DRAFT FINAL TECHNICAL MEMORANDUM

PROJECT: San Francisquito Creek **DATE**: June 5, 2023

SUBJECT: Existing Conditions Hydraulic Model Update
Post 2022 New Year's Eve Flood

PREPARED: Jack Xu, PE, CFM

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1. PURPOSE

This report aims to determine why the observed flooding that occurred during the New Years Eve (NYE) flood event on December 31st, 2022, deviates so drastically from the expected flooding informed by the existing conditions San Francisquito Creek model. The second half of the report details how the existing conditions model will be revised given this new information.

2.1 MODEL HISTORY

The original base model was built in 2009 by Noble Consultants for USACE[1] (2009 Noble Model). This study performed historical calibrations and served as the baseline geometry on which all subsequent models were produced. Work included a flow calibration using high water marks from 3,730 cubic feet per second (cfs) to 4,840cfs on historical storm events between 2000 and 2006, as well as a qualitative assessment of the 1998 storm of record.

Over time, various minor and localized changes to the Creek were added to the model geometry, as well as geometry and parameter enhancements. Roughness values were not changed. Hydraulics[2] and hydrology were updated by Valley Water in 2015 and 2016. This model also included 2D overland floodplains connected to the 1D model[3], utilizing new features of the HEC-RAS[4] modeling software. The model went through USACE District Quality Control (2016 Valley Water (VW) Model) and was used as the existing conditions baseline model for project planning and design.

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[1] Noble Consultants, USACE. San Francisquito Creek - Development and Calibration/Verification of Hydraulic Model. April 17th, 2009.

[2] Xu, Jack. Santa Clara Valley Water District. San Francisquito Creek – Pre-Project Conditions Hydraulic Model. November 9th, 2016.

[3] 1D (one-dimensional) models are typically used for design and capacity analysis in channels. 2D (two-dimensional) models are used for floodplain analysis and are more time/labor/data intensive.

[4] Hydraulic Engineering Center – River Analysis System. Free modeling software used extensively and developed/maintained by the US Army Corps of Engineers.

2.2 MODEL DISCREPANCY

When running the NYE storm event through the 2016 VW Model, Water surface elevations (WSEs) were two feet lower in many locations (Figure 1) when compared to collected High Water Marks (HWMs). Appendix B shows the 2016 VW Model's projected 100yr flooding versus the NYE flooding, which was near a 25yr event. From the data, the model severely underpredicts both the flooding and WSE in areas downstream of Pope Chaucer Street Bridge.

2.3 MODEL INVESTIGATION

Three general input parameters in the existing model were checked to determine if they could cause a two-foot difference in WSEs:

- Model hydrologic input data.
- Model physical geometry input data.
- Model empirical roughness coefficient.

2.4 MODEL INVESTIGATION: HYDROLOGIC DATA

The USGS stream gage at Stanford, which is almost 4 miles above the most upstream flooded locations downstream of Middlefield Road, recorded a peak flow of 5,880cfs for the NYE storm. Several uncertainties exist with this data:

- Between the stream gage and the first flood location, there is additional runoff from storm drains and natural flows.
- There is a slight attenuation of the flood peak from the stream gage to the flood location as water volume is diffused within the creek channel.
- There is also some error and uncertainty in the United States Geological Survey (USGS) peak flow value. The morning of the flood, the gage read upwards of 7,600cfs. This peak flow was revised shortly afterwards to 6,340cfs, and eventually to the current value of 5,880cfs based on a high flow measurement of 4,460cfs during the flood. The last value has been approved by USGS and is official.

To account for local inflow, the USGS recorded flow was increased by 7% (approximately 400cfs). The additional 400cfs is approximately the runoff accrued between the USGS gage and Pope Chaucer in the hydrologic model[5] for design storms between the 10yr and 100yr return period (NYE was about a 25yr return period). This estimate Is essentially residual baseflow and is similar for most return periods due to the lag time between the peak rainfall and peak creek flow.

When performing sensitivity analyses by increasing the recorded USGS flow, the resulting WSEs increase by about a foot upstream of Pope Chaucer Bridge but are smaller downstream. This shows that flow errors in the model (within reason) could not have been solely responsible for the unanticipated two-foot rise in WSE downstream of the Pope Chaucer Bridge.

[5] Xu, Jack. SCVWD. San Francisquito Creek Hydrology Study – Final (Addendum #1). December 2016.

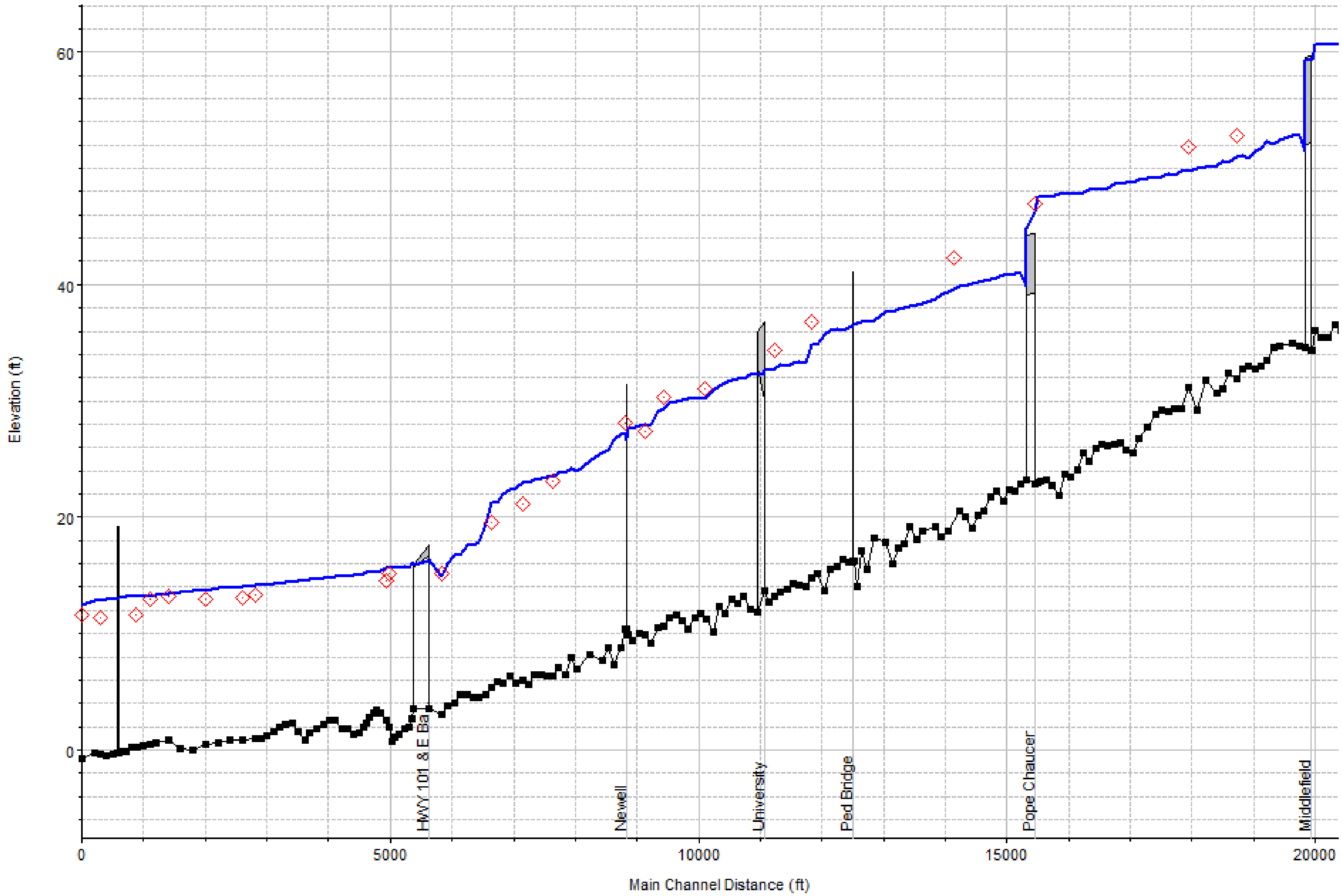

FIGURE 1: 2016 VW Model WSE (Blue) & Observed HWMs (Red) for NYE

2.5 MODEL INVESTIGATION: PHYSICAL GEOMETRY

Physical geometric data in the model that would cause a two-foot increase in WSEs would come from the 1D cross-section data used for channel hydraulics. It is possible that changes in the Creek from erosion and sediment deposition may significantly change the shape of the channel. To determine if there were changes to the channel geometry since the original model development and historic flood observations, comparisons were made to a fly-over LiDAR scan done in 2020 for areas where there is open sky and limited vegetation cover. Initial indications show little change that would significantly affect hydraulics and WSEs. Bridge cross-section data were also verified against existing ground surveys.

These cross-section spots-checks only cover a fraction of the Creek, and do not compare well under vegetation canopy since LiDAR cannot penetrate dense foliage. A future in-channel survey is planned to be performed in the summer once the prevailing baseflow in the Creek is low enough to fully discern differences.

2.6 MODEL INVESTIGATION: ROUGHNESS COEFFICIENT

After eliminating possible sources of error from the hydrologic and physical geometry data, the roughness coefficient remained as the most likely reason for the WSE discrepancy in the model. Either the physical properties of the Creek differed so much from the past that the WSEs were higher, or that the original model underpredicted the roughness, or both. Roughness increases could come from either or both of the two most likely sources: increased vegetation growth in the channel and an increased presence of debris caught on the vegetation.

CREEK CHANGES

To compare historic conditions, pictures and descriptions from Valley Water's 2012 flood report[6] were used. Older flood reports, such as the one from 1998, do not have quality pictures to compare. Analysis does not show any significant difference in vegetation (Figure 3). In addition, Valley Water maintenance staff perform a creek walk every fall and have not flagged any significant differences in recent memory. The Creek's steep banks and frequent high velocity flows also would inhibit the establishment of long-term vegetation. All this evidence supports the conclusion that vegetation has not changed significantly.

However, the difference in observed floating debris is very stark upstream of Pope Chaucer Bridge. Figure 4 shows significantly more floating debris in the NYE flood event at a peak flow of 5,880cfs versus the 2012 flood event with a peak flow of 5,400cfs (USGS gage at Stanford). However, in the previous Figure 3, the debris remaining on vegetation limbs appear similar.

Floating debris are typically seen during the larger 'first flush' storm events of the season, like the NYE flood. In 2012, there was a 3,000cfs flow a few weeks prior which likely flushed all the floating debris. From the evidence, there was likely more debris present during the NYE flood, causing increased roughness in the channel by creating impediments to water flow. This is backed up by comparing recently acquired data on breakout locations between the NYE flood and the 1998 flood of record (Figure 2), which shows similar breakout points for both storm events although the NYE flood was approximately 800cfs less.

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[6] Santa Clara Valley Water District. Flooding and Flood Related Damages Report – San Francisquito Creek, Santa Clara County, December 21 – 23, 2012. September 2013.

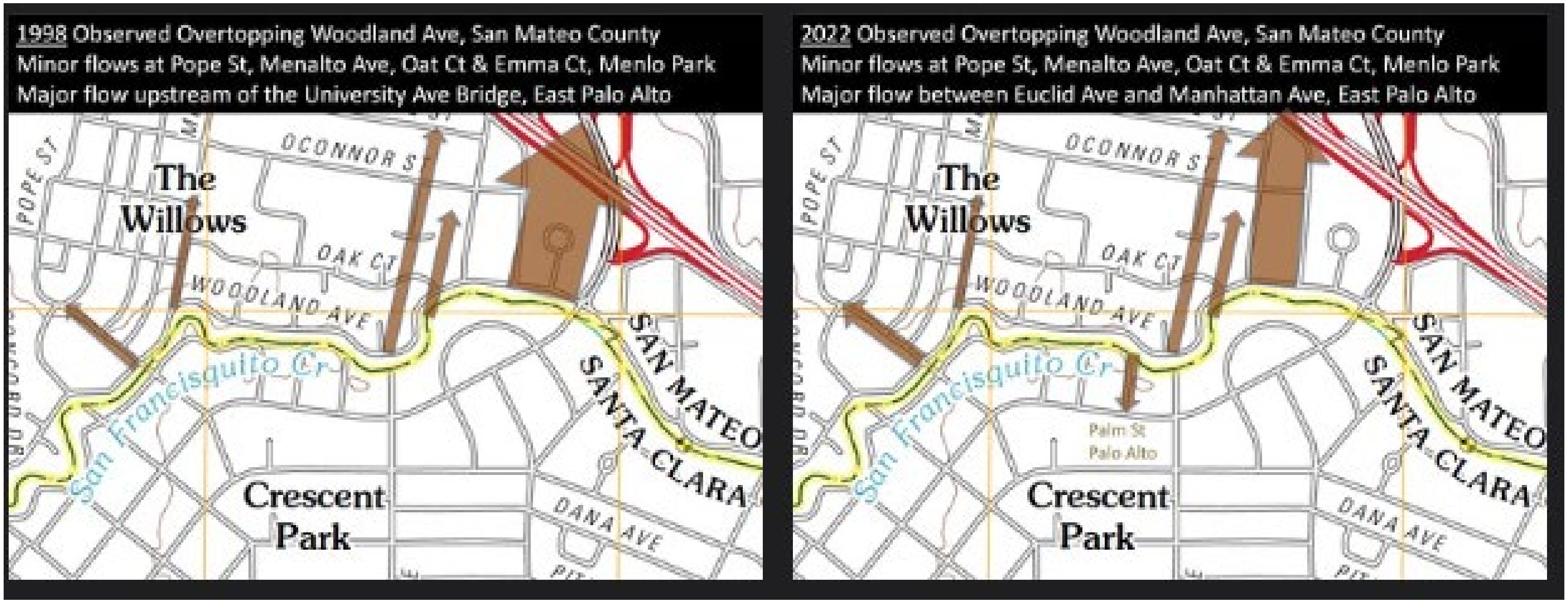


FIGURE 2: Flow Breakout Comparison Between 1998 (left) and 2022 (right). Credit: Jim Wiley, Menlo Park Resident.

FIGURE 3: Post Flood Picture in December 2012 (Top) and December 2022 (Bottom) upstream of University Avenue.

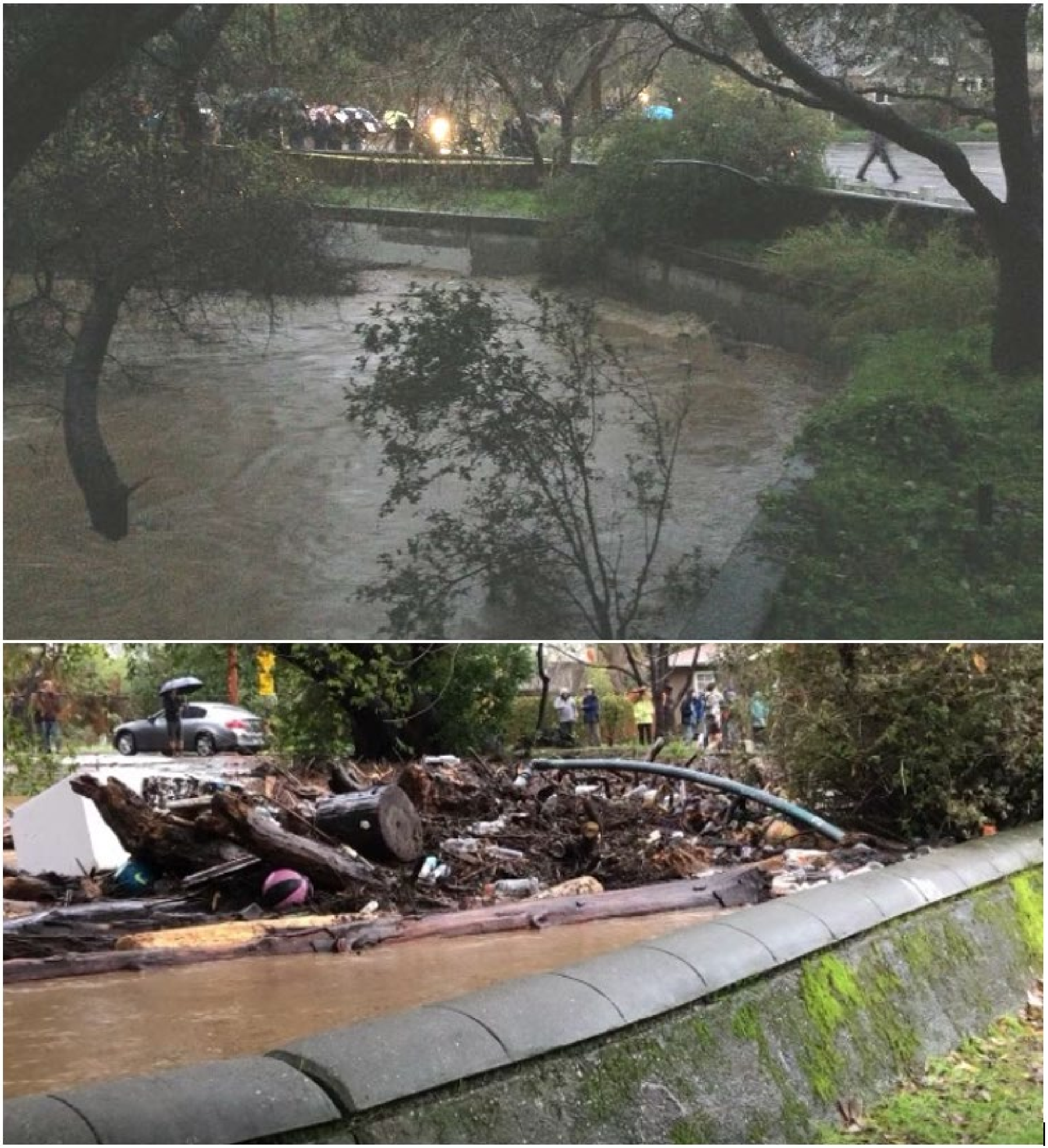


FIGURE 4: Debris Amount in December 2012 (Top) and December 2022 (Bottom) upstream of Pope Chaucer Bridge

ORIGINAL MODEL

Looking beyond possible changes to the Creek over time, the origin of the base roughness values was also explored. In the 2009 Noble Model, calibrations were only done at four locations along the entire length of the Creek for several storm events ranging from 3,730cfs to 4,840cfs between 2000 and 2006. Only one calibration point at Pope-Chaucer Bridge was in the vicinity of the flooding. This specific calibration point is not useful to determine roughness in the channel because it is immediately upstream of a location where the WSE is heavily controlled by the bridge constriction instead of the vegetation. This renders the roughness calibration in the flooding reaches ineffective in validating the model.

Work was also done in the 2009 Noble Model to look at the 1998 flow of the record. Qualitative comparisons were done with the water surface elevations with respect to the top of banks at known flooding areas and a conclusion was reached that they were generally in agreement. However, it appears that the flow rate in the 1D steady-state model may not have been reduced to account for spilling, assuming a constant peak flow throughout the Creek. The model would show artificially high WSEs for the 1998 event, masking or underestimating roughness.

The calibrations for the 2009 Noble Model also only used the USGS flow data and did not add additional local inflow, likely underestimating the flow moving through the flood-prone reaches slightly. This would have not made a huge impact to the results but would compound the error.

When developing the 2016 VW Model, inundation extents using the 1998 flood were compared, which showed only flooding occurring upstream of Pope Chaucer Bridge. These matched maps published in Valley Water's 1998 Storm Report[7], which we now know to be missing many flooded areas. It is also noted that these maps did not include flooding on the northern side of the Creek, presumably because it was outside the County and not within VW jurisdiction– an important detail that was not clear. Another report[8] that was recently uncovered shows flooding in East Palo Alto, but did not include many breakout locations in Menlo Park or in Palo Alto near University Ave. However, after recent conversations with residents that lived through the 1998 flood, it came to light that many of the same areas downstream of Pope Chaucer Bridge that flooded in 1998 also flooded again during the NYE flood. In addition, a smaller flood in 2012 upstream of University Ave was not included in previous model calibrations due to its localized nature. It was attributed at the time to a fallen tree at the time. A temporary wooden floodwall was since built in that location.

[7] Santa Clara Valley Water District. Report on Flooding and Flood Related Damages in Santa Clara County, February 2-9, 1998.

[8] Cushing, Katherine Kao. After the Flood Waters Receded: Assessing the Economic Impacts of San Francisquito Creek's February 1998 Flooding. March 1999.

CONCLUSION

These investigations reveal that the most significant contributor to the mismatch in observed verses modeled WSE is the underestimation of the roughness values used in the model. This underestimation likely began in the original model, where roughness was first predicted by categorizing vegetation in the field. The 2009 Noble Model was then calibrated to the available limited data. The underpredicted roughness coefficients were then carried forward in subsequent iterations of the model into the 2016 VW Model.

Calibrations performed in the 2016 VW Model were made by comparing the 1998 flood extents with available flood reports. The modeled breakouts matched the report, which we now know to be missing key flooding information. In addition, smaller scale flooding in 2012 was also attributed to fallen trees instead of overall creek capacity. These two scarce data points falsely validated the original coefficients.

These findings suggest that if the Reach 2 project were implemented as currently proposed, and the Pope-Chaucer Bridge were replaced with a new bridge that does not restrict flow, less flooding would occur during an event similar to the New Years Eve storm at the bridge and upstream at Hale and Seneca, but more flooding would occur downstream of the bridge at Palm Street in Palo Alto, Menalto Road and Oak Avenue in Menlo Park, University Avenue in Palo Alto and East Palo Alto, and Cooley Road in East Palo Alto. Flood waters that currently exit the channel upstream of the Pope-Chaucer Bridge would be transferred downstream, and much of the low-lying areas on both sides of the creek would continue to be in the floodplain.

3.1 REVISED MODEL: PHYSICAL GEOMETRY

Based on the conclusions detailed previously in the model investigations section, the existing conditions 2016 VW Model were updated.

TOP OF BANK - LATERAL STRUCTURES

In the 2016 VW Model, HEC-RAS lateral structure elements were used to connect the riverine cross sections to the 2D floodplain. The tops of the lateral structures, which represent the top of bank and first flood elevations, were based off the 1D cross sections. The 1D cross sections were originally built in the 2009 Noble Model and relied on an elevation surface created from a combination of field surveys and LiDAR.

In the revised model, old and new survey data for the tops of banks were gathered and reviewed (Figure 5). The points were conflated to match with the lateral structure placements, as these points were close but not identical to the lateral structure locations in the model due to overlap with existing cross sections. LiDAR data was not used due to the heavy vegetation canopy on most of the bank.

A handful of areas that experienced overbanking and did not match observed flooding were also reviewed and modified accordingly by shifting the elevation points slightly to “plug holes”. This was only done if the editing appeared reasonable given the relative density of survey points nearby, suggesting a possible outlier.

LiDAR 2D TERRAIN

The 2016 VW Model used a 2006 LiDAR scan as the terrain model for 2D flow modeling. The revised model uses a 2020 LiDAR scan for 2D flow modeling.

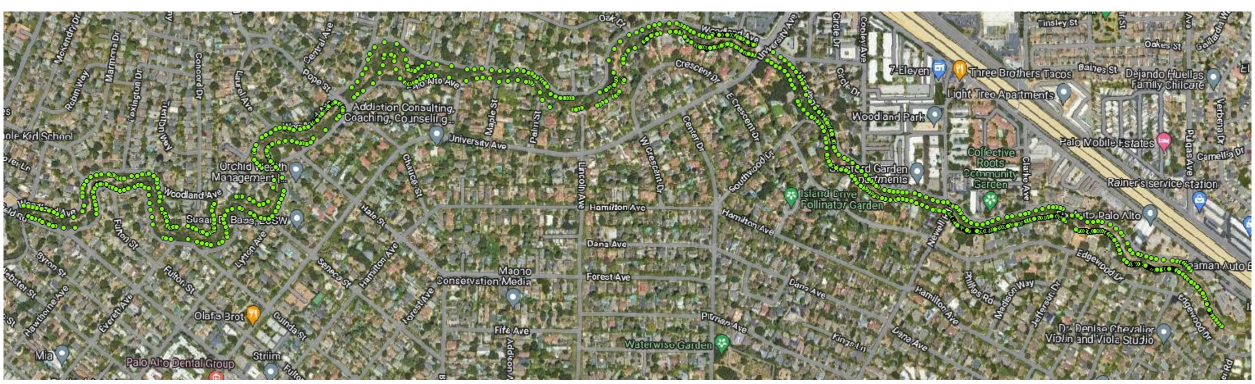


FIGURE 5: Top of Bank Survey Shots

2D ROUGHNESS VALUES

At the time the 2016 VW Model was completed, 2D modeling using HEC-RAS was relatively new and methodology on overland flow roughness values was based on best judgement at the time. Since then, additional guidance has been issued by the USACE User's Manual for HEC-RAS. Coupling that with the known overland flooding patterns in the NYE flood event helped further refine the roughness values. In general, 2D roughness values were increased significantly given the prevalence of shallow flooding in this area (Table 1). Since the floodplain for the Creek is mostly developed urban space, the increase was done across the board and no effort was made to calibrate land covers that do not appear in the flooding area.

It is worth noting that these values do not affect creek capacity but make more of an impact on the inundation floodplain for shallow overland flooding.

TABLE 1: Overland 2D Roughness

Land Cover Name	Revised n-Value	Superseded n-Value
Barren Land Rock/Sand/Clay	0.2	0.025
Cultivated Crops	0.3	0.06
Deciduous Forest	0.3	0.1
Developed, High Intensity	0.3	0.025
Developed, Low Intensity	0.3	0.035
Developed, Medium Intensity	0.3	0.035
Developed, Open Space	0.3	0.03
Emergent Herbaceous Wetlands	0.3	0.045
Evergreen Forest	0.3	0.1
Grassland/Herbaceous	0.3	0.03
Mixed Forest	0.3	0.1
Pasture/Hay	0.3	0.035
Shrub/Scrub	0.3	0.04
NoData	n/a	0.03
Building*	2.0	1.0
Street	0.03	0.02

CHANNEL CROSS SECTIONS

To rule out bank erosion, sediment deposition, and/or scour issues (outside of the sediment that was mobilized during the event), in-channel creek surveys are planned to be performed in the summer of 2023 when prevailing flows dissipate. The model and this report will be updated with the results of the in-channel surveys.

3.2 REVISED MODEL: ROUGHNESS COEFFICIENT

Updated 1D roughness coefficients for the channel are detailed below in Table 2. In general, there is a substantial increase in roughness downstream of Middlefield through Newell Road, which is the region of the creek channel where the flooding occurred. The model roughness coefficient was increased after all available physical updates were applied.

TABLE 2: 1D Channel Roughness

Reach	Original Roughness	New Roughness
Upstream Middlefield	0.0408	No Change
Middlefield to Pope Chaucer	0.0408	0.065
Pope Chaucer to Newell	0.038	0.050
Newell to US-101	0.0285 - 0.038	0.028 - 0.035
Downstream US-101	0.03	No Change

Roughness values were increased from the original roughness coefficient until the WSE generally matched the observed HWMs (Figure 6). This validates the 1D roughness values in the channel. In addition, overbank locations and inundations areas were also compared to validate the 2D model (Figure B-2). Flooding areas and extents generally match. Deviations due to storm drains and physical barriers (property fences and walls) are expected. For example, it is known that on the southern side of the Creek, Palo Alto storm drains mostly flow towards a pump station that was collecting overflow during the NYE storm, reducing the flood footprint. The model corroborated observations that reported little to no flooding during the NYE second peak, which reached 5,430cfs at the USGS gage.

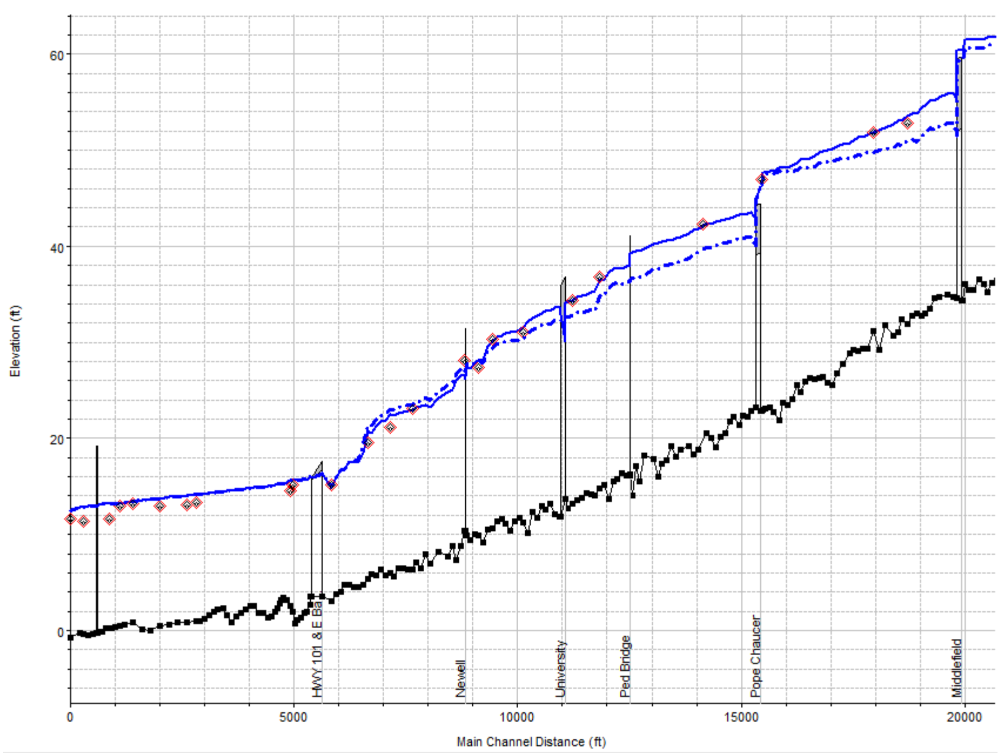


FIGURE 6: Revised Existing Conditions Model (Solid Blue), 2016 VW Model (Dashed Blue) & Observed HWMs (Red) for NYE

3.3 CALIBRATION UNCERTAINTY

The HWMs collected during the NYE storm will have some level of inaccuracy. In addition, the HEC-RAS model of the Creek channel is inherently a 1D model and cannot account for WSE increases due to bends in the Creek. Roughness values are also generalized within a reach and will not account for localized jumps in the WSE from debris and vegetation. There is some level of uncertainty in the final calibrated model, likely within +/- one foot. Table 3 details the differences in WSEs and HWMs based on surveyed data. Appendix A details the differences in WSEs and HWMs based on field pictures (taken by multiple sources) when compared with topographic LiDAR. Given how close the WSE for the NYE storm event was to the top of bank, any flood risk reduction project design utilizing this model should take this uncertainty into account.

TABLE 3: Revised Model Water Surface vs. Observed High Water Marks (Surveys)

Station	Observed HWM minus Modeled WSE (feet)
49+26	-0.6
49+75	-0.2
58+38	0.0
66+38	-1.6
71+40	-1.5
76+39	0.1
88+14	1.6
91+30	-0.6
94+31	0.5
101+13	0.0
112+33	-0.8
118+33	0.2
141+33	1.1
154+45	1.1
179+43	1.0
187+21	0.1

4.1 EXISTING CREEK CAPACITY

A full review of historical and recent flows and flooding observations was conducted to determine the true creek capacity of San Francisquito Creek and summarized below.

TABLE 4: Historical Peak Flows and Flood Impacts Upstream US-101

Year	USGS Peak Flow (cfs)	Flood Impacts
02/03/1998	7,200	Middlefield Road, Pope Chaucer Road, Woodland Avenue upstream and downstream of University Avenue.
12/31/2022	5,880	Pope Chaucer Road, Woodland Avenue and Palo Alto side upstream and downstream of University Avenue.
12/22/1955	5,560	Pope Chaucer, Middlefield Road, US-101.
12/31/2022	5,430	Second peak from the NYE flood – Pope Chaucer did not overtop.
12/23/2012	5,400	Flooding along Woodland Avenue upstream and downstream of University Avenue, with most spills occurring near Euclid and traveling northward through East Palo Alto.
01/04/1982	5,220	Slight overbanking near University Avenue.
02/07/2017	4,860	None reported upstream of US-101.

Discarding the data from 1955 due to heavy changes to the channel since the rapid urbanization of the surrounding land, and utilizing the data within recent memory, the following observations are made:

- Downstream of Middlefield, the Creek has capacity up to about 5,000cfs (measured at the USGS gage) before flooding occurs.
- Somewhere between 5,000cfs and 5,400cfs, flooding begins around University Avenue on both the Palo Alto and East Palo Alto sides of the channel.
- Between 5,400cfs and 5,880cfs, areas upstream of Pope Chaucer begin overtopping.

Since these are all based on flow measurements at the USGS gage, there are uncertainties about the actual capacities due to additional local runoff and measurement errors. To translate the above observations into actual capacities, adding 400cfs would be a safe assumption. For example, the entire creek likely has a capacity near 5,400cfs (first bullet point).

4.2 RESIDUAL 100-YR FLOW

Using the revised model, the 100yr design flow[9] was routed through the model to determine flow distributions after channel overbanking. The resulting flow distribution is compared with the previous 2016 VW model below. Appendix B also compares the revised 100yr floodplain to the 2016 VW model.

Results show that much more flow leaves the Pope Chaucer area as compared to the 2016 model run. Additional overbanking also occurs in the University Avenue area, which matches observed NYE flooding, when compared to the 2016 run.

[9] Xu, Jack. SCVWD. San Francisquito Creek Hydrology Study – Final (Addendum #1). December 2016.

An item of note is the slight increased capacity of Middlefield Road. With the change in existing conditions and roughness, the bridge hydraulics efficiency has slightly increased for Middlefield Road, allowing more water to flow under the bridge. This increase in hydraulic performance is attributed to a change in culvert control conditions due to the submergence of the downstream outlet of the bridge.

TABLE 5: 100yr Flow in Existing Conditions for Old and New Models

Index Point	Existing Condition New (cfs)	Existing Condition Old[10] (cfs)	Difference (cfs)
Middlefield	7,750	7,500	+250
Pope Chaucer	6,360	6,550	-190
University	6,050	6,550	-500
Newell	5,950	6,550	+600
West Bayshore	6,230	6,810	-580

4.3 REVISED REACH 2 PROJECT MODEL SCENARIOS

BASE PROPOSED REACH 2

The current proposed Reach 2 project focuses on localized channel widening in select constriction areas between Pope Chaucer Bridge and Newell Bridge. The revised existing conditions model was updated to create a revised Reach 2 project model. Updates include:

- Planned Reach 2 widening locations.
- Proposed Newell Road Bridge.
- Sedimentation blockage to the US-101 / West Bayshore Bridge in the north culvert cell.
    - The cell was 50% blocked as observed after the NYE storm event.

The Pope Chaucer Bridge was left as existing and the fourth bore of the US-101 Bridge remained closed.

[10] Xu, Jack. Valley Water. SFC Phase 2 Design Flows. 3/16/21.

REVISED RECOMMENDED ALTERNATIVES

With the change in existing conditions, the proposed widening with limited floodwalls will not achieve the same level of protection as originally thought. However, the widening would provide some increase in flow conveyance when compared to the existing conditions.

Three possible alternatives (Alts) based on key flow rates were identified below. These flow rates are through the project reach in question, not at the USGS gage.

1. 5,500cfs – This flow would be safely passed with Reach 2 widening and have approximately 1' of freeboard. The wooden floodwall upstream University Avenue on the East Palo Alto side would need to be replaced. No other top of bank (floodwall) elements are needed. This would theoretically have passed the flows in December 2012 that caused flooding with an extra foot of freeboard within the project reach after water overbanked upstream of Pope Chaucer Bridge.
2. 6,000cfs – This flow would be passed with the same elements as Alt 1 and have no freeboard. This is also approximately the flow that passed downstream of Pope Chaucer Bridge during the NYE flood. Theoretically, if this design criterion were used, the NYE flood would only have affected the area upstream Pope Chaucer and spared the downstream areas.
3. 6,400cfs – This is the flow that would be passed through the existing Pope Chaucer Bridge during a 100yr storm (Table 4).

Resulting WSEs are plotted in Figure C-1 in the Appendix.

DISCUSSION

In general, low spots that limit the conveyance capacity of Reach 2 are mostly focused between Pope Chaucer Bridge and Newell Bridge. There may also be isolated areas of low and high spots due to landscaping features on private property on the Palo Alto side of the creek. Therefore, the findings below are generalized and presented with more of a broad stroke.

To achieve Alt #1, the original Reach 2 widening at several constriction points need to be done. In addition, the wooden floodwall upstream University Avenue on the East Palo Side would need to be replaced.

To achieve Alt #2 above (6,000cfs) and have 1' of freeboard, 2000 linear feet of top of bank floodwalls for approximately 1,000' upstream and downstream of University Avenue would be necessary. These floodwalls would only need to be a foot or so tall.

To achieve Alt #3 (6,400cfs) and have 1' of freeboard, the improvements mentioned previously for Alt #2 would need to be generally a foot higher. In addition, the improvements upstream of University Avenue would need to be extended another 1,000' upstream for a total of approximately 3000 linear feet. In addition, there are private pedestrian bridges that may need to be replaced. This would be due to the existing soffits built at the current channel top of bank, which would be raised if floodwalls were built.

It was also found that sediment blockage of the culvert cell at US-101 caused a slight increase in WSE near the bridge, but the WSE difference became negligible at the locations of flood concern.

TRANSFER OF FLOOD RISK

The Pope Chaucer Bridge provides a constriction that limits the flow that can pass downstream. If capacity was increased at Pope Chaucer and/or the surrounding area, that would increase flows downstream. Therefore, in all these alternatives mentioned above, the Pope Chaucer Bridge is assumed to remain as-is with no other improvements upstream.

However, if improvements were to be made at the Pope Chaucer Bridge, the resulting transfer of flood risk to the downstream reaches would need to be mitigated by increasing Alt 3 to account for the extra flow. This would almost certainly involve increasing the height of existing floodwalls and building new floodwalls along the Creek. In addition, the existing raised asphalt curb gravity wall on the East Palo Alto side and the sackcrete wall on the Palo Alto side upstream of US-101 to Newell Road may also need to be evaluated for structural stability due to the increased WSE from the additional flow.

For Alt 1 and Alt 2, analyses would also need to be performed to ensure that there is no additional flood risk during flows that are larger than the designed flow. For example, if Alt 1 was designed for 5,500cfs with freeboard and the 100yr flow brings 6,400cfs through the reach, flooding may occur in locations that did not flood before due to the improvements.

CREEK SUPERELEVATION

Creek superelevation is a phenomenon that occurs when water flows around a bend in a creek. The water on the outside of the bend moves faster than the water on the inside of the bend, which creates a higher water level on the outside. There are areas on the outside of bends that are shown to have flooded on NYE, but the revised models do not. Superelevation is not considered in the HEC-RAS model and must be accounted for separately.

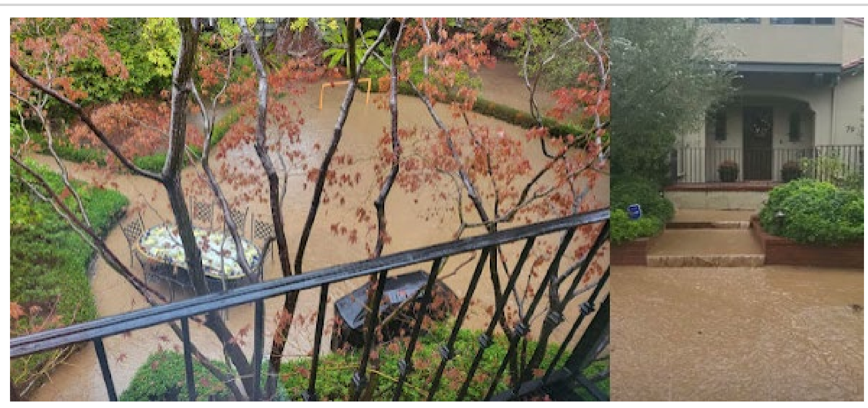
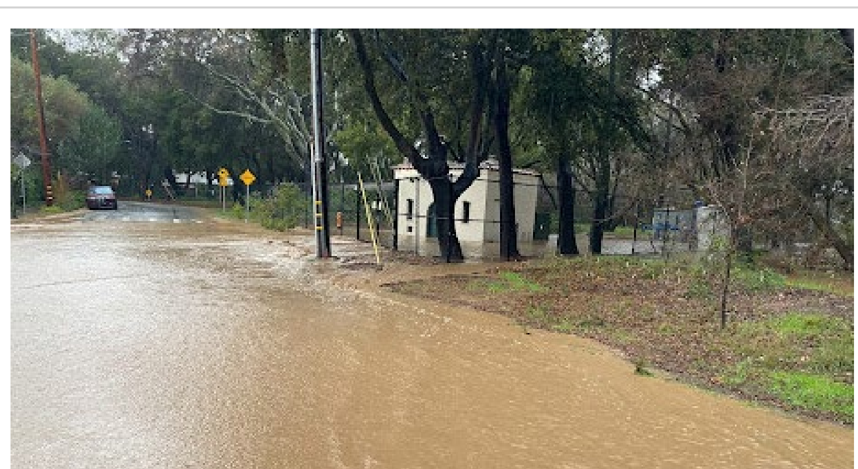
Using a simple methodology[11] from the US Army Corps, an estimate for recommended additional freeboard due to superelevation at various locations ranges from 0.75’ to just under 2.0’ based on the following parameters:

- Channel width at WSE: 60’ – 100’
- Mean Channel Velocity: 5 ft/s – 10 ft/s
- Radius of Curvature: 100’

Whatever alternative is eventually selected, a comprehensive assessment of bends in the creek should be performed and the proper factors of safety applied.

[11] USACE. EM 1110-2-1601 Hydraulic Design of Flood Control Channels. 7/1/1991, Revised 6/30/1994.

APPENDIX A: Revised Model Water Surface vs. Observed High Water Marks (Photos & LiDAR)

Picture Location	LiDAR Elevation	Modeled Elevation	Picture
Upstream University Avenue, Left Bank	34' at Pavement	34.5'	
Private Pedestrian Bridge 1,500' Upstream of University Avenue	40' at Top of Bank	39.5'	
Creek Overflow through Private Residence on Crescent Road Upstream University Avenue	35'	35.5'	
Woodland Avenue near Emma Lane	41' on Roadway	40.5'	
Palo Alto Ave Upstream Pope Chaucer Bridge near the City of Palo Alto Pump	47'	48'	

APPENDIX B: Modeled and Observed Inundation Mapping

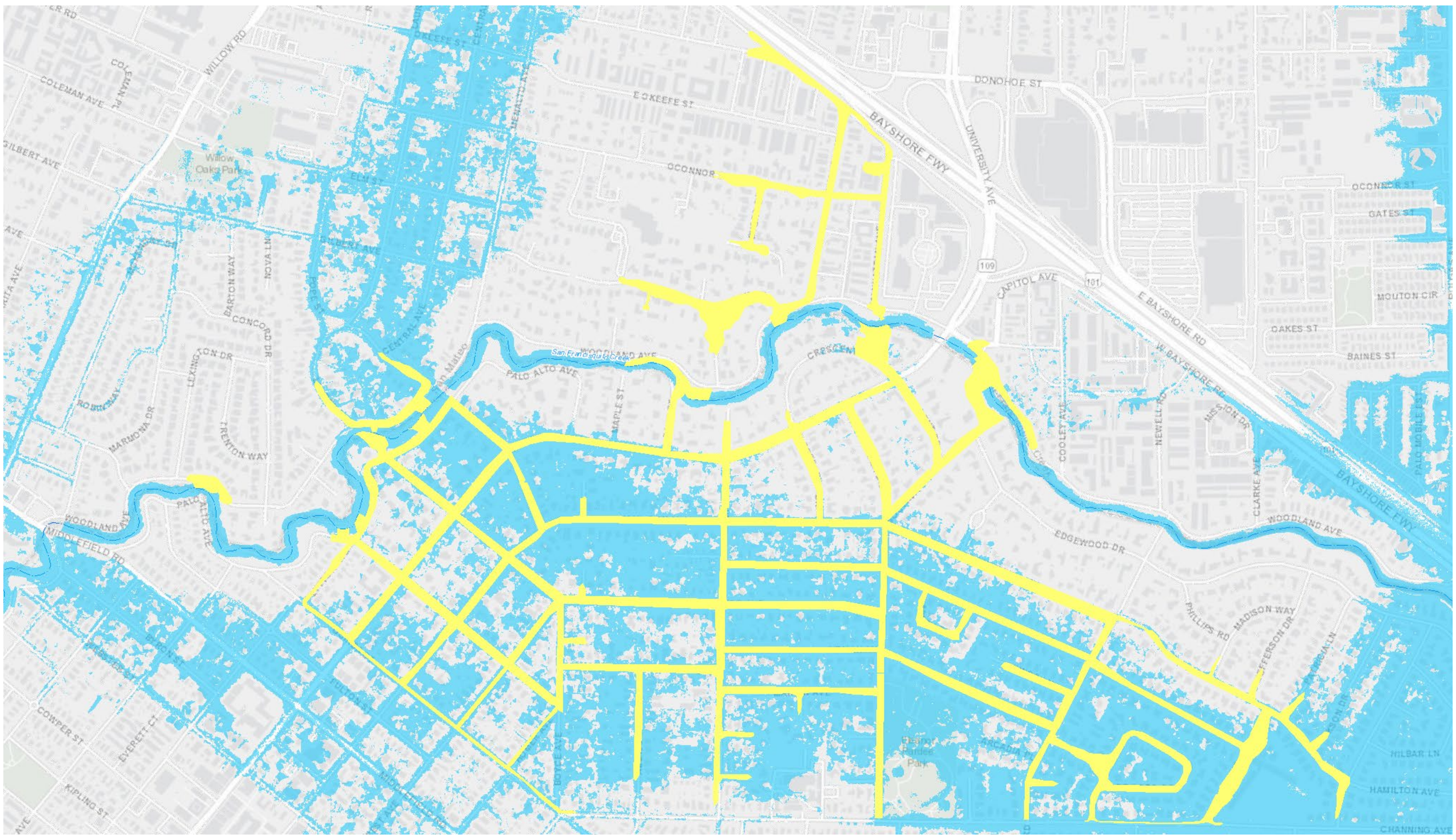


FIGURE B-1: 100yr 2016 VW Model Flooding (Blue), NYE Flooding (Yellow)

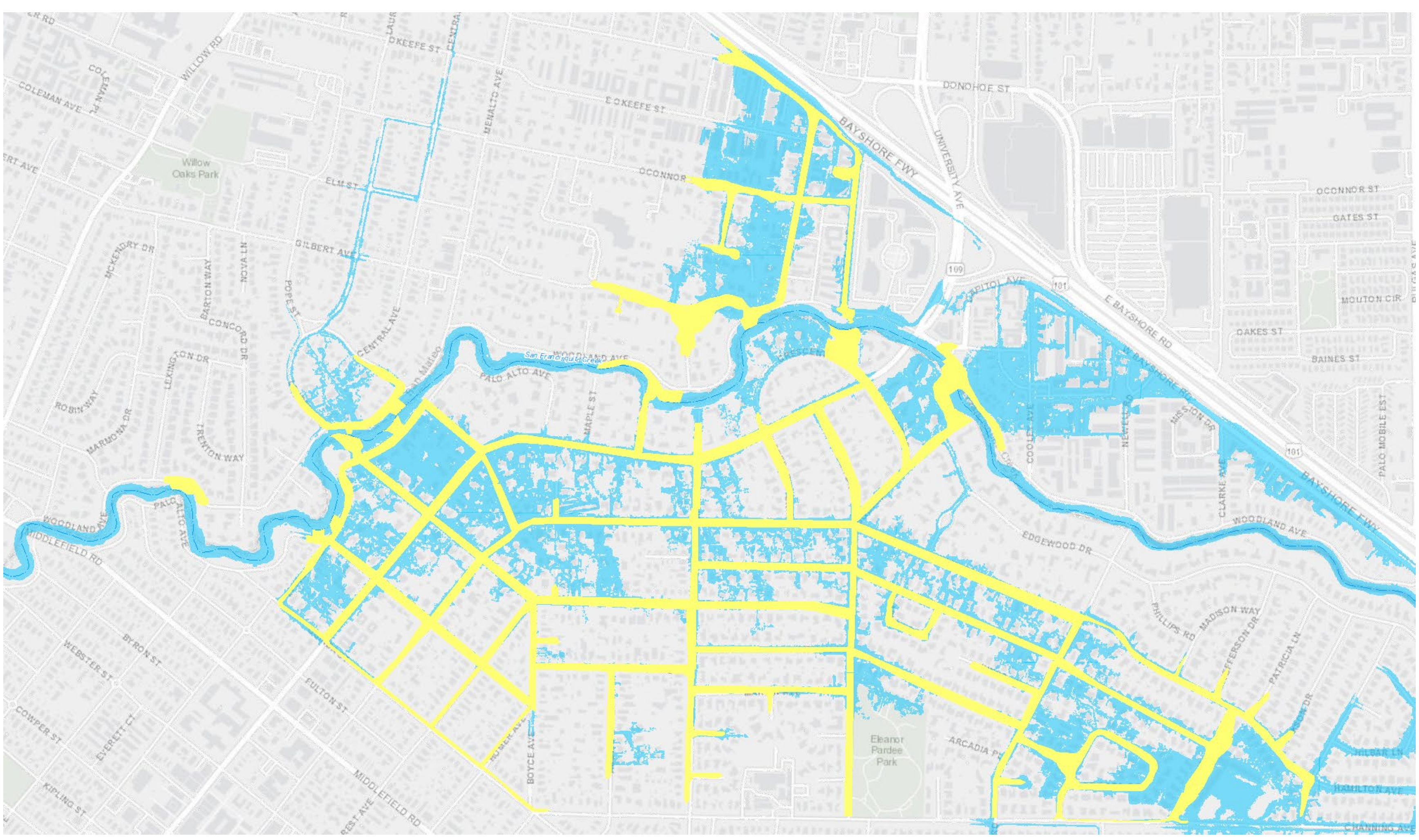


FIGURE B-2: Revised Model NYE Flooding (Blue), NYE Approximate Observed Flooding (Yellow)

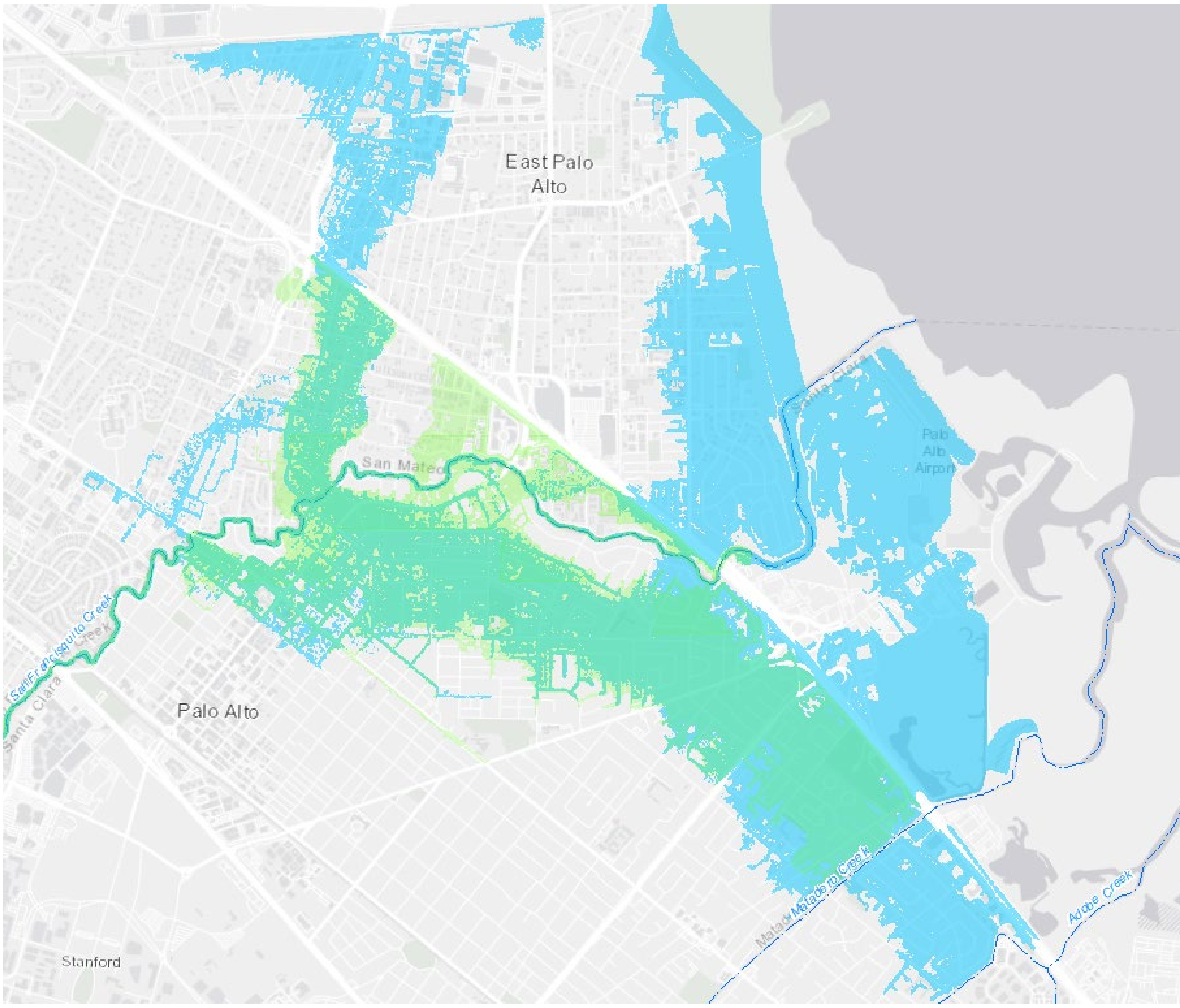


FIGURE B-3: Revised Model 100yr (Green), 2016 WY Model 100yr (Blue)

APPENDIX C: Revised Proposed Reach 2 WSE

FIGURE C-1: Proposed Reach 2 Widening WSE for Select Flows with Revised Model