vehicles and trail users. Steel sheet piles were installed at all four corners of the structure to retain the roadway embankment.



Figure 5: View of Palo Alto Flood Basin Tide Gate Structure from Land Side

⁸ Historical Ecology information provided by San Francisco Estuary Institute, 2005.

The tide gate structure is supported on timber piles. A 14' long rock apron grouted with concrete was installed on the Bay side and basin side of the structure. The top of the structure has elevation of 7.6 feet NGVD'29 (10.4 NAVD'88) and the bottom slab elevation is at -5.0 feet NGVD'29 (-2.2 feet NAVD'88) on the basin side. The basin side of the structure includes trash racks to minimize debris jams within the gates (Figure 6).



Figure 6: Palo Alto Tide Gate Structure Trash Racks

A field inspection was performed by Mark Thomas & Co and Collins Engineers, Inc in February 2014. The primary purpose of the investigation was to determine the condition of the structural components and appurtenances located in the water at the time of the inspection both above and below the waterline.

The channel bottom in the vicinity of the structure consisted of riprap typically measuring between 1 and 2 feet in diameter and soft mud. Overall, the channel bottom was found to be in good condition.

The sheet pile wingwalls typically exhibited ½ inch of marine growth consisting of barnacles and various areas of surface corrosion with no section loss below water (Figure 7). The protective coating was generally found to be in good condition. Deterioration was typically located on the top of sheet piles where above the water surface and included minor to medium steel delamination. The tide gates and hardware were found to be in good condition with no apparent section loss.

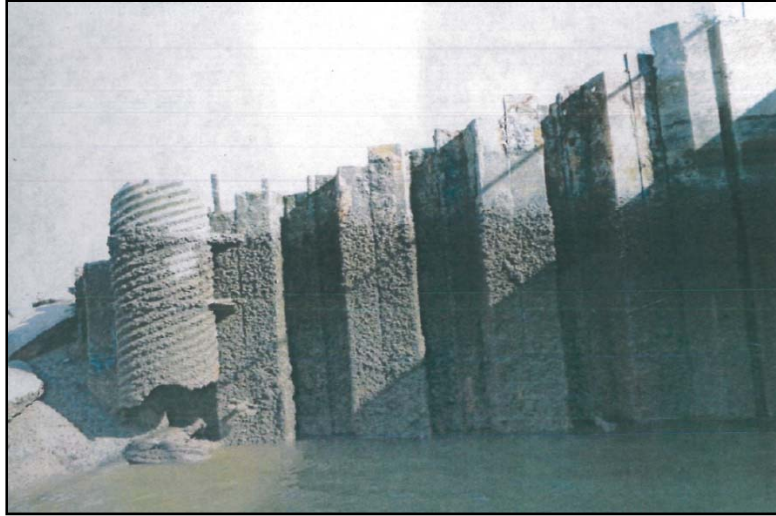


Figure 7: Sheet Pile Wing Walls with Marine Growth

Similar to the wingwalls, the gates were typically covered in $\frac{1}{4}$ to $\frac{1}{2}$ inch of marine growth. The concrete at the north face of the structure was found to be in good condition with no noticeable scaling or pitting. The concrete exhibited typical marine growth similar to that on the steel. Overall, the concrete inside of each barrel was found to be in satisfactory to good condition.

Deteriorated seals were found at several gates, corrosion spall was observed at various locations for all cells (Figure 8). Exposed reinforcing bars with various degrees of percent section loss were also observed at various locations inside the cells and on top of the deck and other locations.



Figure 8: Center Pier Open Corrosion Spall with Exposed Steel Reinforcement

Based on inspection findings, the tide gate structure was determined to be generally in good condition with the majority of deterioration located inside the cells and on top of the concrete deck. The trash racks, steel sheet pile wing walls, and gates were all found to be in good condition. The report recommended the following repairs:

- The leaking seals located at Gates 2B and 4A should be taken care of during the next round of routine maintenance.
- The concrete cracks inside the cells should be considered for repair due to extensive spalling and loss of steel section in the reinforcing bars.
- Remove concrete waste on top of the bottom slab on the bayside of the structure
- It is highly recommended to clean and overlay the top concrete deck with polyester concrete. This repair will stop further deterioration of the concrete deck and prolong the service life of the structure
- Replace and extend the steel fence ten feet beyond the end of the structure for safety protection for the trail users and bicyclists.

In addition to the report recommendations, the underwater inspection report prepared by Collins Engineers, Inc. recommended that underwater inspection of the structure should continue at intervals not to exceed 60 months unless a significant high water/high flow event is experienced. In the event of such an event, an interim underwater inspection should be conducted if any damage or other detrimental conditions are suspected.

2.2.3 Existing PAFB Levees

The earthen levees in the PAFB area were originally constructed in 1958 in a cooperative effort between San Mateo County and the Santa Clara County Flood Control and Water Conservation District to provide flood protection (the Santa Clara County Flood Control District was the predecessor of the District). The levees are no longer at their 1958 “As-Built” elevations due to land subsidence, settlement and erosion and are not FEMA certified.

2.2.4 Geology and Soils

Geology

The Project site is in the Baylands at the mouths of Matadero Creek, Barron Creek, and Adobe Creek. The site is essentially a flat, tidal marsh, just above and just below the level of San Francisco Bay. The flat surface has been incised by meandering stream channels to depths of 2 to 4 feet, forming the present sloughs, and by other smaller, shallower drainage channels, creating meandering patterns.

Deep foundation exploration borings performed in 2018 (approximately 100 feet deep) indicate the site to be underlain by approximately 8 feet of sand to silty sand (levee fill) followed by about 30 feet of clays, then about 20 feet of sands/gravel, and finally clays to the maximum exploration depth

The filed exploration program consisted of drilling exploratory borings and performing Cone Penetration Tests (CPT). The investigation included two borings and two CPTs located in the proposed construction area (Figure 9).



Figure 9: Geotechnical Boring/CPT Locations

Results from the 2018 investigation that will be used for structural design of the new tide gate structure are provided in Table 4.

Table 4: Geotechnical Investigation Boring/CPT Characteristics

Boring/ CPT No.	Approximate Elev. of Top of Boring (Surface of Levee) (NAVD88 ft)	Boring/CPT Depth (ft)	General Subsurface Soil Conditions
B-1	11	98.5	Approximately 8 feet stiff Lean CLAY/ Sandy Lean CLAY (Levee Fill) underlain by about 26 feet of very soft to soft Elastic Silt/Fat CLAY (Young Bay Mud) and about 4 feet of stiff Fat Clay. This is followed by medium dense to dense Sandy/Gravelly soils to a depth of 76 feet below ground surface (bgs) with the exception of very stiff Lean CLAY layer between 59 and 65 feet. Below 76 feet bgs to the maximum depth explored, boring encountered very stiff Lean CLAY.
B-2	11	101.5	Approximately 7 feet stiff Lean CLAY (Levee Fill) underlain by about 30 feet of very soft to soft Fat CLAY (Young Bay Mud), followed by 16 feet of medium dense to dense Sandy/Gravelly soils. This is underlain by about 48 feet of stiff to very stiff Lean CLAY to the maximum exploration depth.
CPT-1	11	100	Approximately 8 feet of sand to silty sand and sandy silt followed by about 33 feet of clays. This is underlain by about 15 feet of sands, about 8 feet of clays and about 8 feet of sands, followed by clays to the maximum depth explored.
CPT-2	11	100	Approximately 7 feet of sands followed by about 27 feet of clays. This is underlain by about 20 feet of sands, about 8 feet of clays and about 8 feet of sands, followed by clays to the maximum depth explored.

Seismicity

There is no surface evidence of active faults in the local area of the Project. Older faults, which may be concealed beneath the most recently deposited sediments, may occur here and in nearby areas. If they do occur, these older faults would offset only the older bedrock and the lower portion of the valley fill deposits; hence, these faults are considered inactive.

Major faults in the region include the San Andreas Fault, located 9 miles to the southwest in the Santa Cruz Mountains; the Silver Creek Fault located 6 miles to the east; the Cascade Fault located 5 miles to the southeast; the Hayward Fault, located 13 miles to the northeast along the northeastern edge of the Santa Clara Valley; and the Calaveras Fault, located 17 miles to the northeast in the Diablo Range. Because of the proximity of these major active faults, the regional area of the Project site is considered a relatively high seismically active area. Within the lifetime of the Project, a large earthquake and several moderate earthquakes affecting the site can be expected in the region. Figure 10 shows the approximate locations of faults relative to the project location.

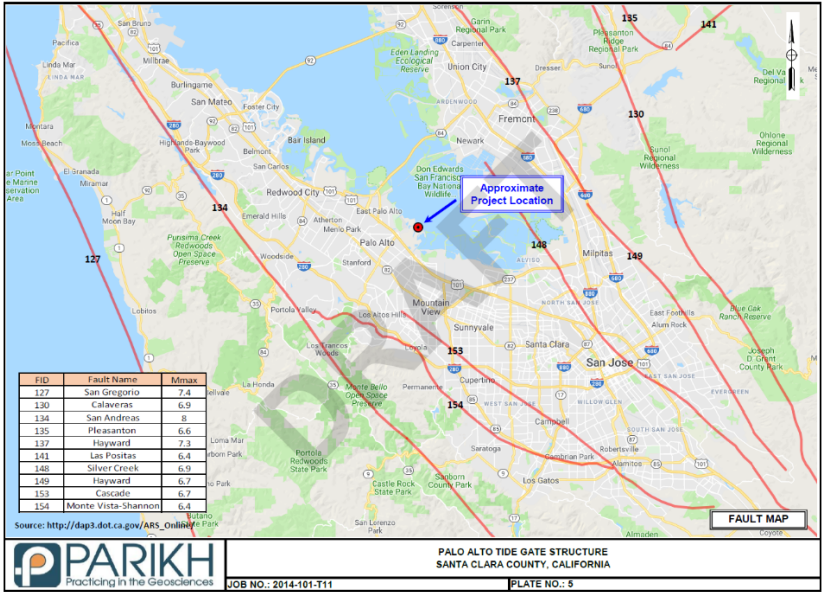


Figure 10: Fault Map of Active Faults Near Project Site

All areas within the Santa Clara Valley are subject to ground shaking from moderate and large earthquakes. Generally, the worst effects of ground shaking and possible ground failure within the valley floor occur in those areas underlain by saturated, weak, clayey soils, such as those found in the Baylands. Under strong or moderate seismic shaking, the levee and the weak levee foundation may tend to lose stability, causing settlement and lateral spreading, which may lead to levee failure, particularly if liquefaction occurs. This would cause flooding in acres adjacent to the breached levees during flood flow conditions.

Soils

Soils in the flood basin are classified as clayey tidal marsh soil or Holocene San Francisco Bay Mud. These soils are affected by surface saltwater and highly salty groundwater occurring at shallow depths;

consequently, they cannot be easily used for agricultural purposes. However, salt marsh vegetation requiring saline conditions thrives in such soils.

Liquefaction Susceptibility

According to the Draft Geotechnical Data Report for the Palo Alto Tide Gate Structure Project prepared by Parikh Consultants, Inc. dated November 9, 2018, liquefaction susceptibility is generally classified as “moderate” for the Holocene San Francisco Bay Mud. The report states, “Preliminary analysis indicates the presence of potentially liquefiable soil layers between 38 and 45 feet below ground surface with a potential post-liquefaction settlement of up to 3 inches.”

Liquefaction has two components that must be considered in the design of the replacement tide gate structure. Firstly deep foundations (e.g. piles) must be designed to proper depths to account for loss of skin friction and potential down drag caused from liquefaction. The potential post-liquefaction settlement of up to 3 inches discussed in the above paragraph would not apply to the new tide gate structure founded on piles, however the settlement would apply to the adjacent levee. Secondly, the foundation design for the new tide gate structure must be designed for seismic taking into account any reduction of lateral stiffness due to liquefiable soils. The seismic design will likely control the type, size, and number of piles required for the new tide gate structure.

Lateral Spreading

According to the Draft Geotechnical Data Report for the Palo Alto Tide Gate Structure Project prepared by Parikh Consultants, Inc. dated November 9, 2018, “lateral spreading is unlikely at the levee because it appears that the potentially liquefiable soil exists at a depth that is much deeper than the height of the levee embankment.”

Land Subsidence

Approximately 5.5 feet of land subsidence has occurred in the Project area due to significant pumping of the Santa Clara Valley ground water basin which began around the turn of the twentieth century and continued to increase until 1965. As ground water production increased, eventually leading to a condition of overdraft, the water table began to decline steadily in the forebay and upper aquifer zone and the artesian flows from the lower aquifer ceased as ground water pressures declined. A decline in the artesian pressure resulted in compaction of lower aquifer zone sediments and eventual land subsidence. Most of the compaction occurred in fine grained silt and clay deposits (aquitards), which are more compressible than the coarse-grained aquifer materials. In some locations, the land subsided as much as 13 feet.

Overdraft ceased in 1965 with the importation of surface waters from the State Water Project and City of San Francisco’s Hetch Hetchy system. Increased imports of surface water allowed the District to greatly expand the ground water recharge program, leading to the substantial recovery of ground water levels. Land subsidence ceased in 1969 as a result of ground water level recoveries and development of artesian pressures in the lower aquifer zone. In most recent years, pressures in the lower aquifer zone have recovered to the extent that wells within the basin interior have again become artesian and now flow on an intermittent seasonal basis. However, ground surface elevations within the forebay and in certain large pumping areas within the basin have not recovered to their pre-overdraft levels because the compression of clay underlying the Santa Clara Valley is irreversible.

2.2.5 Hydrology

The District updated hydrology and hydraulics for the PAFB in 2014 (Schaaf & Wheeler, 2016) following emergency repair work at the outlet structure completed in September of 2012. The update included re-evaluating hydrology and hydraulics work previously prepared for the District's Matadero and Barron Creeks Long-Term Remediation Project in 2002. The update was necessary to reflect: updated rainfall statistics, an additional 12 years of flow records, additional maximum tide records, changes to the Palo Alto Landfill, and completion of the San Francisquito Creek Pump Station in 2009.

Based on an aerial topographic survey conducted in 1999, it was determined that minimal change to the PAFB storage capacity had occurred since 1974.

Based on updated hydrology and hydraulics, statistical values for the 50-percent, 90-percent, and 95-percent confidence limits for the 100-year PAFB water surface elevations were calculated (Table 5). The table provides the non-exceedance probability; that is, the confidence that a given water surface elevation will not be exceeded during the design 100-year event⁹. A fifty percent confidence means that the given water surface elevation is just as likely to be exceeded as not.

Table 5: Summary of PAFB Water Surface Elevation Uncertainty¹⁰

Scenario	50% Confidence (feet NGVD)	90% Confidence (feet NGVD)	95% Confidence (feet NGVD)
Maximum WSEL in PAFB	5.1	5.9	6.0
WSEL in PAFB when Matadero Creek inflow is at its peak	2.7	3.4	3.5
WSEL in PAFB when Adobe Creek inflow is at its peak	2.0	2.4	2.5

The 90- and 95-percent confidence limits are provided since those statistical abstractions were used in the risk and uncertainty analysis of the Matadero Creek floodwalls, which assumed a maximum PAFB water surface elevation of 7.2 feet NGVD'29 (10.0 NAVD'88) and a PAFB stage of 4.6 feet when Matadero Creek inflow is at its peak, for risk-based backwater analysis. These assumptions remain valid, however conservative, based on the updated statistics¹¹.

2.2.6 Ground Water

The unconsolidated alluvial sediments which underlie the valley floor area of Santa Clara Valley constitute a large and significant groundwater basin. The Project site lies within the interior Baylands area of the Santa Clara Valley where the underlying materials consist of a very thick clayey section, complexly interspersed with thin channels, beds and lenses of sand and gravel. The principal aquifers are these sand and gravel layers.

⁹ Unlike traditional District flood protection methods which consider the 100-year fluvial event and 10-year tide or vice versa, the 100-year water surface elevations for this study are based on a worst-case combination of rainfall and tide cycle timing (see Schaaf & Wheeler, 2016 for details).

¹⁰ From the Hydrology report prepared by Schaaf & Wheeler, 2016.

¹¹ From the Hydrology report prepared by Schaaf & Wheeler, 2016.

The groundwater in the Project area is generally divided into two broad units, the upper zone and the lower zone. These zones are separated by an extensive clay layer, or “aquitard”, which effectively delineates the two zones at depths of about 150 feet. All waters occurring in the lower zone are confined (under pressure) by this clay layer which thins out to the west unconfined zone (water table condition).

The uppermost groundwater in the upper zone of the Baylands is considered semi-perched. This condition implies that this groundwater is perched on clay layers within the predominantly clayey section, but with an unsaturated zone occurring between the perched groundwater and main groundwater below it. Water levels in the upper zones, whether confined or semi-perched, are generally shallow, at depths of less than 5 feet. The upper zone is recharged from stream flow seepage and percolation of rainfall through the imperfections of clayey confining layers or from unconfined areas west of the Project site. Groundwater moves generally toward local wells.

Groundwater in the lower zone occurs confined and is recharged from the unconfined zone (forebay) to the west beyond the thin edge of the extensive confining layers. The only connection between the upper and lower zones within the Project area would be through improperly constructed or defective wells. Movement of groundwater in the lower zone would be from its forebay along the western edge of the valley to areas of pumping in the valley interior.

With the development of groundwater for agricultural and municipal uses starting about the turn of the century, water levels in the upper zone began declining. This induced seawater intrusion in the upper zone created by an inland gradient condition from San Francisco Bay. With the lowering of the piezometric pressure within the confined lower zone, land subsidence started.

Within the Project area, the land surface subsided four to five feet between 1934 and 1967. Subsidence stopped in 1969 due to the partial recovery of the piezometric pressure caused by the reduction of pumping in the area, and several above normal rainfalls of the years since 1969. Reduction of pumping resulted from the substitution of imported water from the City of San Francisco’s Hetch Hetchy Project and the State’s South Bay Aqueduct for the local groundwater. As long as the present piezometric levels are maintained or improved, subsidence is not expected to resume. Conversely, if piezometric levels begin to decline below their pre-1969 levels, land subsidence will resume, resulting in further sinking of the PAFB levees; if the amount exceeded that allowed in the design, levees would have to be raised again. Future over drafting would also further induce seawater intrusion, lowering water quality in some wells and rendering others unusable.

2.2.7 Water Quality

In terms of dissolved minerals, runoff from Matadero Creek, Barron Creek, and Adobe Creek is a magnesium-calcium bicarbonate type of good quality. During individual storms, the early runoff from the upstream urban areas primarily washes contaminants from paved surfaces and becomes degraded. Subsequent runoff largely reduces this water quality degradation by dilution of contaminants.

When the runoff stagnates within the sloughs of the PAFB, it becomes brackish by mixing with Bay waters leaking through the tide gates or passing through one of the gates, which is managed by the City

of Palo Alto¹², by the addition of salt from leaching the inherently salty soils, by concentration from evaporation, and by rise in temperature (which reduces dissolved oxygen levels).

Surface waters in the sloughs vary widely in total dissolved solid content, ranging from 1,000 to 50,000 milligrams per liter (mg/l), and in chloride content, ranging from 3400 to 20,000 mg/l. Biological oxygen demand and large changes in chemical oxygen demand are also experienced in the sloughs. A July 1974 sampling gave a total dissolved solids content of 1120 mg/l in Matadero Creek.

Upper zone groundwater in the Project area is degraded by saltwater to varying degrees with upper levels of total dissolved solids of nearly 50,000 mg/l; and chlorides of 25,000 mg/l. According to the few available logs in the Project area, the depth of the affected zone is almost 100 feet.

Groundwater in the lower zone is not affected by seawater intrusion in the Project area; consequently, the quality is suitable for most domestic and industrial uses. The water quality in the lower zone could be adversely affected by operating improperly constructed or defective wells which would allow degraded waters in the upper zone to contaminate the lower zone. This problem can largely be eliminated by proper well construction techniques.

2.2.8 *Habitat Area*

The PAFB was originally tidal salt marsh. Since the area was diked off to provide a holding basin for excessive storm water runoff, the effects of tidal action on the vegetation have been substantially reduced. The low flow, deep channels are the only areas within the basin affected by tidal waters. The observable significant variations in the vegetation are apparently the direct result of elevation differences affecting the relative soil salinity and amount of tidal flushing. Fresh water inflows from Adobe Creek and Matadero Creek also play a distinct role in creating and maintaining the types of vegetation present. The PAFB performs the ecological functions of reoxygenation, photosynthesis and providing wildlife habitat.

Flora

Three major vegetation types or associations account for most of the PAFB area: annual grassland, salt marsh, and mixed riparian. The grassland covers about 60 percent of the PAFB with Italian rye grass (*Lolium multiflorum*) as the dominant species. Other important species present in this association include ripgut grass (*Bromus diandrus*), wheat (*Triticum*) and barley (*Hordeum vulgare*) grasses, wild oat grass (*Avena fatua*) and *Heleochoa schoenoides* (no common name). The presence of these upland grasses is a direct result of secondary successional change due to altered environmental conditions. The exclusion of saltwater tidal action enables salt-intolerant grass species to take advantage of the upper soil which has been leached of salts.

The pickleweed-fat hen association is the remnant of the previously existing salt marsh. It is found at a lower elevation than the grassland and requires a specific minimum salt content in the soil. Other halophytes (plants restricted to saline soils) found with this association include *Frankenia*, saltbush (*Extriplex californica*), sand spurrey (*Spergularia atrosperma*), brass buttons (*Cotula coronopifolia*), and

¹² The City of Palo Alto actively manages one of the sixteen tide gates to increase saltwater circulation within the PAFB during summer months to improve water quality. However, improved circulation is limited to an area near the tide gate structures. Measures to increase the influence of saltwater circulation will be investigated as part of alternatives development

salt grass (*Distichlis spicata*). Some of the pickleweed is infested with the parasitic marsh dodder, indicating that at least some of the pickleweed may be growing under marginal conditions. This vegetation association is found in sinks and various abandoned channels immediately below the grassland elevations.

The third major association is mixed riparian (the term “mixed” is applied due to the origins of species present). Representatives of riparian communities, freshwater marsh communities, escaped introduced exotics and other naturalized weedy species make up this conglomeration of plant communities. The dominant plants are three species of willows (*Salix laevigata*, *Salix lasiolepis*, and *Salix lucida*), which are common to indigenous riparian communities in Santa Clara Valley. Coyote brush (*Baccharis pilularis*) is also found closely associated with most of the riparian vegetation. This streamside plant community relies on the perennial freshwater supplied by Matadero Creek; the limited available freshwater restricts this community for the PAFB northwestern fringe.

Several smaller groups of plant associations are scattered over a wide area in the PAFB. Some of those represented include freshwater marsh, dominated by cattails (*Typha latifolia*) and bulrushes (*Schoenoplectus californicus*) and large areas of mesic ruderal weeds (upland weeds of disturbed-soil conditions) such as poison hemlock (*Conium maculatum*), thistles (*Cirsium arvense*), mustard (*Brassica tournefortii*), wild beet (*Beta vulgaris*), cheeseweed (*Malva parviflora*), wild radish (*Raphanus raphanistrum*), and sweet fennel (*Foeniculum vulgare*). Several areas are dominated by hydrophilic weeds such as spiny cocklebur (*Xanthium spinosum*), curly dock (*Rumex crispus*), and stinging nettle (*Urtica dioica*).

The freshwater marsh is located primarily along the Adobe Creek outfall into the PAFB but is scattered into the riparian community also. Mesic ruderal weeds, as mentioned above, dominate the roadside levee slopes and other disturbed soil areas.

A California Natural Diversity Data Base search yielded the presence of Point Reyes salty birds’ beak (*Cordylanthus maritimus*), Hoover’s button-celery (*Eryngium aristulatum*), and alkali milk vetch (*Astragalus tener*) potentiality within the PAFB. These are special status plants that should be considered. Invasive species, *Phragmites australis*, common reed, has been reported in the PAFB¹³. Where conditions are suitable this reed can grow to 18 feet high and spread at by 16 feet or more per year by horizontal runners, which put down roots at regular intervals.

Fauna

When enough rainfall occurs, the PAFB supports a great number of species and high density. The three major plant associations contribute to the diversity and multitude of higher animals present. The variety of plant species supports many insects and herbivores, thereby providing ample food sources for the carnivores.

Much of the PAFB is subject to infrequent inundation, putting a severe seasonal strain on wildlife populations within this marshland preserve, by creating cyclic localized population explosions linked to rainfall patterns. Previous periods of heavy rains and flooding have decimated rodent populations upon which many predatory birds rely. These bird species include the common egret, great blue heron, hawks, kites, and owls. The latter three bird groups are more severely affected by heavy rodent losses because of their more specialized food requirements (SCVWD, 1976).

¹³ Personal communication with District biologist and City of Palo Alto parks staff.

Wildlife field observations referred to in this report were made in November 1974, which was a particularly good seed year. This, augmented by lack of inundation, resulting in unusually high rodent populations. Raptor numbers were also high, as evidenced by the many white-tailed kites, Northern harrier and American kestrel observed. Egrets and great blue herons also took advantage of the seasonal abundance of rodents to supplement their diet.

Large populations of ducks winter in the PADB, as it is one of the few remaining major marsh areas left in Santa Clara County. San Francisco Bay is on the Pacific Flyway for many species of migratory waterfowl and is, therefore, critical to the continued survival of many bird species. The more common ducks observed included ruddy duck, mallard, pintail, cinnamon teal, shoveler, and canvasback. Large numbers of American coot were also observed.

Fresh and brackish water habitats encourage several species of shorebirds to forage in these areas of the PAFB. Observed species include black-necked stilt, avocet, killdeer, long-billed dowitcher, lesser yellow legs, and sandpipers. The sanitary landfill adjacent to the PAFB is a significant food source for the gulls, substantially supplementing their diets and contributing to their large numbers. They use the PAFB for a foraging and resting area.

The grassland plant association fosters populations of wildlife typical to many California upland meadows. These include large rodent populations, such as California voles. Large numbers of California ground squirrels exist, particularly in the higher elevation areas, such as the levees. Several black-tailed jackrabbits were sighted. Other rodent species are very likely present also. Many species of birds commonly associated with the grassland community have been seen; they include loggerhead shrike, western meadowlark, song sparrow, and American kestrel. Scatological evidence also indicates the presence of rodent-eating carnivores, perhaps either canids (fox or coyote), or usteleids (weasel).

Birds sighted were a single green heron, long billed dowitcher, lesser yellow legs, and Swainson's thrush, indicating a greater diversity of birds than perhaps previously known. The nearby Sand Point salt marsh (where the Palo Alto Baylands Nature Interpretive Center is located) is known to support a population of salt-marsh song sparrows, a locally threatened subspecies which is restricted entirely to San Francisco Bay salt marshes. Positive identification of this subspecies was not made in the PAFB, but since song sparrows were observed, a strong possibility of its presence exists. At least six white-tailed kites were sighted in the PAFB, but it remains threatened by urbanization, as is the burrowing owl. One white pelican was sighted over the PAFB, landing in the adjacent salt pond to the east.

Although the pickleweed habitat does occur in roughly 30 percent of the PAFB, this particular habitat is not subject to direct tidal action; therefore, the existence of the endangered salt marsh harvest mouse is less likely. No direct evidence of the mouse's presence was noted. No other rare or endangered species were observed, but it is likely that the endangered Ridgeway's rail and California least tern inhabit the area. A California Natural Diversity Data Base search showed other species including longfin smelt and salt marsh common yellowthroat within the PAFB area.

Ecosystems

Wide diversity of organisms and high biological productivity are perhaps the best ecological terms to describe the PAFB. As previously indicated, the existing levee system eliminated all but minor tidal influence in the PAFB. Subsequent soil leaching by freshwater has altered the soil salinity substantially, causing instability in the previous climax plant community. The resulting secondary successional changes have largely replaced the salt marsh with a grassland community, riparian associations and a mixture of garden escapes and introduced exotics. This floral diversity is responsible for the large

diversity of wildlife. It would appear that this biologically rich area is the result of several ecotones (transitional areas between plant communities) that exist within the PAFB. Sufficient evidence is not available at this time to determine if a new level of ecological stability has already been achieved or if the area is still undergoing distributional changes in vegetation.

In an effort to improve water quality during the summer months, the City of Palo Alto opens one of the sixteen tide gates to increase brackish water circulation within the PAFB.

2.2.9 Regular Maintenance

Sediment Deposition

Sediment originates from the upland areas of the Matadero catchment, and is transported down the natural and concrete channels, with a portion of that transported sediment reaching the natural channel in the PAFB. Significant volumes of sediment have been deposited within the overbank of this channel reach. These deposits are believed to exacerbate flooding potential for urban areas upstream of Highway 101.

An overflow bypass was constructed in the PAFB as part of the Matadero/Barron Creeks Long Term Remediation Project (District, 2002). Average total sediment accumulated from 1971 to 1999 is estimated to be 900 cubic yards per year.

The operation and maintenance of Matadero, Barron, and Adobe Creeks are the responsibility of the District. The Watersheds Field Operations Unit Manager directs the operations and maintenance procedures for these three creeks.

Matadero, Barron, and Adobe Creeks are inspected annually to assess channel conditions and sediment removal requirements. The following thresholds have been set to trigger channel maintenance and/or sediment removal for various portions of each creek, as described below.

Matadero Creek – PAFB to Highway 101

- Vegetation growth along the banks of the low-flow channel is to be trimmed to maintain a minimum clear floodway of approximately 20 feet.
- Sediment deposition along the bottom of the low-flow channel shall be monitored by ground survey every year for a period of five years. After the five-year period, the need for sediment removal will be determined.
- Sediment within the overflow bypass at the downstream side of Highway 101 is to be removed when it exceeds a depth of one foot above the concrete channel lining.
- Sediment within the sediment basin at the entrance of the bypass shall be removed when it exceeds a depth of two feet as measured at the concrete invert.
- Sediment deposition under East Bayshore Road will be inspected annually. Sediment will be removed from underneath East Bayshore Road to 100 feet downstream when sediment depth reaches one foot.

- Debris shall be removed from the nose of the pier at Highway 101 when it exceeds a total width of 3 feet.
- Sediment under Highway 101 will be removed when sediment reaches an average depth of 1 foot above the concrete invert at Highway 101 or in conjunction with sediment removal under Highway 101.
- In 2018, the District removed approximately, 3,000 cubic yards of sediment in the reach between Highway 101 and Louis Road.

Adobe Creek – PAFB to Hwy 101

There is no program for sediment removal. Sediment deposition in the greater PAFB is considered to be minimal as evidenced by a comparison of two elevation-storage curves prepared by the District in 1974 and Towill Inc. and MacKay & Soms in 1999. Both curves are included in Figure 11. No additional basin topography has been gathered in subsequent years, it is assumed that the storage has not changed significantly to date.

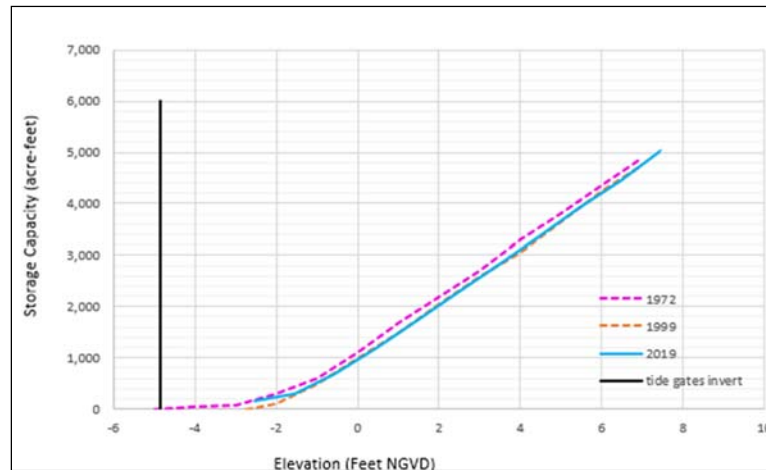


Figure 11: PAFB Storage-Elevation Curves

Vector Management

The Santa Clara County Vector Control District (SCCVCD) is responsible for vector control at the PAFB. In February 2015, the SCCVCD applied a biological control agent and insect growth regulator by helicopter to inhibit commonly called the “winter salt marsh mosquito” *Aedes squamiger* which lays its eggs in the moist soil in late spring and early summer.

The SCCVCD closely monitors the development of mosquito larva in the PAFB. In Spring 2015, mosquito growth trends indicated a high probability that a significant number of salt marsh mosquitoes would become adults in early to mid-March if left untreated. The mosquito fly-off could affect residents from the north coastal areas of the county to as far south as the southernmost part of the City of San Jose and east to Milpitas. The aerial treatment was intended to minimize the number of mosquitoes and reduce the risk of mosquito bites to residents in the surrounding communities.

The City of Palo Alto open and closes the motor-driven gate to control hatch rates for mosquitos.¹⁴

2.2.10 Public Access to the PAFB

The City of Palo Alto owns and maintains a network of trails in the Baylands Nature Preserve (Figure 12). The preserve is the largest tract of undisturbed marshland remaining in the San Francisco Bay.

Fifteen miles of multi-use trails connect to the San Francisco Bay Trail¹⁵ and provide access to a unique mixture of tidal and freshwater habitats. The preserve encompasses 1,940 acres in both Palo Alto and East Palo Alto. The preserve is an important habitat for migratory birds and is considered one of the best bird watching spots on the West Coast.

The preserve consists of the former Yacht Harbor area, the Palo Alto Airport, the Municipal Golf Course, the Duck Pond and public picnic area, the Baylands Athletic Center, the Sailing Station, the Lucy Evans Baylands Nature Interpretive Center, the Harriet Mundy Marsh, the Emily Renzel Wetlands, and the PAFB.

Activities at the preserve include walking, running or biking, bird watching, wind surfing and boating (non-motorized craft). The City of Palo Alto also offers nature walks and programs on ecology and natural history.



Figure 12: Map of Palo Alto Baylands Nature Preserve

2.2.11 Cultural Resources

Cultural resources information was not discovered as part of the problem definition investigation. Per standard contract specifications, best management practices will be included during the construction phase to avoid impacts to cultural resources that may be discovered during excavation work.

¹⁴ Based on "Tide Gate Operations edited 2018" provided by the City of Palo Alto.

¹⁵ Senate Bill 100, passed into law in 1987, directed the Association of Bay Area Governments to develop a plan for a trail around the Bay and included a specific alignment for the Bay Trail.

2.2.12 Hazardous Materials

Hazardous materials information was not discovered as part of the problem definition investigation. Per standard contract specifications, hazardous material testing will be done prior to final design, and is not anticipated to have any effect on the evaluation of the various alternatives.

2.2.13 Right of Way

The District and City of Palo Alto executed a right of way agreement on November 28, 1967. The easement grants the District the right to construct, reconstruct, inspect, maintain and repair a channel and basin, protection works and appurtenant structures for flood control and storm drainage purposes. District right of way easement at the PAFBA generally includes the levee, embankment, and tide gate structure, at the perimeter of the basin (Figure 13).



Figure 13: Map with Approximate Location of District Easement at PAFB

2.2.14 Public Services and Utilities

Public services and utilities are provided to the Project area by the following organizations and agencies (Table 6):

Table 6: Public Services and Utilities Provided to the Project Area

Utility	Agency
Power	City of Palo Alto, Pacific Gas and Electric Company
Water Supply	City of San Francisco (wholesaler) City of Palo Alto (retailer)
Sewage Treatment and Solid Waste Disposal	City of Palo Alto
Flood Protection	Santa Clara Valley Water District
Parks and Recreation	Santa Clara Parks and Recreation Department; Mid-Peninsula Regional Parks District; City of Palo Alto Parks Division and Recreation Department
School Districts	Palo Alto Unified School District and Foothill College District
Environmental Quality	California Department of Fish and Wildlife Services, NOAA National Marine Fisheries, Regional Water Quality Control Board, Santa Clara County Creeks Coalition, Santa Clara Valley Audubon Society, United States Environmental Protection Agency, Bay Area Conservation and Development Agency, United States Fish and Wildlife Service, United States Army Corps of Engineers, City of Palo Alto, and possible others
Fire Protection	City of Palo Alto
Police Protection	City of Palo Alto

Chapter 3: Problem Definition

3.1 Description of the Levee Settlement Problem

A 1974 District report recommended inboard PAFB levee elevations be constructed and maintained at 9.8 feet (NAVD'88). Based partly on the flood basin's designation as a wetland preserve, the City of Palo

Alto opposed raising the levees to 9.8 feet (NAVD'88). Eventually, the District and City reached a negotiated compromise, whereby the minimum PAFB levee elevation was set to 8.9 feet (NAVD'88).¹⁶

Upon inspection of the topographic survey performed in 2019, the Project team has identified multiple sections of the PAFB levee that appear to be lower than 8.9 feet (NAVD'88). These areas are located between the PAFB and East Bayshore Road and between the PAFB and the Renzel Marsh.

If the tide gate structure fails, annual frequency peak high tide events (8.6+ NAVD'88)¹⁷ could close Hwy 101 and cause flood damage to approximately 400 to 700 parcels. It should also be noted that 2-year high tide events (9.0+ NAVD'88) would top the inner-levees regardless if PAFB was opened up to the bay.

3.2 Description of Tide Gate Structure Problem

The PAFB tide gate structure has been compromised by the effects of ageing. This is evidenced by concrete spalling and corrosion of the structure's concrete steel reinforcement as noted during structural inspections (MTCO, 2014). In addition to this immediate problem, the Adobe, Barron, and Matadero Creek flood protection facilities and PAFB ecological habitats are vulnerable to the effects of possible future SLR.

3.2.1 Immediate Problem -Ageing Infrastructure

As described in Section 2.2.2, the tide gate structure is significantly deteriorated due to typical marine corrosion and natural weathering processes. Constructed in 1956 and 1957, the tide gate structure is more than 60 years old and has exceeded its service life expectation.

Structural engineering inspection of the tide gate structure occurred on February 25, 2014 at 9:50 am. At that time, the water elevation on the Bay side of the tide gate structure was approximately 7.5 feet above Mean Lower Low Water (MLLW). The water surface on the Basin side remained approximately 3 feet deep or approximately 2 feet above MLLW.

According to the field report, the channel bottom in the vicinity of the structure consisted of rip rap typically measuring between 1 and 2 feet in diameter and soft mud. The steel sheet piles typically exhibited ½ inch of marine growth consisting of barnacles and various areas of surface corrosion with no section loss below water. The protective coating was typically found to be in good condition. Deterioration was typically located on top of the sheet piles where above the water surface and included minor to medium steel delamination. The tide gates and hardware were in good condition with no apparent section loss.

The gates were typically covered in ¼ to ½ inch of marine growth, similar to the wing walls. The concrete at the north face of the structure was typically found to be in good condition with no noticeable scaling or pitting. The concrete exhibited typical marine growth similar to that on the steel. Overall, the concrete inside of each barrel was found to be in satisfactory to good condition.

Deteriorated seals were found at several gates and corrosion spalls were observed at various locations in all 8 cells. Additionally, exposed reinforcing bars with various degrees of section loss were observed at various locations on the interior of the cells, on top of the deck, and at various other locations.

¹⁶ Information taken from the Matadero and Barron Creeks Remediation Project Final Engineer's Report (2002)

¹⁷ Information sourced from page B-43 the San Francisco Bay Tidal Datums and Extreme Tides Study Final Report (2016) by AECOM

3.2.2 Future Problem -SLR Impacts

Results of HEC-RAS simulations for existing conditions are presented graphically and in tabular form herein. Figure 14 shows a summary of PAFB operation for the tidal shift (29 hours) that produces the maximum 100-year water surface elevation in the basin, which is 6.0 feet NGVD'29 (8.8 NAVD'88). Basin stage is labeled on the left-hand y-axis; flow is labeled on the right-hand axis. Tide elevation, PAFB elevation, total flow through the tide gate structure (eight gates), flow through each individual gate, and the total flow into the PAFB are all charted over a one-week period. Simulated gates operation does not allow reverse flow, and the minor negative flow spikes are considered a small model instability that does not affect the overall result.

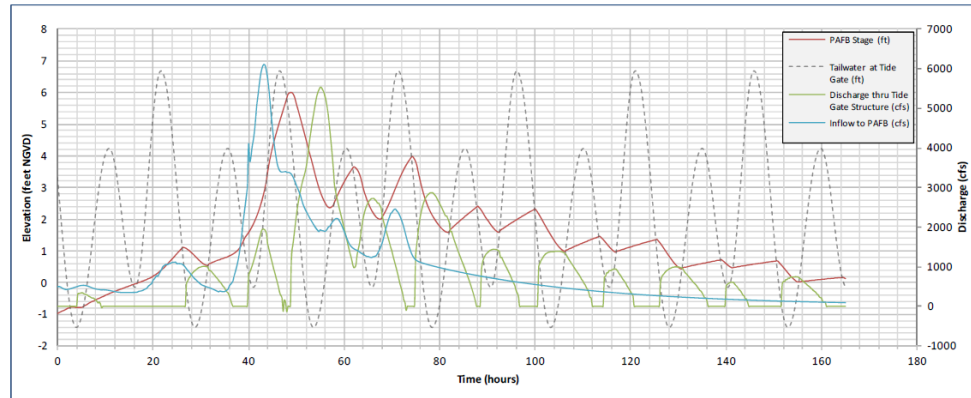


Figure 14: PAFB Operation with Maximum Stage Based on Random Tidal Shift

SLR scenarios were adopted from recent projections from the National Research Council¹⁸. SLR predictions are added directly to the coincident tide cycles, essentially modeling the rise in Bay tide cycle as a uniform vertical datum adjustment. Despite some evidence that the difference in the intertidal range (i.e. between MHHW and MLLW) may be widening along with the overall trend of rising seas, the California Climate Change Center “assumes that all tide datums, e.g. mean high tide and flood elevations, will increase by the same amount as mean sea level.”

Low and high range of the projections are both used to reflect the uncertainty bounds inherent in developing the projections and applying them to a single location. Table 7 provides a summary of the range of SLR projections contained in the 2012 NRC document.

¹⁸ National Research Council, Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past Present, and Future, National Academies Press, Washington, 2012.

Table 7: Summary of NRC SLR Scenarios

Time Period	Low Range SLR (feet)	High Range SLR (feet)
2000 – 2030	0.13	0.98
2000 – 2050	0.39	2.00
2000 – 2100	1.38	5.48

If no improvements are made to the PAFB, SLR will result in a significant change to the maximum PAFB stage. Maximum stage in PAFB resulting from SLR predictions is estimated from a worst-case combination of rainfall and tide cycle timing with the existing tidal gates¹⁹. Table 8 provides a summary of the predicted maximum stage in the PAFB without levee overtopping²⁰ for the predicted ranges of three SLR rise scenarios (2030, 2050 and 2100) assuming the configuration of the flood basin and tide gate structure are not changed. It is problematic that at several locations along the PAFB containment levees, including at the bike path adjacent to East Bayshore Road, the top of the levee elevation is less than 7.0 feet NGVD'29 (9.8 NAVD'88). These locations can be expected to be overtopped under existing conditions and for all SLR scenarios.

Table 8: Impact of SLR on Maximum PAFB Stage

SLR Scenario	Sea Level Rise (feet)	100-year Coincident Tide (feet NGVD)	Maximum PAFB Stage (feet NGVD)
Existing	n/a	7.20	6.00
2030 Low	0.13	7.33	6.16
2050 Low	0.39	7.59	6.56
2030 High	0.98	8.18	6.93
2100 Low	1.38	8.58	7.00
2050 High	2.00	9.20	7.67
2100 High	5.48	12.68	11.31

3.2.2.1 Adobe, Barron, and Matadero Creek Starting Water Surface Elevations

Flood improvements constructed by the District provide flood protection to Adobe, Barron, and Matadero creeks, satisfy standards set forth by the Federal Emergency Management Agency (FEMA), and reduce the burden of flood insurance purchases within the City of Palo Alto.

¹⁹ See Schaaf & Wheeler, 2016 Corrected Final Report for hydrology p. 37.

²⁰ PAFB levees are modeled to contain water volumes with no spilling to determine minimum levee crest elevations required for alternatives that include modification of existing levees or floodwalls or construction of new ones.

Starting water surface elevations (SWSE) used for hydraulic design of flood improvements (levees, floodwalls, culverts, etc.) on these creeks were determined based on statistical abstractions and uncertainty analyses.

For Matadero Creek, the SWSE of 4.6 feet NGVD'29 (7.4 NAVD'88) was used for risk-based back water analysis (Schaaf & Wheeler, 2016). The SWSE used for Adobe Creek was 5.0 feet NGVD'29 (7.8 NAVD'88)²¹. Because both Barron Creek and Adobe Creek share the same outlet to the PAFB, the SWSE for Barron Creek is expected to be equal to Adobe Creek at 5.0 feet NGVD'29 (7.8 NAVD'88).

FEMA guidelines suggest that the worst-case levee failure scenario should be mapped. If the outboard levees do not hold, as must be assumed for FEMA analysis, the PAFB is exposed to direct tidal action from the Bay. The SWSE recognized by FEMA for each of the three creeks is the expected MHHW elevation which is equal to 4.5 feet NGVD'29 (7.4 NAVD'88)²².

Because hydraulic analyses for each creek include SWSEs above MHHW, flood improvements for these creeks will continue to satisfy traditional FEMA starting water requirements (100-year creek discharge with MHHW SWSE) until SLR causes the statistical value of MHHW to exceed SWSEs. For Matadero Creek a greater than 0.1 foot increased to MHHW could affect FEMA certification for existing flood improvements.

3.2.2.2 *Tidal Flooding in Palo Alto*

The National Oceanic and Atmospheric Administration (NOAA) has developed a useful tool to depict the potential for inundation across various SLR scenarios²³. Figure 15 shows the NOAA predicted flood area that is expected for a 2 foot rise in sea level with a Mean Higher High Water tide elevation (depth increases from light to dark). Tidal flooding under this scenario would increase the FEMA Special Flood Hazard Area.

²¹ Information based on personal communication with District hydraulics staff, 2014.

²² The MHHW was determined based on a 19-year mean at the Dumbarton Bridge (Schaaf & Wheeler, 2016).

²³ NOAA SLR and Coastal Flooding Impacts website: <http://www.coast.noaa.gov/slr/>.

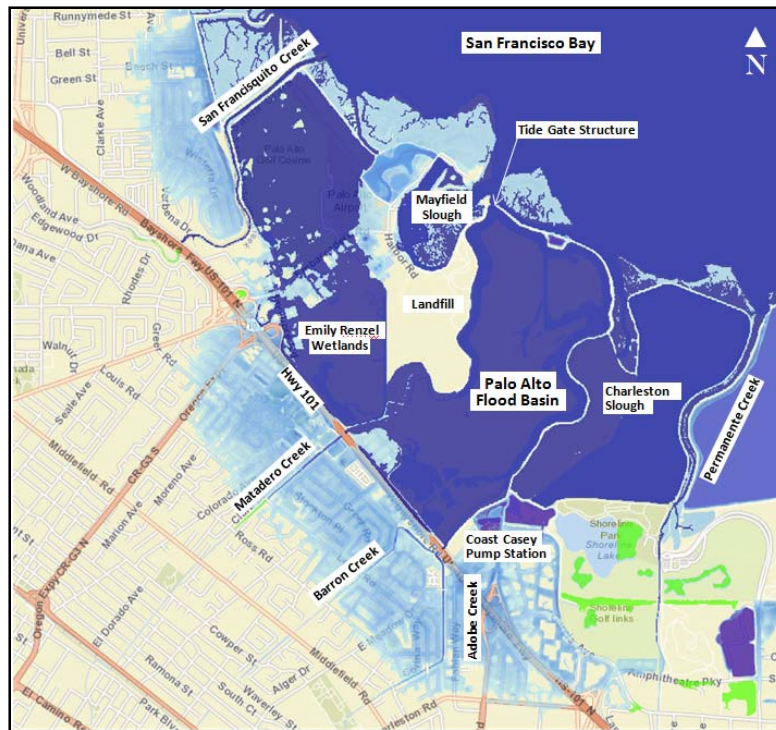


Figure 15: Map with NOAA Tidal Inundation for 2-foot SLR and MHHW Tide

3.2.2.3 Biological Resources

SLR is expected to inundate sensitive habitat areas in the PAFB. Because a comprehensive survey of biological areas within the PAFB has not been conducted for over 40-years, the impacts or benefits associated with increased water surface elevations and existing habitat are not known. The Project performed a detailed LIDAR, ground, bathymetric, topographic, and wetland delineation surveys in 2019. Detailed habitat surveys will facilitate careful evaluation of Project alternatives with respect to biological and flood protection trade-offs.

3.2.2.4 Levee Erosion

SLR is likely to result in reduced stability and increased overtopping of the existing barrier levees facing the Bay. Wind wave attack on existing levees is expected to cause greater erosion as the effective levee width²⁴ available to resist wave action will be reduced by SLR. Overtopping of levees by wind waves erode levee crests and back slopes.

3.2.3 Vector Management

Detailed records are maintained by the Santa Clara County Vector Control District (SCCVCD) concerning major mosquito breeding areas, population densities, and control techniques and materials. The PAFB is considered a known or potential mosquito problem area (South Bay Salt Pond Restoration Project

²⁴ Levee width decreases in the direction of the levee crest (i.e. the base is wider than the top).

(SBSPRP, 2007). Mosquitoes serve as vectors for several diseases, including the West Nile Virus which has been found in Santa Clara County, that pose health concerns for humans and domestic animals.

Mosquito control techniques employed by the SCCVCD emphasize minimization and disruption of suitable habitat, and control of larvae through chemical and biological means, as opposed to spraying of adults.

The Project will coordinate closely with the SCCVCD to develop mosquito management solutions as part of the project.

3.2.4 Water Quality

Volunteer water quality monitoring at the PAFB was conducted at 21 sites on a semi-monthly basis between 2003 and 2006 (SBSPRP, 2007). The volunteers used data sondes (probes) to take measurements of temperature, conductivity, dissolved oxygen, and pH. The City of Palo Alto manages this data.

Chapter 4: Community Outreach

The project team is coordinating with the City of Palo Alto to conduct public meetings in Spring 2020. The project team has met with project stakeholders including the City of Palo Alto, City of Mountain View, and the San Francisquito Creek Joint Powers Authority to gain support for replacement of the tide gate structure. These stakeholders have reviewed and provided comments to develop the Preliminary Design Criteria Memorandum²⁵ that has been used to develop preliminary alternatives included in the Project Planning Study Report.

On January 8, 2018, the District project team met with the City of Palo Alto to coordinate ongoing efforts and next steps. During the meeting the group discussed project coordination with the San Francisquito Creek Joint Powers Authority (SFCJPA) SAFER Bay Project, The City of Mountain View South Bay Salt Pond Restoration Project Mountain View Ponds (Mountain View Ponds), and the South Bay Shoreline Levee project. The project team also discussed an interagency cost share agreement to fund the tide gate structure replacement project, PAFB data sharing, and the District's ongoing effort to prepare an emergency action plan for the PAFB.

On October 29, 2018, the District project team met with the City of Palo Alto, City of Mountain View, and the SFCJPA to ensure inter-agency coordination to advance planning, design, and construction of a new tide gate structure. As a result of the meeting, the project team learned that the SAFER Bay project expects to complete planning within the next eight years and the Mountain View Ponds project expects to begin construction in 2020. At the time of this report, the new tide gate structure is included in one of the three SAFER Bay conceptual alternative. Given the immediate risk of tide gate structure failure, the group agreed that the water district project team should proceed with planning, design, and construction of a new tide gate structure.

²⁵ Preliminary Design Criteria Memorandum (Appendix A)

Chapter 5: Opportunities and Constraints

This project has evolved over several planning iterations as follows:

In 2012, emergency repairs were completed to arrest flow beneath the structure. As part of that work, approximately 1,200 cubic yards of concrete was pumped into the void beneath and surrounding the tide gate structure.

In 2014, a structural engineering assessment of the structure suggested the structure could last about 5 additional years if minor maintenance repairs in the amount of approximately \$200,000 were completed.

In 2016, a Problem Definition Report/Conceptual Alternatives Report was drafted to consider several opportunities to protect flood facilities on Adobe Creek, Barron Creek, and Matadero Creek while improving habitat conditions in the PAFB. These opportunities resulted from stakeholder engagement with the JPA, the City of Palo Alto, and the South Bay Shoreline Project. Opportunities and constraints evaluation resulted in project alternatives ranging from replacing the tide gate structure and constructing new barrier levees to reducing the flood basin size by about two thirds with an ecotone levee and pump station²⁶. Due to the high cost and complexity of these alternatives, which would delay construction funding and permitting, and the urgent need to replace the tide gate structure, the project objectives were refined to include an alternative to complete minor maintenance repairs to the existing structure.

In 2017, minor maintenance repairs were attempted; however, the construction contract was cancelled due to difficulties encountered during the dewatering phase.

Like the draft 2016 Problem Definition Report (PDR), this PDR is constrained by the urgent need to replace the tide gate structure before expected failure(s) occur. This PDR recommends replacing the existing tide gate structure and maximizing gravity drainage opportunities to practicably address anticipated SLR impacts to flood protection facilities on tributary creeks to the flood basin.

Chapter 6: Changes to Project Objectives/Next Steps

The original Project Objectives have been refined based on information discovered during the problem definition phase and after an attempt to implement minor maintenance repairs in 2017. The original Project Objectives were developed and refined in 2014, refined again in 2016, and are refined again per this Problem Definition Report. Project Objectives are presented as follows:

1. ~~Replace or repair the existing structure to improve the functionality of the flood barrier system (2014).~~

~~Replace or repair the existing structure to improve the functionality of the flood barrier system in the short term (2016).~~

Replace the existing structure to improve the functionality of the flood barrier system.

²⁶ Palo Alto Flood Basin Tide Gate Structure Improvements Project Draft Problem Definition and Refined Objectives/Next Steps Report (SCVWD, 2016).

2. ~~Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks (2014).~~

~~Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks in cooperation with local planning efforts (intermediate term, 5 years +/-) (2016).~~

Maximize gravity drainage opportunities to practicably address impacts to flood protection facilities due to future SLR and the 100-year fluvial flood in cooperation with local planning efforts.

3. ~~Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail (2014).~~

~~Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail in cooperation with local planning efforts (intermediate term, 5 years +/-) (2016).~~

Limit impacts to habitat areas within the PAFB.

4. ~~Prevent impacts to flood protection due to future SLR and the 100-year fluvial flood.~~

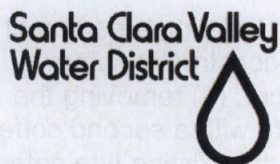
~~Prevent impacts to flood protection due to future SLR and the 100-year fluvial flood in cooperation with local planning efforts (intermediate term, 5 years +/-) (2016)~~

Having determined problems facing the Project and discovering external projects also considering improvements at the PAFB (SFCJPA SAFER Bay, SCVWD Shoreline, etc.), the Project team recommends that Project Objective 1 take immediate priority to advance replacement of the tide gate structure and coordinate with long-term collaborative flood protection and habitat enhancement project to account for anticipated SLR impacts. The next steps include completing the planning formulation phase of the Project.

Appendix A

Preliminary Design Criteria Memo

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**DRAFT MEMORANDUM**

FC 14 (01-02-07)

TO: Ngoc Nguyen**FROM:** Roger Narsim**SUBJECT:** Palo Alto Flood Basin Tide Gates Structure
Project Preliminary Design Criteria**DATE:** 1/14/2019**PURPOSE:**

This memo provides an update to management of the project status and recommends preliminary design criteria for use in planning and design of a new tide gates structure.

BACKGROUND:

The Palo Alto Flood Basin (PAFB) tides gates structure was constructed in 1956 or 1957 by the City of Palo Alto with support from the Santa Clara Valley Water District ¹ (Water District). In 2011, Water District completed emergency repairs to arrest flow beneath the structure. In 2017, Water District attempted minor maintenance repairs that would extend use of the structure by five years; however, efforts were halted due to challenges faced while dewatering the work area. An assessment report prepared by Mark Thomas (October 2017), recommended that the structure be replaced and added that the structure should continue to function for a couple of years. In 2018, Water District management directed the project team to complete planning, design, and construction of a new tide gates structure.

The project team met with the City of Palo Alto on January 8, 2018 to coordinate ongoing efforts and next steps. During the meeting the group discussed project coordination with Task 2 of the San Francisquito Creek Joint Powers Authority (SFCJPA) Strategy to Advance Flood protection, Ecosystems and Recreation (SAFER Bay) Project, the City of Mountain View South Bay Salt Pond Restoration Project Mountain View Ponds (Mountain View Ponds), and the South Bay Shoreline Levee project. The project team also discussed an inter-agency cost share agreement to fund the tide gates project, PAFB data sharing, and Water District's ongoing effort to prepare an emergency action plan for the PAFB.

The project team met with the City of Palo Alto, the City of Mountain View, and the SFCJPA on October 29, 2018 to ensure inter-agency coordination to advance planning, design, and construction of a new tide gates structure. As a result of the meeting, the project team learned that the SAFER Bay project expects to complete planning in the next eight years and the Mountain View Ponds project expects to begin construction in 2020. At the time of this memo, the new tide gates structure is included in one of the three SAFER Bay conceptual alternatives ². Given the immediate risk of tide gates structure failure, the group agreed that the Water District project team should proceed with planning, design, and construction of a new tide gates structure.

PROJECT DESCRIPTION:

This project will construct a new tide gates structure located approximately 100 feet south of the existing tide gate. The new structure will include additional tide gates for increased conveyance and

¹ Referred to as Santa Clara County Flood Control & Water Conservation District in construction plans.

² Preliminary Alternatives Report, SAFER Bay Project, Task Order 2, SFCJPA (May 2015)

structural features to adapt to future Sea Level Rise (SLR). The work includes (a) isolating a portion of the existing levee with a coffer dam, (b) constructing a temporary detour trail, (c) constructing a new tide gates structure in the levee while maintaining operation of the existing structure, (d) removing the coffer dam after completion of the new structure, (e) isolating the existing structure with a second coffer dam and removing the existing structure, (f) constructing a new levee in place of the existing tide gates structure, and (g) removing the temporary trail and opening the original Adobe Loop Trail alignment.

In October 2018, the project team completed a geotechnical investigation at the approximate location of the new tide gate structure. This work was originally planned for May 2018 and was delayed by four months to avoid impacts during the Ridgeway Rail's breeding season (February 1 to August 31). Prior to the geotechnical investigation, a Notice of Exemption for CEQA was completed.

Upon completion of the project, the new tide gates structure will protect the existing condition level of service for flood protection to Matadero, Adobe, and Barron creeks and will maintain ecological conditions for wildlife and aquatic habitats in the PAFB. In addition, the new structure will be designed to accommodate future SLR scenarios.

PROJECT OBJECTIVES:

Replace the aging PAFB tide gates structure to:

- a) Mitigate potential failure of the existing tide gates structure
- b) Adapt to future sea level rise scenarios
- c) Provide existing or better level of service for Matadero, Adobe, and Barron creeks
- d) Coordinate with the SAFER Bay, South Bay Shoreline, and Mountain View Ponds projects
- e) Protect habitat in the PAFB and around the work area

PROJECT FUNDING:

The project is funded by the Santa Clara Valley Water District Watershed and Stream Stewardship Fund. The total estimated cost to construct a new tide gates structure, including planning design, and construction, is \$14 million.

PRELIMINARY DESIGN CRITERIA:

Sea Level Rise

Table 1 presents values of SLR under three projected scenarios³. This project will maximize gravity options to practicably address the highest SLR scenario. This approach is consistent with design criteria for the City of Mountain View Ponds project.

Table 1. Projected Sea Level Rise 50 Years from Base Year (2017)

Sea Level Rise (ft)		
Low (SLR Curve I)	Intermediate (SLR Curve II)	High (SLR Curve III)
0.51	1.01	2.59

³ Preliminary Feasibility Study for South San Francisco Bay Shoreline...Draft Report (December 2016)

Top of Tide Gates Structure Elevation:

The target elevation for the top of new tide gates structure will be equal to anticipated settlement plus 15.2 (NAVD88) which is consistent with the post settlement finished grade levee crest elevation for the Mountain View Ponds Project ⁴.

Existing Habitat

The PAFB includes 600 +/- acres of wildlife habitat and ecological area. This project will provide a new tide gates structure with increased flow capacity and SLR adaptability to maintain water levels in the PAFB. To avoid disturbing nesting birds and other ecological features, habitat areas and vegetation in the work area will be mapped prior to construction and best management practices will be carefully employed.

PAFB Water Surface Elevation:

Matadero, Adobe, and Barron creek facilities drain into the PAFB and are dependent on Starting Water Surface Elevation (SWSE) conditions resulting from the PAFB and tide gates structure. For Matadero Creek, a SWSE of 7.4 NAVD88 and a one percent discharge (3,100 cubic feet per second) was used for risk-based back water analysis (Shaaf & Wheeler, 2002). The project will maintain a SWSE of 7.4 (NAVD88) for the one percent discharge on Matadero Creek. This condition will also serve as the SWSE for Adobe and Barron creeks.

Table 2. Maximum PAFB Stage and PAFB Stage at Peak Matadero Creek Inflow for Risk-Based Design ⁵

Time	Matadero Flow (cfs)	PAFB Stage (NAVD88 ft)
42 hours	3,100	7.4
47 hours	1,250	9.3

Emergency Action Plan

The Water District is in the final stages of preparing an Emergency Action Plan (EAP) that will provide the City of Palo Alto with recommendations for flood warnings based on water surface elevations in the PAFB, and Matadero, Barron, and Adobe creeks. In addition, the EAP will outline roles and responsibilities for inter-agency coordination and will include notification charts with up to date contact information to be used during emergency events. The EAP is expected to be completed by February 2019.

⁴ The project team confirmed via email communications with City of Mountain View that the final top of Coast Casey Levee elevation is 15.2 NAVD88. This elevation includes post construction levee settlement.

⁵ Appendix G – Palo Alto Flood Basin Operation, Matadero and Barron Creek Remediation Project Final Engineer's Report. P G-14. Schaaf & Wheeler, 2002.

RECOMMENDATION:

This preliminary design memorandum was distributed to project partners (SFCJPA, City of Palo Alto, City of Mountain View, and the Water District's Shoreline Project team) for review and concurrence on December 11, 2018.

This memorandum incorporates comments provided by SFCJPA, City of Palo Alto, and Water District staff. No comments were received from the City of Mountain View; however, coordination discussions were conducted, and City of Mountain View staff provided the project team with 60 percent design plans for the Mountain View Ponds project including the Coast Casey Levee improvements.

The project team and project partners recommend that Water District commit available resources to complete planning, design, environmental documentation and construction of the new tide gates structure using preliminary design criteria included herein.



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Design and Construction Unit 5 #336

CC: M. Richardson, L. Xiu, K. Sibley, A. Mohan, L. Materman, M. Jeremias, R. Wong
(Palo Alto Tide Gates Structure Project Preliminary Design Criteria)

Time (hrs)	Flow (cfs)	Wave Stage (ft)
45 hours	1,000	1.5
47 hours	1,200	1.5

Appendix B

Palo Alto Flood Basin Hydrology Final Report

Prepared by Schaaf & Wheeler, July 2016

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Palo Alto Flood Basin Hydrology



Corrected Final Report Prepared for

Santa Clara Valley Water District



July 2016

Schaaf & Wheeler
Consulting Civil Engineers

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Introduction

Purpose

This report documents a re-evaluation of watershed hydrology and hydraulic performance for the Palo Alto Flood Basin (PAFB). Flood basin hydrology was most recently studied in detail for the Santa Clara Valley Water District's Matadero and Barron Creeks Long-Term Remediation Project in 2002.

The District is interested in potentially repairing, modifying, or replacing the existing tide gate structure to improve the functionality of the tidal flood barrier system. This update will focus on a planning-level assessment of the tide basin as described in more detail herein.

Eventually the District will evaluate potential projects that could reduce flood risks within the lower reaches of Adobe, Barron, and Matadero Creeks; examine the environmental impacts due to submergence of salt marsh harvest mouse, California clapper rail, and black rail habitats within the flood basin; and understand the impact of potential sea level rise scenarios on flood protection during a 100-year fluvial flood event. This updated PAFB analysis forms the basis to examine the impact of sea level rise on flood basin performance and the efficacy of potential tide gate modifications with respect to the aforementioned District objectives.

A recently discovered model input error that affected results published in the Final Report dated July 2014 is corrected herein.

Background

The Palo Alto Flood Basin (PAFB) was created in 1956 with the construction of levees surrounding a 600-acre portion of the Palo Alto Baylands. It is maintained by the Santa Clara Valley Water District (SCVWD). Figure 1 shows a recent aerial image of the flood basin. The PAFB extends east-northeast from Highway 101 and receives inflow from Matadero Creek, Adobe Creek, Barron Creek, and the Coast Casey Storm Water Pumping Station, with a total tributary drainage area of roughly 31.5 square miles exclusive of the 585 acres of the flood basin itself. Inflow is stored in the PAFB and released to Mayfield Slough through a reinforced concrete tide gate structure whenever the water level in the PAFB is higher than the tide.

The tide gate structure consists of 8 box culverts, each with two 5-feet by 5-foot flap gates on the downstream face. The flap gates open when the water elevation in the PAFB is higher than the San Francisco Bay tide elevation. The gates close when San Francisco Bay tides rise above the elevation of stored water in the PAFB to prevent Bay waters from entering the PAFB, thereby maintaining available volume for holding creek runoff during high flow events. During the summer months the City of Palo Alto opens one of the tide gates to allow circulation of brackish Bay water within the PAFB. The tide gates have an invert elevation of -5.1 feet NGVD.

This study updates watershed hydrology and the modeling of flood basin operation to reflect the following:

1. Updated rainfall statistics compared to those used for the 2002 analysis.
2. An additional 12 years of peak annual stream flow records.
3. Additional annual maximum tide records for San Francisco Bay.
4. Changes in the Palo Alto Landfill, which drains directly to the PAFB.
5. The completion of the San Francisquito Creek Pump Station in 2009.



Figure 1. Palo Alto Flood Basin

Previous Studies

Several studies of the Palo Alto Flood Basin have been conducted over the years, in addition to the referenced 2002 Engineer's Report. These are briefly summarized for general background information.

1974 Santa Clara Valley Water District

A Report on the Storage Capability of the Palo Alto Flood Basin was completed by the Santa Clara Valley Water District in March 1974. The final construction phase of the PAFB, scheduled to begin in 1974, involved additional excavation on 440 acres in the Basin and filling approximately 100 acres along Highway 101. However in April 1973 the City of Palo Alto designated the PAFB as a Wetland Preserve in the Open Space Element of the Palo Alto General Plan. This prompted the SCVWD to determine whether the existing levees and floodwalls provided adequate flood protection, thus eliminating the need for additional excavation and filling. The results of this study recommended that the levees surrounding the PAFB be raised to an elevation of 7.0 feet (presumably NGVD), with no additional excavation or filling necessary.

1975 City of Palo Alto

The *Mathematical Model Study of the Palo Alto Flood Basin and Yacht Harbor* was completed by Water Resources Engineers for the City of Palo Alto in March 1975. This study used computer models to examine whether reintroducing a tidal marsh environment to the PAFB would affect the PAFB's ability to store 100-year flood flows. The study also modeled the addition of tide gates facing the Palo Alto Yacht Harbor to improve circulation and release sediment from the PAFB.

1984 City of Palo Alto

In the early 1980s the District again proposed to raise the levees surrounding the Palo Alto Flood Basin. This proposal was made in anticipation of improvements to the channels of the three creeks upstream of Highway 101 and into the foothills. Such improvements could increase peak flows downstream. The City of Palo Alto challenged this proposal and authorized an independent study of the situation. The *Hydrologic Analysis of the Palo Alto Flood Basin* report was then prepared by Linsley, Kraeger Associates for the City for Palo Alto in April 1984. This analysis determined that the existing levees in the PAFB provided adequate flood protection.

Summary of Work

Our basic scope of services and the work undertaken to complete this planning level study of the Palo Alto Flood Basin are summarized herein.

Information Gathering and Site Visit

The District provided record plans of the existing tide gate structures. A basin survey conducted in September 1999 is used as a basis of analysis at District direction. That survey, supplemented by 2007 County LiDAR topographic information, is used to evaluate storage-elevation relationships and the top of levee elevations. Pump station capacity data has been verified for Matadero Pump Station (Palo Alto) and Coast Casey Pump Station (Mountain View).

An initial kickoff meeting to discuss project objectives was held on March 26, 2014 at District headquarters in San Jose. A site visit to the PAFB and surrounding areas for visual observation of general conditions and photo-documentation was made on April 2, 2014 during a period of low tide.

Updated Flood Basin Hydrology and Hydraulics

This study updates watershed hydrology and the modeling of flood basin operation to reflect the use of the District's preferred rainfall statistics, verification of model calibration with an additional 12 years of peak annual stream flow records, the evaluation of additional annual maximum tide records for San Francisco Bay, and incorporating changes in the Palo Alto Landfill, which drains directly to the PAFB.

Design Storm

The 2002 analysis was based upon the U.S. Army Corps of Engineers 72-hour storm pattern for Northern California, balanced to the District's 100-year "global regional equation" statistics for ungaged basins. For this study, the Corps' 72-hour storm pattern has been rebalanced using the 2013 return period-duration-specific equation (TDS) rainfall statistics provided by the District. It is assumed that mean annual precipitation has not substantially changed over the past eleven years.

Palo Alto Flood Basin Watershed Model

The watershed model built for the 2002 analysis is used for this work, largely without change, but antecedent moisture conditions have been verified against the flood-frequency curves for the USGS stream flow gaging stations at Matadero Creek and the San Francisquito Creek stream flow gage, which has an additional 12 points of data since the 2002 analysis was completed using gage data through 2000. The watershed model has been updated to incorporate the rebalanced design storm and converted to the HEC-HMS platform. Model parameters such as tributary areas, unit hydrographs, land uses, soil losses, and stream routing are assumed to be unchanged.

Updated Tidal Boundary Condition

Palo Alto Flood Basin performance during extreme runoff events is heavily predicated upon the elevation of low tides. The 2002 report concluded that there is a correlation between episodes of heavy stream runoff, storm surge, and significantly higher tides than those predicted astronomically. The coincident tide cycle previously used to analyze the flood basin has been updated to include the addition of recorded San Francisquito Creek peak annual discharges and coincident tides that have occurred since the original analysis was completed.

Flood Basin Performance

Updated inflow hydrographs and tidal boundary conditions have been used to reanalyze flood basin performance for the 100-year combined fluvial/tidal event. Levee containment elevations and storage-elevation data for the flood basin based on a detailed aerial survey completed by Towill in April 1999 are assumed to remain valid for this planning level study. Surveys show that there was a minimal decrease in basin capacity between 1972 and 1999, and this trend is assumed to remain true. The original analysis was based on the UNET model platform, which is outdated, so the re-analysis has been converted to unsteady HEC-RAS. The completed HEC-RAS model can be used to establish maximum one-percent flood basin elevations based on current conditions. The model has also been used to assess the relative risk of flooding due to the random nature of timing between rainfall and high tides.

Flood Basin Modeling

PAFB operation was modeled in 2002 using UNET, a one-dimensional unsteady flow model for open channels and storage areas. UNET has since been fully supplanted by the unsteady mode of HEC-RAS, so a new PAFB model has been created using HEC-RAS.

Figure 2 illustrates the HEC-RAS model that has been created and provided digitally as Appendix D. Model elements include the basin itself, labeled “PAFB”, which is represented by a storage-elevation relationship. The PAFB is connected to Mayfield Slough, labeled “Slough”, through a storage area to storage area connection with a series of 16 gates modeled after the tide gate structure, labeled “Gates”. A set of rules written into the HEC-RAS input file prevents water from moving from the Slough into the PAFB, simulating the flap gates. Mayfield Slough is modeled with cross sectional data to open water, labeled “Tide 1”, and a secondary branch, labeled “Tide 2” also connects the slough to open water on the east side of the mudflat island that is visible in Figure 2.

Modeling is completed by assigning boundary conditions, which include inflow to the PAFB from Matadero Creek (“Matadero”), Adobe Creek (“Adobe”, which also includes Barron Creek discharges) and the Coast Casey Pump Station (“Coast Casey”); and the San Francisco Bay tide cycle. Interior runoff to the PAFB from the adjacent Palo Alto Landfill and direct rainfall are also incorporated into the HEC-RAS model.



Figure 2. HEC-RAS Model of PAFB

Palo Alto Flood Basin

The Palo Alto Flood Basin extends east-northeast from Highway 101 and receives inflow from Matadero Creek, Adobe Creek, Barron Creek, and the Coast Casey Storm Water Pumping Station. Inflow is stored in the PAFB and released to San Francisco Bay through a tide gate structure when the water level, or stage, in the PAFB is higher than the San Francisco Bay tides.

In the HEC-RAS model, the PAFB is represented by a storage-elevation curve that defines the volume of water that is stored at any given elevation. Towill, Inc. and MacKay & Soms conducted an aerial topographic survey of the PAFB in April 1999. From this topographic survey, a storage-elevation curve was developed. This curve is plotted against the elevation-storage curve that had been prepared by SCVWD in their 1974 PAFB analysis. Both curves are shown in Figure 3. They indicate that there was minimal change in PAFB storage capacity between 1974 and 1999. Since no additional basin topography has been gathered in subsequent years, this study assumes that the storage-elevation curve developed from 1999 data remains valid.

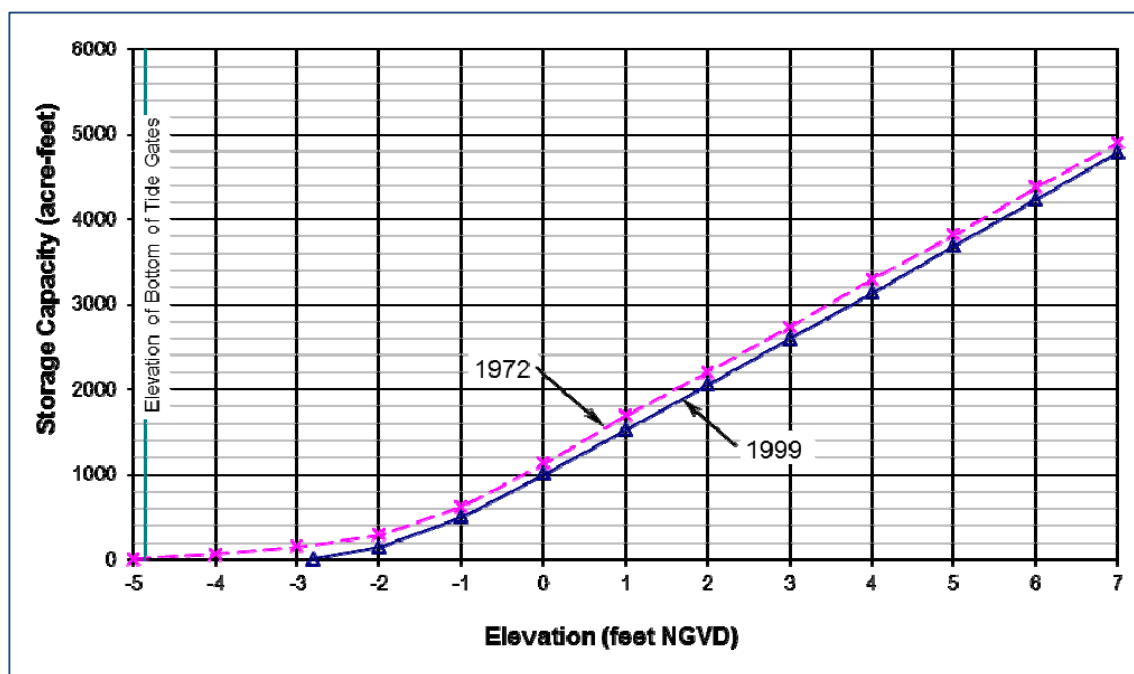


Figure 3. PAFB Storage-Elevation Curve

Mayfield Slough

The PAFB does not discharge directly to San Francisco Bay. Rather, Mayfield Slough – a smooth, relatively narrow channel that begins at the downstream face of the PAFB tide gates – conveys discharges from the tide gate structure to open water near the Dumbarton Bridge. Mayfield Slough channel geometry has been coded into the geometry file using data taken from the San Francisco Bay and Sacramento-San Joaquin Delta Digital Elevation Model (DEM) created for the California Department of Water Resources in 2012.¹ Figure 4 is clipped from the DEM and shows the general bathymetry near the tide gate structure. Elevations have been converted to the NGVD datum for the HEC-RAS cross sections by subtracting 2.684 feet from the DEM.

¹Rueen-Fang Wang and Eli Ateljevich, San Francisco Bay and Sacramento-San Joaquin Delta DEM, November 2012.
<http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/modelingdata/DEM.cfm>

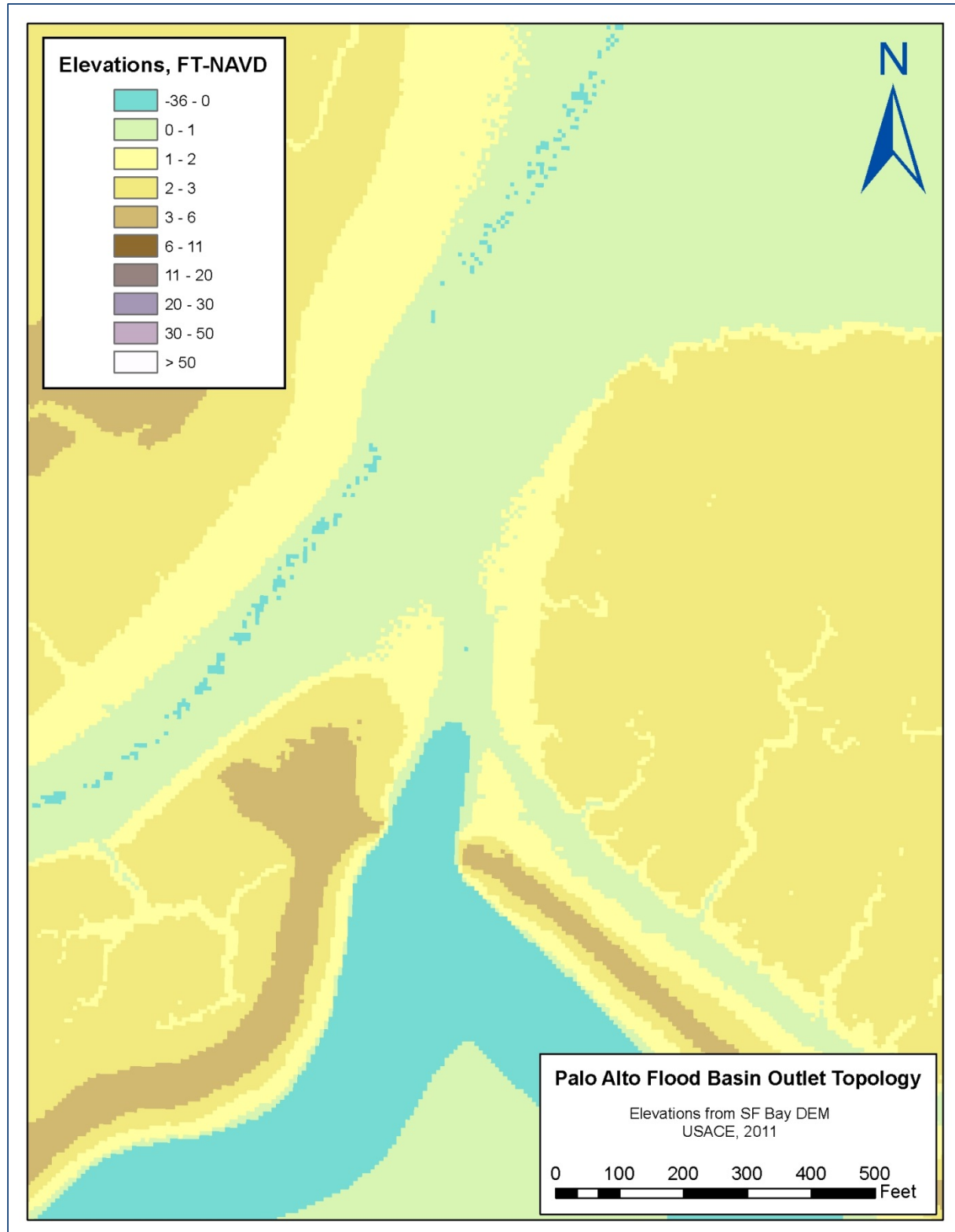


Figure 4. Bathymetry at PAFB Outlet

A channel roughness factor (Manning's "n") of 0.02 is assigned to the Mayfield Slough reach as well as the secondary slough between the PAFB levees and higher mudflats to the immediate north.

Tide Gate

Inflow is stored in the PAFB and released to Mayfield Slough through a tide gate structure when the water level, or stage, in the PAFB is higher than the San Francisco Bay tides. This tide gate structure consists of eight box culverts, each with two 5-foot by 5-foot cast iron flap gates on its downstream face. These flap gates open when the stage in the PAFB is higher than the water surface elevation in Mayfield Slough, which is predominantly controlled by San Francisco Bay tide elevations. The gates close when San Francisco Bay tides rise to prevent Bay waters from entering the PAFB, thereby maintaining available volume for holding creek runoff during high-flow events. During the summer months the City of Palo Alto opens some of the tide gates using a sluice gate feature to allow circulation of brackish bay water into the PAFB. The tide gates have an invert elevation of -5.1 feet NGVD. A plan an elevation of the tide gate structure from record drawings and a photograph taken during the referenced site visit are provided as Figure 5.

In HEC-RAS the tide gate structure is modeled as a connection between the PAFB and Mayfield Slough. Each box culvert has two gates (radial gates mimic manufacturers' head-discharge curves the best in the model), and the gates are coded so as to only allow flow from the PAFB to Mayfield Slough. Each flap gate is assumed to open upon a minimal differential head (0.2 foot) to mimic gate manufacturers' literature.

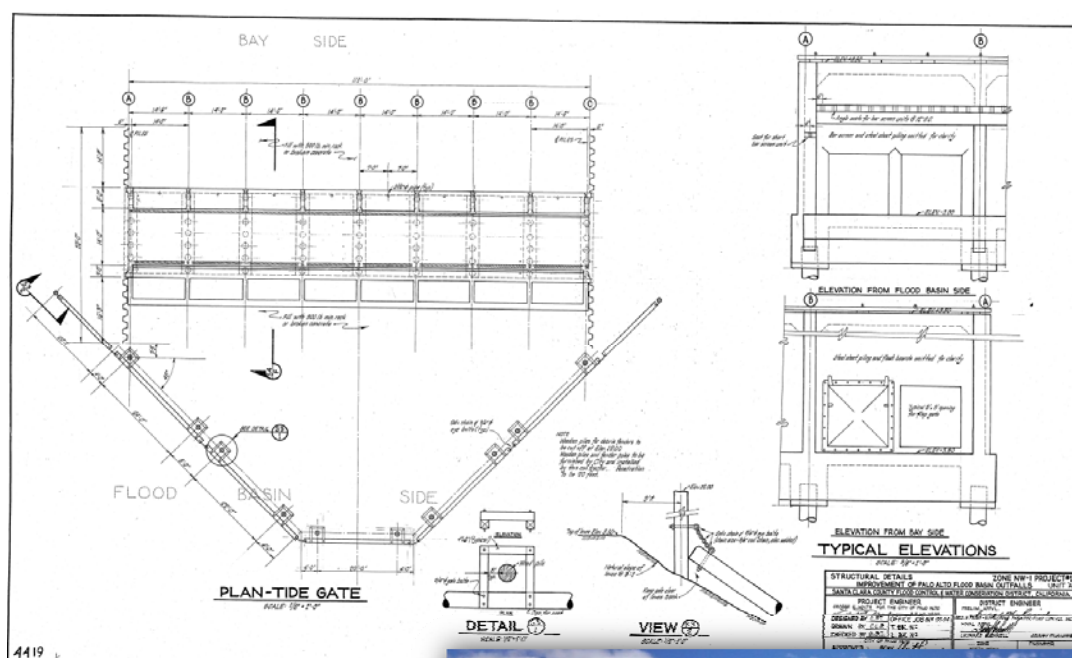


Figure 5. PAFB Tide Gate Structure



Inflow to the PAFB

With the Palo Alto Flood Basin's stage-storage relationship, tide gate structure, and discharge connection to San Francisco Bay modeled, boundary conditions are needed to complete the evaluation of basin performance. The total inflow into the PAFB is one driving boundary condition. Estimates of inflow to the PAFB from a design 100-year, 72-hour precipitation event are based on rainfall-runoff models that have been calibrated to flood-frequency analyses of local stream flow data as described herein. Analytic methods remain largely unchanged from the 2002 Final Engineer's Report, with the exception of the design storm and calibration of antecedent moisture conditions to that storm.

The volume of storm water runoff produced from a given precipitation event depends on a number of factors, most prominently precipitation, watershed losses, and the convolution of unit hydrographs. The rainfall-runoff model for the PAFB watershed completed using HEC-1 in 2002 has been converted to the HEC-HMS platform and provided digitally as Appendix D. Comparing summary results for each model platform, it is clear that simply moving the HEC-1 model to HEC-HMS does not significantly change the watershed model or its numeric results.

Tributary Watershed

Areas tributary to the Palo Alto Flood Basin generally include the areas and tributaries draining to Matadero Creek, Barron Creek, and Adobe Creek; areas that drain to the Coast Casey Pump Station and forebay in Mountain View; a portion of the Palo Alto Landfill; and the PAFB itself. Figure 6 provides the delineated watershed boundaries superimposed over an aerial photograph.

HEC-HMS is used to generate inflow hydrographs (except for direct rainfall on the PAFB itself as explained subsequently) and the watershed is broken into tributary sub-watersheds as shown in Figure 7. Sub-watersheds and their designations are taken directly from the 2002 Engineer's Report. Sub-basin and design point label names were originally designated by the District and have remained unchanged.

Appendix A provides summary tables of the tributary watershed parameters used in the HEC-HMS model (Figures 8 and 9) and described in this section, including identification, basin area, mean annual precipitation at centroid, basin length, length to centroid, basin slope, curve number, percent impervious cover, storm drain system routing using the District's unitized storage curves, and stream routing parameters.

Figure 8 illustrates the HEC-1 model schematic used to complete the 2002 Engineer's Report. Figure 9 shows the conversion of that schematic to the HEC-HMS platform, and the addition of a sub-basin for the Palo Alto Landfill.

Adobe Creek, with sub-basins labeled with an "A" prefix, drains to its junction with Barron Creek (Junction 1), which has a "B" prefix for its sub-basins. The Barron Creek sediment basin and diversion structure, which are located behind Gunn High School off Arastradero Road at Design Point "E", are labeled "BSED" and "BDIV" respectively in Figures 7 through 9. The Barron Creek sediment basin and diversion structure are passively operated (but with the potential for active operation) to limit discharge into the downstream reaches of Barron Creek by diverting flow in an underground culvert along the Bol Park bike path. Where the bike path crosses Matadero Creek (Design Point "C"), another diversion structure ("MDIV") adds additional flow that is diverted from the natural creek at this location. The combined discharge continues in an underground structure known as the Matadero Bypass until it reaches a confluence with the natural Matadero Creek at El Camino Real, also collecting runoff from the Stanford Channel along the way.

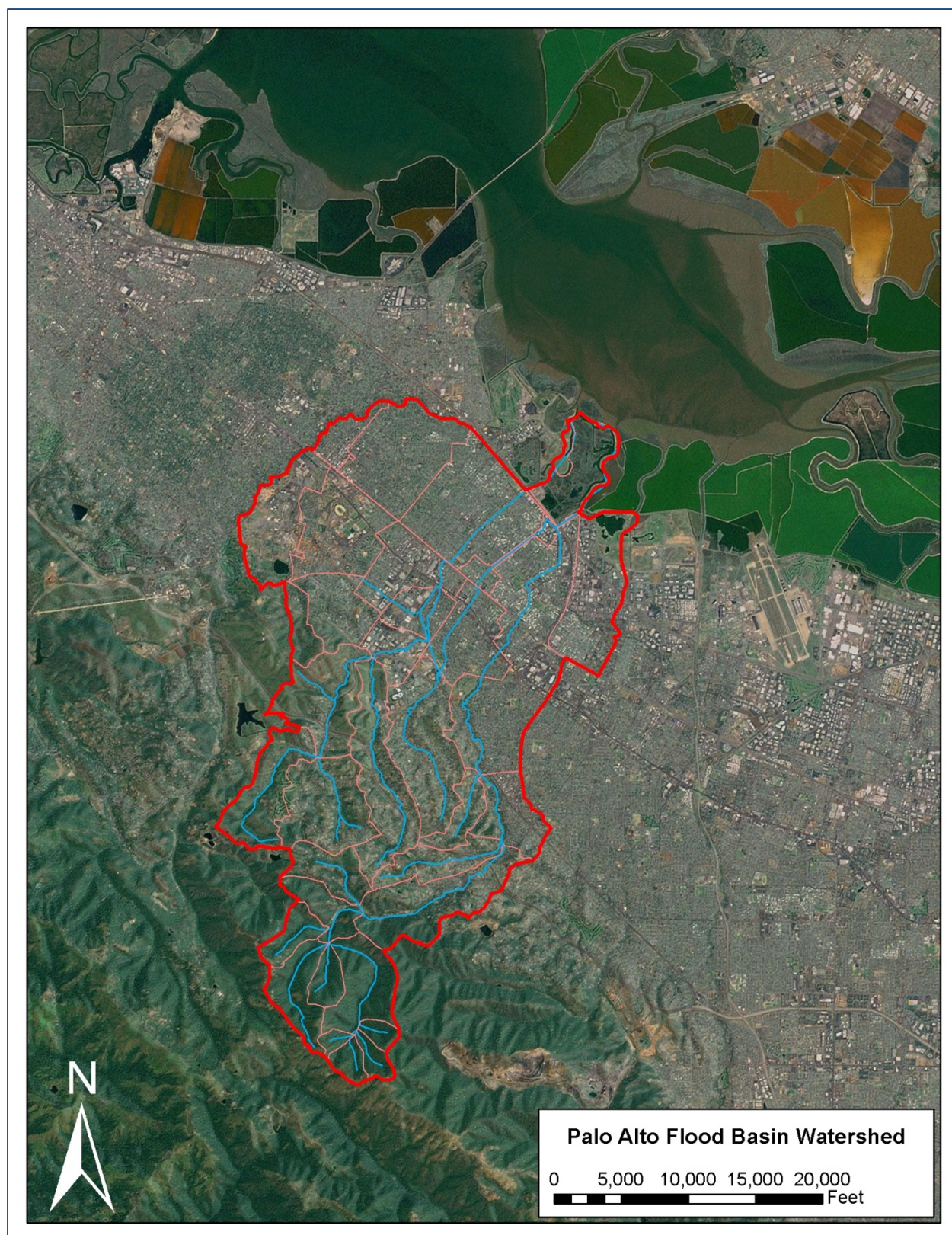


Figure 6. Palo Alto Flood Basin Watershed

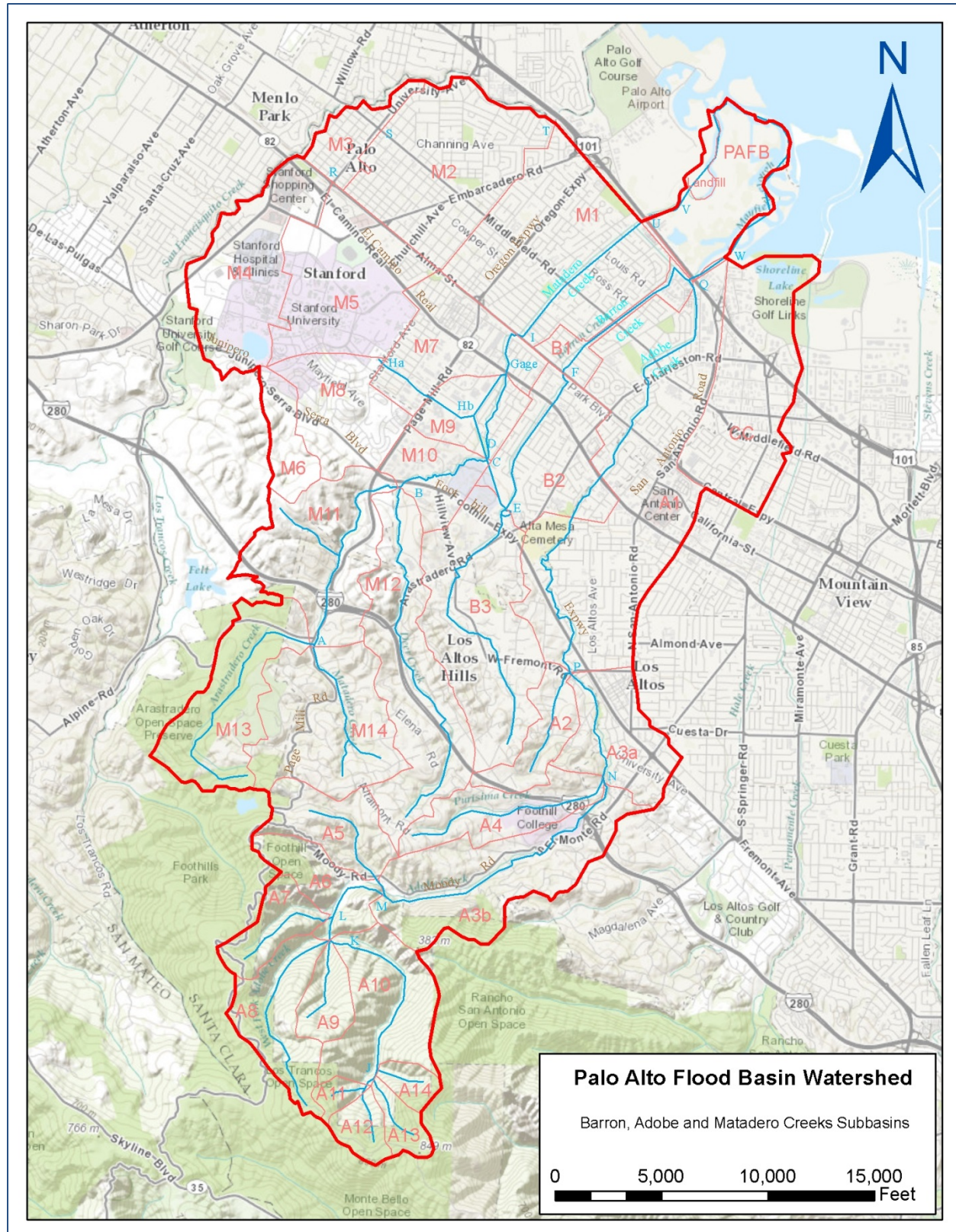


Figure 7. PAFB Sub-basins for HEC-HMS

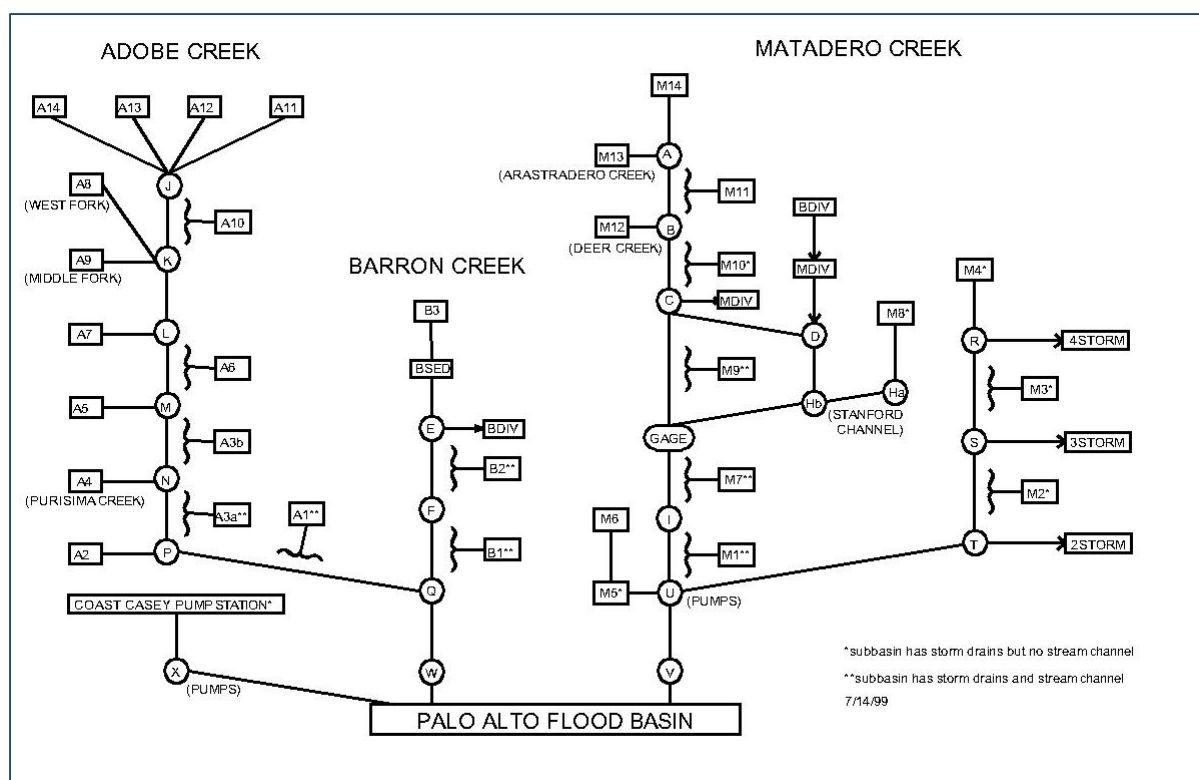


Figure 8. HEC-1 Model Schematic (2002 Engineer's Report)

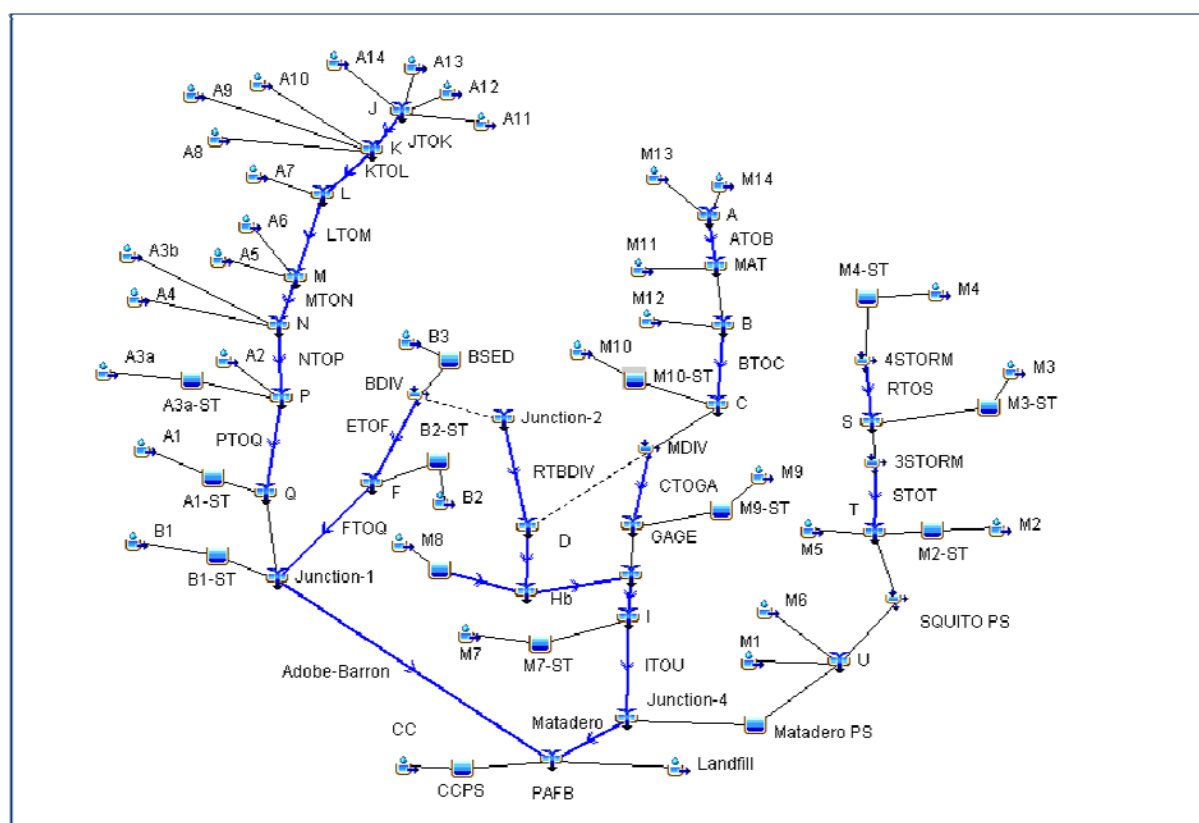


Figure 9. Updated HEC-HMS Watershed Model Schematic

The USGS stream flow gage is located downstream from El Camino Real adjacent to Boulware Park and measures the combined discharge in Matadero Creek. Between the park and Highway 101, Matadero Creek is contained within an engineered channel that is fully concrete-lined between El Camino Real and Greer Road. Matadero Creek is earthen with concrete flood walls between Greer Road and Highway 101. Downstream of the freeway, Matadero Creek bifurcates with substantial discharge carried in a bypass around the City of Palo Alto's Municipal Services Center into the PAFB.

The Matadero Pump Station, owned and operated by the City of Palo Alto, discharges to Matadero Creek nearly half-way between West Bayshore Road (frontage to Highway 101) and Greer Road. In addition to inflow from the pump station's tributary local storm drain system, runoff that exceeds the capacities of storm drain systems tributary to San Francisquito Creek (typically equal to the 10-year return period) naturally flows downhill toward Matadero Creek and to the extent of available storm drain system and pump station capacity (266 cfs), is discharged into Matadero Creek at Design Point "U". The flow of runoff out of the Matadero system and into San Francisquito Creek is marked in the model schematics as "SQUITO PS", "3STORM", and "4STORM". The San Francisquito Creek Pump Station, owned and operated by the City of Palo Alto, has four axial flow pumps with a total pumping capacity of 300 cfs. The sub-basin tributary to Mountain View's Coast Casey Pump Station ("CC") is modeled as is the storage-discharge relationship provided by the Coast Casey Forebay and its 150 cfs pump station. The Coast Casey Pump Station discharges directly into the PAFB through three steel discharge pipes with flap gates at their outfall as shown in Figure 10.



Figure 10. Coast Casey Pump Station Outfall to PAFB

Precipitation

The volume of runoff (Q) depends primarily on the volume of precipitation (P). “Design storm” is a term used to describe the total rainfall volume measured as depth, which is determined from the combination of a return period and storm duration. By definition, the base flood elevation has a 100-year return period, which means that a storm of such magnitude (as measured by total rainfall depth) has a one percent annual chance of being equaled or exceeded in any given year.

The selection of storm duration is rendered irrelevant to the prediction of peak discharge by balancing the design rainfall pattern to replicate local depth-duration-frequency statistics, and by calibrating soil loss parameters to match flood frequency analyses of local stream flow data.

The precipitation pattern used in this analysis is based upon a three-day December 1955 rainfall event compiled by the U.S. Army Corps of Engineers; an event that is still considered to be the storm of record for northern California. This pattern is adjusted to preserve local rainfall statistics using the work of the Santa Clara Valley Water District from 2013.

Rainfall Depth

The Santa Clara Valley Water District’s 2013 Return Period-Duration-Specific (TDS) Regional Equation is used to establish a relationship between precipitation depth and mean annual precipitation for various storm frequencies (return periods). The mean annual precipitation at each sub-basin’s centroid is based on a mean annual precipitation (M.A.P.) map published by the Santa Clara Valley Water District in 1989. Once the mean annual precipitation for a given location is determined, rainfall depths are calculated using the TDS Regional Equation:

$$x_{T,D} = A_{T,D} + (B_{T,D} \text{ MAP})$$

Where $x_{T,D}$ is precipitation depth for a specific return period and storm duration (inches);

T is return period (years);

D is storm duration (hours); and

A, B are coefficients determined from Table 1, which also provides the rainfall depth and percent total for a mean annual precipitation of 17.5 inches.

Table 1. 1% Rainfall Coefficients and Depths for TDS Equation with 17.5" MAP

Duration (hours)	A	B	Depth (inches)	% Total
0.25	0.4618	0.0023	0.50	8.6%
0.5	0.4901	0.0077	0.62	10.7%
1	0.5074	0.0190	0.84	14.4%
2	0.5317	0.0389	1.21	20.8%
3	0.4980	0.0579	1.51	25.9%
6	0.3228	0.1082	2.22	38.0%
12	0.2588	0.1613	3.08	52.9%
24	0.1102	0.2170	3.91	67.0%
48	0.3239	0.2751	5.14	88.1%
72	-0.0876	0.3382	5.83	100.0%

Statistically Balanced Rainfall Patterns

For this study the USACE Christmas 1955 precipitation pattern (Figure 11) has been adjusted to preserve local rainfall statistics compiled by the Santa Clara Valley Water District (SCVWD) for three mean annual precipitation values. That is the peak 15-minute, 30-minute, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour, 24-hour and 48-hour rainfall depths that are embedded within the 72-hour patterns all conform to the statistics provided in Table 1. The statistically balanced rainfall pattern for a mean annual precipitation of 17.5 inches is shown in Figure 12. Statistical balancing has been performed using the hydrograph transformation function (HB card) available in HEC-1, since that function is not incorporated into HEC-HMS.

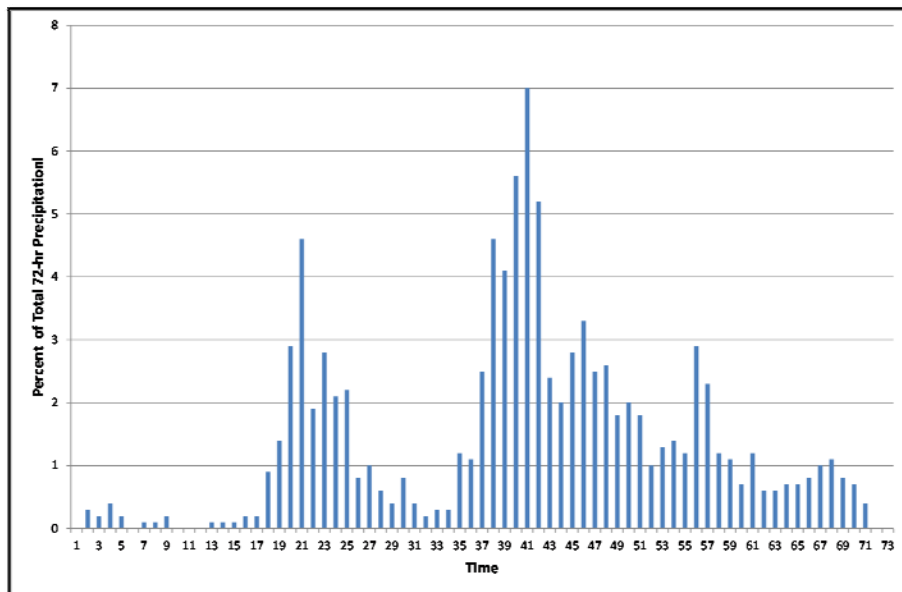


Figure 11. 72-hour USACE Rainfall Pattern (Christmas 1955)

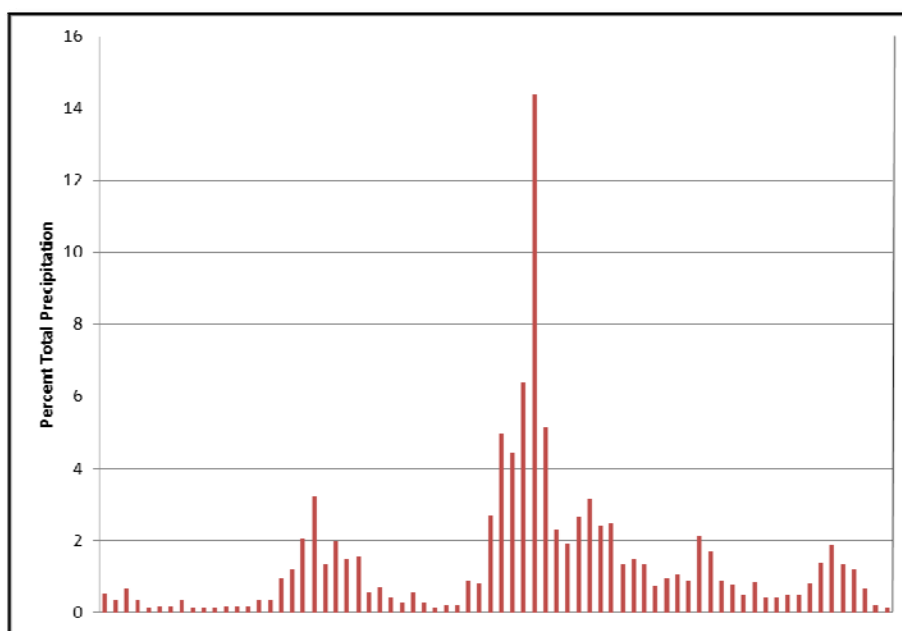


Figure 12. Balanced 15-min, 72-hr Rainfall Pattern (MAP = 17.5")

This approach, together with the soil loss parameter calibration procedure subsequently described, ensures that flood frequency estimates do not depend upon the selection of a storm pattern or duration. Furthermore, since the depth-duration relationships depend only upon mean annual precipitation (MAP) at any particular location, the statistically balanced rainfall pattern may be applied to different watersheds simply by changing the total 72-hour rainfall depth as a function of MAP.

Specific rainfall patterns do depend on the mean annual precipitation, which ranges from 13.5 inches at San Francisco Bay to 37.6 inches at the headwaters of Adobe Creek (Sub-basin A-12). Three distinct rainfall patterns are used (“gages” in HEC-HMS) to account for the range in mean annual precipitation within the PAFB watershed. Table 2 maps the three specified balanced hyetographs (rainfall patterns) that are used in the meteorological model to mean annual precipitation ranges.

Table 2. Hyetographs (“Gages”) Used in HEC-HMS

Gage Name	Low Range Mean Annual Precipitation (inches)	High Range Mean Annual Precipitation (inches)
MAP17.5Pattern	13.5	21.5
MAP25.5Pattern	21.5	25.5
MAP33.5Pattern	25.5	37.6

Runoff Curve Numbers

The Soil Conservation Service (SCS, now the National Resources Conservation Service) Curve Number methodology is used to estimate direct runoff by subtracting soil infiltration and other losses from the rate of rainfall. The Curve Number (CN) method is an empirical methodology wherein the CN reflects potential loss for a given soil and cover (land use) complex. After satisfying an initial abstraction – rainfall absorbed by tree cover, depressions, and soil at the beginning of a storm – the soil becomes saturated at a certain rate so that a higher percentage of the accumulated rainfall is converted to runoff. The initial abstraction is set to $0.2S$ where $S = (1000/CN) - 10$.

Estimates of the CN are made based on the soil types and cover within a drainage basin. The number varies from 0 to 100, and represents the relative runoff potential for a given soil-cover complex for given AMC. Appendix A contains tables showing the development of Curve Numbers for each sub-basin.

Curve numbers for the Palo Alto landfill and PAFB wetlands are based on literature research. The landfill and PAFB are underlain by Bay Mud and the assumed hydrologic soil group is Type “D”, which represents the least permeable soil. For a municipal landfill the Curve Number for HSG “D” is 93;² and for a wetland complex, the Curve Number for HSG “D” is 98.³

² Palos Verdes Landfill Remediation Investigation Report, Appendix E.13 “Hydrologic Evaluation of Landfill Performance (HELP Model), undated.

³ St. John’s River Water Management District Department of Water Resources (Palatka, FL), “A Guide to SCS Runoff Procedures” (Technical Publication No. 85-5), July 1985.

Calibration of Antecedent Moisture Condition and Base Flow

Curve Numbers are adjusted to reflect the antecedent moisture condition (AMC), which is a measure of soil saturation at the beginning of the storm period. AMC is characterized by the SCS as:

AMC I	soils are dry
AMC II	average conditions
AMC III	heavy rainfall, or light rainfall with low temperatures; saturated soil

Rather than select AMC arbitrarily or *a priori*, antecedent moisture conditions are calibrated for the statistically balanced storm patterns used in this study. The following procedure is used to calibrate the PAFB watershed models using flood frequency analyses of recorded stream flow gage data for Matadero Creek and nearby San Francisquito Creek.

1. Perform statistical analyses of stream flow data at the USGS gages on Matadero Creek in Palo Alto and San Francisquito Creek at Stanford. Confirm statistical correlation between gage data.
2. Prepare a rainfall-runoff model for the watershed tributary to the San Francisquito Creek gage, which is adjacent and hydrologically similar to the PAFB watershed.
3. Using the design 100-year rainfall pattern, adjusted for the mean annual precipitation at the centroid of the San Francisquito Creek watershed, calibrate the San Francisquito Creek model by adjusting AMC to replicate 100-year flood frequencies for peak discharge and runoff volume.
4. Use the calibrated AMC to adjust Curve Numbers within the PAFB watershed model.
5. Compare the modeled 100-year discharge at the location of the Matadero Creek gage to the flood-frequency analysis at that gage for a measure of model verification.

Statistical Analysis of Matadero Creek Stream Flow Data

The United States Geologic Survey (USGS) has operated a stream gage (No. 11166000) on Matadero Creek since 1953, with no record in 1992 during construction of channel improvements. Ideally the data set used for statistical analyses of stream flow will provide a representative sample of random and homogeneous natural events, so that annual peak flow data define an unbiased estimation of future flood risk.

Within the Matadero Creek watershed as measured at its gage (Figure 7), however, events have occurred over the years that may introduce bias into the frequency analysis. These events include some increase in basin urbanization since the early 1950s (the basin is now roughly twenty percent impervious), and flow diversions from the Barron Creek began in September 1996 (Water Year 1997). Cumulative urbanization can increase the lesser annual flow peaks relative to what they would have been without urbanization, which can reduce the standard deviation of the data set and thereby the estimates for the magnitude of extreme runoff events. The Barron Creek diversion regulates measured stream flow at the Matadero Creek gage for some annual peaks, is a significant non-homogeneity in the record, and therefore must be accounted for if those peak discharge values are to be included with the systematic record.

Flow diversions from Barron Creek into Matadero Creek were recorded during the peak discharge events in Water Years 1998 and 2000, but not in 1997 or 1999. While it is possible that there were no actual diversions during those years, a continuous record that could verify this does not exist, so data from 1997 and 1999 are excluded from the frequency analysis. Detailed flow diversion records are not available for water years beyond 2000, so the data set remains unchanged from the data set used in the 2002 Engineer's Report and is represented herein for the record.

Recorded annual maximum discharges on February 2-3, 1998 and February 13, 2000 are adjusted to eliminate regulated diversions from the Barron Creek watershed. Based on a physical model study of the diversion structure (CH2M-Hill, 1991), average flow velocity within the Matadero Creek bypass channel while it carries the design discharge is 16 feet per second. Since the total distance from the Barron Creek Sediment Basin to the gage location is 7,500 feet, the travel time is:

$$\frac{7,500 \text{ feet}}{16 \text{ ft/s}} = 470 \text{ s} = 7.8 \text{ minutes}$$

Stage in the Barron Creek diversion basin was recorded every 30 minutes during the two flood events. Since the travel time to the gage is about one-quarter of that recording interval, it is assumed that the stage recorded at the diversion basin is roughly coincident with USGS stream flow measurements at the gage. Correcting the stream gage record to reflect undiverted flows involves subtracting Barron Creek diversions based on recorded stage at the diversion basin, using critical depth for unpressurized flow and the orifice equation when stage reaches the bottom of the steel plate at the diversion gate. Stage-discharge relationships for the flow data adjustment are:

When Stage < 83.7 feet	Diverted Flow = 0	
When 83.7 feet < Stage < 87.7 feet	Critical Depth Control	$Q_{diverted} = b\sqrt{y_c^3 g}$
Where b = net width of open diversion gate(s) = (No. of Gates Open)(9.79 feet)		
$Y_c = (2/3) E_c$		
$E_c = \text{Stage} - 83.7 \text{ feet}$		
When Stage > 87.7 feet	Orifice Control	$Q_{diverted} = C A \sqrt{2 g \Delta h}$
Where C = 0.53 (ref. CH2M-Hill)		
$\Delta h = \text{Stage} - 85.7 \text{ feet (centerline of gate)}$		

Tables 3 and 4 provide the calculations of diversion adjustment for the peak discharges in Water Year 1998 and Water Year 2000, respectively. Flood-frequency analysis procedures outlined in USGS Bulletin #17B are used with the Matadero Creek stream flow data set, adjusted for known diversions to obtain a flood-frequency plot. Following Bulletin 17B procedures for the systematic record of 1953 through 2000 (excluding 1992, 1997, and 1999), the low outlier is 23 cfs. If 1954 (26 cfs) and 1957 (28 cfs) are eliminated, the low outlier is 40 cfs. If 1961 (45 cfs) is eliminated, the low outlier is 50 cfs. If 1976 (81 cfs) is eliminated, the low outlier is 58 cfs, indicating that 1976 belongs in the data set. Table 5 summarizes the statistical results for Matadero Creek with a low outlier test criterion of 50 cfs, and is unchanged from the 2002 Engineer's Report.

Table 3. Matadero Creek Diversion Adjustment February 2-3, 1998

Time	Recorded Flow at Gage (cfs)	Recorded Stage at Basin (feet)	Diversion (cfs)	Adjusted Flow at Gage (cfs)	Remarks
21:30	1156	87.4	430	726	2 gates open
22:00	1320	87.9	494	826	
22:30	1350	86.7	314	1036	
23:00	1380	86.5	283	1097	
23:30	1410	87.0	363	1047	
24:00	2557	88.2	527	2030	
0:30	2541	88.5	279	2262	1 gate closed
1:00	2259	88.6	284	1975	
1:30	1796	88.5	279	1517	
2:00	1778	88.2	264	1514	
2:30	1566	88.0	253	1313	

Table 4. Matadero Creek Diversion Adjustment February 13, 2000

Time	Recorded Flow at Gage (cfs)	Recorded Stage at Basin (feet)	Diversion (cfs)	Adjusted Flow at Gage (cfs)	Remarks
16:58	1065	85.3	61	1004	1 gate open
17:11	1105	85.7	86	1019	
17:14	1146	85.7	86	1060	
17:53	1189	85.8	92	1097	
18:08	1271	86.1	112	1159	
18:14	1316	86.1	112	1204	
18:16	1271	86.1	112	1159	
18:41	1316	86.3	127	1189	
20:00	1321	86.2	120	1201	
20:10	1232	86.2	120	1112	
20:15	1189	85.5	73	1116	
21:00	1026	84.9	40	986	

Table 5. Flood-Frequency Statistics for Matadero Creek

Parameter	Value
Mean of Logarithms	2.606
Standard Deviation (S)	0.335
Station Skew (G)	-0.070
Regional Skew, SCVWD	-0.600
Weighted Skew (G _w)	-0.226
100-year Discharge (Q _{1%})	2,130 cfs

Statistical Analysis of San Francisquito Creek Stream Flow Data

Bulletin 17B suggests that comparisons between computed frequency curves for hydrologically similar regions are useful for testing the reasonableness of flood flow frequency determinations. The centroid of San Francisquito Creek's watershed is roughly six miles from Matadero Creek's watershed centroid, so this is a natural comparison to make. The San Francisquito Creek gage began recording stream flows in 1932, and provides 73 years of record through 2012 with missing data from 1942 to 1950. There are no diversions within the watershed, or substantial urbanization over the period of record.

An updated flood-frequency plot for San Francisquito Creek at Stanford has been created following the same procedures outlined in USGS Bulletin #17B and as modified for low outlier testing as described for the Matadero Creek gage analysis. The final tested low-flow outlier threshold is 139 cfs. Low-flow outliers are 1939 (120 cfs), 1957 (125 cfs), 1961 (12 cfs), 1976 (82 cfs), and 1977 (82 cfs). Figure 13 shows the adjusted flood-frequency curve for San Francisquito Creek at Stanford, updated with verified annual peak discharge data through Water Year 2012. The one percent discharge at the gage location is 7,800 cfs. Table 6 provides a summary of the final synthetic statistics with low outliers removed and the conditional probability adjustment.

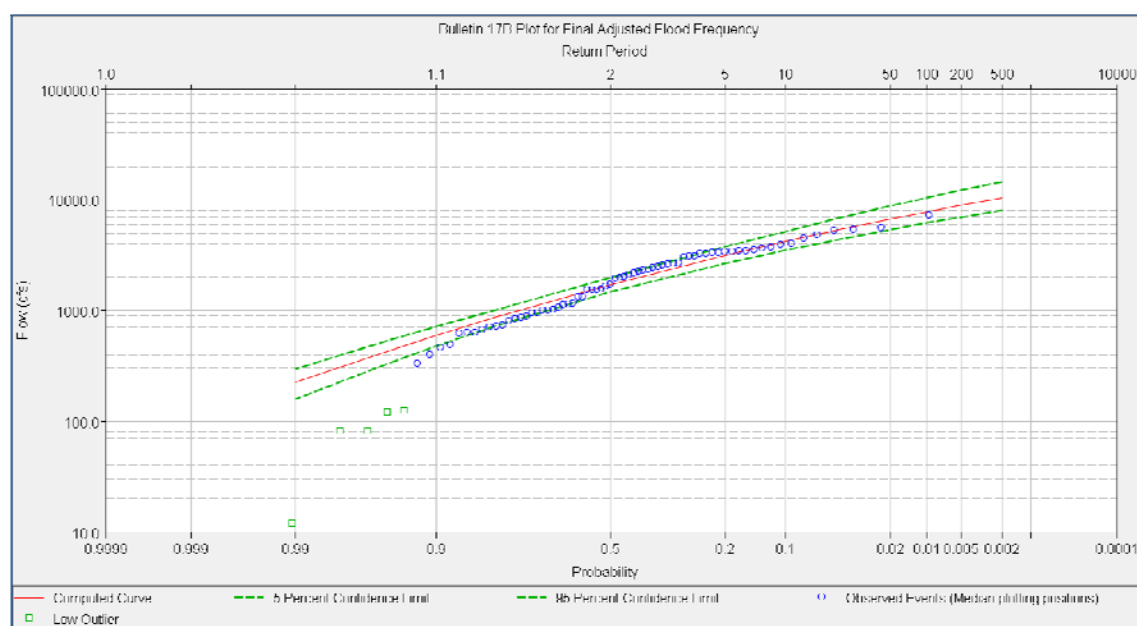


Figure 13. Flood-Frequency Plot for San Francisquito Creek at Stanford

Table 6. Flood-Frequency Statistics for San Francisquito Creek

Parameter	Value
Mean of Logarithms	3.212
Standard Deviation (S)	0.332
Station Skew (G)	-0.309
Regional Skew, SCVWD	-0.600
Weighted Skew (G_w)	-0.376
100-year Discharge ($Q_{1\%}$)	7,810 cfs

Correlation of Matadero Creek to San Francisquito Creek

Bulletin 17B provides a procedure for adjusting a “short” record to reflect experience at a nearby long-record station. “Short” records are defined as those less than 50 years in length, so the Matadero Creek data set qualifies. With 73 years of record, the San Francisquito Creek gage qualifies as a long-record station. The first step of the procedure is to correlate observed peak flows for the short record with concurrent observed peak flows for the long record as follows:

$$\text{Regression Coefficient } b = \frac{\sum X_1 Y_1 - \frac{\sum X_1 \sum Y_1}{N_1}}{\sum X_1^2 - \frac{(\sum X_1)^2}{N_1}}$$

$$\text{Correlation Coefficient } r = b \frac{S_{X_1}}{S_{Y_1}}$$

Excluding outliers, the concurrent record includes 1953, 1955, 1956, 1959, 1960, 1962-1975, 1978-1991, 1993-1996, 1998, and 2000. Table 7 presents statistical parameters for the flood-frequency correlation.

Table 7. Statistics for Flood-Frequency Correlation

Parameter	Value
Number of years peak flow concurrently observed at the two sites (N_1)	40
Number of years peak flows observed at long record site, but not short record site (N_2)	28
Mean of logarithms of flows from long record during concurrent period (X_1)	3.241
Mean of logarithms of flows at long record site for period with no flows at short record site (X_2)	3.247
Mean of logarithms of flows for entire period at long record site (X_3)	3.243
Mean of logarithms of flows from short record during concurrent period (Y_1)	2.637
Standard deviation of logarithms of flow from long record during concurrent period (S_{X_1})	0.329
Standard deviation of logarithms of flow at long record site for period with no flows at short record site (S_{X_2})	0.308
Standard deviation of logarithms of flow from short record during concurrent period (S_{Y_1})	0.311
Regression coefficient (b)	0.886
Correlation coefficient (r)	0.938

Since there is such a strong correlation between data sets (the correlation coefficient is 94%) improved estimates of the short record mean and standard deviation can be made:

$$\bar{Y} = \bar{Y}_1 + b (\bar{X}_3 - \bar{X}_1)^2 = 2.6394$$

Adjusted variance is computed:

$$S_y^2 = \frac{1}{(N_1 + N_2 - 1)} \left[(N_1 - 1)S_{Y_1}^2 + (N_2 - 1)b^2S_{X_2}^2 + \frac{N_2(N_1 - 4)(N_1 - 1)}{(N_1 - 3)(N_1 - 2)}(1 - r^2)S_{Y_1}^2 + \frac{N_1N_2}{N_1 + N_2}b^2(\bar{X}_2 - \bar{X}_1)^2 \right]$$

The adjusted variance (S_y) is 0.3018, which represents a 19 percent reduction in short-station variance. This reduction in variance remains the same from the 2002 Engineer's Report. According to Bulletin 17B, adjustments to the short-station mean and standard deviation are justified if the reduction in variance exceeds ten percent. The adjusted short-record frequency estimate for Matadero Creek (with a station skew of -0.07) is therefore:

$$\log Q = 2.6394 + (2.2747)(0.301782) = 3.3259$$

$$Q = 10^{3.3259} = 2,120 \text{ cfs}$$

The equivalent number of years of record (N_e) for this adjusted estimate, which is used subsequently for model verification, is calculated as:

$$N_e = \frac{N_1}{1 - \frac{N_2}{N_1 + N_2} \left(r^2 - \frac{(1 - r^2)}{(N_1 - 3)} \right)} = 63 \text{ years}$$

Rainfall-Runoff Model for San Francisquito Creek Watershed

Schaaf & Wheeler developed curve numbers and other basin parameters for the San Francisquito Creek watershed as part of the 2002 Engineer's Report, which are summarized in Table 8. The basin time of concentration is calculated using a modified USACE lag equation, which relates the Corps' definitions of basin lag and time of concentration. The USACE lag equation was originally based on their S-graph format for unit hydrographs. Based on model simulations, using the Corps lag equation along with its S-graph for the San Francisco District generally replicates synthetic unit hydrographs produced by Clark unit hydrograph parameters in HEC-1, when the time of concentration equals the modified basin lag. The equation for time of concentration is:

$$t_c = (.862)24N \left(\frac{L L_c}{\sqrt{S}} \right)^{0.38}$$

where N = USACE watershed "roughness" factor relating to density of drainage systems

L = maximum length from watershed divide to outlet in miles

L_c = length along main drainage path from outlet to point perpendicular to basin centroid in miles

S = effective slope along L in feet per mile

Table 8. Watershed Parameters for San Francisquito Creek at Stanford

Parameter	Value	Parameter	Value
Area	37.5 mi ²	N	0.08
SCS Curve Number (AMC II)	68	L	12.08 mi
Percent Impervious	5	L_c	5.30 mi
Mean Annual Precipitation	32 in	S	84 ft/mi
100-year, 72-hour Precipitation Depth	10.73 in	t_c	3.46 hours

The use of the Clark Unit Hydrograph within the District's unit hydrograph procedure requires a second parameter, the storage coefficient R . The ratio of R to the sum of R and t_c is generally between 0.5 and 0.9 for rural areas. Since the shape of the unit hydrograph is sensitive to the selection of R , additional work was performed for the 2002 Engineer's Report to evaluate the relationship between R and t_c .

The San Francisco District S-graph was used in the 2002 Engineer's Report to establish a unit hydrograph for the San Francisquito Creek watershed at the gage. At the time Clark's unit hydrograph was manipulated to replicate results by varying R according to the basin "N" for the same curve number. As demonstrated in Table 9, the ratio of R to t_c does not vary as long as the time of concentration is allowed to vary with basin "N" using the modified Corps lag equation. Basin "N" values range from 0.100 for completely undeveloped sub-basins to 0.025 for highly urbanized sub-basins.

Table 9. Calibration of Storage Coefficient R

Basin N	t_{lag} (hours)	t_c (hours)	Q_{peak} (cfs)	R	$\frac{R}{(R + t_c)}$
0.100	5.0	4.3	6,830	5.0	0.54
0.075	3.8	3.3	8,130	3.8	0.54
0.050	2.5	2.2	10,200	2.5	0.54
0.025	1.3	1.1	12,800	1.4	0.56

A constant relationship between t_c and R is used in the PAFB watershed model:

$$\frac{R}{t_c + R} = 0.54 \text{ or } R = 1.17t_c$$

Table 10 presents a summary of the watershed model calibration for antecedent moisture conditions. With the balanced 100-year precipitation pattern shown in Figure 12 (but for a mean annual precipitation of 32 inches), using an AMC of I $\frac{3}{4}$ best replicates the flood-frequency characteristics of San Francisquito Creek. (The precise calibrated Curve Number to match the gaged 100-year discharge is 63.4, which represents an interpolated AMC of 1.77; however antecedent moisture conditions are generally calibrated to the nearest one-quarter of an integer value.)

Table 10. Calibration of AMC for Watershed Modeling

Return Period	AMC	Adjusted CN	Modeled Peak Discharge (cfs)	Variance from Gage
100-year (1%)	I $\frac{3}{4}$	63	7,730	1.0%

It is noted that in the 2002 Engineer's Report, AMC was calibrated at a value of 1.55 (the adjusted Curve Number to replicate the 100-year discharge was 59). Since watershed parameters have not changed, this indicates that there is less rainfall in the updated 72-hour storm relative to the 2002 Engineer's Report.

Base Flow Recession

Constants for an exponential recession curve have been estimated using the hydrograph recorded at the San Francisquito Creek gage during the February 1998 storm event and adjusted for the HEC-HMS base flow methodology.

San Francisquito Creek's representative extreme-event base flow started at about 560 cfs (equivalent to 15 cfs per square mile); the recession threshold begins at 800 cfs (or 0.11 times the peak discharge); and the exponential decay constant, which is defined by HEC-HMS as the ratio of base flow at time t to the base flow one day earlier, is measured as 0.5 from the recorded hydrograph shown in Figure 14. The base flow constants are reflected in the AMC calibration summarized by Table 10.

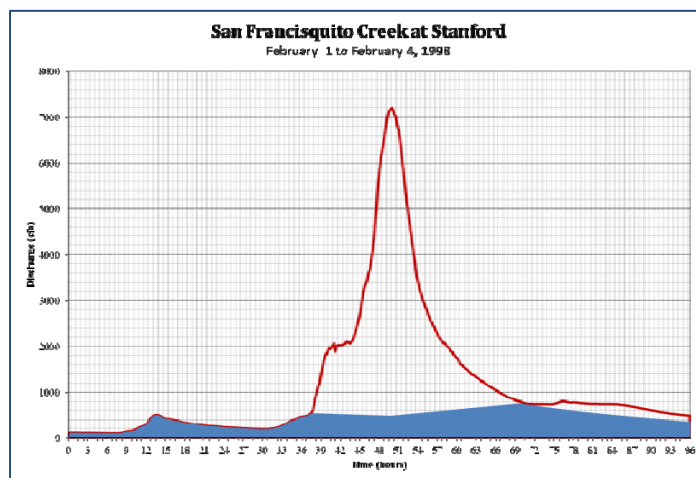


Figure 14. Base Flow Separation

Runoff Calculations

The calibrated AMC is used with the 72-hour balanced patterns for the PAFB watershed to produce 15-minute 100-year runoff hydrographs at the design points shown in Figures 7, 8, and 9 in HEC-HMS. With a 72-hour, 100-year storm more than 12,000 acre-feet flow into the Palo Alto Flood Basin over a seven day period. Table 11 provides a summary of inflow volume to the PAFB, with comparisons to previous studies.

Table 11. Inflow Volume to PAFB

Study	6-hour Volume (acre-ft)	24-hour Volume (acre-ft)	72-hour Volume (acre-ft)
1974 SCVWD	2,400	6,500	n/a
2002 Engineer's Report	2,500	5,700	9,700
2014 Study	2,400	5,800	9,900

Figure 15 shows the combined inflow hydrograph to the PAFB with the storm pattern at the PAFB superimposed. Table 12 provides peak discharges at the major design points in the watershed, comparing them to the peak discharges from the 2002 Engineer's Report at the same location. Variance ranges from zero to 7 percent, well within typical hydrologic accuracy.

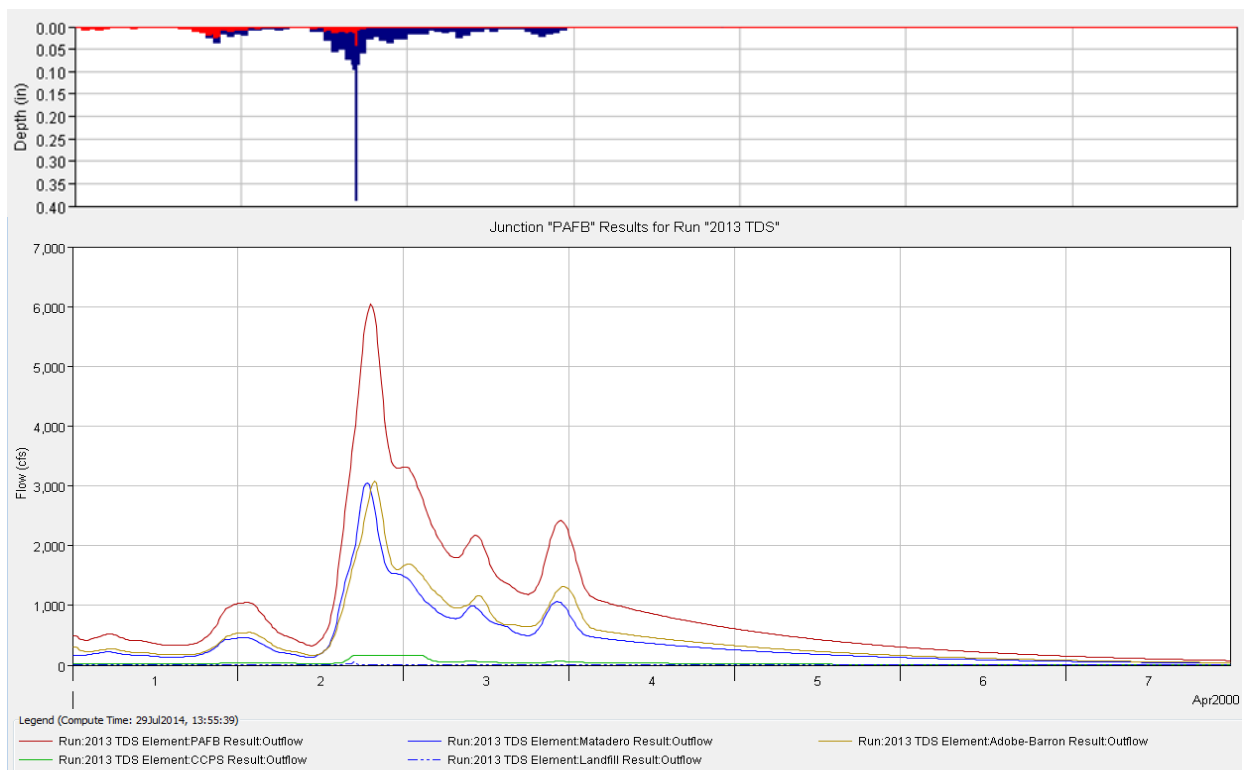


Figure 15. Combined Inflow Hydrograph to PAFB

Table 12. Summary of Watershed Discharges

Model ID	Location	100-year Discharge (cfs)	
		2002 Engineer's Report	Updated HEC-HMS
A	Matadero Creek at confluence with Arastradero Creek	1,145	1,070
B	Matadero Creek at confluence with Deer Creek	1,930	1,880
C	Matadero Creek at Matadero Bypass Diversion	2,030	1,970
D	Matadero Bypass	1,420	1,370
E	Barron Creek upstream from sediment basin	740	700
—	Diversion from Barron Creek to Matadero Bypass	530	500
—	Barron Creek downstream from diversion facility	160	155
F	Barron Creek at Alma Street	250	250
G	Matadero Creek at USGS gaging station (El Camino Real)	2,700	2,670
I	Matadero Creek at Railroad (Caltrain)	2,800	2,790
N	Adobe Creek at Interstate 280	2,500	2,370
P	Adobe Creek at Fremont Road	2,655	2,530
Q	Adobe Creek upstream from confluence with Barron Creek	2,910	2,800
U	Matadero Creek at Highway 101	3,060	3,050
W	Adobe –Barron Creeks at Highway 101	3,190	3,075
PAFB	Palo Alto Flood Basin combined inflow	6,040	6,040

Verification of Flow at Matadero Creek Gage

In the 2002 Engineer's Report design discharges for the Matadero Creek remediation project were based on weighting of different estimates of flow by the equivalent lengths of record used to generate the estimate. Reach discharges for Matadero Creek were based on a weighted estimate at the USGS gage with downstream additions for local storm drain runoff including the Matadero Pump Station. Discharge estimates at the gage location include the correlated flood-frequency analysis of 2,120 cfs with 63 years of equivalent record and the results of the updated HEC-HMS watershed model, which needs to be adjusted for Barron Creek diversion:

Modeled discharge at gage = 2,790 cfs – 500 cfs = 2,290 cfs

The difference in estimates is 8 percent, which is also well within typical error bounds for hydrologic analysis. Bulletin 17B proscribes the use of a ten year record length in the absence of an appraisal of estimation accuracy, and is adopted for the modeled discharge. If the estimates are re-weighted as in the 2002 Engineer's Report, the design discharge for Matadero Creek at the USGS gage location downstream of El Camino Real without Barron Creek diversions is:

$$Q = \frac{(2120)(63) + (2290)(10)}{73} = 2,145 \text{ cfs}$$

The discharge at El Camino Real is obtained by adding 500 cfs to 2,145 cfs, which is rounded to 2,650 cfs. This revised design discharge estimate is within 50 cfs (2 percent) of the design discharge used for the Matadero Creek long-term remediation project (2,700 cfs).

Direct Rainfall into PAFB

Appendix B contains spreadsheet calculations for the conversion of 15-minute rainfall depth over 72 hours into runoff volume using the SCS rainfall-runoff relationship. The volume of rain falling on the area bound by the PAFB levees, while relatively small, should also be accounted for in the PAFB model. For this portion of the analysis, the Soil Conservation Service (SCS, now Natural Resource Conservation Service or NRCS) rainfall-runoff relationship is used to convert the 100-year statistically balanced 72-hour storm pattern into direct runoff, all of which is assumed to flow into the PAFB instantaneously.

The volume of storm water runoff from a given precipitation event depends on a number of factors. In developing the SCS rainfall-runoff relationship, the total rainfall is separated into three components: direct runoff (Q), actual retention (F), and the initial abstraction (I_a) as shown schematically in Figure 16. The SCS equation is used to calculate the amount of direct runoff into the PAFB based on the following relationship:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \text{where:}$$

P is precipitation

I_a is initial abstraction = 0.2S

S is the retention = 1000/CN – 10

CN is the curve number (97 for AMC I³/₄)

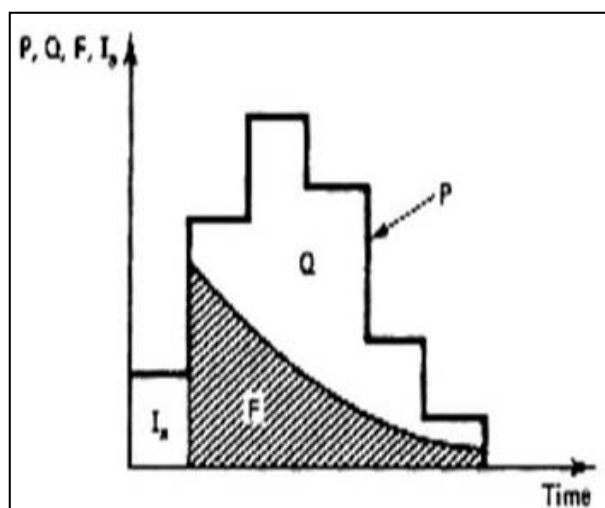


Figure 16. Separation of Rainfall (McCuen, 1989)

Tide Boundary Conditions

The Palo Alto Flood Basin stores the inflow depicted by the hydrograph in Figure 15 and discharges from storage into San Francisco Bay, which forms the downstream boundary of the Palo Alto Flood Basin model depicted in Figure 2. The tide gate structure was constructed to prevent Bay tides from filling the PAFB and to allow the discharge of stored runoff from the basin during ebb (low) tides. The elevation and timing of the tides during storm events plays a crucial role in the filling and draining of the PAFB and have a great impact on the extent and duration of peak water elevations in the basin.

Tide boundary conditions are established based on coincident probability analyses. Earlier analyses of PAFB operation relied on the assumption of average tides. As shown herein, this assumption is not based on a robust analysis of data collected over many years.

Astronomic Tides

A 19-year mean tide cycle is established for San Francisco Bay and other geographical locations on the West Coast. This cycle represents average tide heights over a specific period known as the tidal epoch, which spans the 19 years it takes for every possible combination of relative positions between the sun, moon and earth to occur. A mixed tide cycle predominates on the West Coast of the United States. This cycle consists of two high tides (one higher than the other) and two low tides (one lower than the other) each lunar day.

Based on calculations for these relative celestial positions, it is possible to predict tides for any day of the year at any time of day. *Astronomic tides*, created by the gravitational forces of the moon and sun acting on earth's oceans, are provided in tide prediction calendars. The mean tide cycle is simply the long-term average of astronomic tides. *Observed tides*, on the other hand, are actual tidal elevations recorded by National Oceanic and Atmospheric Administration (NOAA) gaging stations located throughout coastal areas. Table 14 provides the extreme points of the 19-year metonic cycle for the current tidal epoch (1983-2001) and the relevant datum conversions based on local NGS benchmark information and tide translation from the Presidio to the outlet of the PAFB.

A tide station was maintained for a number of years at the Palo Alto Yacht Harbor, but its data are not used because the harbor is not located in open water. Since the PAFB HEC-RAS model includes Mayfield Slough and the secondary slough that carry discharge between the tide gates and open water, the downstream open water boundary is represented by the adjusted tide cycle at the nearby Dumbarton Bridge.

Table 13. Mean Tide Cycle at Dumbarton Bridge

Tide ¹	19-year Mean at Presidio (MLLW)	19-year Mean at Dumbarton (MLLW)	19-year Mean at Dumbarton (NGVD)
Higher High (MHHW)	5.84	8.61	4.52
High (MHW)	5.23	8.00	3.91
Mean Sea Level (MSL)	3.12	4.68	0.59
Low (MLW)	1.13	1.26	-2.83
Lower Low (MLLW)	0.00	0.00	-4.09

1. Epoch data collected from NOAA website at <http://tidesandcurrents.noaa.gov/stations.html?type=Datums>

Establishing a Coincident Boundary Condition

Traditionally Mean Higher High Water (MHHW) has been used as the backwater condition where riverine (freshwater) runoff meets an estuarine (saltwater) body. However, evidence shows that mean tide elevations are not an appropriate boundary condition during storm events and tide elevations in San Francisco Bay are elevated (relative to predicted tides) during periods of heavy rainfall. Furthermore, the relationship between coincident tides and maximum annual runoff can be quantified and used in the model, providing for a more statistically correct solution than an arbitrarily selected tide condition.

Observations from the Storm of Record

The El Niño storm of February 2-3, 1998 provided an ideal event for examining potential correlations between runoff events and tide action. During that event stream runoff measured by local gages approached historic recorded levels and observed tides in San Francisco Bay were substantially higher than predicted. Figure 17 shows predicted and recorded tides in early February 1998 at NOAA's Golden Gate (San Francisco Presidio) gage. Recorded tides during the week of this runoff event were consistently higher (on the order of 2 feet) than the astronomic (predicted) tide heights due to storm surge. As a control, observed tide heights are compared to predicted tides six months later at the same station, using the same sets of data (Figure 18) during early August 1998, when there is very close agreement between the predicted and the actual tides and no rainfall. Both figures present tides on the local Mean Lower Low Water (MLLW) datum.

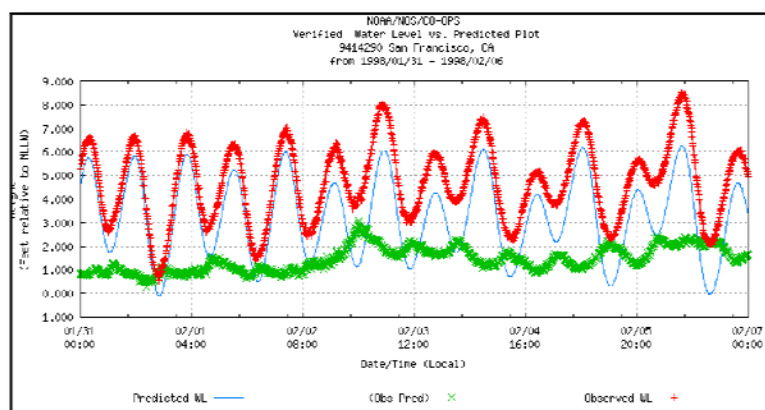


Figure 17. Impact of Storm Surge on San Francisco Bay Tide

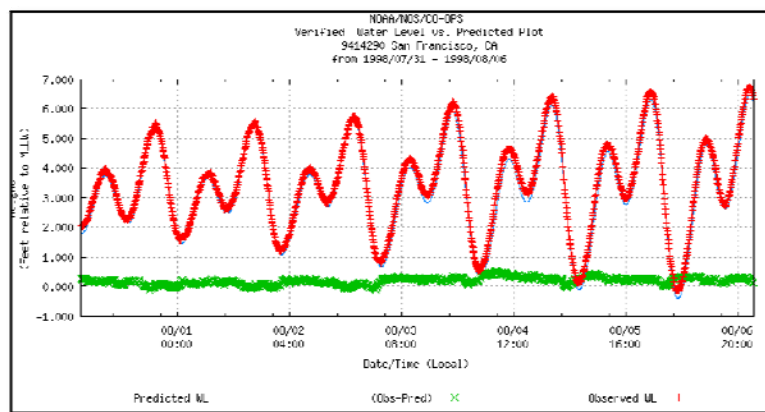


Figure 18. Lack of Storm Surge Effect during Summer Months

Historic tide records have been examined to see whether the phenomenon demonstrated in February 1998 at the Golden Gate occurred elsewhere in the Bay Area and during other heavy runoff events in the past. The observed phenomenon is not strongly dependent upon tide gage location, particularly within San Francisco Bay, and is exhibited during many historic storm events. From observed historical data, it appears that storm-related forces induce higher tides during rainfall events, and by extension, runoff events. NOAA refers to the term “inverse barometer effect”, and defines it as higher tides that are caused by lower barometric pressures associated with winter storm systems. References to “storm surges”, the meteorological effects of low barometric pressures and/or strong southerly winds, are also found in the literature.

Assessing the Conditional Probability of Coincident High Tide

To model an appropriate San Francisco Bay tidal cycle during a storm event of particular return period (with tides adjusted to the nearby Coyote Point Marina location), elevations for each critical point in the tide cycle are adjusted based on the one-percent conditional probability of coincident occurrence with the annual maximum discharge of San Francisco Creek at Stanford, which represents the closest USGS stream flow gaging location with sufficient length of record for analysis; and this gage data is also used to calibrate the rainfall-runoff model. This procedure is as described by Dixon (1986), whose hypothesis was that high tide events tend to occur the same day as flood flow events using conditional probability:

$$P_{(x,y)} = P(x|y) P(y)$$

where $P_{(x,y)}$ is the probability of occurrence of x and y ; $P(x|y)$ is the probability of occurrence of x given y ; $P(y)$ is the probability of occurrence of y ; x is tide elevation; and y is maximum annual peak discharge. Since we are interested only in annual maximum discharges, $P(y)$ is one and the probability of joint occurrence, $P_{(x,y)}$, is equal to the probability of x given y .

Coincident Tides at Golden Gate

Tide cycle points are taken from fitted probability curves of data contained in Appendix C, using the median plotting position for every recorded tide extreme that occurred within 24 hours of the recorded maximum annual discharge. Figures 19 and 20 show the probability distributions for high and low tides, respectively; and Table 14 provides the values for each point on the tide cycle. Observed tide elevations at Golden Gate are translated to the Dumbarton Bridge by adding 2.6 feet to high tides and 0.1 foot to low tides.

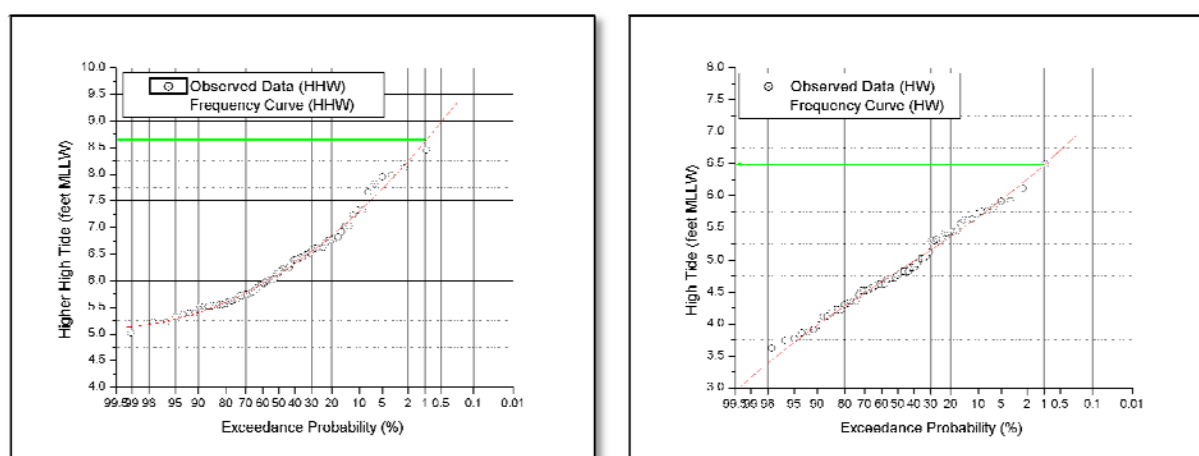


Figure 19. Conditional Probability of High Tides at Golden Gate

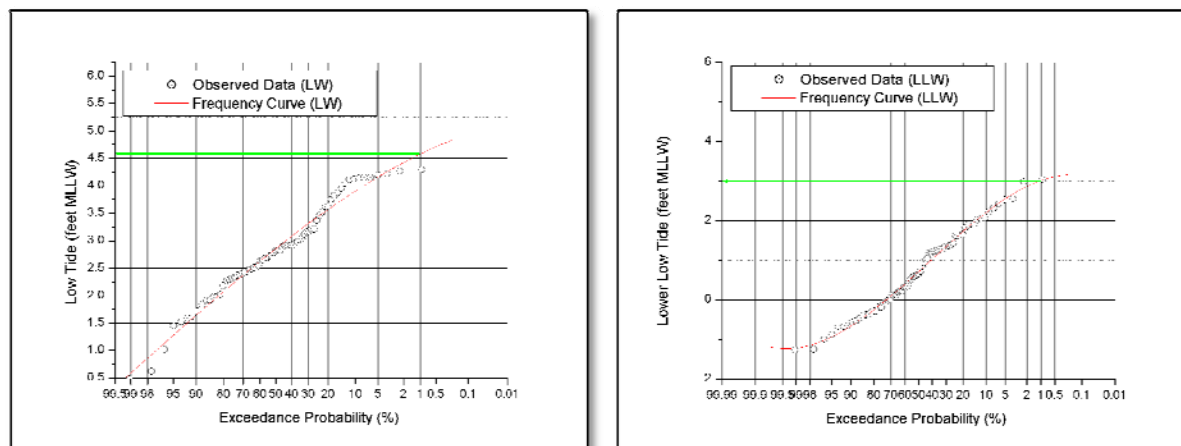


Figure 20. Conditional Probability of Low Tides at Golden Gate

Table 14. San Francisco Bay Boundary Conditions

Tide	100-year Coincident at Golden Gate (feet MLLW)	100-year Coincident at PAFB (feet MLLW)	100-year Coincident at PAFB (feet NGVD)	19-year Mean at PAFB (feet NGVD)
Higher High	8.7	11.3	7.21	4.52
High	6.5	9.1	5.01	3.91
Low	4.6	4.7	0.61	-2.83
Lower Low	3.0	3.1	-0.99	-4.09

Downstream Boundary Condition at PAFB

The coincident tide cycle points listed in Table 14 are used to produce a sinuous design tide cycle based on the timing of the USACE's 19-year mean tide cycle for the Golden Gate Station. To translate tides from Golden Gate to the Dumbarton Bridge, high tide elevations are lagged 1.00 hour and low tide elevations are lagged 1.63 hours from the time of high tide at the Golden Gate. Figure 21 compares the observed February 1998 tide at the Golden Gate transposed to the NOAA Redwood City tide station (the closest tide station with verified observations) to the recorded tide at Redwood City, demonstrating the validity of this methodology, using the tide translation factors from USACE.

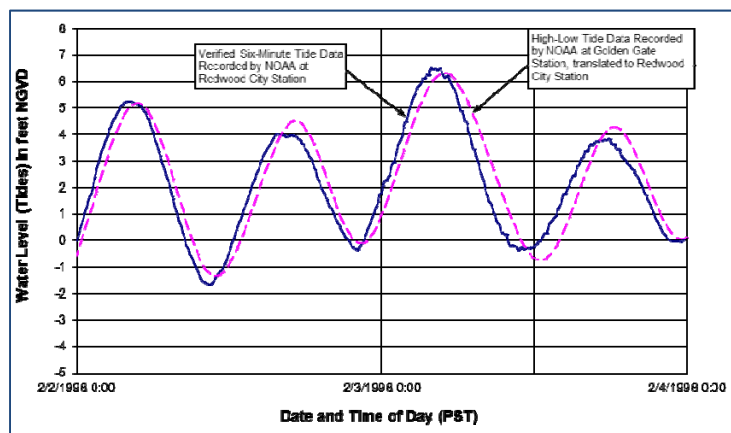


Figure 21. February 1998 Tides at NOAA Redwood City Station

Figure 22 shows the design tide cycle used as the downstream boundary condition for the HEC-RAS analyses. Observed tides at the tide gate outlet are also plotted, shifted to coincide with high and low tides. Design tide cycles published in the 2002 Engineer's Report, which are essentially validated herein with another 12 years of coincident record, are substantially different from the design tide cycles used in earlier studies, which are summarized in Table 15. Figure 23 compares the updated design tide cycle to observed tides at the flood basin outlet from February 1998 and design tides from the District's 1974 study.

With the exception of the Linsley-Kraeger study (1984), the updated design tide is similar to the 1974 and 1975 design tides, but only for the high water points of the tide cycle. A significant disparity is seen between the updated design tide cycle's low water points when compared to those used in earlier studies. As the boundary condition affects the operation of the PAFB, the most important point in the tide cycle is the ebb, or low tide, since its elevation impacts the ability of the tide gates to discharge flood flows from the PAFB.

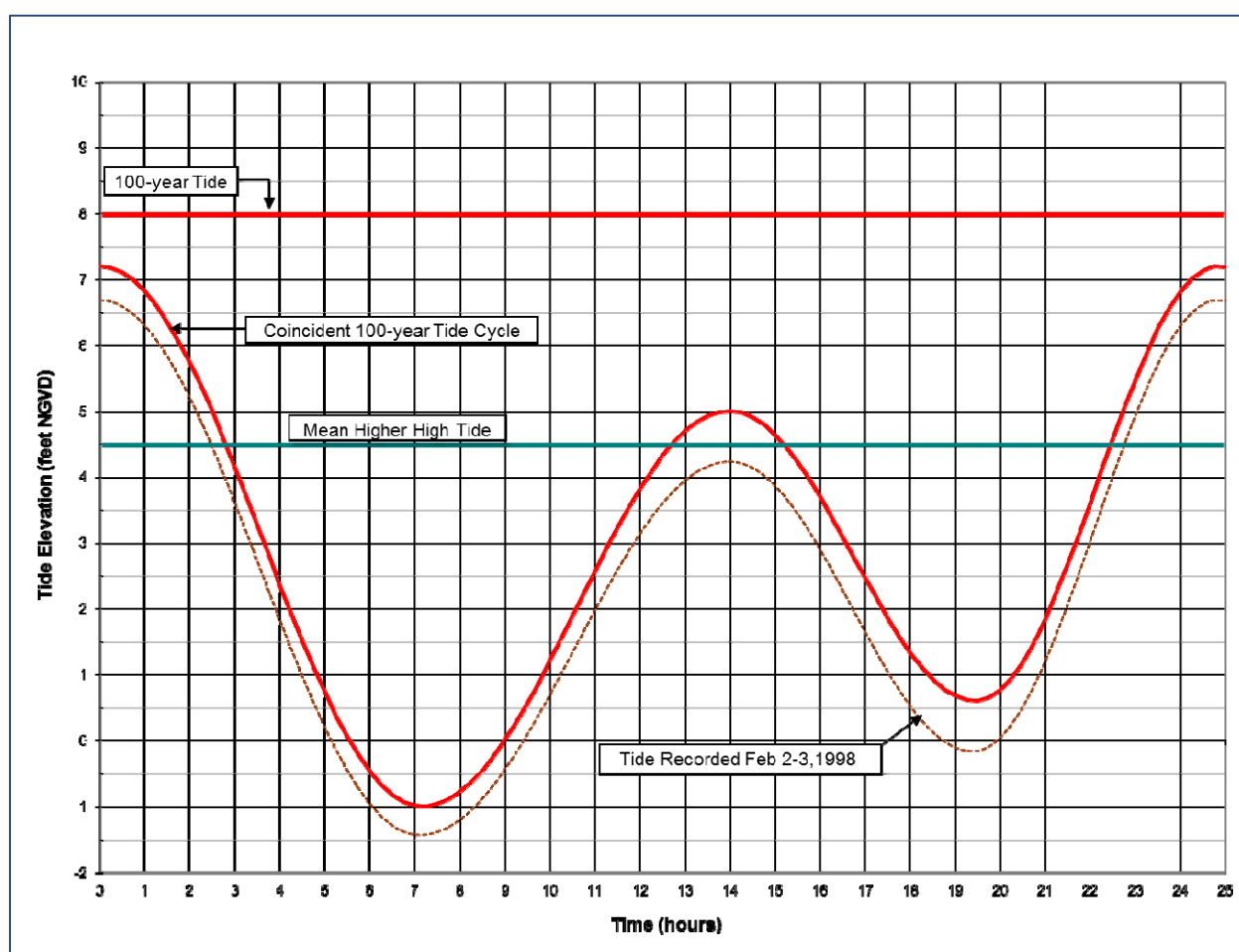


Figure 22. Design Boundary Condition at San Francisco Bay

Table 15. Comparison of Coincident 100-year Design Tide to Previous Design Tides

Tide	Updated Design Tide (feet NGVD)	2002 Engineer's Report (feet NGVD)	1974 SCVWD (feet NGVD)	1975 Water Resources Eng. (feet NGVD)	1984 Linsley Kraeger Assoc. (feet NGVD)
Higher High	7.2	7.2	6.7	6.8	3.0 to 4.0
High	5.0	5.4	4.0	4.4	1.5 to 2.3
Low	0.6	1.0	-2.0	-0.1	-1.6 to -0.7
Lower Low	-1.0	-0.5	-5.6	-4.8	-3.7 to -1.8

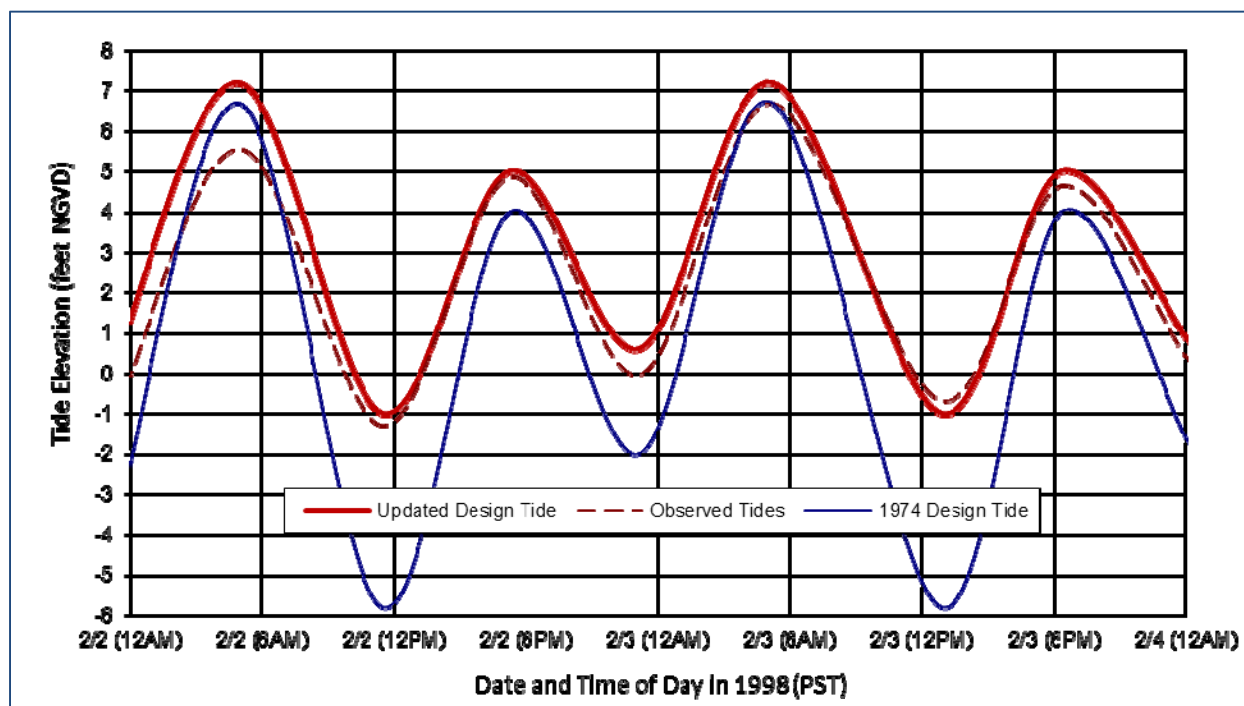


Figure 23. Tide Cycle Comparison

The timing of coincident tide elevations with the beginning of the storm event (rainfall) is a random process. Since there are not sufficient data to statistically analyze the impact of tide timing, a sensitivity analysis has been conducted to quantitatively assess the relative risk of achieving certain 100-year elevations within the Palo Alto Flood Basin. This analysis is fully documented in the next chapter.

With upstream boundaries (flow), downstream boundaries (tide), and the basin fully modeled with a storage-elevation curve connected to the slough reaches with a gated structure; PAFB operation can be evaluated.

Palo Alto Flood Basin Performance

The hydrologic and hydraulic models described in this document are used to evaluate Palo Alto Flood Basin Performance during a design 100-year storm event. With established planning objectives, the HEC-RAS basin model can also be used to assess potential mitigation measures.

Existing Condition Simulations

Using the updated data and assumptions presented herein, the performance of the PAFB under a design 100-year storm loading has been modeled. Results are presented in several formats.

Starting WSEL for Simulations

Unsteady HEC-RAS requires an initial condition of storage in the PAFB at the beginning of storm runoff. In no case would the level of water in the PAFB be below elevation -5 feet NGVD, because this is the invert elevation of the individual tide gates. At the time of aerial survey in 1999, the water elevation within the PAFB was -3 feet NGVD.

The initial water surface elevation has been set to -1.0 foot NGVD, which is equal to the lowest 100-year coincident tide. It is assumed that prior to the rainfall event, without inflow the tide gates are capable of evacuating the flood basin to the elevation of the lowest tide. Rainfall, runoff, flood basin elevation, and tide elevation observations made by the City of Palo Alto during the February 1998 event indicate that this is a reasonable assumption.

Depending upon the timing of the initiation of rainfall against the design tide cycle, the simulation can become unstable. In some instances it has been necessary to lower the starting water surface elevation as much as two feet. A sensitivity analysis indicates that the starting water surface elevation does not change the outcome of simulation (maximum stage in PAFB) when the starting water surface varies between -3.0 feet NGVD and -1.0 feet NGVD.

Tidal Timing Shift

Rather than adjust the timing of incipient precipitation against a static tide cycle, it proved easier to shift the tide cycle to perform the statistical analysis of PAFB flooding risk. After some iteration, a time shift increment of one hour is deemed as an adequate increment to assess PAFB operation.

Levee Containment Elevations

At a few locations along the PAFB containment levees, including the bike path adjacent to East Bayshore Road, the top of levee elevation is between 5 and 6 feet NGVD. Model simulations assume that calculated water surfaces elevations within the PAFB are fully contained, even when they exceed the minimum levee containment elevation, rather than let stored water spill from the flood basin when it exceeds that elevation. This assumption is made so that the relative effect of eventual alternative mitigation measures can be evaluated in full without capping maximum PAFB stage at a particular elevation based on current levee conditions.

100-year Water Surface Elevations in PAFB

Results of HEC-RAS simulations for existing conditions are presented graphically and in tabular form herein. Figure 24 shows a summary of PAFB operation for the tidal shift (29 hours) that produces the maximum 100-year water surface elevation in the basin, which is 6.0 feet NGVD. Stage is labeled on the left-hand y-axis; flow is on the right-hand y-axis. Tide elevation, PAFB elevation, total flow through the tide gate structure (eight gates), flow through each individual gate, and the total flow into the PAFB are all charted over a one-week period. Simulated gate operation does not allow reverse flow, and the minor negative flow spikes are considered a small model instability that does not affect the overall result.

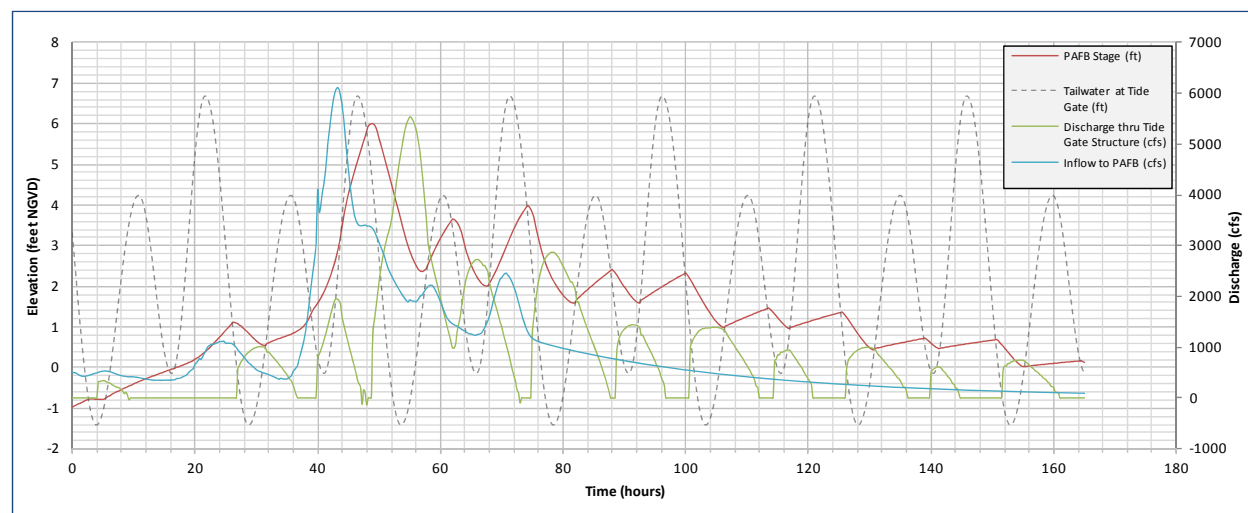


Figure 24. PAFB Operation with Maximum Stage based on Random Tidal Shift

Summary of Tidal Shift Impact

The random nature of relative timing between the beginning of the 100-year storm and the timing of the coincident 100-year tide cycle is captured by shifting the tide cycle in one hour increments until the tide cycle repeats, rerunning the PAFB simulation. Figure 25 presents the impact of this tide cycle shift on the maximum stage in the PAFB as well as the PAFB stage when inflow from Matadero Creek and Adobe-Barron Creek are at their respective peaks. Table 16 summarizes this same information numerically.

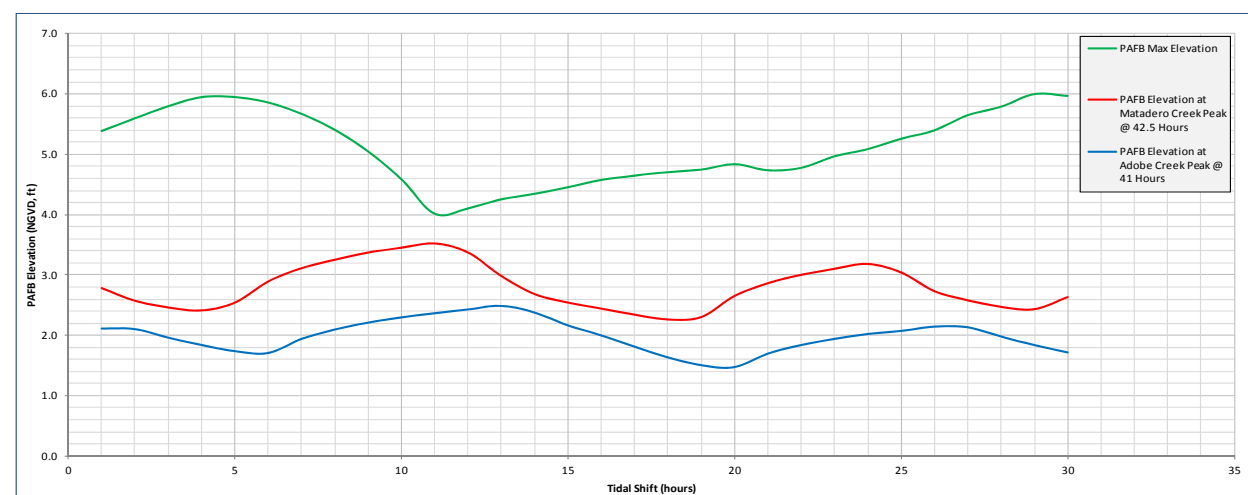


Figure 25. Tidal Shift Impact on PAFB Operation

Table 16. Summary of Tide Shift Impact on PAFB Stage

PAFB WSEL at Matadero Creek Peak (feet NGVD)	PAFB WSEL at Adobe Creek Peak (feet NGVD)	Tidal Time Shift in Hours	Maximum PAFB WSEL (feet NGVD)
2.78	2.11	1	5.39
2.57	2.10	2	5.60
2.46	1.96	3	5.80
2.41	1.84	4	5.95
2.54	1.74	5	5.95
2.89	1.71	6	5.86
3.11	1.94	7	5.67
3.25	2.09	8	5.41
3.37	2.21	9	5.05
3.45	2.29	10	4.59
3.52	2.36	11	4.02
3.37	2.42	12	4.11
2.98	2.48	13	4.26
2.68	2.37	14	4.35
2.54	2.16	15	4.46
2.44	2.00	16	4.58
2.34	1.81	17	4.65
2.26	1.64	18	4.71
2.30	1.51	19	4.75
2.65	1.48	20	4.84
2.86	1.70	21	4.74
3.00	1.84	22	4.78
3.10	1.94	23	4.97
3.18	2.02	24	5.09
3.04	2.07	25	5.26
2.73	2.14	26	5.40
2.58	2.13	27	5.65
2.47	1.98	28	5.79
2.43	1.84	29	6.00
2.63	1.72	30	5.97

Statistical Analysis of Random Tide Shift

The maximum PAFB 100-year water surface elevation of 6.0 feet NGVD depicted in Figure 24 represents a worst case combination of rainfall and tide cycle timing. As such it does not represent a “true” 100-year return period. Rather, the relative risk of various 100-year PAFB water surface elevations – which is analogous to a confidence limit – can be derived by plotting each elevation as a random occurrence on a probability scale. This is done in Figure 26 for the maximum stage, Figure 27 for the stage at peak Matadero Creek inflow, and Figure 28 for the stage at peak Adobe Creek inflow.

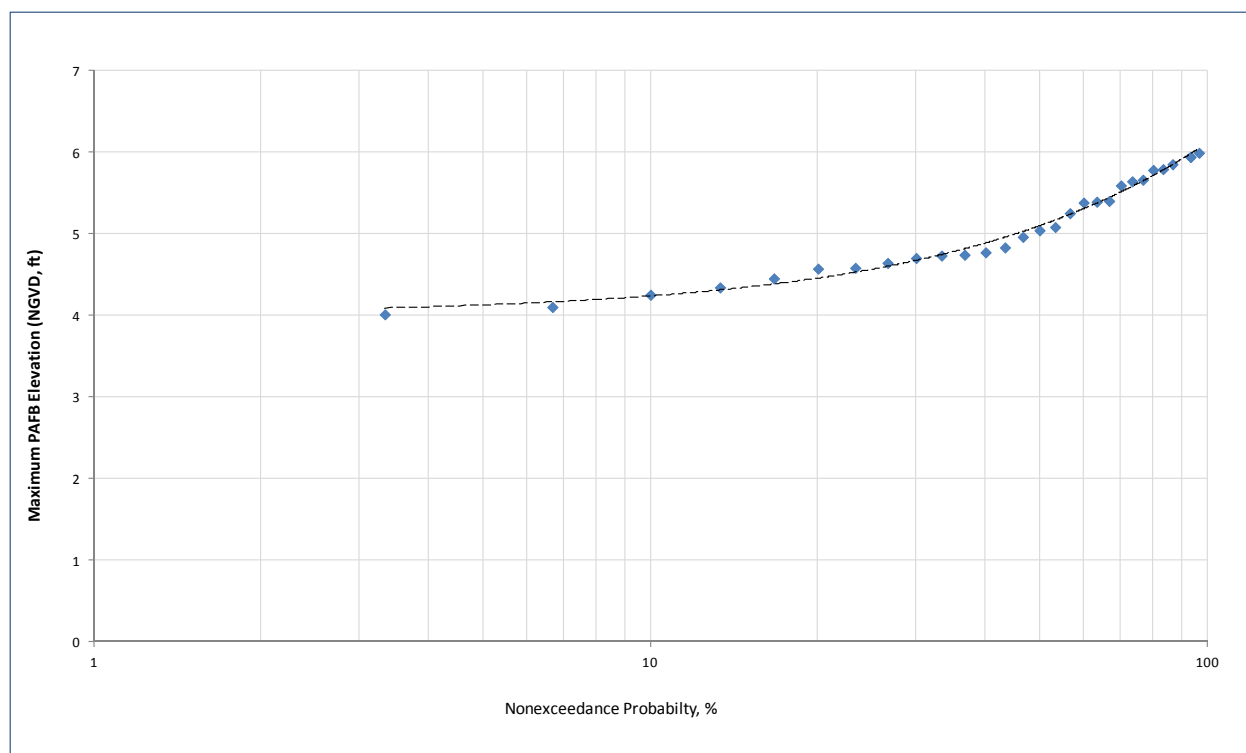


Figure 26. Non-exceedance Probability of Maximum 100-year PAFB Stage

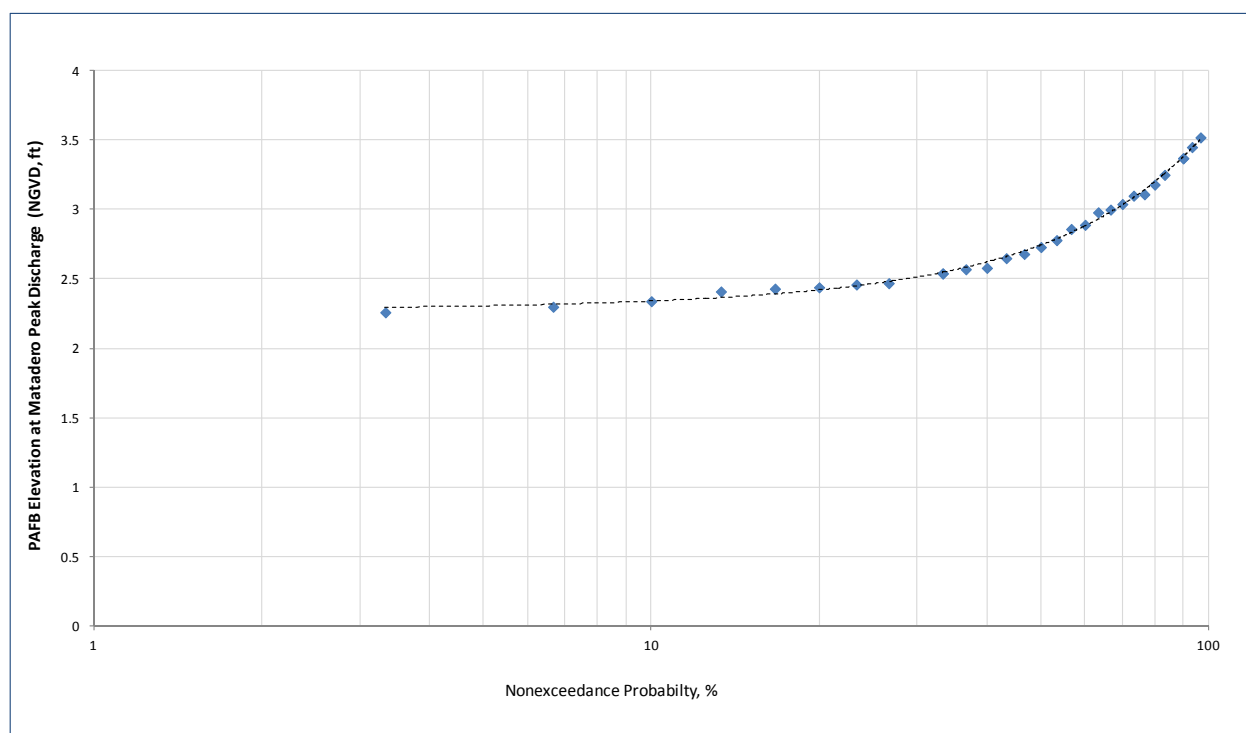


Figure 27. Non-exceedance Probability of PAFB Stage at Time of Matadero Creek Peak Discharge

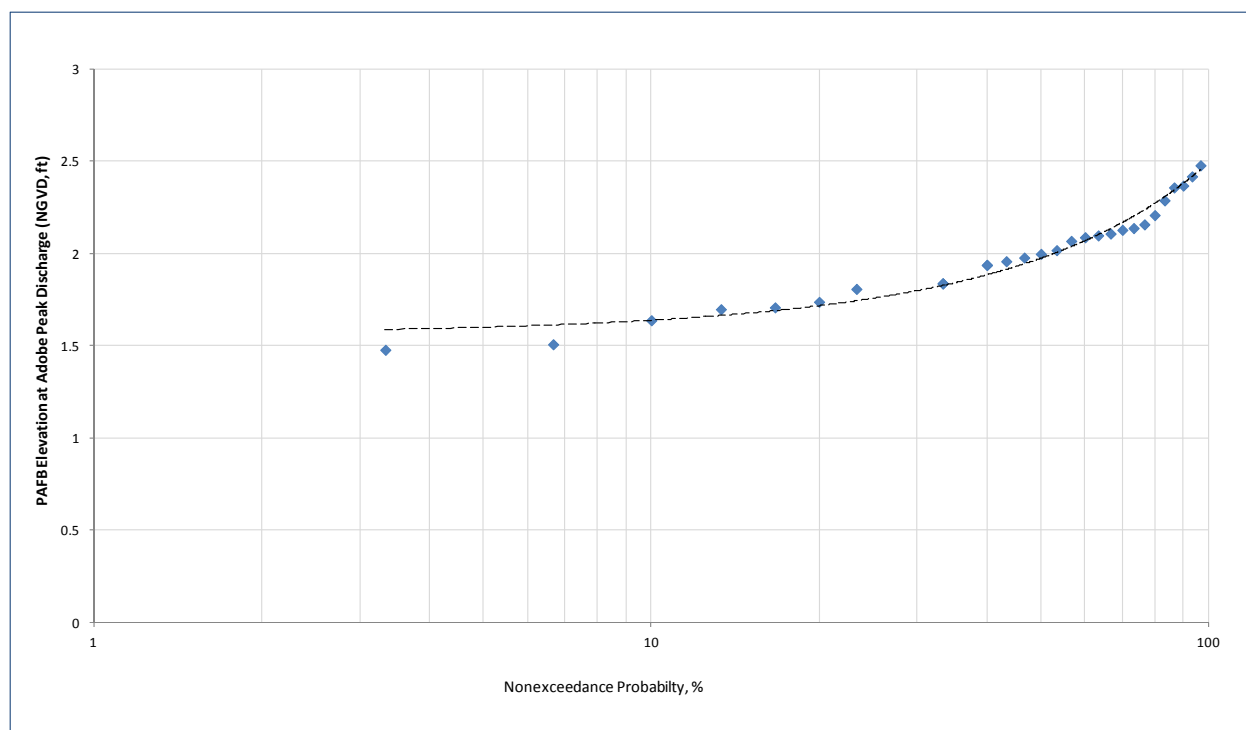


Figure 28. Non-exceedance Probability of PAFB Stage at Time of Adobe Creek Peak Discharge

Table 17 summarizes these statistics providing the 50-, 90- and 95-percent confidence limits for the 100-year PAFB water surface elevations of interest. The table provides the non-exceedance probability; that is, the confidence that a given water surface elevation will not be exceeded during the design 100-year event. A fifty percent confidence means that the given water surface elevation is just as likely to be exceeded as not.

The 90- and 95-percent confidence limits are provided since those statistical abstractions were used in the risk and uncertainty analysis of the Matadero Creek floodwalls, which assumed a maximum PAFB water surface elevation of 7.2 feet NGVD (coincident one-percent tide) and a PAFB stage of 4.6 feet when Matadero Creek inflow is at its peak, for risk-based backwater analysis. These assumptions remain conservative based on the updated statistics.

Table 17. Summary of PAFB Water Surface Elevation Uncertainty

Scenario	50% Confidence (feet NGVD)	90% Confidence (feet NGVD)	95% Confidence (feet NGVD)
Maximum WSEL in PAFB	5.1	5.9	6.0
WSEL in PAFB when Matadero Creek inflow is at its peak	2.7	3.4	3.5
WSEL in PAFB when Adobe Creek inflow is at its peak	2.0	2.4	2.5

For comparison, the coincident 100-year tide is 7.2 feet NGVD and the 100-year stillwater elevation is 8.0 feet NGVD.

Future Planning Scenarios

The Santa Clara Valley Water District has expressed that they may establish project planning objectives wherein the following information may be desirable:

- Maximum allowable water surfaces in the basin to achieve flood protection objectives for the lower reaches of Adobe, Barron, and Matadero Creek.
- Maximum allowable water surfaces in the basin as a function of return period to evaluate and protect different habitats that are found or could be created within the flood basin.
- Impacts to flooding levels caused by sea level rise scenarios, based on BCDC thresholds or other future regulation.
- Changes in PAFB water surfaces that result from various project plan scenarios such as the replacement of the tide gate structure, providing additional storage, and pumping.

With the number of variable inputs including inflow and coincident tide cycles, it is relatively difficult to directly determine the conditions that will produce a target water surface elevation. Rather, the updated PAFB model is run over a range of conditions to produce performance curves and probability distributions. For instance, the maximum water surface in the PAFB can be related to the number of identical gates installed in a rebuilt tide gate structure.

Sea Level Rise

Sea Level Rise (SLR) scenarios are adopted from recent projections from the National Research Council.⁴ Sea level rise predictions are added directly to the coincident tide cycles developed herein, essentially modeling the rise in Bay tide cycle as a uniform vertical datum adjustment. Despite some evidence that the difference in the intertidal range (i.e. between MHHW and MLLW) may be widening along with the overall trend of rising seas, the California Climate Change Center “assumes that all tide datums, e.g. mean high tide and flood elevations, will increase by the same amount as mean sea level.”⁵

Low and high range of the projections are both used to reflect the uncertainty bounds inherent in developing the projections and applying them to a single location. Table 18 provides a summary of the range of SLR projections contained in the 2012 NRC document.

Table 18. Summary of NRC Sea Level Rise Scenarios

Time Period	Low Range SLR (feet)	High Range SLR (feet)
2000 – 2030	0.13	0.98
2000 – 2050	0.39	2.00
2000 – 2100	1.38	5.48

⁴ National Research Council, Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past Present, and Future, National Academies Press, Washington, 2012.

⁵ California Climate Change Center, “The Impacts of Sea-Level Rise on the California Coast,” May 2009, Page 9.

Sea Level Rise Impact with Existing Flood Basin Configuration

Maximum stage in the PAFB resulting from the SLR predictions is estimated from a worst case combination of rainfall and tide cycle timing with the existing tidal gates as performed for the existing conditions. Temporal shifts in the tide cycle on the order of one hour are manually performed to pinpoint when the highest PAFB stage could occur. Furthermore, the water surface elevations associated with random tidal shifts are plotted to evaluate the relative risk of the 100-year PAFB elevation under each SLR scenario in the form of probability distributions.

Table 19 provides a summary of the predicted maximum stage in the PAFB without levee overtopping for the predicted ranges of three SLR rise scenarios (2030, 2050 and 2100) assuming the configuration of the flood basin and tide gate structure are not changed. (Note the table lists SLR scenarios in ascending order according to the magnitude of sea level rise.) Probability plots for the range of sea level rise scenarios have been consolidated into a single graphic (Figure 29) to show how the variability in range of sea level rise projections dominates the variance in maximum PAFB stage.

Table 19. Impact of Sea Level Rise on Maximum PAFB Stage

SLR Scenario	Sea Level Rise (feet)	100-year Coincident Tide (feet NGVD)	Maximum PAFB Stage (feet NGVD)
Existing	n/a	7.20	6.00
2030 Low	0.13	7.33	6.16
2050 Low	0.39	7.59	6.56
2030 High	0.98	8.18	6.93
2100 Low	1.38	8.58	7.00
2050 High	2.00	9.20	7.67
2100 High	5.48	12.68	11.31

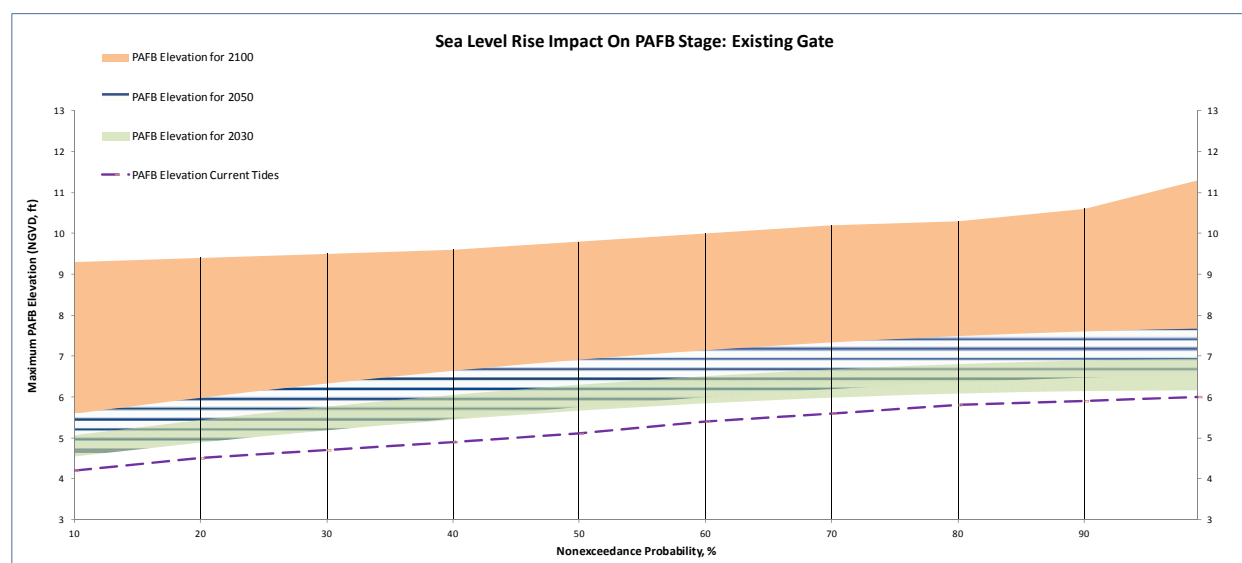


Figure 29. SLR Impact on Maximum PAFB Stage Confidence (Existing Gates)

Tide Gate Structure and Flood Basin Modifications

As depicted in Figure 29, the Palo Alto Flood Basin and lower reaches of Adobe, Barron and Matadero Creeks are vulnerable to the effects of possible future sea level rise. Since the Palo Alto Flood Basin tide gate structure is near the end of its useful life by exhibiting spalling and corrosion that has begun to compromise the concrete reinforcement (Figure 30), the feasibility of modifying the tide gate structure and/or flood basin to also meet the aforementioned planning objectives has been evaluated using the updated PAFB performance model. Potential modifications might include:

- Installing a greater number and/or larger tide gates or modifying their elevation.
- Dredging the flood basin to create additional volume.
- Connecting additional wetland areas to create additional volume.
- Pumped discharge of stored floodwaters.



Figure 30. PAFB Tide Gate Condition

Increasing the Number of Tide Gates

If and when the tide gate structure is rebuilt, there is ample space in the vicinity of the existing structure to build a new structure with additional gated openings to discharge stored flood water at higher rates for a given head differential across the tide gate than under existing conditions. Alternative rebuilt tide gate structures with 32 gates (double the total net discharge area), 48 gates (triple) and 64 gates (quadruple) have been modeled with various sea level rise scenarios.

For all modeling scenarios individual gates are assumed to be identical to the existing gates. That is, 5-foot by 5-foot rectangular openings with an invert elevation of -5.1 feet NGVD and a flap gate to prevent backflow. Modeling results are presented in the summary tables and figures.

Creating Additional Storage

Increasing the volume of storage is another means of reducing PAFB stage, whether alone or in combination with a rebuilt tide gate structure with additional discharge capacity. Without commenting on the feasibility of such an alternative, Figure 31 shows the Renzel Marsh directly connected to the PAFB across Matadero Creek. (Details of an overflow structure are not considered at this planning level.) Figure 32 presents the change in storage and Figure 33 shows the modified HEC-RAS model for this scenario. The mitigation area sandwiched between Renzel Marsh, Matadero Creek, and the Palo Alto Landfill is not included in the additional storage area to avoid mitigating the mitigation. Neither the potential environmental impacts to Renzel Marsh nor the regulatory hurdles that would need to be overcome are considered in this evaluation. Modeling results are presented in the summary tables and figures.



Figure 31. Overflow to Renzel Marsh to Create Additional Storage

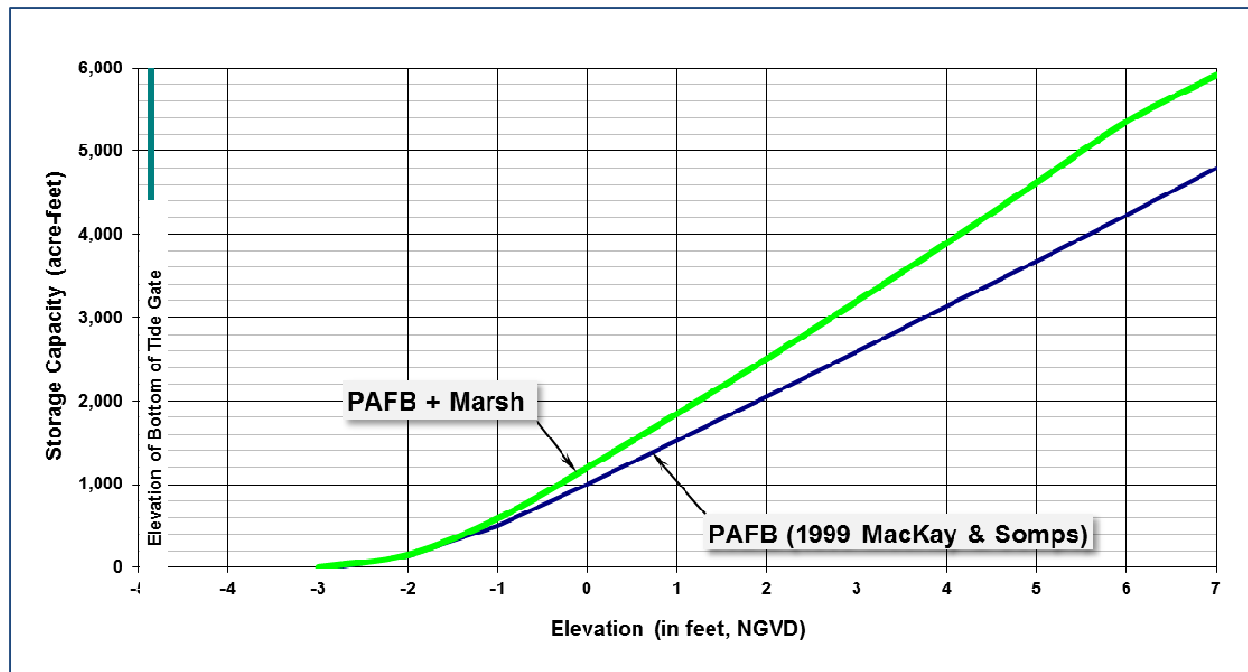


Figure 32. Change in Storage with Addition of Renzel Marsh



Figure 33. HEC-RAS Model with Renzel Marsh Storage Added

Gravity Remediation Alternatives

Storage volume can be increased in combination with additional tide gate discharge. Table 20 provides a comparative summary of maximum predicted PAFB stages for various rehabilitation alternatives and SLR scenarios. Figure 34 provides a side-by-side graphic comparison for this same information. Clearly none of the identified gravity options (additional gates or additional storage) can overcome high-range sea level rise projections, and increasing tide levels mute the benefits of any remedial alternative. Providing additional discharge through a rebuilt tide gate appears to be more effective than providing additional storage, and dimensioning returns are demonstrated when the number of gates is increased by a factor of more than two.

Assuming that doubling the number of gates would be considered for future tide gate modifications and increasing storage is not effective, confidence limits for maximum PAFB stage with 32 gates for the range of SLR scenarios are shown in Figure 35.

Table 20. Sea Level Rise Mitigation Using Gravity Remediation Alternatives

SLR Scenario	SLR (ft)	Maximum Stage in Palo Alto Flood Basin (feet NGVD)						
		Gate Modification Only				Add Renzel Marsh Volume		
		Existing Gate Structure	Double No. of Gates	Triple No. of Gates	Quadruple No. of Gates	Existing Gate Structure	Double No. of Gates	Triple No. of Gates
Existing	n/a	6.00	5.46	5.24	5.20	5.25	4.54	4.15
2030 Low	0.13	6.16	5.55	5.43	5.31	5.79	4.67	4.38
2050 Low	0.39	6.56	5.77	5.65	5.56	5.51	4.90	4.64
2030 High	0.98	6.93	6.27	6.10	6.05	5.92	5.49	5.53
2100 Low	1.38	7.00	6.61	6.50	6.41	6.26	5.84	5.68
2050 High	2.00	7.67	7.09	7.03	6.87	6.82	6.56	6.48
2100 High	5.48	11.31	11.32	11.20	11.20	11.22	11.11	11.0

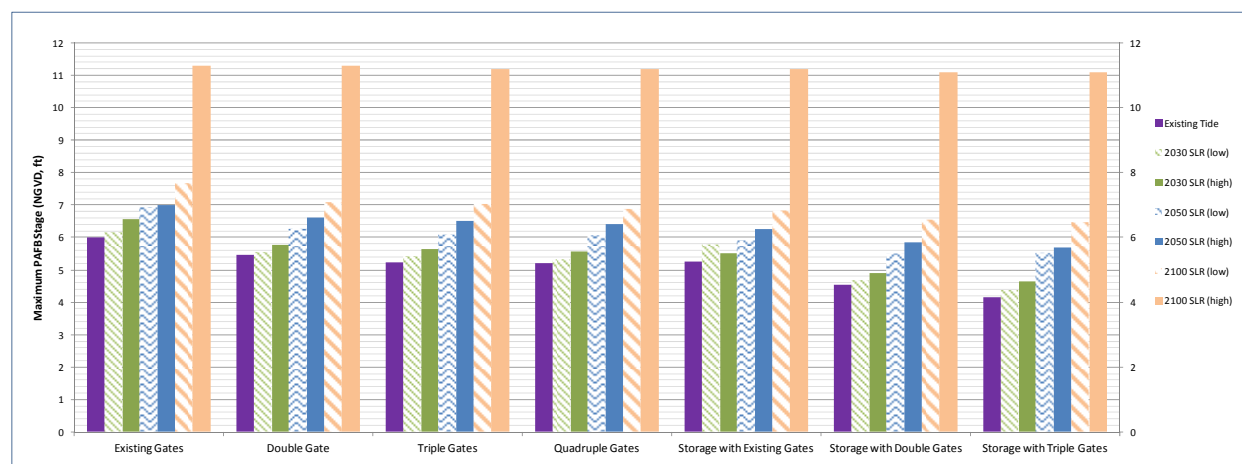


Figure 34. Graphic Representation of SLR Mitigation with Gravity Remediation Alternatives

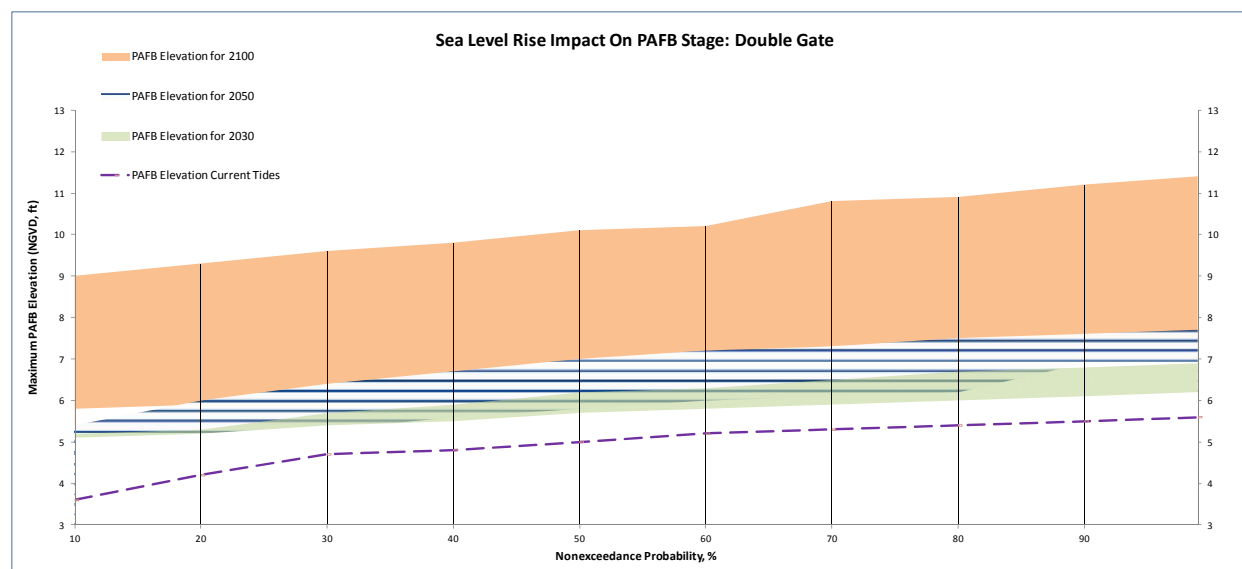


Figure 35. SLR Impact on Maximum PAFB Stage Confidence with Increase to 32 Gates

As an illustrative example of how to use this information, assume that the 2050 high-range SLR estimate of a 2 feet increase in tidal elevations is adopted as a planning horizon. If the PAFB configuration is not changed, SLR will cause rises in maximum PAFB water surface elevation from 6.0 feet NGVD to 7.7 feet NGVD, with the 90% confidence-level WSEL increasing from 5.9 feet NGVD to 7.6 feet NGVD (Figure 29). These elevations are problematic for the existing flood basin containment levees and interior areas of Palo Alto south of Highway 101.

Table 20 and Figure 34 can be used to ascertain the relative benefit achieved by various combinations of gravity remediation alternatives. For the same 2050 high-range SLR scenario, doubling the number of tide gates reduces the maximum PAFB WSEL by 0.58 foot from 7.67 feet NGVD to 7.09 feet NGVD. An additional 0.06 foot reduction could be achieved by tripling the number of gates, but that extra expense does not seem warranted. Even under existing tide conditions, tripling the number of gates reduces the maximum flood basin stage by less than 3 inches more when compared to doubling the number of gates.

Adding Renzel Marsh volume to the PAFB appears to provide more efficient reductions in stage than increasing the number of tide gates. With additional flood basin storage, rising sea levels would not create truly problematic maximum PAFB stages until the 2100 high SLR scenario.

If the goal is to maintain existing 100-year flood basin performance, but against rising tides due to climate change, doubling the number of tide gates would stem the deleterious predicted high-range tide increase until about 2030. Additional gravity remediation alternatives such as adding even more tide gates or adding Renzel Marsh storage would not substantially change this prediction. Any further increase in tidal stage at the downstream boundary of this system would require mechanical pumping to keep 100-year PAFB flood stage from exceeding its current maximum.

Pumping

At some point in the future gravity alternatives to decrease PAFB stage will no longer be sufficient to mitigate sea level rise. The only remaining alternative is to pump the stored flood water against high tide. The effects of adding pumping capacity to the existing system on the maximum PAFB stage (with 90 percent confidence) for the existing tide gate structure configuration and a rebuilt structure with twice as many tide gates are presented in Figures 36 and 37.

Ultimate required pumping capacity to meet various target maximum water surface elevations can be somewhat reduced if a new tide gate structure with 32 gates is constructed, but as is the case with gravity remediation alternatives there is a decreasing benefit with increased sea level rise. For example, to hold maximum flood stage to 5.9 feet NGVD (the existing 90% confidence limit) with the 2030 high-range SLR scenario the 400 cfs pumping plant required with the existing tide gate configuration could only be reduced to 350 cfs if the number of tide gates is doubled. Other scenarios can be examined to evaluate the efficacy of adding tide gates in addition to pumping. The 2100 high-range SLR curves are not shown, but a 2,200 cfs pump station would be required to maintain existing PAFB stage. This represents a pumping rate equivalent to more than 40 percent of the combined peak inflow. At this level of sea level rise pumping is essential to provide interior flood protection during extreme runoff events.

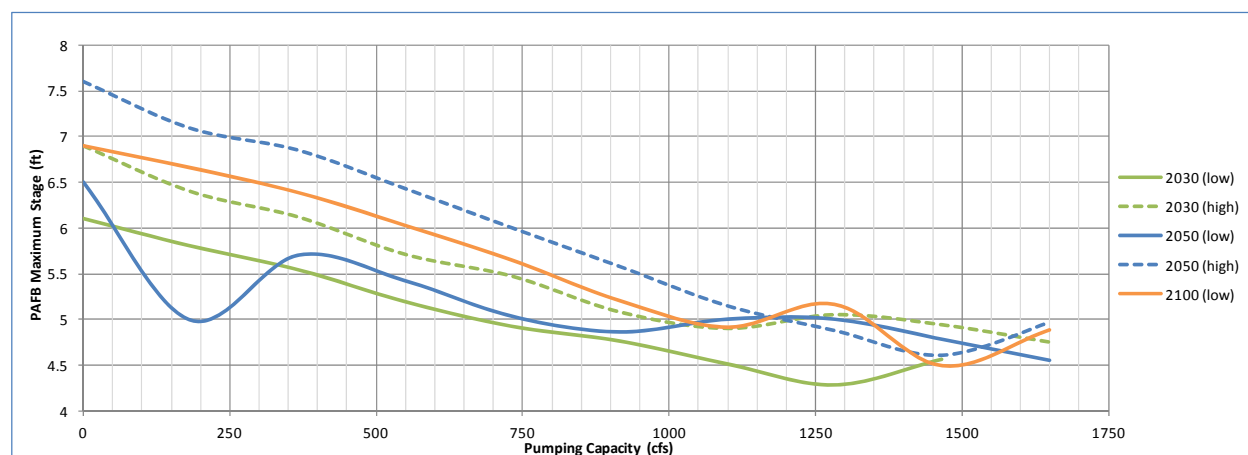


Figure 36. Pumping Capacity Required to Meet Target WSELs in PAFB w/ 16 Tide Gates

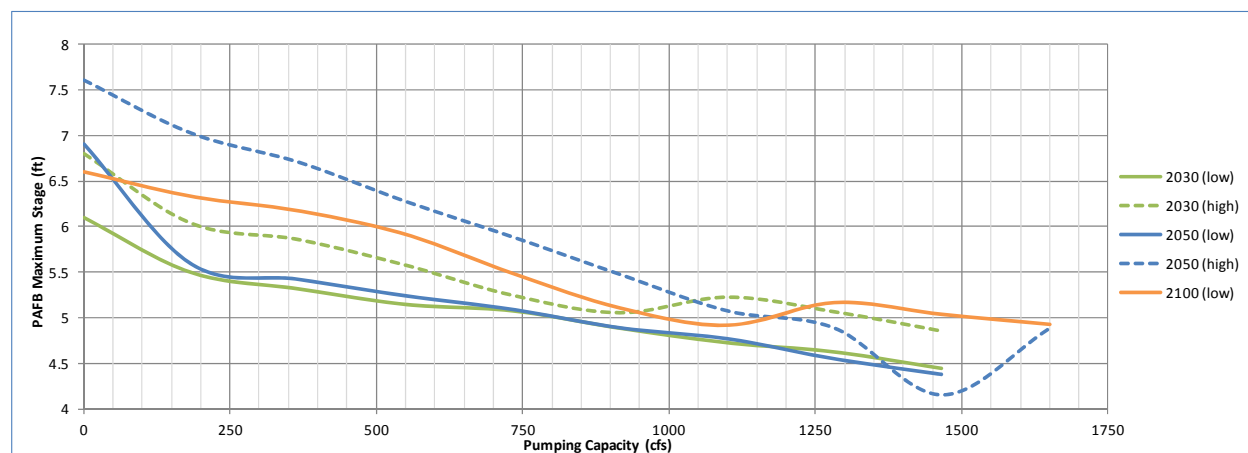


Figure 37. Pumping Capacity Required to Meet Target WSELs in PAFB w/ 32 Tide Gates

Conclusions

The functionality of the Palo Alto Flood Basin is driven by the coincident tide cycle. Maximum 100-year PAFB stage with 90 percent confidence is less than the coincident 100-year tide in San Francisco Bay, meaning the PAFB has sufficient storage volume for creek runoff during high flow events. The basin provides additional flood protection by controlling starting backwater conditions during the peak discharges of Matadero Creek and Adobe Creek and protects those waterways from direct exposure to San Francisco Bay tides.

With higher low tides than originally accounted for in the basin design, the basin may be too small, depending upon the target maximum stage. The 90 percent confidence limit of the maximum one-percent stage probably exceeds PAFB containment elevations adjacent to East Bayshore Road, and there is less than one foot of containment freeboard above the 50 percent confidence limit of the maximum one-percent stage. Since antecedent storage in the PAFB for the 100-year event is predicated on the storm-surcharged mean lower low tide, dredging the basin below an elevation of about -1.0 foot NGVD will not have any impact on PAFB operation. Furthermore adding discharge capacity during low tide periods by installing additional tide gates appears to be as effective as adding storage volume.

Alternative mitigation measures include rebuilding the tide gate structure with additional and/or larger gates to discharge more flow during the shorter periods of low tide, until rising tide levels force the use of mechanical pumping. If the higher range of predicted sea level rise comes to fruition, not only will outboard levees need to be substantially increased in elevation, but a pumping facility with 2,200 cfs capacity may ultimately be needed for interior flood protection. This would be a facility with something like 6,000 installed horsepower and could cost on the order of \$50 million to construct.

Appendices

For convenience appended material is provided digitally under separate cover. Appendices include the following data.

Appendix A. PAFB Watershed Modeling Parameters

Appendix A includes watershed sub-basin delineation; mean annual precipitation at the centroid of each sub-basin; lag parameters including length, length to centroid, basin slope, and basin “N” value; soil data, curve number estimation, and percent impervious cover by sub-basin; stream routing parameters; and the unitized urban storm drain routing curves.

Appendix B. Calculation of Runoff from Precipitation Directly Falling over PAFB

Appendix B contains spreadsheet calculations for the conversion of 15-minute rainfall depth over 72 hours into runoff volume using the SCS rainfall-runoff relationship. Incremental runoff volumes are converted into flow rates for input into the HEC-RAS model as direct inflow into a storage basin by dividing the 15-minute runoff volume by 900 seconds to compute the equivalent constant discharge over 15 minutes that would result in the 15-minute incremental direct runoff volume.

Appendix C. Coincident Tide Data

Appendix C contains spreadsheets that match coincident tide data during the day of the annual peak discharge for San Francisquito Creek, which is ranked using the Median Plotting Position to produce joint probability statistics for the higher high, high, low, and lower low tidal flood elevations.

Appendix D. HEC-HMS and HEC-RAS Models

Appendix B
Cost Details
(May 2020)

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Appendix B: Cost Details			
Alternative F: Replace Tide Gate Structure Nearby on New Alignment			
		No Contingencies	15% Contingencies
	Planning	\$ 950,000	\$ 1,093,000
	Design Engineering	\$ 1,663,000	\$ 1,913,000
	Construction Engineering Support	\$ 1,188,000	\$ 1,367,000
	Construction Management	\$ 1,979,000	\$ 2,276,000
	Construction	\$ 21,765,000	\$ 25,030,000
	CEQA/permits	\$ 950,000	\$ 1,093,000
	Land Acquisition	\$ -	\$ -
	Total Lifetime Cost	\$ 28,495,000	\$ 32,772,000
For the Alternative Comparison Matrix, Costs are lumped into the following 3 categories:			
	Construction Cost =	\$	28,673,000
	Planning & Design Cost =	\$	3,006,000
	Permitting Cost =	\$	1,093,000
	Total Cost =	\$	32,772,000

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Appendix C
Problem Definition/Refined Objectives Report
(June 2016)

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Palo Alto Flood Basin Tide Gate Structure Improvements Project

Problem Definition and Refined Objectives/Next Steps Report



March 2016



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FOR SCVWD STAFF USE ONLY

SANTA CLARA VALLEY WATER District

**PALO ALTO FLOOD BASIN TIDE GATE
STRUCTURE IMPROVEMENTS PROJECT**

PLANNING STUDY

Project No. 10394001

**PROBLEM DEFINITION /
REFINED OBJECTIVES REPORT**

Prepared by the Capital Program Services:

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Kevin Sibley, P.E., Associate Civil Engineer

Melanie Richardson
Deputy Operating Officer

March 2016

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EXECUTIVE SUMMARY

Introduction

The Palo Alto Flood Basin (PAFB) Tide Gate Structure Improvements Project (Project), funded by Santa Clara Valley Water District (District) Watershed and Stream Stewardship Fund, is located within the City of Palo Alto and the North Western portion of Santa Clara County. The Project study area includes the PAFB and the lower reaches of Adobe, Barron, and Matadero creeks (**Figure 1**).

The Problem

The Project initiated from emergency repair work on the Palo Alto tide gates which was completed in September 2012. The repair work addressed water flow occurring beneath the tide gate structure which was originally constructed in 1956. The temporary repair arrested significant under flow; however, District staff are concerned that additional and permanent improvements are required to avoid future loss in level of service which could result in fluvial flooding in the lower reaches of Matadero, Adobe, and Barron creeks and impacts to wildlife and aquatic habitats in the flood basin.

The tide gates have outlived their initial 50-year structural life and now exhibit signs of aging such as spalling concrete and exposed reinforcement steel, as well as the very significant seepage problem which was addressed by an emergency project in 2012. Without suggested improvements, the tide gate structure has an increased potential for future failure.

The PAFB and tide gate structures provide significant flood protection benefits during less than 100-year tidal events and also protect significant brackish marsh habitats. However, the PAFB outboard levees and tide gate structure do not meet FEMA requirements and areas surrounding the PAFB are mapped by FEMA as AE Zone with a 100-year tide elevation of 11.0 feet NGVD29 (13.75 NAVD88).

Furthermore, starting water surface elevations for flood protection improvements on tributary creeks to the PAFB including Adobe Creek, Barron Creek, and Matadero Creek are set to MHHW which is independent of the PAFB and tide gate structure and affected by sea level rise. For Matadero Creek, a greater than 0.1 foot increased to MHHW could affect FEMA certification for existing flood improvements.

Refined Project Objectives

The original Project Objectives have been refined based on information discovered during the problem definition phase. The original Project Objectives, in strikethrough text, and proposed revised Project Objectives are as follows:

1. ~~Replace or repair the existing structure to improve the functionality of the flood barrier system.~~
Replace or repair the existing structure to improve the functionality of the flood barrier system *in the short term*.
2. ~~Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks.~~

Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks *in cooperation with local planning efforts (intermediate term, 5 years +/-).*

3. ~~Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail.~~

Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail *in cooperation with local planning efforts (intermediate term, 5 years +/-).*

4. ~~Prevent impacts to flood protection due to future seal level rise and the 100-year fluvial flood.~~

Prevent impacts to flood protection due to future seal level rise and the 100-year fluvial flood *in cooperation with local planning efforts (intermediate term, 5 years +/-)*

Revised Project Objectives and Next Steps

Having determined problems facing the Project and discovering external projects also considering improvements at the PAFB (SFCJPA SAFER Bay, SCVWD Shoreline, etc), the Project team recommends that Project Objective 1 take immediate priority to facilitate a short-term recommended maintenance project (Alternative B) and an intermediate-term collaborative flood protection and habitat enhancement project (potentially Alternative C or D) to account for anticipated sea level rise impacts.

Preliminary Recommended Project

The Project team recommends Alternative B, based on an immediate need to extend the useful level of service of the existing tide gate structure. To maintain the existing functionality of the tide gates the following repairs are recommended:

1. Replace leaking seals located at Gates 2B and 4A.
2. Repair concrete cracks inside the cells due to extensive spalling and loss of steel section in the reinforcing bars.
3. Remove concrete waste located on top of the bottom slab on the bayside of the structure.
4. Overlay the concrete deck with polyester concrete.
5. Replace and extend the steel fence by approximately ten feet beyond the end of the structure.

The total estimated cost to complete minor repairs to maintain the tide gate structure is estimated to be \$200,000. Long term maintenance costs have not been determined at the time of this report.

Community Outreach

No community outreach has been completed at the time of this report. There is an opportunity to coordinate public outreach for this Project with the SFCJPA SAFER Bay project.

Project Implementation

If the Project Owner elects to authorize staff to continue the Project work the following milestones are expected as the next steps for Project implementation:

- Commence design plans and specifications preparation: Spring 2016
- Complete permit acquisition and design plans and specifications: Spring 2016
- Commence construction: Summer 2016

Chapter 1: INTRODUCTION

This report has been prepared as part of the Palo Alto Flood Basin (PAFB) Tide Gate Structure Improvements Project (Project) planning study to describe existing site conditions and facilities, identify potential problems within the Project area, define opportunities and constraints, refine Project Objectives, and present preliminary conceptual alternatives.

Chapter one introduces the Project's background and objectives and reviews previous and ongoing engineering projects and other studies that contribute to the Project planning study.

Chapter two details existing conditions within the Project Area and briefly describes the Project's watershed and creeks that flow into the Project Area. Existing condition characterization includes: the outlet structure and tide gates, levees, geology, groundwater, habitat area, water quality, regular maintenance, public access, cultural resources, hazardous materials, and right of way.

Chapter three describes findings and defines problems identified during initial investigations including: ageing infrastructure, sea level rise (SLR) impact to: flood protection, biological resources, and levees forming the Palo Alto Flood Basin. The chapter concludes with a discussion of the problems, constraints, and opportunities that have thus far been identified for the Project.

Chapter four summarizes input received at public outreach meetings and stakeholder workshops.

Chapter five discusses potential changes to the Project Objectives based on Project team findings and stakeholder input. This chapter includes a general description of next steps to complete planning formulation.

Chapter six presents preliminary conceptual measures and alternatives that address the ageing outlet structure, future sea level effects, and satisfy Project Objectives. Conceptual alternatives include basic schematic drawings and estimates to initiate review by the Quality Control team members and engage stakeholders with similar interest in the Project Area.

1.1 Background and Origin of Study

This Project initiated from emergency repair work on the Palo Alto tide gates which was completed in September 2012. The repair work addressed unwanted water flow occurring beneath the tide gate structure which was originally constructed in 1956. A map delineating the PAFB and indicating the location of the tide gates is included as **Figure 1**.



Figure 1: Map of Palo Alto Flood Basin Surrounding Areas

The temporary repair arrested significant under flow; however, Santa Clara Valley Water District (District) staff are concerned that additional and permanent improvements are required to avoid future loss in level of service which could result in fluvial flooding in the lower reaches of Matadero, Adobe, and Barron creeks and impacts to wildlife and aquatic habitats in the flood basin.

The original purpose of the tide gate structure was to control the downstream water surface elevation for Matadero, Adobe, and Barron Creek, which all drain to the PAFB. The PAFB controls the downstream boundary condition (starting water surface elevation) for these creeks by keeping the high tide out and allowing the PAFB to empty during the low tides which occur twice daily.

Of the current 16 tide gates, 15 are operated by the District and one is operated by the City of Palo Alto. The latter is operated to allow some tidal inflow to the PAFB, subject to an elevation limit to protect PAFB flood capacity and limit salt water inundation of fresh water habitats. Since San Francisco Bay (Bay) waters have limited access to the PAFB, it has developed a brackish habitat, different from adjacent tidal saltmarsh. This habitat would be changed if the tide gates become ineffective.

Because the PAFB levees and tide gate structure do not meet current FEMA freeboard requirements, the PAFB and surrounding areas are mapped by FEMA as AE Zone with a 100-year

tide elevation of 11.0 feet NGVD29 (13.75 NAVD88). It should be noted that this is the current flood elevation and does not account for anticipated future SLR.

The PAFB and tide gate structures provide significant flood protection benefits during lesser tidal events and also protect significant brackish marsh habitat. The tide gates have outlived their initial 50-year structural life and now exhibit signs of aging such as spalling concrete and exposed reinforcement steel, as well as the very significant seepage problem which was addressed by an emergency project in 2012. Without improvements, the tide gate structure has an increased potential for future failure.

The Project is funded by the District's Watershed and Stream Stewardship Fund.1.2 Goals and Objectives of the Study

The mission of the District is to provide Silicon Valley with safe, clean water for a healthy life, environment, and economy.

The following Board Ends Policies are applicable to this Project:

- Board Ends Policy E-3, Article 3.1: "Provide natural flood protection for residents, businesses, and visitors."
- Board Ends Policy E-4, Article 4.1: "Protect and restore creek, Bay and other aquatic organisms"
- Board Ends Policy E-4, Article 4.2: "Improved quality of life in Santa Clara County through appropriate public access to trails, open space, and District facilities."

The original Project Objectives have been refined based on information discovered during the problem definition phase. The original Project Objectives, in strikethrough text, and proposed revised Project Objectives are as follows:

1. ~~Replace or repair the existing structure to improve the functionality of the flood barrier system.~~
Replace or repair the existing structure to improve the functionality of the flood barrier system *in the short term*.
2. ~~Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks.~~
Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks *in cooperation with local planning efforts (intermediate term, 5 years +/-)*.
3. ~~Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail.~~
Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail *in cooperation with local planning efforts (intermediate term, 5 years +/-)*.

4. ~~Prevent impacts to flood protection due to future sea level rise and the 100-year fluvial flood.~~

Prevent impacts to flood protection due to future sea level rise and the 100-year fluvial flood *in cooperation with local planning efforts (intermediate term, 5 years +/-)*

1.3 Previous and Current Engineering Studies and Improvement Projects

Multiple watershed studies and capital improvement flood protection projects have been completed at the PAFB and on creeks tributary to the PAFB. A brief review and chronological listing of these projects follows.

- *Storage Capacity of the Palo Alto Flood Basin* – prepared by District, March 1974.

The objective of the study was to determine if the PAFB would provide flood control protection to existing residential, commercial and industrial development if the entire +/- 600 acre basin were converted to flood storage. The study recommended that portions of the levees be raised to a minimum elevation of 7.0 NGVD29 (9.8 NAVD88) including 2.4 feet of freeboard to account for wave action and future subsidence.

- *Mathematical Model Study of the Palo Alto Flood Basin and Yacht Harbor* – prepared by Water Resources Engineers for the City of Palo Alto, March 1975.

This study used computer models to examine whether reintroducing a tidal marsh environment to the PAFB would affect the basins ability to store 100-year flood flows. The study also modeled the addition of tide gates facing the Palo Alto Yacht Harbor to improve circulation and release sediment from the PAFB.

- *Engineer's Report and Final Impact Report on Proposed Flood Control Measures On The Palo Alto Flood Basin* – prepared by District, September 1976.

The report discusses the potentials of the Project for reduction of flooding southwesterly of Bayshore Freeway. The report assesses the potential for damage from flooding in the community, considers the beneficial and adverse impacts which would arise from a flood protection project and alternatives to it and concludes that flood protection should be provided in the area.

The report recommends a combination of levees and floodwalls along a portion of Matadero Creek, around the Municipal Service Center, and along the northeast side of the East Bayshore Road.

- *Hydrologic Analysis of the Palo Alto Flood Basin* – prepared by Linsley, Kraeger Associates for the City of Palo Alto, March 1984.

In the early 1980s the District again proposed to raise the levees surrounding the PAFB. This proposal was made in anticipation of improvements to Adobe, Matadero, and

Barron Creeks. The analysis in this report determined that the existing levees in the PAFB provided adequate flood protection.

- *Engineer's Report and Final Negative Declaration on Matadero and Barron Creeks Planning Study (Palo Alto Flood Basin to Foothill Expressway)* – prepared by District, April 1988.

The report is the final planning study report on the Matadero and Barron Creeks proposed flood control project. The project consisted of replacing nine bridges and 2,500 feet of concrete channel, additional floodwalls along 8,000 feet of lower Matadero Creek, construction of a one-mile long underground high flow bypass channel and a 2,000 foot long underground diversion channel, and miscellaneous erosion repairs and access ramps in the upper reaches of Matadero Creek near Foothill Expressway.

- *Physical Model Studies of Barron Creek/Matadero Creek Flood Control Structures* – prepared by CH2M Hill for the District, December 1991.

The District prepared preliminary designs of diversion works and conveyance structures for improvements described in the 1988 Engineer's Report. Hydraulics for these features were sufficiently complex to make accurate water surface predictions difficult using only analytical means i.e., HEC-2 and standard head loss equations. Therefore, the District authorized CH2M Hill to conduct a more detailed hydraulic analysis to study these structures using physical modeling combined with refined calculations. This report includes the results of the model study and the preliminary design layouts needed by the District to prepare final design documents for construction of the modeled facilities.

- *Final Engineer's Report on Matadero/Barron Creeks Long-Term Remediation Project* - prepared by Schaaf & Wheeler for the District, October 2002.

In 1997, the District completed a series of flood protection improvements on Matadero and Barron Creeks. While these improvements were intended to provide flood protection meeting National Flood Insurance Program standards, subsequent analyses and system performance during the February 1998 El Nino flood demonstrated that the completed improvements did not provide flood protection meeting national standards.

This report provides an understanding of flood protection problems within the Matadero and Barron Creek Watersheds, shows how the recommended remediation plan was selected from a number of alternatives, and provides the District's Board of Directors and the public with information necessary to make informed choices regarding the proposed remediation plan and its alternatives.

- *Final Environmental Impact Report on Matadero/Barron Creeks Long-Term Remediation Project* - prepared by Schaaf & Wheeler for the District, October 2002.

This document, along with the Draft Environmental Impact Report (DEIR), constitutes the Final Environmental Impact Report (FEIR) for the Matadero and Barron Creeks Long-Term Remediation Project. The FEIR provides objective information regarding the

environmental consequences of the proposed project. The FEIR also examines mitigation measures and alternatives to the project intended to reduce or eliminate significant environmental impacts.

The completed project includes a combination of bypass construction, channel modifications (including work within the PAFB), and floodwall modifications. The project allowed the District to cease emergency operation of the Barron Creek diversion facility, and provide 100-year riverine flood protection along both Matadero Creek and Barron Creek from Foothill Expressway to San Francisco Bay. Tidal flooding, which affects areas from the Bay to approximately Middlefield Road, is not addressed by the project.

- *Baylands & Creeks of South San Francisco Bay* -prepared by San Francisco Estuary Institute for the District, 2005.

The San Francisco Estuary Institute prepared a map for the Oakland Museum which presents both the historical and modern landscape of the South Bay. One side shows the salt marshes as they were prior to the gold rush. The other side presents the modern day salt ponds and the lower reaches of the creeks in the area south of the Dumbarton Bridge.

- *SAFER Bay Project* –presently ongoing San Francisco Creek Joint Powers Authority project.

The SFCJPA has retained consultant services to plan, design, and construct new flood protection facilities that consider the current tidal floodplain and projected SLR over a 50-year period to satisfy FEMA requirements. The project also seeks to explore cost-effective and innovative designs that can adapt to changing climate, enable enhancement of historic marshlands, including those that are part of the South Bay Salt Pond Restoration Project, and expand opportunities for recreation and community connectivity provided by the San Francisco Bay Trail.

- *Inspection Report of the Palo Alto Flood Basin Floodgate Structure* - prepared by Mark Thomas & Company, Inc. for the District, April 2014.

This report summarizes findings resulting from inspection of the PAFB Floodgate Structure conducted February 25, 2014. The investigation was made to determine the effectiveness of emergency repairs to arrest seepage beneath the tide gate structure which were implemented by the District in September 2012. The report concludes that the floodgate structure is considered to be generally in good condition, with the majority of the deterioration located inside the cells and on top of the concrete deck. The trash racks, steel sheet pile wing walls, and tide gates were all found to be in good condition. The report recommends minor improvements to extend the structure's expected years of service.

- *Palo Alto Flood Basin Hydrology* - prepared by Shaaf & Wheeler for the District, July 2014.

This report documents a re-evaluation of watershed hydrology and hydraulic performance for the PAFB. The report improves prior hydrology and hydraulic work that was prepared in detail for the District's Matadero and Barron Creeks Long-Term Remediation Project in 2002. The report forms a basis to examine the impact of SLR on flood basin performance and the efficacy of potential tide gate modifications with respect to reducing flood risks within the lower reaches of Adobe, Barron, and Matadero Creeks and impacts due to submergence of sensitive biological habitats.

Chapter 2: PROJECT AREA

The PAFB is located in the City of Palo Alto and near the northern limit of the District's jurisdiction. The PAFB collects floodwater runoffs from Adobe, Barron, and Matadero Creeks. These creeks originate in the foothills of the Santa Cruz Mountains in Santa Clara County and generally flow northeastward into San Francisco Bay through the PAFB. The total tributary drainage area of the PAFB is approximately 31.5 square miles (excluding 585 acres of the basin itself and including the Coast Casey Pump Station) ¹. As the creeks flow in well-defined ² channels of the valley floors, they pass through highly urbanized areas of the City of Palo Alto, and the Towns of Los Altos, and Los Altos Hills, thereby furnishing outfalls for the city storm drains systems.

These creeks historically discharged directly into the Bay through Mayfield and Charleston Sloughs. As floodwaters combined with Bay waters, flooding of the lowlands occurred during times of high tide. The flooding was intensified due to ground subsidence, which averaged approximately 5.5 feet over the years. To prevent flooding, levees were constructed in 1956 together with the flood gate structure which includes 16 tide gates. The levees and the tide gates were constructed by the District to create a flood basin, later named the PAFB. The PAFB, as it exists today, contains approximately 600 acres and is shown on **Figure 2**.

¹ Drainage area provided by Schaaf & Wheeler, 2014.

² Several sections of Adobe, Matadero and Barron Creeks have been constructed with concrete trapezoidal and u-frame channels.



Figure 2: Map of Palo Alto Flood Basin

The floodwaters stored in the PAFB are released to the Bay through sixteen tide (flap) gates. The purpose of the tide gate structure is to regulate flows through the basin. When the water surface elevation in the basin is higher than the tidal elevation of the Bay, the flap gates are pushed open by water pressure and discharge from the basin to the Bay. The flap gates are otherwise held shut by gravity and water pressure from the Bay.

The City of Palo Alto opens one of the sixteen flap gate during summer months to circulate Bay water within the PAFB in the vicinity of the outlet structure.

2.1 Description of Tributary Creek Watersheds

There are three major creek watersheds which drain in to the PAFB. They are: Adobe Creek, Barron creek and Matadero Creek.

The elevations of the watersheds range from slightly above mean sea level in the valley floor to about 2,000 feet above mean sea level in the mountainous regions. The total drainage area of the watersheds is 31.5 square miles. Of this area, approximately 9 square miles are hill lands and the balance is in the relatively flat valley floor³.

All three watersheds are located in Santa Clara County. They are bounded by the San Francisquito Creek basin on the west side, the Santa Cruz Mountains on the south side, the Permanente Creek basin on the east side and the San Francisco Bay on the north side. **Figure 3** shows a map of the combined creek watersheds and illustrates the general topography and land

³ Land use area provided by District, 1976.

use of the areas. Most of the hill lands are characteristically brushy woodland; however, there is some development consisting of streets and private residential homes. The gentle sloping valley floors of the watersheds are highly developed into residential, commercial and industrial uses.

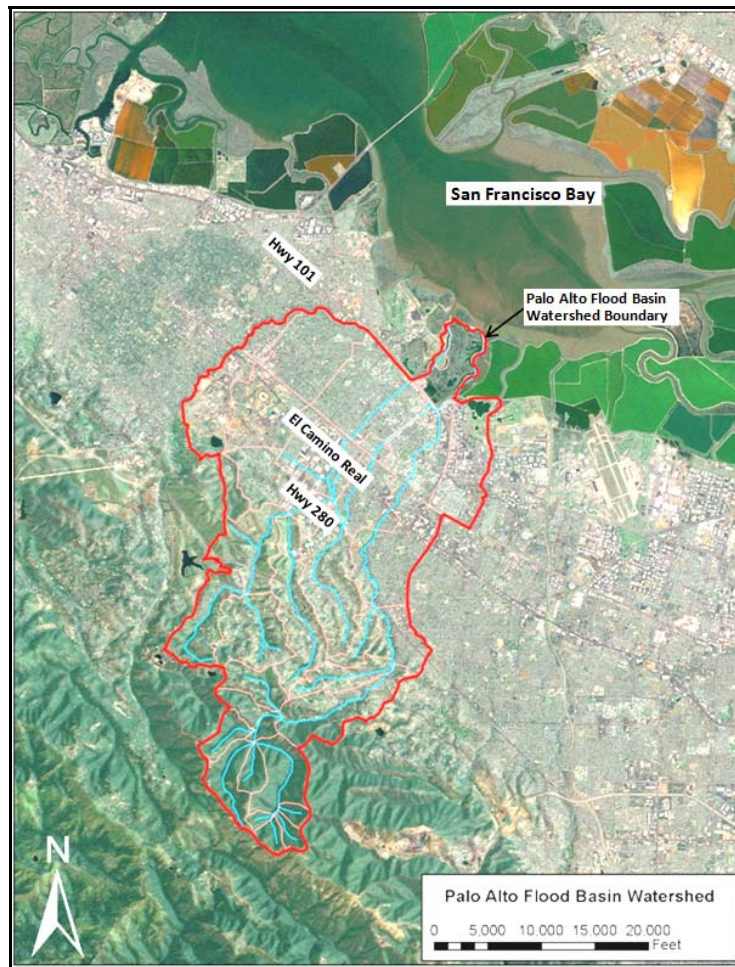


Figure 3: Map of Palo Alto Flood Basin Watershed Area

The watershed areas have a relatively mild climate. Temperatures range from an average high of about 80 degrees during July to an average low of about 40 degrees in January. The hill lands of the watershed areas have a mean annual precipitation of approximately 30 inches and the valley floor about 19-inches⁴. The area receives approximately 90 percent of this rainfall from November through March and January is usually the month with the most rainfall. The steep nature of the upper portions of the watershed results in short duration, high intensity runoffs for most of the major storms. After each major runoff, low flow continues in the creeks for several weeks as water temporarily stored in the natural storages of the watersheds is returned to the creeks. Although the stream is usually dry during the summer months thereby reducing the fish life, they support various animal life that can find water elsewhere during the dry months. The lower reaches of these creeks were reconstructed to minimize bank erosion and to provide needed flow carrying capacity during high flow events.

⁴ Mean annual precipitation values based on Appendix C of Shaaf & Wheeler, 2014.

2.1.1 Adobe Creek

Adobe Creek runs primarily in a natural channel from its tributary sources in the hills above Interstate 280, downstream to Foothill Expressway. The Adobe Creek Watershed drains 11 square miles, of which 7 square miles are mountainous, and 4 square miles are gently sloping valley floor. The creek's course runs 11 miles.

Adobe Creek's upper tributaries are, in order, the Middle Fork Adobe Creek, then immediately the West Fork Adobe Creek. Next the North Fork Adobe Creek, originating on Page Mill Road, joins Adobe Creek by the Duveneck's main house at Hidden Villa. The North Fork Adobe Creek is also known locally as Bunny Creek. The upper watershed of Adobe Creek is completely protected by Hidden Villa and the Mid-Peninsula Regional Open Space District.

Below the confluences of the "three forks", Adobe Creek is joined by three seasonal creeks in Los Altos Hills. The first is 1.3-mile-long Moody Creek. Next comes 2.0-mile-long Purissima Creek and then Robleda Creek in Los Altos Hills. From that point, Adobe Creek departs mountainous and hilly terrain and enters the valley floor to descend through the cities of Los Altos, Mountain View and Palo Alto.

From 2003 to 2009, the Upper Reach 5 of Adobe Creek (between Foothill Expressway and West Edith Avenue) was restored in an innovative partnership called the Adobe Creek Watershed Group with representatives from the District, local residents and representatives of the City of Los Altos and the Town of Los Altos Hills. The 7.2 million dollar project improved flood conveyance capacity in Reach 5, and also enhanced the creek ecosystem by removing the existing concrete banks and bottom, repairing and stabilizing the eroded banks using minimal hardscape, removing many non-native trees, and establishing a riparian area along 700 feet of bank using mostly shrubs and trees native to the Adobe Creek watershed.

Several sections of Adobe Creek have been re-aligned, including the trapezoidal concrete drainage channel between El Camino Real and U.S. Highway 101 (the portion between Alma Street and El Camino Real was constructed by the District in 1959).

Before passing under Highway 101 and entering the PAFB, Adobe Creek is joined by Barron Creek just upstream of Highway 101. The 100-year flows for Adobe Creek are included in **Table 1**.

Table 1: 100-year Flows Adobe Creek ⁵

Location	100-year Peak (cfs)
At Francemont Avenue	1,800
At Bypass Channel Entrance	2,000
At Bypass Channel Confluence	1,100
Adobe Creek u/s Purissima Creek Confluence	2,000
Adobe Creek at Foothill Expressway	2,700
Adobe Creek at El Camino Real	2,900
Adobe Creek u/s Barron Creek	3,080

⁵ Flows determined from Adobe Creek Engineer's Report, 1999.

2.1.2 Barron Creek

Barron Creek begins in the hills above Interstate 280 in the Town of Los Altos Hills, and flows as a natural stream to Gunn High School, just downstream of Foothill Expressway. Barron Creek runs primarily in a modified creek with 67% of its course classified as hardened between Foothill Expressway and its confluence with Adobe Creek. The Barron Creek watershed is about 3 square miles, of which 2 miles are mountainous and 1 square mile is gently sloping valley floor. The creek's course runs 5.8 miles long.

The Baron Sediment Basin and Barron Diversion Structure have been built to divert high flood flows from the Barron Creek watershed into the Matadero Creek Watershed. Low flows leaving the diversion structure are conveyed to Barron Creek in a storm drain pipe underneath the Gunn High School playing fields.

From Gunn High School to Laguna Avenue, Barron Creek flows in a natural stream channel adjacent to residential properties. Between Laguna Avenue and El Camion Real (a distance of 3,000 feet), creek discharge is conveyed in a buried 60-inch diameter pipe. Between El Camino Real and about 1,000 feet above the confluence with Adobe Creek, Barron Creek is concrete-lined and trapezoidal in section. Concrete floodwalls have been built downstream of Louis Road. In the lower reaches of Barron Creek, the channel is concrete lined. Downstream of Highway 101, Adobe Creek flows through a riparian corridor until it reaches the PAFB. The 100-year flows for Barron Creek are included in **Table 2**.

Table 2: 100-year Flows Barron Creek ⁶

Location	100-year Peak (cfs)
At Foothill Expressway	740
At Laguna Avenue	160
At SPRR	250
At Adobe Creek	250

2.1.3 Matadero Creek

Matadero Creek runs primarily in a natural channel from its tributary sources in the hills above Interstate 280, downstream to El Camino Real. The Matadero Watershed drains 14 square miles, of which 11 square miles are mountainous, and 3 square miles are gently sloping valley floor. The creek's course runs 8 miles.

The creek drains the foothills through a relatively narrow canyon that stretches from the confluence with Arastradero Creek alongside Old Page Mill Road, downstream to the intersection of Old Page Mill Road with Page Mill Road near Foothill Expressway. Valuable riparian habitat is located along these creek reaches, although horse pastures located between Deer Creek Road and Foothill Expressway have degraded the quality of adjacent stream habitats. Scattered rural residents are also located close to the creek throughout the canyon and upstream watershed.

⁶ Flows determined from Matadero and Barron Creeks Remediation Project Final Engineer's Report, Schaaf & Wheeler, 1999.

Construction of the Matadero Bypass Channel has reduced flood damage potential while maintaining the natural riparian corridor from Foothill Expressway to El Camino Real. The only disruption to the natural creek through this reach is an 800-foot long underground culvert beneath the Stanford management Group Tibco Campus near Hillview Avenue. In 1988, the bypass channel alternative was selected for this reach since it was the least costly plan and received strong support from the community (District, 1988).

Downstream from El Camino Real, Matadero Creek is contained within a concrete-lined channel of rectangular u-frame section to the Union Pacific Railroad. The vertical concrete walls of the u-frame section have been extended above the natural channel bank as necessary to contain water and/or provide freeboard.

Below Alma Street, which is immediately downstream of the railroad, Matadero Creek is conveyed in a concrete-lined trapezoidal channel. Concrete floodwalls have been built to contain floodwater and/or provide freeboard. Closer to the Bay, the concrete-lining ends at Greer Road and the creek channel transitions to a sacked concrete-lined slope with an earthen bottom. Emergent wetland vegetation has established itself within this reach, which is prone to the accumulation of sediments, particularly bed load.

The Matadero Pump Station, owned and operated by the City of Palo Alto, discharges to Matadero Creek nearly half-way between West Bayshore Road (frontage to Highway 101) and Greer Road. In addition to inflow from the pump station's tributary local storm drain system, runoff that exceeds the capacities of storm drain systems tributary to San Francisquito Creek (typically equal to the 10-year return period) naturally flows downhill toward Matadero Creek and to the extent of available storm drain system and pump station capacity (266 cfs), is discharged into Matadero Creek.

Downstream of Highway 101, Matadero Creek flows through a riparian corridor before it enters the PAFB. The 100-year flows for Barron Creek are included in **Table 3**.

Table 3: 100-year Flows Matadero Creek ⁷

Location	100-year Peak (cfs)
At Foothill Expressway	1,900
At El Camino Real	2,700
At SPRR	2,800
At Middlefield Road	2,800
At Louis Road	2,800
At Highway 101	3,100

2.1.4 Coast Casey Pump Station

The Coast Casey Pump Station is a sub-basin tributary to the PAFB with a maximum pumping discharge of 150 cfs (**Figure 4**). The Coast Casey Pump Station discharges flood water from the City of Mountain View directly into the PAFB through three steel discharge pipes with flap gates

⁷ Flows determined from Matadero and Barron Creeks Remediation Project Final Engineer's Report, Schaaf & Wheeler, 1999.

at their outfall. The Coast Casey pump station drains approximately 1.6 square miles of mixed residential and business park area in the City of Mountain View.



Figure 4: Coast Casey Pump Station Inlet

2.2 Description of Palo Alto Flood Basin

The PAFB was constructed by the District in 1956 and is located in the City of Palo Alto in the County of Santa Clara. The PAFB is bounded on the north by the San Francisco Bay, on the east by Charleston Slough, on the south by a light industrial complex and Highway 101, on the west by the City of Palo Alto refuse disposal area.

Matadero Creek, Adobe Creek, and Barron Creek receive surface water runoffs from outfalls for city storm drain systems. These creeks historically discharged directly into San Francisco Bay through Mayfield Slough and Charleston Slough. As subsidence occurred, a levee system was constructed to prevent saltwater flooding from the Bay. The PAFB was constructed with levees surrounding a 600-acre portion of the Palo Alto Baylands.

The PAFB was constructed to prevent a repeat of the floods of 1955, when a high tide prevented the escape runoff from Matadero, Adobe, and Barron Creeks into the San Francisco Bay. The trapped runoff waters overflowed upstream creek banks and caused severe flooding in Palo Alto. In order to control the flow of water into the flood basin, a tide gate structure was placed at the confluence of Adobe Creek, Matadero Creek, and the San Francisco Bay, so that the flood basin could be maintained at approximately 2 feet below sea level, creating room to detain floodwaters. The flood basin is relatively flat and mostly 0.6 feet below mean sea level with levees varying in elevation from a low of about one foot to a high of about 11.3 feet above mean sea level.

The PAFB is one of the few remaining wetlands in the San Francisco Bay area that is relatively undisturbed. Its 600-acre area provides a permanent habitat and nesting area for a number of species of fish, birds and mammals. It also provides a wintering ground for numerous migratory birds which complement the adjoining tidal marsh plant community.

2.2.1 Historical Ecology

Prior to Spanish colonization in the late 1700s, the South Bay landscape reflected a combination of natural processes and the influences of indigenous peoples. The native Ohlone used the Bay and its marshlands extensively, to hunt fish and waterfowl, harvest salt, and collect shellfish.

Spanish colonization included land reclamation to convert wetland, marsh, and willow groves typically found in the lowlands between the mountains and the Bay into sheep and cattle grazing areas. Following the defeat of Mexico in 1848, American reclamation projects included routing the outlet of San Francisquito Creek away from Mayfield Slough to its current location and concentrating and extending lowland drainages via constructed channels. As a result, Matadero Creek, Barron Creek, and Adobe Creek were each extended in 1877-1898. Matadero Creek and Barron Creek were hydraulically connected to the Mayfield Slough and Adobe creek was similarly connected to the Charleston Slough. The area between these two sloughs was a complex tidal marshland including intricate small channels and panes (shallow tidally filled ponds). This area supported remarkable waterfowl, shorebirds, fish, and other native species that were reported in early accounts.

The Bay's tidal marshes played an early and lasting role in the development of local infrastructure. Prior to railroads and automobiles, the Bay was the primary means of transport, with the tidal sloughs providing links between land and deep water. Tidal flows into and out of the marshes maintained natural deepwater channels extending through the tidal flats. Where the channels came close to land, entrepreneurs established landings. From these landings, grain, fruit, vegetables, animal products, redwood timber, and other materials were shipped to San Francisco and beyond. San Francisquito Creek included Soto's Landing and Wilson's/Clark's Landing while Matadero Creek included Clarke's Landing.

2.2.2 Outlet Structure and Tide Gates

The flood gate is a 113' long concrete structure with eight concrete cells to house the flood gates (**Figure 5**). The top of the structure has a 14' wide concrete surface with chain link fence on both sides for maintenance vehicles and trail users. Steel sheet piles were installed at all four corners of the structure to retain the roadway embankment. Steel trash racks were installed on the basin side to prevent debris from getting into the concrete cells.

⁸ Historical Ecology information provided by San Francisco Estuary Institute, 2005.



Figure 5: View of Palo Alto Flood Gates from Land Side

The flood gate is supported on concrete piles. A 14' long rock apron grouted with concrete was installed on the Bay side and basin side of the structure. The top of the structure has elevation of 9.5 feet NGVD29 (12.3 NAVD88) and the bottom slab elevation is at -3.0 feet NGVD29 (-0.3 feet NAVD88). The land side of the structure includes trash racks to minimize debris jams within the gates (**Figure 6**).



Figure 6: Palo Alto Flood Gate Trash Racks

A field inspection was performed by Mark Thomas & Co and Collins Engineers, Inc in February 2014. The primary purpose of the investigation was to determine the condition of the structural

components and appurtenances located in the water at the time of the inspection both above and below the waterline.

The channel bottom in the vicinity of the structure consisted of riprap typically measuring between 1 and 2 feet in diameter and soft mud. Overall, the channel bottom was found to be in good condition.

The sheet pile wingwalls typically exhibited $\frac{1}{2}$ inch of marine growth consisting of barnacles and various areas of surface corrosion with no section loss below water (**Figure 7**). The protective coating was generally found to be in good condition. Deterioration was typically located on the top of sheet piles where above the water surface and included minor to medium steel delamination. The floodgates and hardware were found to be in good condition with no apparent section loss.

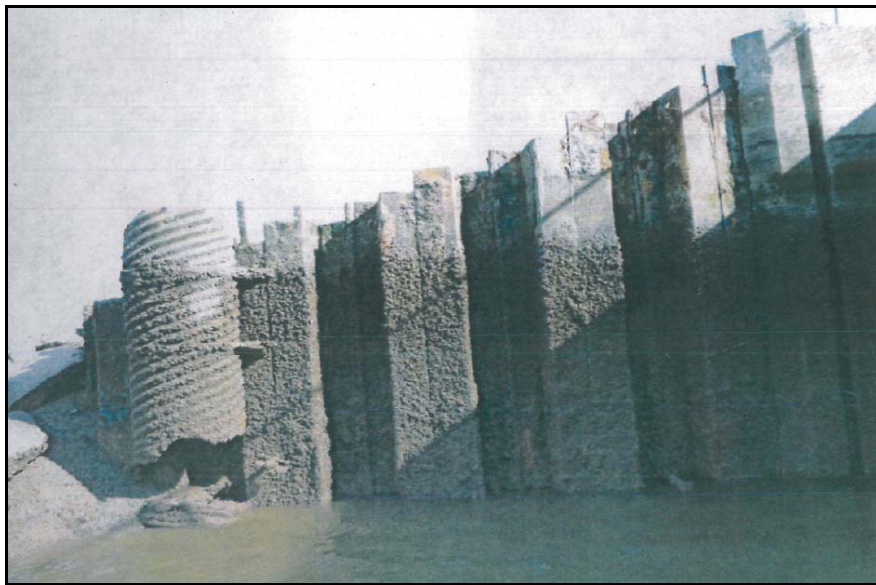


Figure 7: Sheet Pile Wing Walls with Marine Growth

Similar to the wingwalls, the gates were typically covered in $\frac{1}{4}$ to $\frac{1}{2}$ inch of marine growth. The concrete at the north face of the structure was found to be in good condition with no noticeable scaling or pitting. The concrete exhibited typical marine growth similar to that on the steel. Overall, the concrete inside of each barrel was found to be in satisfactory to good condition.

Deteriorated seals were found at several gates, corrosion spall was observed at various locations for all cells (**Figure 8**). Exposed reinforcing bars with various degrees of percent section loss were also observed at various locations inside the cells and on top of the deck and other locations.



Figure 8: Center Pier Open Corrosion Spall with Exposed Steel Reinforcement

Based on inspection findings, the flood gate structure was determined to be generally in good condition with the majority of deterioration located inside the cells and on top of the concrete deck. The trash racks, steel sheet pile wing walls, and gates were all found to be in good condition. The report recommended the following repairs:

- The leaking seals located at Gates 2B and 4A should be taken care of during the next round of routine maintenance.
- The concrete cracks inside the cells should be considered for repair due to extensive spalling and loss of steel section in the reinforcing bars.
- Remove concrete waste on top of the bottom slab on the bayside of the structure
- It is highly recommended to clean and overlay the top concrete deck with polyester concrete. This repair will stop further deterioration of the concrete deck and prolong the service life of the structure
- Replace and extend the steel fence ten feet beyond the end of the structure for safety protection for the trail users and bicyclists.

In addition to the report recommendations, the underwater inspection report prepared by Collins Engineers, Inc. recommended that underwater inspection of the structure should continue at intervals not to exceed 60 months unless a significant high water/high flow event is experienced. In the event of such an event, an interim underwater inspection should be conducted if any damage or other detrimental conditions are suspected.

2.2.3 Existing Palo Alto Flood Basin Levees

The earthen levees in the PAFB area were originally constructed in 1958 in a cooperative effort between San Mateo County and the Santa Clara County Flood Control and Water Conservation District to provide flood protection (the Santa Clara County Flood Control District was the

predecessor of the District). The levees are no longer at their 1958 “As-Built” elevations due to land subsidence, settlement and erosion.

At several locations along the PAFB containment levees, including the bike path adjacent to East Bayshore Road, the top of levee elevation is less than the 7.0 feet NGVD29 (9.75 NAVD88) minimum crest elevation which was recommended by the District’s 1974 report.

The existing levees are not certified by FEMA.

2.2.4 Geology and Soils

Geology

The Project site is located in the Baylands at the mouths of Matadero Creek, Barron Creek, and Adobe Creek. The site is essentially a flat, tidal marsh, just above and just below the level of San Francisco Bay. The flat surface has been incised by meandering stream channels to depths of 2 to 4 feet, forming the present sloughs, and by other smaller, shallower drainage channels, creating meandering patterns.

Local water well logs indicate that the Project site is underlain by clay and silty clay with interbeds of sands and gravels. Shallower foundation exploration borings (less than 50 feet deep) indicate the site to be underlain by soft, compressible “Bay muds” varying in depths from 1 to 10 feet. The Bay muds consist of gray-black, fat clay⁹ and silty clay deposited in a marshland environment with particularly high organic content in the uppermost zone. These Bay muds are underlain by more compacted and firm gray-black clays and silty clays. The Bay mud clays are interspersed by thin beds and lenses of sand, silty sand and minor amounts of gravel.

Seismicity

There is no surface evidence of active faults in the local area of the Project. Older faults, which may be concealed beneath the most recently deposited sediments, may occur here and in nearby areas. If they do occur, these older faults would offset only the older bedrock and the lower portion of the valley fill deposits; hence, these faults are considered inactive.

Major faults in the region include the San Andreas Fault, located 8 miles to the southwest in the Santa Cruz Mountains; the Hayward Fault, located 13 miles to the northeast along the northeastern edge of the Santa Clara Valley; and the Calaveras Fault, located 17 miles to the northeast in the Diablo Range. Because of the proximity of these three major active faults, the regional area of the Project site is considered a relatively high seismically active area. Within the lifetime of the Project, a large earthquake and several moderate earthquakes affecting the site can be expected in the region¹⁰.

All areas within the Santa Clara Valley are subject to ground shaking from moderate and large earthquakes. Generally, the worst effects of ground shaking and possible ground failure within the valley floor occur in those areas underlain by saturated, weak, clayey soils, such as those found in the Baylands. Under strong or moderate seismic shaking, the levee and the weak levee foundation may tend to lose stability, causing settlement and lateral spreading, which may lead

⁹ Fat clay is a highly plastic clay with a liquid limit of 50% or greater.

¹⁰ Large (“major” and “great”) earthquakes are larger than 6.8 on the Richter Scale. Moderate earthquakes range from 5.2 to 6.8 on this scale (after Gutenberg and Richter, 1949).

to levee failure, particularly if liquefaction occurs. This would cause flooding in acres adjacent to the breached levees during flood flow conditions.

Soils

The shallow exploration well-boring logs referred to above do not indicate the presence of the fine-grained, clean sand zones within the shallow zone which cause liquefaction; consequently, the probability of liquefaction is low to moderate, but it is still a hazard due to the presence of weak saturated clays. Liquefaction would aggravate already existing weak foundation conditions.

Soils in the flood basin are classified as clayey tidal marsh soil. These soils are affected by surface saltwater and highly salty groundwater occurring at shallow depths; consequently, they cannot be easily used for agricultural purposes. However, salt marsh vegetation requiring saline conditions thrives in such soils.

Land Subsidence

Approximately 5.5 feet of land subsidence has occurred in the Project area due to significant pumping of the Santa Clara Valley ground water basin which began around the turn of the twentieth century and continued to increase until 1965. As ground water production increased, eventually leading to a condition of overdraft, the water table began to decline steadily in the forebay and upper aquifer zone and the artesian flows from the lower aquifer ceased as ground water pressures declined. A decline in the artesian pressure resulted in compaction of lower aquifer zone sediments and eventual land subsidence. Most of the compaction occurred in fine grained silt and clay deposits (aquitards), which are more compressible than the coarse grained aquifer materials. In some locations, the land subsided as much as 13 feet.

Overdraft ceased in 1965 with the importation of surface waters from the State Water Project and City of San Francisco's Hetch Hetchy system. Increased imports of surface water allowed the District to greatly expand the ground water recharge program, leading to the substantial recovery of ground water levels. Land subsidence ceased in 1969 as a result of ground water level recoveries and development of artesian pressures in the lower aquifer zone. In most recent years, pressures in the lower aquifer zone have recovered to the extent that wells within the basin interior have again become artesian and now flow on an intermittent seasonal basis. However, ground surface elevations within the forebay and in certain large pumping areas within the basin have not recovered to their pre-overdraft levels because the compression of clay underlying the Santa Clara Valley is irreversible.

2.2.5 Hydrology

The District updated hydrology and hydraulics for the PAFB in 2014 (Schaaf & Wheeler, 2014) following emergency repair work at the outlet structure completed in September of 2012. The update included re-evaluating hydrology and hydraulics work previously prepared for the District's Matadero and Barron Creeks Long-Term Remediation Project in 2002. The update was necessary to reflect: updated rainfall statistics, an additional 12 years of flow records, additional maximum tide records, changes to the Palo Alto Landfill, and completion of the San Francisquito Creek Pump Station in 2009.

Based on an aerial topographic survey conducted in 1999, it was determined that minimal change to the PAFB storage capacity had occurred since 1974.

Based on updated hydrology and hydraulics, statistical values for the 50-percent, 90-percent, and 95-percent confidence limits for the 100-year PAFB water surface elevations were calculated (**Table 4**). The table provides the non-exceedance probability; that is, the confidence that a given water surface elevation will not be exceeded during the design 100-year event ¹¹. A fifty percent confidence means that the given water surface elevation is just as likely to be exceeded as not.

Table 4: Summary of PAFB Water Surface Elevation Uncertainty ¹²

Scenario	50% Confidence (feet NGVD)	90% Confidence (feet NGVD)	95% Confidence (feet NGVD)
Maximum WSEL in PAFB	6.35	7.25	7.40
WSEL in PAFB when Matadero Creek inflow is at its peak	3.25	4.45	4.55
WSEL in PAFB when Adobe Creek inflow is at its peak	2.30	3.65	3.80

The 90- and 95-percent confidence limits are provided since those statistical abstractions were used in the risk and uncertainty analysis of the Matadero Creek floodwalls, which assumed a maximum PAFB water surface elevation of 7.2 feet NGVD29 (10.0 NAVD88) and a PAFB stage of 4.6 feet for risk-based backwater analysis. These assumptions remain valid based on the updated statistics.

2.2.6 Ground Water

The unconsolidated alluvial sediments which underlie the valley floor area of Santa Clara Valley constitute a large and significant groundwater basin. The Project site lies within the interior Baylands area of the Santa Clara Valley where the underlying materials consist of a very thick clayey section, complexly interspersed with thin channels, beds and lenses of sand and gravel. The principal aquifers are these sand and gravel layers.

The groundwater in the Project area is generally divided into two broad units, the upper zone and the lower zone. These zones are separated by an extensive clay layer, or “aquitarde”, which effectively delineates the two zones at depths of about 150 feet. All waters occurring in the lower zone are confined (under pressure) by this clay layer which thins out to the west unconfined zone (water table condition).

The uppermost groundwater in the upper zone of the baylands is considered semi-perched. This condition implies that this groundwater is perched on clay layers within the predominantly clayey section, but with an unsaturated zone occurring between the perched groundwater and main groundwater below it. Water levels in the upper zones, whether confined or semi-perched, are generally shallow, at depths of less than 5 feet. The upper zone is recharged from stream flow seepage and percolation of rainfall through the imperfections of clayey confining layers or from unconfined areas west of the Project site. Groundwater moves generally toward local wells.

¹¹ Unlike traditional District flood protection methods which consider the 100-year fluvial event and 10-year tide or vice versa, the 100-year water surface elevations for this study are based on a worst case combination of rainfall and tide cycle timing (see Shaaf & Wheeler, 2014 for details).

¹² From the Hydrology report prepared by Shaaf & Wheeler, 2014.

Groundwater in the lower zone occurs confined and is recharged from the unconfined zone (forebay) to the west beyond the thin edge of the extensive confining layers. The only connection between the upper and lower zones within the Project area would be through improperly constructed or defective wells. Movement of groundwater in the lower zone would be from its forebay along the western edge of the valley to areas of pumping in the valley interior.

With the development of groundwater for agricultural and municipal uses starting about the turn of the century, water levels in the upper zone began declining. This induced seawater intrusion in the upper zone created by an inland gradient condition from San Francisco Bay. With the lowering of the piezometric pressure within the confined lower zone, land subsidence started.

Within the Project area, the land surface subsided four to five feet between 1934 and 1967. Subsidence stopped in 1969 due to the partial recovery of the piezometric pressure caused by the reduction of pumping in the area, and several above normal rainfalls of the years since 1969. Reduction of pumping resulted from the substitution of imported water from the City of San Francisco's Hetch Hetchy Project and the State's South Bay Aqueduct for the local groundwater. As long as the present piezometric levels are maintained or improved, subsidence is not expected to resume. Conversely, if piezometric levels begin to decline below their pre-1969 levels, land subsidence will resume, resulting in further sinking of the PAFB levees; if the amount exceeded that allowed in the design, levees would have to be raised again. Future over drafting would also further induce seawater intrusion, lowering water quality in some wells and rendering others unusable.

2.2.7 Water Quality

In terms of dissolved minerals, runoff from Matadero Creek, Barron Creek, and Adobe Creek is a magnesium-calcium bicarbonate type of good quality. During individual storms, the early runoff from the upstream urban areas primarily washes contaminants from paved surfaces and becomes degraded. Subsequent runoff largely reduces this water quality degradation by dilution of contaminants.

When the runoff stagnates within the sloughs of the PAFB, it becomes brackish by mixing with Bay waters leaking through the tide gates or passing through one of the gates, which is managed by the City of Palo Alto ¹³, by the addition of salt from leaching the inherently salty soils, by concentration from evaporation, and by rise in temperature (which reduces dissolved oxygen levels).

Surface waters in the sloughs vary widely in total dissolved solid content, ranging from 1,000 to 50,000 milligrams per liter (mg/l), and in chloride content, ranging from 3400 to 20,000 mg/l. Biological oxygen demand and large changes in chemical oxygen demand are also experienced in the sloughs. A July 1974 sampling gave a total dissolved solids content of 1120 mg/l in Matadero Creek.

¹³ The City of Palo Alto actively manages one of the sixteen tide gates to increase salt water circulation within the PAFB during summer months to improve water quality. However, improved circulation is limited to an area near the tide gate structures. Measures to increase the influence of salt water circulation will be investigated as part of alternatives development

Upper zone groundwater in the Project area is degraded by saltwater to varying degrees with upper levels of total dissolved solids of nearly 50,000 mg/l; and chlorides of 25,000 mg/l. According to the few available logs in the Project area, the depth of the affected zone is almost 100 feet.

Groundwater in the lower zone is not affected by seawater intrusion in the Project area; consequently, the quality is suitable for most domestic and industrial uses. The water quality in the lower zone could be adversely affected by operating improperly constructed or defective wells which would allow degraded waters in the upper zone to contaminate the lower zone. This problem can largely be eliminated by proper well construction techniques.

2.2.8 Habitat Area

The PAFB was originally tidal salt marsh. Since the area was diked off to provide a holding basin for excessive storm water runoff, the effects of tidal action on the vegetation have been substantially reduced. The low flow, deep channels are the only areas within the basin affected by tidal waters. The observable significant variations in the vegetation are apparently the direct result of elevation differences affecting the relative soil salinity and amount of tidal flushing. Fresh water inflows from Adobe Creek and Matadero Creek also play a distinct role in creating and maintaining the types of vegetation present. The PAFB performs the ecological functions of reoxygenation, photosynthesis and providing wildlife habitat.

Flora

Three major vegetation types or associations account for most of the PAFB area: annual grassland, salt marsh, and mixed riparian. The grassland covers about 60 percent of the PAFB with Italian rye grass (*Lolium multiflorum*) as the dominant species. Other important species present in this association include ripgut grass (*Bromus diandrus*), wheat (*Triticum*) and barley (*Hordeum vulgare*) grasses, wild oat grass (*Avena fatua*) and *Heleochloa schoenoides* (no common name). The presence of these upland grasses is a direct result of secondary successional change due to altered environmental conditions. The exclusion of saltwater tidal action enables salt-intolerant grass species to take advantage of the upper soil which has been leached of salts.

The pickleweed-fat hen association is the remnant of the previously existing salt marsh. It is found at a lower elevation than the grassland and requires a specific minimum salt content in the soil. Other halophytes (plants restricted to saline soils) found with this association include *Frankenia*, saltbush (*Extriplex californica*), sand spurrey (*Spergularia atrosperma*), brass buttons (*Cotula coronopifolia*), and salt grass (*Distichlis spicata*). Some of the pickleweed is infested with the parasitic marsh dodder, indicating that at least some of the pickleweed may be growing under marginal conditions. This vegetation association is found in sinks and various abandoned channels immediately below the grassland elevations.

The third major association is mixed riparian (the term "mixed" is applied due to the origins of species present). Representatives of riparian communities, freshwater marsh communities, escaped introduced exotics and other naturalized weedy species make up this conglomeration of plant communities. The dominant plants are three species of willows (*Salix laevigata*, *Salix lasiolepis*, and *Salix lucida*), which are common to indigenous riparian communities in Santa Clara Valley. Coyote brush (*Baccharis pilularis*) is also found closely associated with most of the riparian vegetation. This streamside plant community relies on the perennial freshwater

supplied by Matadero Creek; the limited available freshwater restricts this community for the PAFB northwestern fringe.

Several smaller groups of plant associations are scattered over a wide area in the PAFB. Some of those represented include freshwater marsh, dominated by cattails (*Typha latifolia*) and bulrushes (*Schoenoplectus californicus*) and large areas of mesic ruderal weeds (upland weeds of disturbed-soil conditions) such as poison hemlock (*Conium maculatum*), thistles (*Cirsium arvense*), mustard (*Brassica tournefortii*), wild beet (*Beta vulgaris*), cheeseweed (*Malva parviflora*), wild radish (*Raphanus raphanistrum*), and sweet fennel (*Foeniculum vulgare*). Several areas are dominated by hydrophilic weeds such as spiny cocklebur (*Xanthium spinosum*), curly dock (*Rumex crispus*), and stinging nettle (*Urtica dioica*).

The freshwater marsh is located primarily along the Adobe Creek outfall into the PAFB, but is scattered into the riparian community also. Mesic ruderal weeds, as mentioned above, dominate the roadside levee slopes and other disturbed soil areas.

A California Natural Diversity Data Base search yielded the presence of Point Reyes salty birds beak (*Cordylanthus maritimus*), Hoover's button-celery (*Eryngium aristulatum*), and alkali milk vetch (*Astragalus tener*) potentiality within the PAFB. These are special status plants that should be considered. Invasive species, Phragmites australis, common reed, has been reported in the PAFB 14. Where conditions are suitable this reed can grow to 18 feet high and spread at by 16 feet or more per year by horizontal runners, which put down roots at regular intervals.

Fauna

When sufficient rainfall occurs, the PAFB supports a great number of species and high density. The three major plant associations contribute to the diversity and multitude of higher animals present. The variety of plant species supports many insects and herbivores, thereby providing ample food sources for the carnivores.

Much of the PAFB is subject to infrequent inundation, putting a severe seasonal strain on wildlife populations within this marshland preserve, by creating cyclic localized population explosions linked to rainfall patterns. Previous periods of heavy rains and flooding have decimated rodent populations upon which many predatory birds rely. These bird species include the common egret, great blue heron, hawks, kites, and owls. The latter three bird groups are more severely affected by heavy rodent losses because of their more specialized food requirements (SCVWD, 1976).

Wildlife field observations referred to in this report were made in November 1974, which was a particularly good seed year. This, augmented by lack of inundation, resulting in unusually high rodent populations. Raptor numbers were also high, as evidenced by the many white-tailed kites, Northern harrier and American kestrel observed. Egrets and great blue herons also took advantage of the seasonal abundance of rodents to supplement their diet.

Large populations of ducks winter in the PADB, as it is one of the few remaining major marsh areas left in Santa Clara County. San Francisco Bay is on the Pacific Flyway for many species of migratory waterfowl and is, therefore, critical to the continued survival of many bird species. The more common ducks observed included ruddy duck, mallard, pintail, cinnamon teal, shoveler, and canvasback. Large numbers of American coot were also observed.

¹⁴ Personal communication with District biologist and City of Palo Alto parks staff.

Fresh and brackish water habitats encourage several species of shorebirds to forage in these areas of the PAFB. Observed species include black-necked stilt, avocet, killdeer, long-billed dowitcher, lesser yellow legs, and sandpipers. The sanitary landfill adjacent to the PAFB is a significant food source for the gulls, substantially supplementing their diets and contributing to their large numbers. They use the PAFB for a foraging and resting area.

The grassland plant association fosters populations of wildlife typical to many California upland meadows. These include large rodent populations, such as California voles. Large numbers of California ground squirrels exist, particularly in the higher elevation areas, such as the levees. Several black-tailed jackrabbits were sighted. Other rodent species are very likely present also. Many species of birds commonly associated with the grassland community have been seen; they include loggerhead shrike, western meadowlark, song sparrow, and American kestrel. Scatological evidence also indicates the presence of rodent-eating carnivores, perhaps either *canids* (fox or coyote), or *ustelids* (weasel).

Birds sighted were a single green heron, long billed dowitcher, lesser yellow legs, and Swainson's thrush, indicating a greater diversity of birds than perhaps previously known. The nearby Sand Point salt marsh (where the Palo Alto Baylands Nature Interpretive Center is located) is known to support a population of salt-marsh song sparrows, a locally threatened subspecies which is restricted entirely to San Francisco Bay salt marshes. Positive identification of this subspecies was not made in the PAFB, but since song sparrows were observed, a strong possibility of its presence exists. At least six white-tailed kites were sighted in the PAFB, but it remains threatened by urbanization, as is the burrowing owl. One white pelican was sighted over the PAFB, landing in the adjacent salt pond to the east.

Although the pickleweed habitat does occur in roughly 30 percent of the PAFB, this particular habitat is not subject to direct tidal action; therefore, the existence of the endangered salt marsh harvest mouse is less likely. No direct evidence of the mouse's presence was noted. No other rare or endangered species were observed, but it is likely that the endangered Ridgeway's rail and California least tern inhabit the area. A California Natural Diversity Data Base search showed other species including longfin smelt and salt marsh common yellowthroat within the PAFB area.

Ecosystems

Wide diversity of organisms and high biological productivity are perhaps the best ecological terms to describe the PAFB. As previously indicated, the existing levee system eliminated all but minor tidal influence in the PAFB. Subsequent soil leaching by freshwater has altered the soil salinity substantially, causing instability in the previous climax plant community. The resulting secondary successional changes have largely replaced the salt marsh with a grassland community, riparian associations and a mixture of garden escapes and introduced exotics. This floral diversity is responsible for the large diversity of wildlife. It would appear that this biologically rich area is the result of several ecotones (transitional areas between plant communities) that exist within the PAFB. Sufficient evidence is not available at this time to determine if a new level of ecological stability has already been achieved or if the area is still undergoing distributional changes in vegetation.

In an effort to improve water quality during the summer months, the City of Palo Alto opens one of the sixteen flap gates to increase brackish water circulation within the PAFB.

2.2.9 Regular Maintenance

Sediment Deposition

Sediment originates from the upland areas of the Matadero catchment, and is transported down the natural and concrete channels, with a portion of that transported sediment reaching the natural channel in the PAFB. Significant volumes of sediment have been deposited within the overbank of this channel reach. These deposits are believed to exacerbate flooding potential for urban areas upstream of Highway 101.

An overflow bypass was constructed in the PAFB as part of the Matadero/Barron Creeks Long Term Remediation Project (District, 2002). Average total sediment accumulated from 1971 to 1999 is estimated to be 900 cubic yards per year.

The operation and maintenance of Matadero, Barron, and Adobe Creeks are the responsibility of the District. The Watersheds Field Operations Unit Manager directs the operations and maintenance procedures for these three creeks.

Matadero, Barron, and Adobe Creeks are inspected annually to assess channel conditions and sediment removal requirements. The following thresholds have been set to trigger channel maintenance and/or sediment removal for various portions of each creek, as described below.

Matadero Creek – PAFB to Highway 101

- Vegetation growth along the banks of the low-flow channel is to be trimmed to maintain a minimum clear floodway of approximately 20 feet.
- Sediment deposition along the bottom of the low-flow channel shall be monitored by ground survey every year for a period of five years. After the five-year period, the need for sediment removal will be determined.
- Sediment within the overflow bypass at the downstream side of Highway 101 is to be removed when it exceeds a depth of one foot above the concrete channel lining.
- Sediment within the sediment basin at the entrance of the bypass shall be removed when it exceeds a depth of two feet as measured at the concrete invert.
- Sediment deposition under East Bayshore Road will be inspected annually. Sediment will be removed from underneath East Bayshore Road to 100 feet downstream when sediment depth reaches one foot.
- Debris shall be removed from the nose of the pier at Highway 101 when it exceeds a total width of 3 feet.
- Sediment under Highway 101 will be removed when sediment reaches an average depth of 1 foot above the concrete invert at Highway 101 or in conjunction with sediment removal under Highway 101.

Adobe Creek – PAFB to Hwy 101

There is no program for sediment removal. Sediment deposition in the greater PAFB is considered to be minimal as evidenced by a comparison of two elevation-storage curves prepared by the District in 1974 and Towill Inc. and MacKay & Soms in 1999. Both curves are

included in **Figure 9**. No additional basin topography has been gathered in subsequent years, it is assumed that the storage has not changed significantly to date.

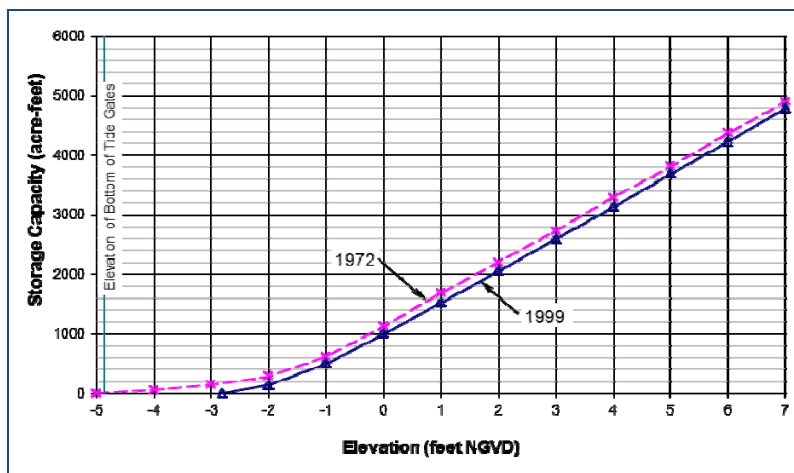


Figure 9: Palo Alto Flood Basin Storage-Elevation Curves

Vector Management

The Santa Clara County Vector Control District (SCCVCD) is responsible for vector control at the PAFB. In February 2015, the SCCVCD applied a biological control agent and insect growth regulator by helicopter to inhibit commonly called the “winter salt marsh mosquito” *Aedes squamiger* which lays its eggs in the moist soil in late spring and early summer.

The SCCVCD closely monitors the development of mosquito larva in the PAFB. In Spring 2015, mosquito growth trends indicated a high probability that a significant number of salt marsh mosquitoes would become adults in early to mid-March if left untreated. The mosquito fly-off could affect residents from the north coastal areas of the county to as far south as the southernmost part of the City of San Jose and east to Milpitas. The aerial treatment was intended to minimize the number of mosquitoes and reduce the risk of mosquito bites to residents in the surrounding communities.

2.2.10 Public Access to the Palo Alto Flood Basin

The City of Palo Alto owns and maintains a network of trails in the Baylands Nature Preserve (**Figure 10**). The preserve is the largest tract of undisturbed marshland remaining in the San Francisco Bay.

Fifteen miles of multi-use trails connect to the San Francisco Bay Trail¹⁵ and provide access to a unique mixture of tidal and fresh water habitats. The preserve encompasses 1,940 acres in both Palo Alto and East Palo Alto. The preserve is an important habitat for migratory birds and is considered one of the best bird watching spots on the West Coast.

The preserve consists of the former Yacht Harbor area, the Palo Alto Airport, the Municipal Golf Course, the Duck Pond and public picnic area, the Baylands Athletic Center, the Sailing Station,

¹⁵ Senate Bill 100, passed into law in 1987, directed the Association of Bay Area Governments to develop a plan for a trail around the Bay and included a specific alignment for the Bay Trail.

the Lucy Evans Baylands Nature Interpretive Center, the Harriet Mundy Marsh, the Emily Renzel Wetlands, and the PAFB.

Activities at the preserve include walking, running or biking, bird watching, wind surfing and boating (non-motorized craft). The City of Palo Alto also offers nature walks and programs on ecology and natural history.

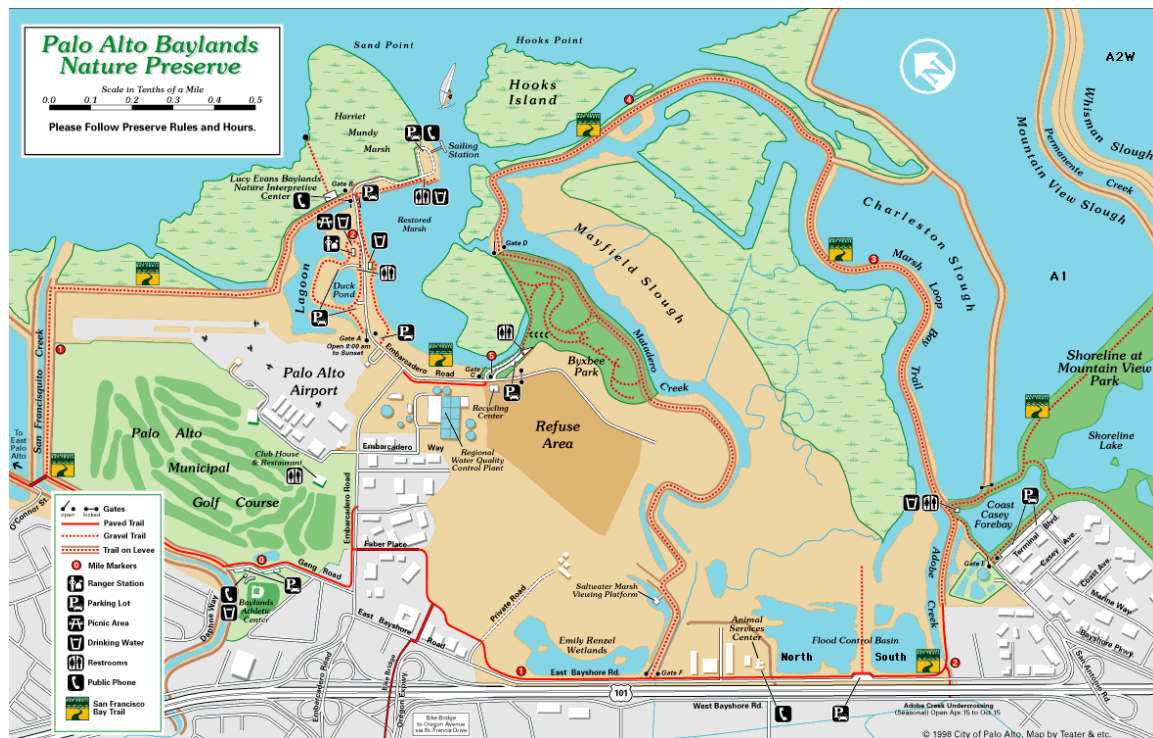


Figure 10: Map of Palo Alto Baylands Nature Preserve

2.2.11 Cultural Resources

Cultural resources information was not discovered as part of the problem definition investigation. Given the sensitivity of Native American historical presence in the San Francisco Creek Watershed, a cultural resources study will be completed to inform feasible alternatives evaluation.

2.2.12 Hazardous Materials

Hazardous materials information was not discovered as part of the problem definition investigation. Given the proximity of the Palo Alto Land Fill, a hazardous materials study will be completed to inform feasible alternatives evaluation.

2.2.13 Right of Way

The District and City of Palo Alto executed a right of way agreement on November 28, 1967. The easement grants the District the right to construct, reconstruct, inspect, maintain and repair a channel and basin, protection works and appurtenant structures for flood control and storm drainage purposes. District right of way easement at the PAFBA generally includes the levee, embankment, and tide gate structure, at the perimeter of the basin (**Figure 11**).



Figure 11: Map with Approximate Location of District Easement at Palo Alto Flood Basin

2.2.14 Public Services and Utilities

Public services and utilities are provided to the Project area by the following organizations and agencies (**Table 5**):

Table 5: Public Services and Utilities Provided to the Project Area

Utility	Agency
Power	Pacific Gas and Electric Company
Water Supply	City of San Francisco (wholesaler) City of Palo Alto (retailer)
Sewage Treatment and Solid Waste Disposal	City of Palo Alto
Flood Protection	Santa Clara Valley Water District

Parks and Recreation	Santa Clara Parks and Recreation Department; Mid-Peninsula Regional Parks District; City of Palo Alto Parks Division and Recreation Department
School Districts	Palo Alto Unified School District and Foothill College District
Environmental Quality	California Department of Fish and Wildlife Services, NOAA National Marine Fisheries, Regional Water Quality Control Board, Santa Clara County Creeks Coalition, Santa Clara Valley Audubon Society, United States Environmental Protection Agency, Bay Area Conservation and Development Agency, United States Fish and Wildlife Service, United States Army Corps of Engineers, City of Palo Alto, and possible others
Fire Protection	City of Palo Alto
Police Protection	City of Palo Alto

Chapter 3: PROBLEM DEFINITION

3.1 Description of Flood Gate Problem

The PAFB tide gates structure has been compromised by the effects of ageing. This is evidenced by spalling and corrosion of the structures concrete reinforcement. In addition to this immediate problem, the Adobe, Barron, and Matadero Creek flood protection facilities and PAFB ecological habitats are vulnerable to the effects of possible future seal level rise.

3.1.1 Immediate Problem -Ageing Infrastructure

As described in Section 2.2.2, the tide gate structure is significantly deteriorated due to typical marine corrosion and natural weathering processes. Constructed in 1954, the tide gate structure is more than 60 years old and has exceeded its useful life expectation.

Inspection of the tide gate structure occurred on February 25, 2014 at 9:50 am. At that time, the water elevation on the Bay side of the tide gate structure was approximately 7.5 feet above Mean Lower Low Water (MLLW). The water surface on the Basin side remained approximately 3 feet deep or approximately 2 feet above MLLW.

According to the field report, the channel bottom in the vicinity of the structure consisted of rip rap typically measuring between 1 and 2 feet in diameter and soft mud. The steel sheet piles typically exhibited ½ inch of marine growth consisting of barnacles and various areas of surface corrosion with no section loss below water. The protective coating was typically found to be in good condition. Deterioration was typically located on top of the sheet piles where above the water surface and included minor to medium steel delamination. The flood gates and hardware were in good condition with no apparent section loss.

The gates were typically covered in ¼ to ½ inch of marine growth, similar to the wing walls. The concrete at the north face of the structure was typically found to be in good condition with no noticeable scaling or pitting. The concrete exhibited typical marine growth similar to that on the steel. Overall, the concrete inside of each barrel was found to be in satisfactory to good condition.

Deteriorated seals were found at several gates and corrosion spall was observed at various locations for all cells. Additionally, exposed reinforcing bars with various degrees of percent section loss were observed at various locations inside the cells, on top of the deck, and at various other locations.

3.1.2 Future Problem -SLR Impacts

Results of HEC-RAS simulations for existing conditions are presented graphically and in tabular form herein. **Figure 12** shows a summary of PAFB operation for the tidal shift (52 hours) that produces the maximum 100-year water surface elevation in the basin, which is 7.4 feet NGVD (10.2 NAVD88). Stage is labeled on the left-hand y-axis; flow is on the right-hand y-axis. Tide elevation, PAFB elevation, total flow through the tide gate structure (eight gates), flow through each individual gate, and the total flow into the PAFB are all charted over a one-week period. Simulated gate operation does not allow reverse flow, and the minor negative flow spikes are considered a small model instability that does not affect the overall result.

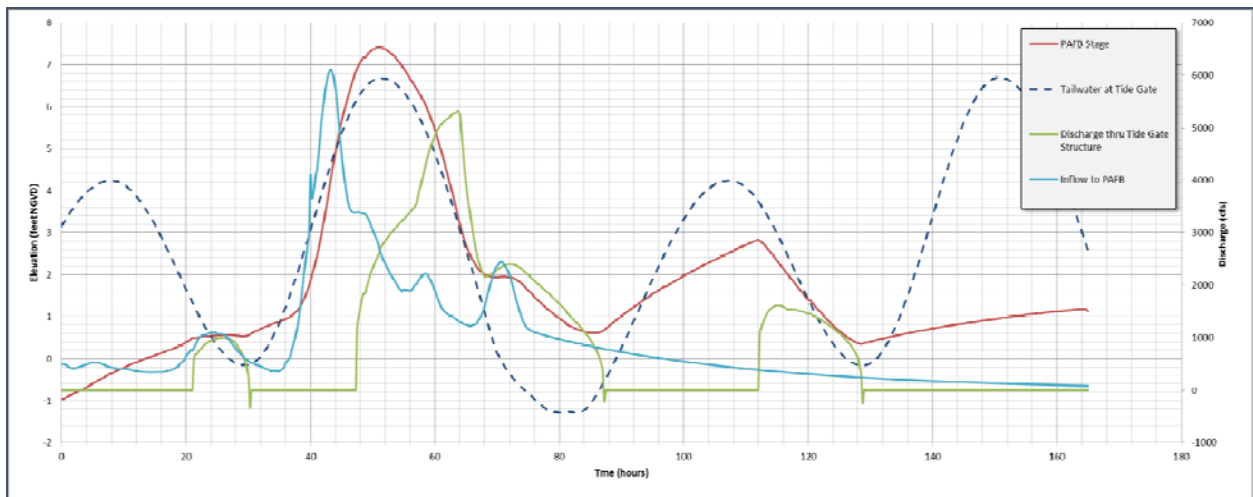


Figure 12: PAFB Operation with Maximum Stage Based on Random Tidal Shift

SLR scenarios were adopted from recent projections from the National Research Council¹⁶. SLR in Bay tide cycle as a uniform vertical datum adjustment. Despite some evidence that the difference in the intertidal range (i.e. between MHHW and MLLW) may be widening along with the overall trend of rising seas, the California Climate Change Center “assumes that all tide datums, e.g. mean high tide and flood elevations, will increase by the same amount as mean sea level.”

Low and high range of the projections are both used to reflect the uncertainty bounds inherent in developing the projections and applying them to a single location. **Table 6** provides a summary of the range of SLR projections contained in the 2012 NRC document.

¹⁶ National Research Council, Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past Present, and Future, National Academies Press, Washington, 2012.

Table 6: Summary of NRC SLR Scenarios

Time Period	Low Range SLR (feet)	High Range SLR (feet)
2000 – 2030	0.13	0.98
2000 – 2050	0.39	2.00
2000 – 2100	1.38	5.48

If no improvements are made to the PAFB, SLR will result in a significant change to the maximum PAFB stage. Maximum stage in PAFB resulting from SLR predictions is estimated from a worst case combination of rainfall and tide cycle timing with the existing tidal gates ¹⁷. **Table 7** provides a summary of the predicted maximum stage in the PAFB without levee overtopping ¹⁸ for the predicted ranges of three SLR rise scenarios (2030, 2050 and 2100) assuming the configuration of the flood basin and tide gate structure are not changed. It is problematic that at several locations along the PAFB containment levees, including at the bike path adjacent to East Bayshore Road, the top of the levee elevation is less than 7.0 feet NGVD29 (9.8 NAVD88). These locations can be expected to be overtopped under existing conditions and for all SLR scenarios.

Table 7: Impact of SLR on Maximum PAFB Stage

SLR Scenario	Sea Level Rise (feet)	100-year Coincident Tide (feet NGVD)	Maximum PAFB Stage (feet NGVD)
Existing	n/a	7.20	7.41
2030 Low	0.13	7.33	7.54
2050 Low	0.39	7.59	7.77
2030 High	0.98	8.18	8.31
2100 Low	1.38	8.58	8.71
2050 High	2.00	9.20	9.14
2100 High	5.48	12.68	12.28

¹⁷ See Schaaf & Wheeler, 2014 report for hydrology, hydraulics, and model results details.

¹⁸ PAFB levees are modeled to contain water volumes with no spilling to determine minimum levee crest elevations required for alternatives that include modification of existing levees or floodwalls or construction of new ones.

3.1.2.1 Adobe, Barron, and Matadero Creek Starting Water Surface Elevations

Flood improvements constructed by the District provide flood protection to Adobe, Barron, and Matadero creeks to satisfy standards set forth by the Federal Emergency Management Agency (FEMA) and reduce the burden of flood insurance purchases within the City of Palo Alto.

Starting water surface elevations (SWSE) used for hydraulic design of flood improvements (levee's, floodwalls, culverts, etc) on these creeks were determined based on statistical abstractions and uncertainty analyses.

For Matadero Creek, the SWSE of 4.6 feet NGVD29 (7.4 NAVD88) was used for risk-based back water analysis (Shaaf & Wheeler, 2014). The SWSE used for Adobe Creek was 5.0 feet NGVD29 (7.8 NAVD88) ¹⁹. Because both Barron Creek and Adobe Creek share the same outlet to the PAFB, the SWSE for Barron Creek is expected to be equal to Adobe Creek and 5.0 feet NGVD29 (7.7 NAVD88).

FEMA guidelines suggest that the worst-case levee failure scenario should be mapped. If the outboard levees do not hold, as must be assumed for FEMA analysis, the PAFB is exposed to direct tidal action from the Bay. The SWSE recognized by FEMA for each of the three creeks is the expected MHHW elevation which is equal to 4.5 feet NGVD29 (7.3 NAVD88) ²⁰.

Because hydraulic analyses for each creek include SWSEs above MHHW, flood improvements for these creeks will continue to satisfy traditional FEMA starting water requirements (100-year creek discharge with MHHW SWSE) until SLR causes the statistical value of MHHW to exceed SWSEs. For Matadero Creek a greater than 0.1 foot increased to MHHW could affect FEMA certification for existing flood improvements.

3.1.2.2 Tidal Flooding in Palo Alto

The National Oceanic and Atmospheric Administration (NOAA) has developed a useful tool to depict the potential for inundation across various SLR scenarios ²¹. **Figure 13** shows the NOAA predicted flood area that is expected for a 2 foot rise in sea level with a Mean Higher High Water tide elevation (depth increases from light to dark). Tidal flooding under this scenario would increase the FEMA Special Flood Hazard Area.

¹⁹ Information based on personal communication with District hydraulics staff, 2014.

²⁰ The MHHW was determined based on a 19-year mean at the Dumbarton Bridge (Shaaf & Wheeler, 2014).

²¹ NOAA Sea Level Rise and Coastal Flooding Impacts website: <http://www.coast.noaa.gov/slr/>.

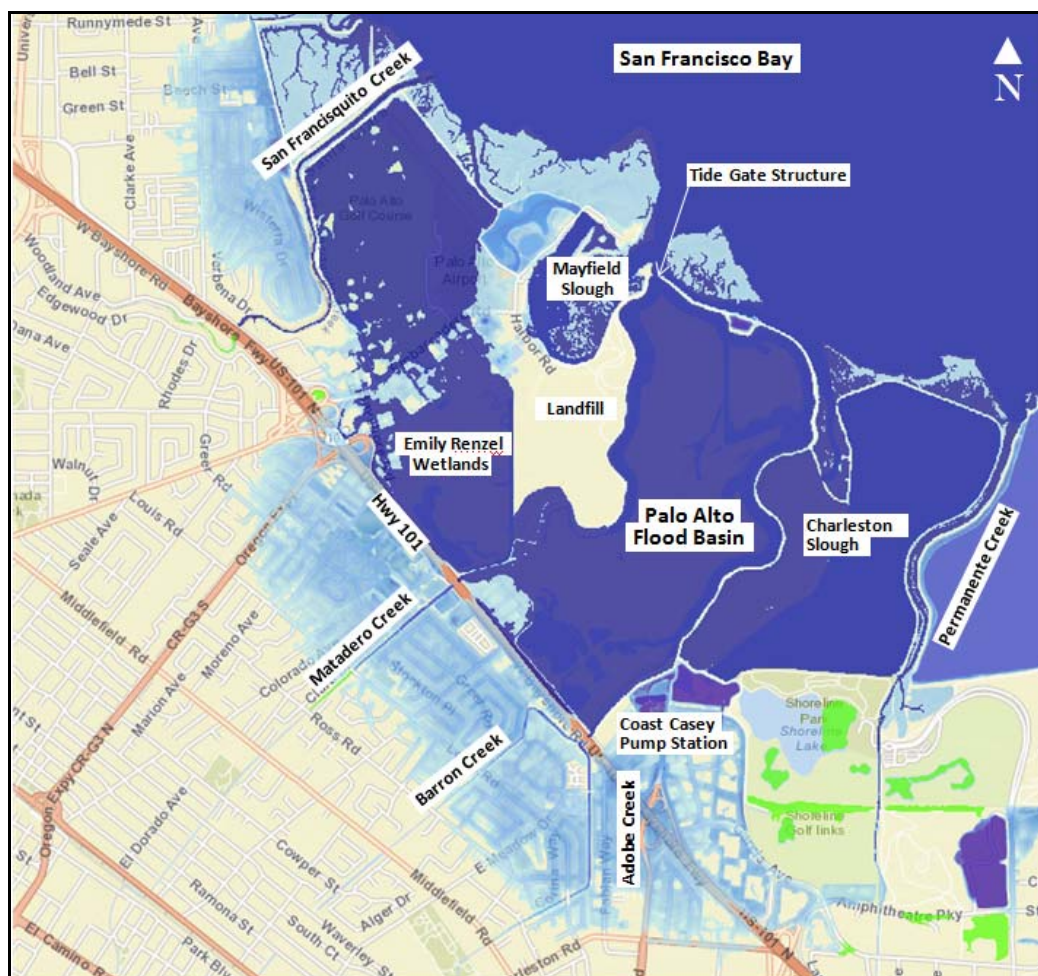


Figure 13: Map with NOAA Tidal Inundation for 2-foot SLR and MHHW Tide

3.1.2.3 Biological Resources

SLR is expected to inundate sensitive habitat areas in the PAFB. Because a comprehensive survey of biological areas within the PAFB has not been conducted for over 40-years, the impacts or benefits associated with increased water surface elevations and existing habitat are not known. This Project will perform a detailed LIDAR, ground, and aquatic habitat survey in later phases of the planning study to facilitate careful evaluation of Project alternatives with respect to biological and flood protection trade-offs.

3.1.2.4 Levee Erosion

SLR is likely to result in reduced stability and increased overtopping of the existing levees. Wind wave attack on existing levees is expected to cause greater erosion as the effective levee width²² available to resist wave action will be reduced by SLR. Overtopping of levees by wind waves erode levee crests and back slopes.

²² Levee width decreases in the direction of the levee crest (i.e. the base is wider than the top).

3.1.3 Vector Management

Detailed records are maintained by the Santa Clara County Vector Control District (SCCVCD) concerning major mosquito breeding areas, population densities, and control techniques and materials. The PAFB is considered a known or potential mosquito problem area (SBSPRP, 2007). Mosquitoes serve as vectors for several diseases, including the West Nile Virus which has been found in Santa Clara County, that pose health concerns for humans and domestic animals.

Mosquito control techniques employed by the SCCVCD emphasize minimization and disruption of suitable habitat, and control of larvae through chemical and biological means, as opposed to spraying of adults.

The Project will coordinate closely with the SCCVCD to develop mosquito management solutions as part of the alternatives evaluation phase.

3.1.4 Water Quality

Volunteer water quality monitoring at the PAFB was conducted at 21 sites on a semi-monthly basis between 2003 and 2006 (SBSPRP, 2007). The volunteers used data sondes (probes) to take measurements of temperature, conductivity, dissolved oxygen, and pH. The City of Palo Alto manages this data.

Chapter 4: COMMUNITY OUTREACH

No community outreach has been completed at the time of this report. There is an opportunity to coordinate public outreach for this Project with the SFCJPA SAFER Bay project.

Chapter 5: POTENTIAL CHANGES TO THE PROJECT OBJECTIVES/ NEXT STEPS

The Project team proposes changes to the Project Objectives. In the immediate interest to maintain function of the existing tide gate structure, the Project team recommends that the Project Owner prioritize Objective 1 (replace/repair the structure) over Objectives 2-3 (reduce flooding on tributary creeks, prevent environmental impacts, and address future SLR impacts).

Placing priority on Objective 1 will promote an alternative to complete basic maintenance work at the tide gate structure over the short term. As such, intermediate term Objectives 2-3 could be realized in cooperation with other interested parties or projects (e.g. SFCJPA, City of Mountain View, SBSP, SCVWD Shoreline Project, etc) with a slower time line for completion.

The original Project Objectives have been refined based on information discovered during the problem definition phase. The original Project Objectives, in strikethrough text, and proposed revised Project Objectives are as follows:

1. ~~Replace or repair the existing structure to improve the functionality of the flood barrier system.~~
Replace or repair the existing structure to improve the functionality of the flood barrier system *in the short term*.
2. ~~Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks.~~

Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks *in cooperation with local planning efforts (intermediate term, 5 years +/-).*

3. ~~Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail.~~

Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, Ridgeway's Rail, and the Black Rail *in cooperation with local planning efforts (intermediate term, 5 years +/-).*

4. ~~Prevent impacts to flood protection due to future sea level rise and the 100-year fluvial flood.~~

Prevent impacts to flood protection due to future sea level rise and the 100-year fluvial flood *in cooperation with local planning efforts (intermediate term, 5 years +/-)*

The next steps include completing the planning formulation phase of the Project. The Project team has prepared conceptual measures based on a structural investigation of the existing tide gate structure (MTCO, 2014), a recent hydrology report (Shaaf & Wheeler, 2014), and communications with the SAFER Project team (Section 6.1). The Project team has combined conceptual measures to develop conceptual alternatives (Section 6.2) which include two short term scenarios (Alternative A and B) and two intermediate term scenarios (Alternative C and D).

Chapter 6: PLANNING FORMULATION

Conceptual alternatives were determined to achieve the following Project Objectives:

1. Replace or repair the existing structure to improve the functionality of the flood barrier system
2. Reduce the possibility of flooding in the lower reaches of Matadero, Adobe, and Barron Creeks
3. Prevent environmental impacts due to the submergence of habitat areas within the PAFB for habitats including Salt Marsh Harvest Mouse, California Clapper Rail, and the Black Rail.
4. Prevent impacts to flood protection due to future sea level rise and the 100-year fluvial flood

These objectives identify the need to address problems related to the ageing tide gate structure which controls hydraulic criteria for recently completed flood improvements on Adobe, Barron, and Matadero Creeks. In addition, these objectives recognize the biological value of the PAFB and the impending impact of SLR to: ecosystem habitats, tide gate structure function, and existing levee function/durability.

6.1 Conceptual Measures

A number of conceptual measures were brainstormed as tools that could meet Project Objectives. Potential measures included:

- Perform maintenance to ensure continued function of the existing tide gate structure
- Installing additional and/or larger tide gates or modifying their elevation
- Dredging the PAFB to create additional volume (this measure was screened out due to expected impacts to ecosystem habitats)
- Connecting additional wetland areas to create additional volume elevation
- Constructing new levees or floodwalls or modifying existing levees with higher crest elevations elevation
- Discharging stored waters with pumps

A description of conceptual measures included in conceptual alternatives follows.

6.1.1 Maintain Existing Tide Gate Structure

The existing structure is determined to be in relatively good shape; however, following injection of concrete slurry to arrest underflow beneath the structure in 2012, a structural investigation identified a need for relatively basic structural repairs.

6.1.2 Increase the Number of Tide Gates

There is ample space in the vicinity of the existing tide gate structure to rebuild and/or build a new structure with additional gated openings to discharge stored flood water at higher rates for a given head differential across the tide gate than under existing conditions. Alternative rebuilt tide gate structures with 32 gates (double the total net discharge area), 48 gates (triple) and 64 gates (quadruple) have been modeled with various SLR scenarios.

For all modeling scenarios individual gates are assumed to be identical to the existing gates. That is, 5-foot by 5-foot rectangular openings with an invert elevation of -5.1 feet NGVD29 (-2.4 NAVD88) and a flap gate to prevent backflow. Modeling results are presented in the summary tables and figures.

6.1.3 Connect the Emily Renzel Marsh to Create Additional Storage

Increasing the volume of storage is a means to reduce PAFB stage. **Figure 14** shows the Emily Renzel Marsh area directly connected to the PAFB across Matadero Creek. **Figure 15** illustrates the relationship between PAFB storage versus stage for (1) the existing PAFB and (2) the existing PAFB with additional storage area contributed by the Renzel Marsh. The mitigation area located between Renzel Marsh, Matadero Creek, and the Palo Alto Landfill is not included in the additional storage area to avoid impacting the existing mitigation area. Neither the potential environmental impacts to Renzel Marsh nor the regulatory hurdles that would need to be overcome are considered in this evaluation.



Figure 14: Map of Overflow to Emily Renzel Marsh to Create Additional Storage

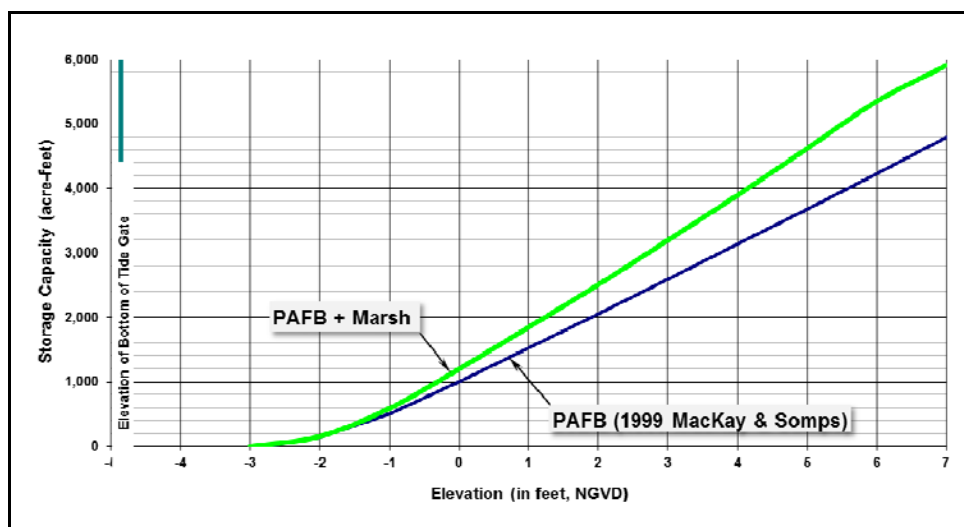


Figure 15: Change in Storage with Addition of Emily Renzel Marsh

6.1.4 Construct Levees or Floodwalls

The levees surrounding the PAFB were constructed in 1956 and do not meet current FEMA criteria. SLR is likely to result in reduced stability and increased overtopping of the existing levees. Whether the existing levees can be modified for a rise in sea level depends on the availability of material for raising the levee, the stability of the foundation material to support the additional weight of the material, the stability of the levee with the increased water level, and the accessibility of additional area for widening the base of the levee.

The soil beneath the PAFB is comprised of Young Bay Mud. As such, special considerations will be necessary during the alternatives evaluation and design phases to analyze stability, seepage, and settlement.

6.1.5 Construct Pump Station(s)

One or more pump stations could be constructed as a means to maintain water surface levels in the PAFB with SLR. A pump station would consist of intake pipes within the PAFB, a pump house including a generator a control system, and outfall to the Bay. Careful consideration to avoid impacts to aquatic habitat would be required for the intake system and would likely include fish screens.

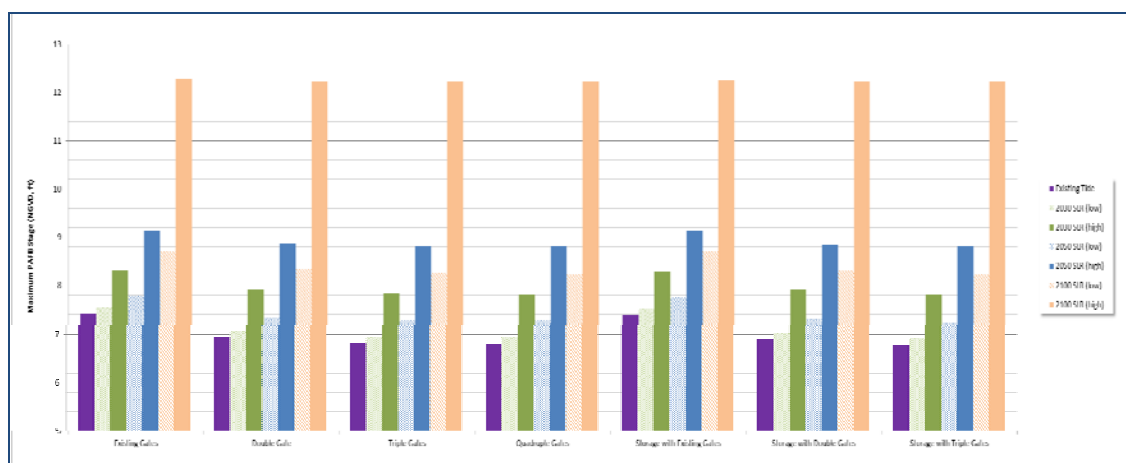
6.2 Conceptual Alternatives

Conceptual Alternatives were developed based on the measures described in Section 6.1. Storage volume can be increased in combination with additional tide gate discharge. **Table 8** provides a comparative summary of maximum predicted PAFB stages for various rehabilitation alternatives and SLR scenarios. **Figure 16**²³ provides a side-by-side graphic comparison for this same information.

²³ Refer to Appendix A for a 11" x 17" print out

Table 8: SLR Mitigation Using Gravity Remediation Alternatives

SLR Scenario	SLR (ft)	Maximum Stage in Palo Alto Flood Basin (feet NGVD)						
		Gate Modification Only				Add Renzel Marsh Volume		
		Existing Gate Structure	Double No. of Gates	Triple No. of Gates	Quadruple No. of Gates	Existing Gate Structure	Double No. of Gates	Triple No. of Gates
Existing	n/a	7.41	6.95	6.82	6.80	7.37	6.91	6.79
2030 Low	0.13	7.54	7.08	6.95	6.94	7.51	7.04	6.92
2050 Low	0.39	7.77	7.33	7.28	7.27	7.74	7.30	7.21
2030 High	0.98	8.31	7.92	7.82	7.81	8.29	7.90	7.81
2100 Low	1.38	8.71	8.33	8.24	8.23	8.69	8.30	8.21
2050 High	2.00	9.14	8.86	8.81	8.80	9.12	8.85	8.80
2100 High	5.48	12.28	12.25	12.24	12.23	12.27	12.24	12.23

**Figure 16: Graphic of SLR Mitigation with Gravity Remediation Alternatives**

Clearly none of the identified gravity remediation measures (additional gates or additional storage) can overcome high-range SLR projections, and increasing tide levels mute the benefits of any remedial alternative. Providing additional discharge through a rebuilt tide gate appears to be more effective than providing additional storage, and diminishing returns are demonstrated when the number of gates is increased by a factor of more than two.

Assuming that doubling the number of gates would be considered for future tide gate modifications and increasing storage is not effective, confidence limits for maximum PAFB stage with 32 gates for the range of SLR scenarios are shown in **Figure 17**²⁴.

²⁴ Refer to Appendix A for a 11" x 17" print out

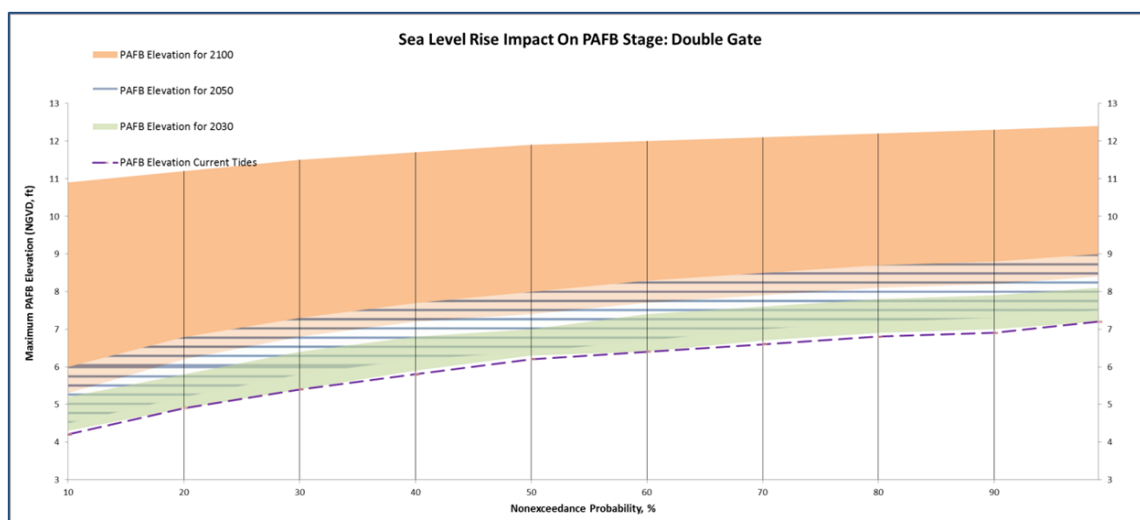


Figure 17: SLR Impact on Maximum PAFB Stage Confidence with Increase to 32 Gates

At some point in the future, gravity remediation measures (tide gates and increased storage area) to decrease PAFB stage will no longer be sufficient to mitigate SLR. The only remaining alternative will be to pump the stored flood water against high tide. The effects of adding pumping capacity to the existing system on the maximum PAFB stage (with 90 percent confidence) for the existing tide gate structure configuration and a rebuilt structure with twice as many tide gates are presented in **Figure 18**²⁵ and **Figure 19**²⁶.

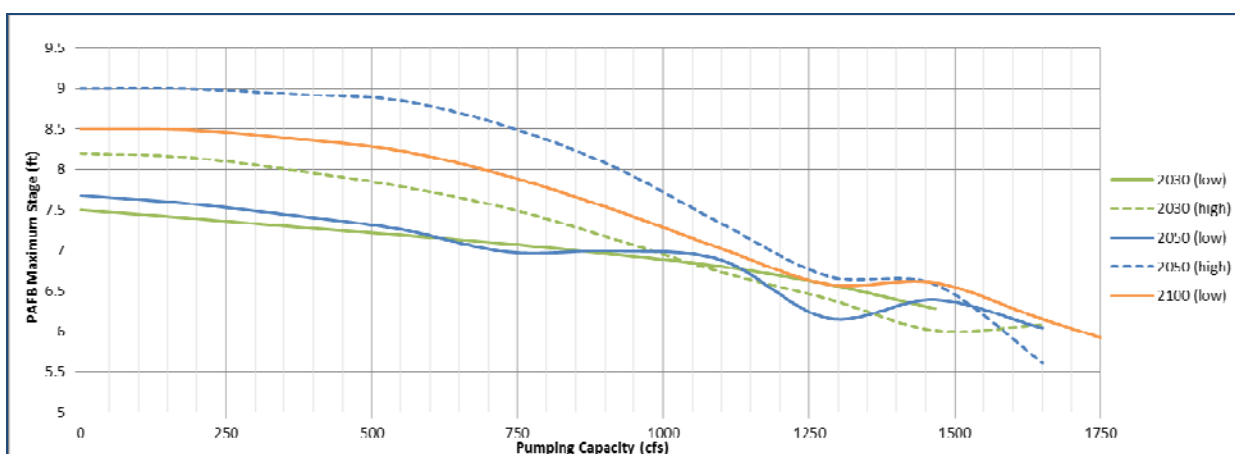


Figure 18: Pumping Capacity Required to Meet Target WSELs in PAFB w/ 16 Tide Gates

²⁵ Refer to Appendix A for a 11" x 17" print out

²⁶ Refer to Appendix A for a 11" x 17" print out

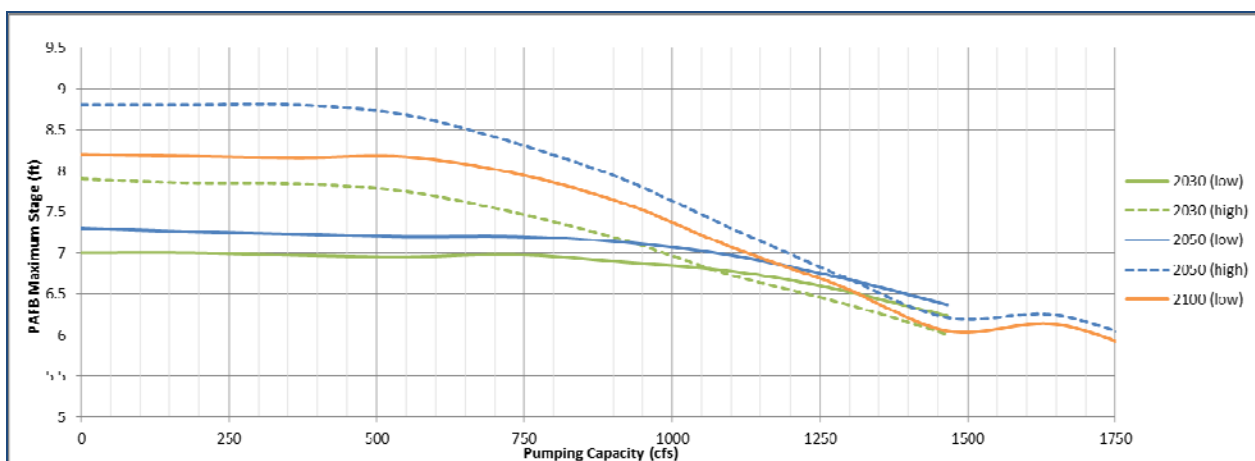


Figure 19: Pumping Capacity Required to Meet Target WSELs in PAFB w/ 32 Tide Gates

Ultimate required pumping capacity to meet various target maximum water surface elevations can be somewhat reduced if a new tide gate structure with 32 gates is constructed, but as is the case with gravity remediation alternatives there is a decreasing benefit with increased SLR.

For example, to hold maximum flood stage to 7.3 feet NGVD29 (10.1 NAVD88), the existing 90% confidence limit, with the 2030 high-range SLR scenario (0.98 feet), the 875 cfs pumping plant required with the existing tide gate configuration could only be reduced to 850 cfs if the number of tide gates is doubled.

Other scenarios can be examined to evaluate the efficacy of adding tide gates in addition to pumping. The 2100 high-range SLR (5.48 feet) curves are not shown, but a 2,500 cfs pump station would be required to maintain existing PAFB stage. This represents a pumping rate equivalent to more than 40 percent of the combined peak inflow. At this level of SLR, pumping is essential to provide interior flood protection during extreme runoff events.

6.2.1 Conceptual Alternative A: No Action

Under the No Action alternative,

- Corrosion and deterioration of the existing tide-gate structure is expected to continue and the structure will eventually fail.
- Starting water surface elevations for hydraulic models for Adobe, Barron, and Matadero Creeks will be exceeded and may require revision to FEMA flood maps by 2030.
- Habitat areas within the PAFB will be inundated and potentially damaged.
- Bridge hydraulic performance at East Bayshore Road, Hwy 101, and West Bayshore Road will be compromised.

6.2.2 Conceptual Alternative B: Perform Minor Repairs to Maintain Function of the Tide Gate Structure

To maintain the existing functionality of the tide gates the following repairs would be completed:

6. The leaking seals located at Gates 2B and 4A would be taken care of during the next round of routine maintenance.
7. The concrete cracks inside the cells due to extensive spalling and loss of steel section in the reinforcing bars would be repaired.
8. Concrete waste located on top of the bottom slab on the bayside of the structure would be removed.
9. The concrete deck would be cleaned and overlaid with polyester concrete. This repair will stop further deterioration of the concrete deck and prolong the service life of the structure
10. The steel fence would be replaced and extended approximately ten feet beyond the end of the structure for safety protection for trail users.

To complete items 1-5 above, the tide gate structure would be dewatered and isolated from daily tides with coffer dams and a pumping system. The coffer dam would be constructed with sheet piles located on either side of the tide gate structure. With the tide gate structure dry and accessible, work would commence to replace leaking seals at gates, patch spalled concrete, and remove concrete waste. Remaining work to overlay the deck and install additional fencing would be completed after the coffer dam and pumping system was removed. The total estimated cost to complete minor repairs to maintain the tide gate structure is estimated to be \$200,000.

6.2.3 Conceptual Alternative C: Double Number of Tide Gates, Construct Pump Station, and Raise Levees

The most effective combination of conceptual measures to maintain existing PAFB tide levels with SLR is to double the number of existing tide gates, construct a pump station, and raise existing containment levees (**Figure 20**).



Figure 20: Conceptual Alternative C: Double Number of Tide Gates, Construct Pump Station, and Raise Levees

The timing of these measures could be completed as a result of observed SLR and as needed to maintain FEMA certification for flood improvements on Adobe, Barron, and Matadero Creeks. For example, the first phase could be to replace the existing 16 gate structure with one that includes 32 gates. At some point, SLR will require a pump station and raised levees to maintain PAFB water levels. If the higher range of predicted SLR occurs, the outboard levees would need to be substantially increased in elevation and a pumping facility with 2,500 cfs capacity may ultimately be needed for interior flood protection. A pump station of this magnitude would provide over 6,000 installed horsepower and could cost on the order of \$50 million to construct.

The preliminary construction cost for Conceptual Alternative C is included in **Table 9**²⁷:

²⁷ Refer to for preliminary cost details

Table 9: Alternative C Cost Summary

Item	Amount
Tide Gate Structure	\$ 2,885,000
Levees	\$ 11,203,000
Floodwalls	\$18,610,000
Pump Station	\$42,500,000
Mobilization	\$7,520,000
Planning, Design, PSE	\$7,520,000
Geotechnical Investigation	\$120,000
Topographic Survey	\$ 80,000
Biological Survey	\$ 100,000
Environmental Documentation	\$ 1,000,000
Real Estate	\$ 0
Traffic Control	\$ 100,000
Permitting	\$ 100,000
Total	91,738,000
Preliminary Cost with 25% Contingency	\$ 114,673,000

6.2.4 Conceptual Alternative D: SAFER BAY: Double Number of Tide Gates, Construct Pump Station, Raise Levees at PAFB, Raise Floodwalls along Barron and Adobe Creeks

This conceptual alternative is under consideration by the SFCJPA's SAFER Bay project. It consists of a levee extending from high ground at the Palo Alto Landfill across the PAFB and along the north side of Adobe Creek to East Bayshore Road. A second levee will continue on the southern side of Adobe Creek from East Bayshore Road to a tie in at the City of Mountain View border near the Coast Casey Pump Station (**Figure 21**).



Figure 21: Conceptual Alternative D: SAFER BAY: Double Number of Tide Gates, Construct Pump Station, Raise Levees at PAFB, Raise Floodwalls along Barron and Adobe Creeks

The northern area of the PAFB would be opened and restored to tidal marsh habitat. Adobe Creek would be directly connected to San Francisco Bay. The remaining PAFB would be constructed with new tide gates and a pump station (similar in size or larger than Conceptual Alternative C) that would convey Matadero Creek discharge to the Bay. In addition to these levees, in order to maintain flood protection, floodwalls will require raising along both banks of Barron and Adobe Creeks upstream and west of Highway 101 to the upstream extent of tidal backwater effects.

The preliminary construction cost for Conceptual Alternative D is included in **Table 10** ²⁸:

Table 10: Alternative D Cost Summary

Item	Amount	Diff. from Alt C
Tide Gate Structure	\$ 2,885,000	-
Levees	\$ 32,233,000	\$ 21,030,000
Floodwalls	\$2,572,000	\$ (16,038,000)
Pump Station	\$70,834,000	\$ 28,334,000
Mobilization	\$10,853,000	\$ 3,333,000
Planning, Design, PSE	\$10,853,000	\$ 3,333,000
Geotechnical Investigation	\$120,000	-
Topographic Survey	\$ 80,000	-
Biological Survey	\$ 100,000	-
Environmental Documentation	\$ 1,000,000	-
Real Estate	\$ 0	-
Traffic Control	\$ 100,000	-
Permitting	\$ 100,000	-
Total	131,729,000	\$ 39,991,000
Preliminary Cost with 25% Contingency	\$ 164,662,000	\$ 49,989,000

Alternative D represents a significant opportunity for large-scale tidal marsh and transition zone habitat restoration. The PAFB would be re-connected to tidal exchange which would, over time restore to a tidal marsh. To restore the northern portion of the basin, the outer levee would be breached in strategic locations to create a natural, dendric slough channel network and the remainder of the levee lowered. Material from the levees could be used to fill/block existing borrow ditches and facilitate a dendritic slough channel network.

Additionally, the basin is adjacent to Charleston Slough to the east, which is likely to be restored to tidal marsh by SBSRP and the City of Mountain View. Removing the levee between the PAFB and Charleston Slough would create a large, contiguous marsh with freshwater input from Adobe Creek. This freshwater input to the marshes would supply sediment and create a gradient of freshwater, brackish, and salt marshes. Moreover, this option would provide ample space for restoration of a broad 30 horizontal to 1 vertical transition zone along the outboard side of the new levee, which would transition into the restored tidal salt marsh. The large transition zone would allow for tidal marsh migration due to SLR. Alternative D provides the greatest opportunity to restore transition zone habitat.

Chapter 7: PRELIMINARY CONCLUSION AND RECOMMENDATIONS

Proper function of the existing tide gate structure is necessary to maintain relatively low water surface elevations within the PAFB. These low water elevations, or low tide conditions, serve to

²⁸ Refer to Appendix B for preliminary cost details

increase flow delivery and thereby provide flood protection for creeks tributary to the PAFB (Adobe, Barron, and Matadero Creeks). The PAFB also supports fresh and brackish water habitats for a wide range of wildlife.

The tide gate structure was originally constructed in 1956. Emergency repairs were completed by the Water District in September of 2012 to address unintended water flow beneath the structure. Immediately following these repairs, which mainly consisted of pumping concrete to fill voids beneath the slab, a physical inspection was performed to confirm the overall structural integrity of the tide gate structure. An inspection report (Mark Thomas & Co, 2014) was prepared to summarize the above and below water investigation. The report determined that the tide gate structure was generally in good condition and recommended relatively low cost repairs to extend the structures life time. Conceptual Alternative B would execute these recommended repairs over the short term without addressing SLR affects to the PAFB.

In 2014, a hydrology and hydraulics study (Schaaf & Wheeler, 2014) was prepared to assess the PAFB and contributing watershed. As part of the effort, a planning level report was prepared with conceptual measures to address SLR effects to the PAFB. The report revised existing watershed hydrology and updated the PAFB hydraulic model. The report concluded that adding volume to the PAFB by connecting the Renzel marsh or dredging the bottom of the basin would provide little and no improvement, respectively. The report further concluded that installing additional tide gates would be more effective than increasing storage volume to increase PAFB hydraulic performance. The report also concludes that at some point, SLR impacts are expected to require the use of mechanical pumping and an increase to the height of outboard levees to maintain PAFB hydraulics.

Conceptual Alternative C provides some detail for this scenario; however this alternative will require a high level of cooperation with other projects to acquire funding, complete plan and design, and obtain construction permits from multiple agencies. As such, Conceptual Alternative C would not be constructed for a number of years.

Conceptual Alternative D is a variation of Conceptual Alternative C that provides greater habitat improvements; however this alternative would likely require additional flood protection improvements (i.e. floodwall increases) to Adobe, Barron, and Matadero Creeks and would require a significantly larger pump station to maintain PAFB hydraulic performance. Similar to Conceptual Alternative C, this project would require a number of years to construct.

The Project team recommends a two phased approach to improving the PAFB. In the first phase, Conceptual Alternative B will be implemented to immediately repair the tide gate structure and ensure the hydraulic performance of Adobe, Barron, and Matadero Creeks. The estimated cost for Conceptual Alternative B, is estimated to be \$200,000.

The second phase will be to coordinate District resources over the intermediate term with ongoing external efforts that include the PAFB. These projects include the SFCJPA SAFER Bay Project, the District's Shoreline Project, the South Bay Salt Pond Restoration Project and projects under development by the City of Mountain View. The Project team expects that this intermediate term and collaborative project would likely result in a variation of either Conceptual Alternative C or D. The estimated cost for Conceptual Alternatives C and D are \$114,673,000 and \$164,662,000, respectively.

Chapter 8: REFERENCES

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