TECHNICAL MEMORANDUM

TO: Aaron Fulton, Sonoma Water

CC: Carlos Diaz, Sonoma Water

PREPARED BY: Katie Hogan, PE, CFM, Woodard & Curran
Millicent Cowley-Crawford, PE, CFM, Woodard & Curran

REVIEWED BY: Kathleen Higgins, PE, Woodard & Curran

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RE: Upper Petaluma River Watershed Detention Feasibility Analysis

1. SUMMARY AND BACKGROUND

The Petaluma River and its tributaries are subject to severe flooding during heavy storm events. The Sonoma County Water Agency (Sonoma Water) is responsible for the maintenance of several flood control channels in portions of Zone 2A in the Petaluma watershed. Sonoma Water's Upper Petaluma River Watershed Flood Control Project (Project) investigates the feasibility of flood reduction and groundwater recharge in the Upper Petaluma River watershed. This technical memorandum (TM) documents the efforts of Sonoma Water and its contractor, Woodard & Curran, along with sub-consultants Balance Hydrologics and McMillan Jacobs (the Team) to assess the potential of various concepts to achieve project benefits.

Previous phases of the Project have included Scoping, a Hydraulic Model Update, and Concept Screening. These efforts identified objectives and approaches to flood reduction and groundwater recharge and evaluated floodplain and detention storage concepts at generalized locations in five tributaries across the watershed to determine their relative effectiveness. This phase of the Project leverages prior findings to conduct a Feasibility Analysis that screens areas of the watershed, locates project concepts, and simulates their effect on flooding along the Petaluma River and its tributaries. This technical memorandum (TM) includes discussions of:

- Extending a Previous Ranking of Subwatershed Effectiveness to Unmodeled Subwatersheds
- Preliminary Screening to Identify Locations for Basin Analysis
- Quantification of Hydraulic Impacts of Basins
- Basin Viability Scoring, Based on Flood Reduction, Constructability, and Potential Costs

- Results and Recommendations for Next Steps

Results of the analyses demonstrate that offline detention basins have the potential to provide significant flood reduction in Zone 2A, as measured at a variety of locations. Flood reductions of up to 0.8 feet may be possible in certain locations of the lower watershed. Localized flood reductions on the order of 1 to 3 feet may also be expected immediately below some detention basins. Considering the potential impact of these individual basin concepts, a hypothetical multi-location project was also investigated and has the potential to provide significant cumulative flood reductions. Overall, analyses indicate that some locations are more effective than others at providing flood reduction benefits and may cost less to implement. These feasibility differentiators provide a context for engaging landowners and identifying a future project location for implementation.

2. SUBWATERSHED RANKING

The previous phase of the Project included a concept screening process that investigated the relative benefit of implementing floodplain and offline storage within the Willow Brook, Liberty, Lichau, Marin, and Lynch creeks (shown in teal on **Figure 1**) based on a combination of hydrologic and hydraulic characteristics and modeling. The process resulted in a ranking table summarizing the most effective project type (offline detention or floodplain storage) by subwatershed for the 10-year and 100-year events. Previous findings are documented in the Concept Screening Analysis Memorandum dated July 2020 and the Tributary Selection Memorandum dated May 2019. It should be noted that the concept screening focused on Willow Brook, Liberty, Lichau, and Lynch creeks, which represented a range of typical watershed characteristics and expected responses to flood detention in the study area but did not include modeling or analysis on Wiggins, Wilson, Corona, and Capri Creek subwatersheds or the Upper Petaluma River subwatershed. Updating previous analyses to include these additional subwatersheds is essential to understanding how detention projects along Wiggins, Wilson, Corona, and Capri Creeks and the Upper Petaluma River watershed perform relative to other subbasins and to ensure a comprehensive assessment of where detention projects have the highest potential to reduce flooding.

The first task of this phase of the project entailed extrapolating the ranking of concepts and tributaries to un-modeled tributaries (as shown in blue on **Figure 1**) to obtain a more complete representation of potential project effectiveness across all subbasins. The extrapolation was based on similarities in the characteristics of watershed area, rainfall, soils, land use, and peak flood flows to infer the response of un-modeled tributaries to floodplain and offline storage projects and potential flood reduction benefits. Based on these watershed characteristics, it was determined that Marin Creek was most similar to Wilson and Wiggins creeks, Lynch Creek was most similar to Corona and Capri creeks, and Liberty was most similar to the Upper Petaluma River. This extrapolation process resulted in an updated ranking table for all subwatersheds that provides perspective on the best areas for potential projects to meet flood reduction objectives. The ranking table has been split into two tables for this TM: detention basin scenarios (Table 1) and floodplain modification scenarios (**Table 2**) for both the 10-year and 100-year events. Results indicate that extrapolating the detention basin ranking to un-modeled tributaries shifted the original rankings for both the 10-yr and 100-yr scenarios. For the 10-yr scenario Wiggins and Upper Petaluma moved into a rank of four, comparable to Marin and Liberty creeks, and pushed Lynch to the lowest rank of 13. For the 100-yr scenario, Wiggins moved into a rank of three, comparable to Marin Creek, and Wilson moved into a rank of five. Extending the ranking analysis to un-modeled basins determined that previously unconsidered projects on Wiggins and Wilson Creek, and to a lesser extent on Upper Petaluma are expected to provide a similar flood reduction response as Marin and Liberty Creeks. This information was used to support decision-making during the later prioritization of concept locations discussed in **Section 3**.

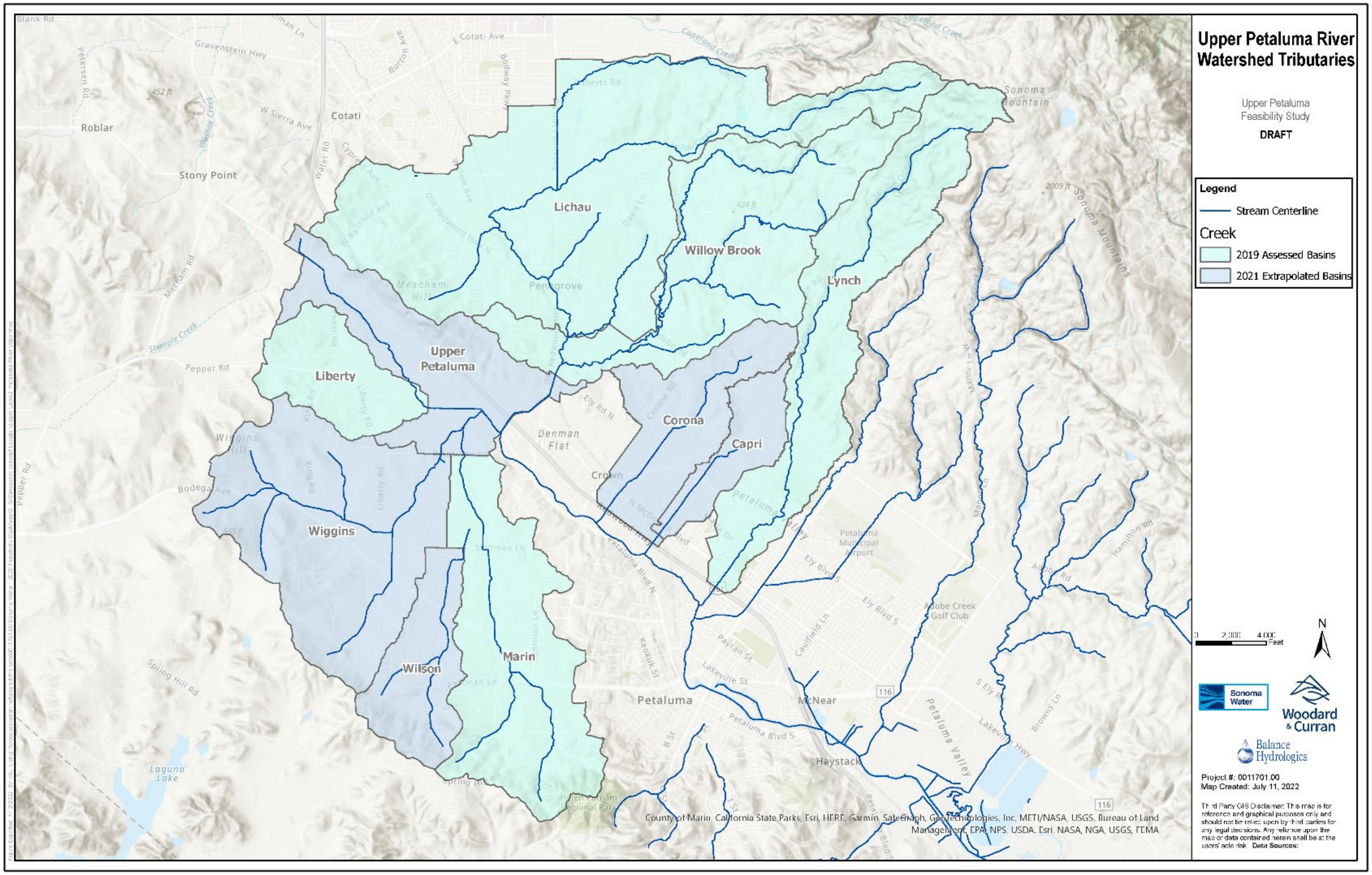


Figure 1: Upper Petaluma River Watershed Tributaries

Table 1: Subwatershed Ranking – Detention Basin Scenario

Design Event	Willow Brook*	Lichau*	Marin*	Liberty*	Lynch*	Wilson	Wiggins	Upper Petaluma	Corona	Capri
10-Year: Score	54	56	43	43	33	43	43	43	33	33
Rank	2	1	4	4	13	8	4	4	13	13
Notes						*Marin*	*Marin*	*Liberty*	*Lynch*	*Lynch*
100-Year: Score	59	61	53	51	39	53	53	51	39	39
Rank	2	1	3	6	10	5	3	6	10	10
Notes						*Marin*	*Marin*	*Liberty*	*Lynch*	*Lynch*
Overall Score	**113**	**117**	**96**	**94**	**72**	**96**	**96**	**94**	**72**	**72**
Rank	**2**	**1**	**3**	**6**	**10**	**5**	**3**	**6**	**10**	**10**

**Unmodeled tributaries mapped to modeled tributaries based on flow rates.*

Table 2: Subwatershed Ranking – Floodplain Modification Scenario

Design Event	Willow Brook*	Lichau*	Marin*	Liberty*	Lynch*	Wilson	Wiggins	Upper Petaluma	Corona	Capri
10-Year: Score	35	47	34	33	29	34	34	33	29	29
Rank	9	3	10	13	18	12	10	13	18	18
Notes						*Marin*	*Marin*	*Liberty*	*Lynch*	*Lynch*
100-Year: Score	43	40	34	39	30	34	34	39	30	30
Rank	8	9	15	10	18	17	15	10	18	18
Notes						*Marin*	*Marin*	*Liberty*	*Lynch*	*Lynch*
Overall Score	**78**	**87**	**68**	**72**	**59**	**68**	**68**	**72**	**59**	**59**
Rank	**9**	**8**	**15**	**10**	**18**	**17**	**15**	**10**	**18**	**18**

**Unmodeled tributaries mapped to modeled tributaries based on flow rates.*

3. PRELIMINARY LOCATION SCREENING

Task 2 of this phase of the Feasibility Study included a desktop screening of locations throughout the watershed to identify areas with favorable conditions for constructing a detention basin. **Figure 2** shows the criteria that were developed and used to screen the watershed using ESRI's Geographic Information System (GIS):

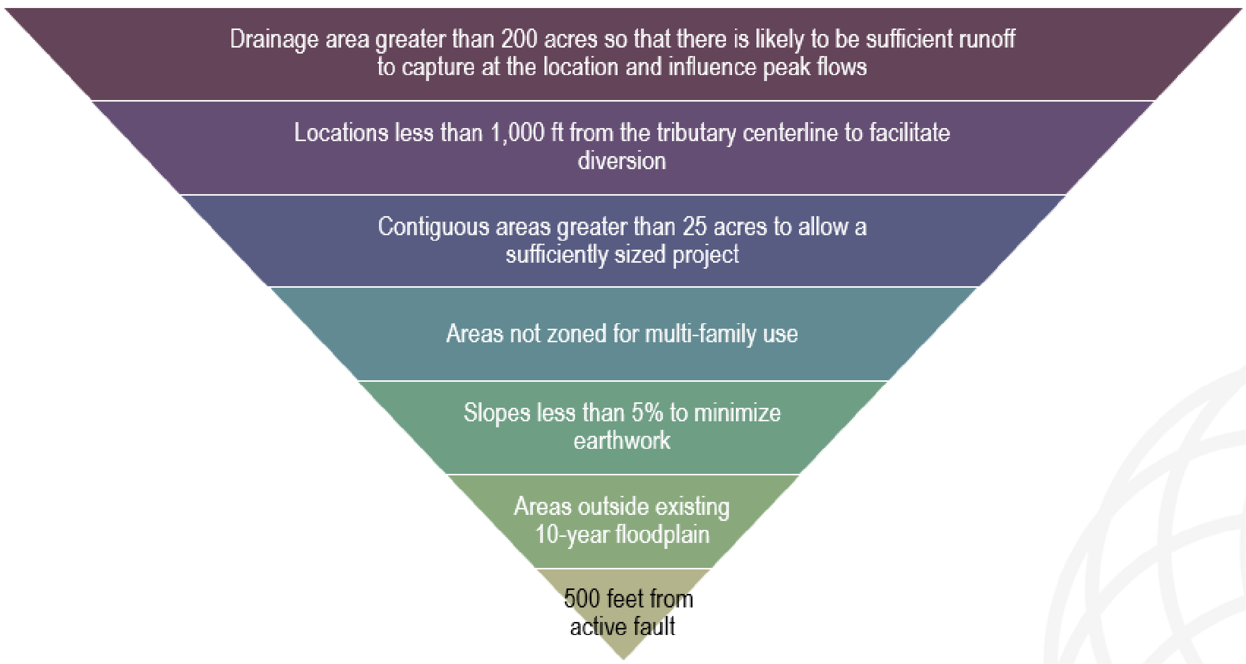


Figure 2: Screening Criteria

The screening process started with the entire Upper Petaluma River Watershed and incrementally removed areas that did not meet the screening criteria in **Figure 2**. A summary of the screening criteria basis is provided below:

- **Drainage Area greater than 200 acres** – A drainage area of at least 200 acres is required to reduce flood levels because watersheds less than 200 acres do not generate enough run-off on their own to make appreciable flood reductions. Locations with upstream drainage areas less than 200 acres were removed from the analysis.
- **Locations less than 1,000 feet from tributary centerline** – Detention basins require a physical connection (channel, pipe, etc.) between the tributary where flows are diverted and the basin. Locations more than 1,000 feet from a tributary would necessitate significant right-of-way acquisition and diversion channel or conduit construction and would be cost prohibitive. Locations more than 1,000 feet from a tributary centerline were removed from the analysis.

- **Contiguous areas greater than 25 acres** – Assuming an average basin depth of four feet and an initial target flood storage volume of 100 acre-feet, potential project locations would need to initially provide approximately 25 acres of contiguous and available land to appreciably reduce flood flows. Locations that did not provide approximately 25 Acres were removed from the analysis.
- **Areas not zoned for multi-family use** – The intent of this screening criteria was to acknowledge the demand for multi-family developments in meeting housing goals. Placing a flood detention basin at a location slated for higher density housing may be a detriment to long term planning. Overall, this screening criteria did not influence the screening analysis as most locations zoned for multi-family housing are significantly less than the required 25-acre contiguous screening criteria.
- **Slopes less than 5%** – Slopes higher than 5% may lead to higher construction costs by way of higher fill volume requirements. As such, locations with slopes greater than 5% were removed from consideration.
- **Areas outside existing 10-year floodplain** – Locations within the existing 10-year floodplain already provide some level of flood detention for downstream areas by temporarily storing floodwaters. Placing a detention basin within an area already providing flood detention may exacerbate downstream flooding or produce minimal net flood reductions because floodplain storage would not appreciably increase. Sites located outside existing 10-yr floodplains could create new storage that may lead to downstream flood reductions. Therefore, locations entirely within the existing 10-year floodplain were removed from the analysis. Only locations that were on the fringe of the 10-yr floodplain or contained portions of the 10-year floodplain were left in the analysis area.
- **500 feet from an active fault** – Constructing a detention basin and appurtenant facilities in areas susceptible to fault rupture pose significant design challenges to counteract or account for seismic deformation. Locations within 500 feet of an active fault were removed from consideration to avoid potential seismic fault rupture considerations. Overall, this screening criteria did not influence the screening analysis as the previous screening alternatives ruled out locations near active faults.

In total, the desktop screening analysis reduced the total area of the watershed under consideration from 57,600 acres to 420 acres and included a total of 37 locations. Preliminary results of the screening process are shown in **Figure 3**.

A Screening Workshop was held with Sonoma Water on October 15, 2021 to discuss the GIS-based preliminary screening results. The following additional screenings were made:

- Satellite imagery was reviewed to screen out developed areas with insufficient contiguous space for a detention basin.

- Additional consideration was given to using depth to bedrock and soil type as screening characteristics considering the importance of groundwater recharge to a multi-benefit project. However, during the Screening Workshop and through further research into available subsurface data, it was determined that available information was insufficient to determine whether infiltration could be achieved at any particular location. Furthermore, the variability and confidence in existing depth to bedrock and soils data may result in screening out areas that could meet flood reduction objectives. It is acknowledged that some locations have generally more favorable soils, but location-specific testing will still be required to verify local conditions prior to implementing a project that intends to increase groundwater recharge. In short, depth to bedrock and subsurface soils data were not incorporated into the screening analysis to ensure all potential watershed locations were included.
- During the Screening Workshop, projects identified in the Stormwater Water Resources Plan (SWRP [Sonoma Water, 2019]) were cross-referenced with the suitable areas shown on **Figure 3**. However, these projects were found to be unlikely to meet the objectives of the current analysis and were not advanced under this feasibility study. These projects included:
    - SWRP Project 1 – The Petaluma River Corona Reach Linear Overflow Channel
    - SWRP Project 4 – Willow Brook Flood Detention Basin
    - SWRP Project 56 – Upper Lichau Creek Stormwater Detention

Although large contiguous areas remained after screening, it was deemed unnecessary to model projects that would be hydrologically similar and in close proximity to one another. Because the goal of the project is to determine the benefits of flood storage at a range of viable locations in the watershed, evaluating two closely spaced and similar sized basins would provide similar information and little additional clarity on flood reduction benefits. Of the 37 potential locations discussed in the workshop, 20 locations were selected for further analysis based on the subwatershed ranking, the GIS screening results and the proximity to other areas selected for study. Although not modeled due to the expected similarity of results, feasible areas adjacent to those modeled in this phase may provide an opportunity to increase flood storage of a project concept. Future phases of landowner outreach and detailed engineering could consider a larger project and more substantial flood reduction if landowners are amenable.

The 20 locations recommended for hydrologic and hydraulic analyses in the Screening Workshop were studied during the 10-year and 100-year storm events to quantify potential benefits. The approximate project locations are shown on **Figure 4**.

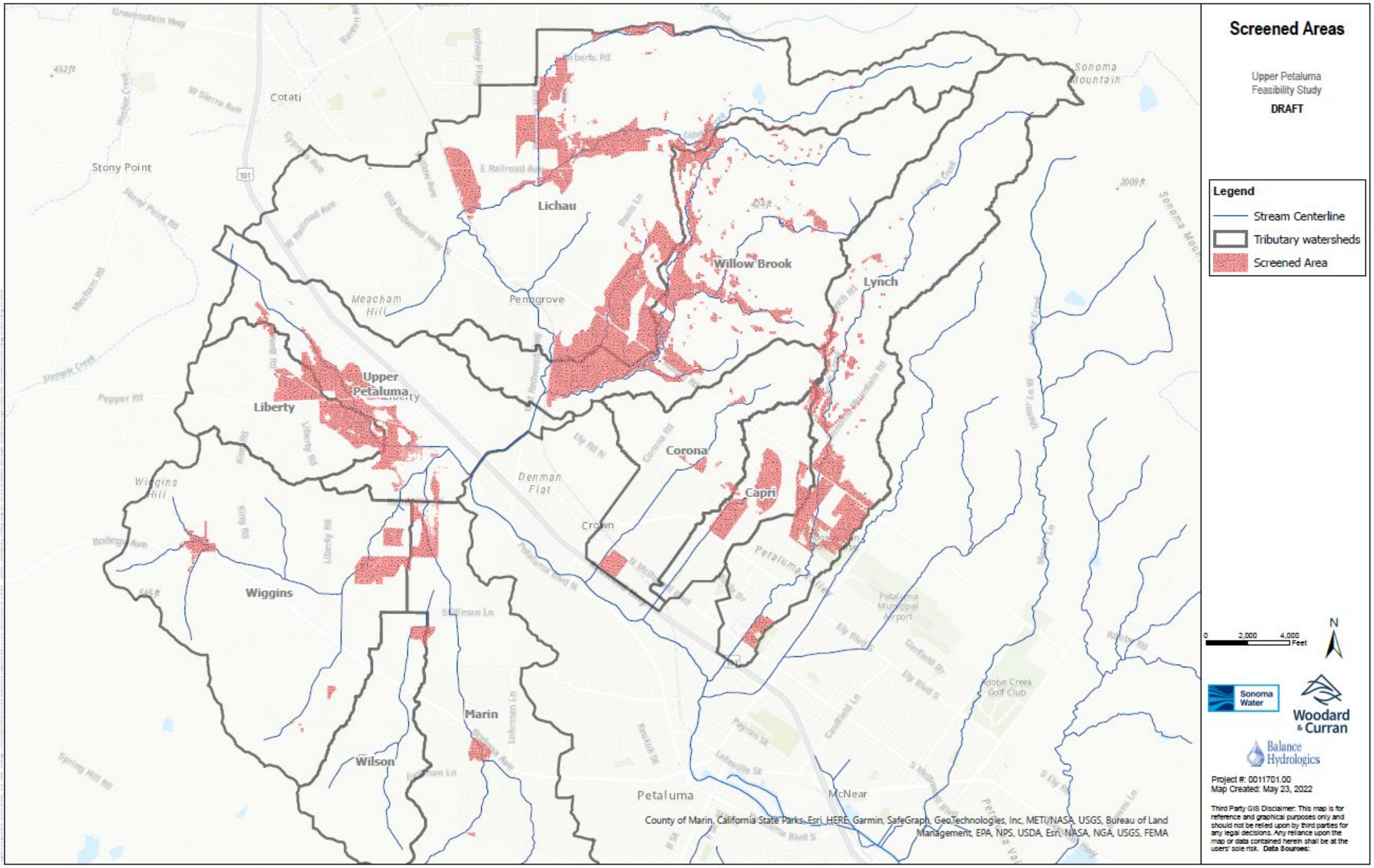


Figure 3: Screened Areas – Locations within Upper Petaluma Watershed that Meet Screening Criteria

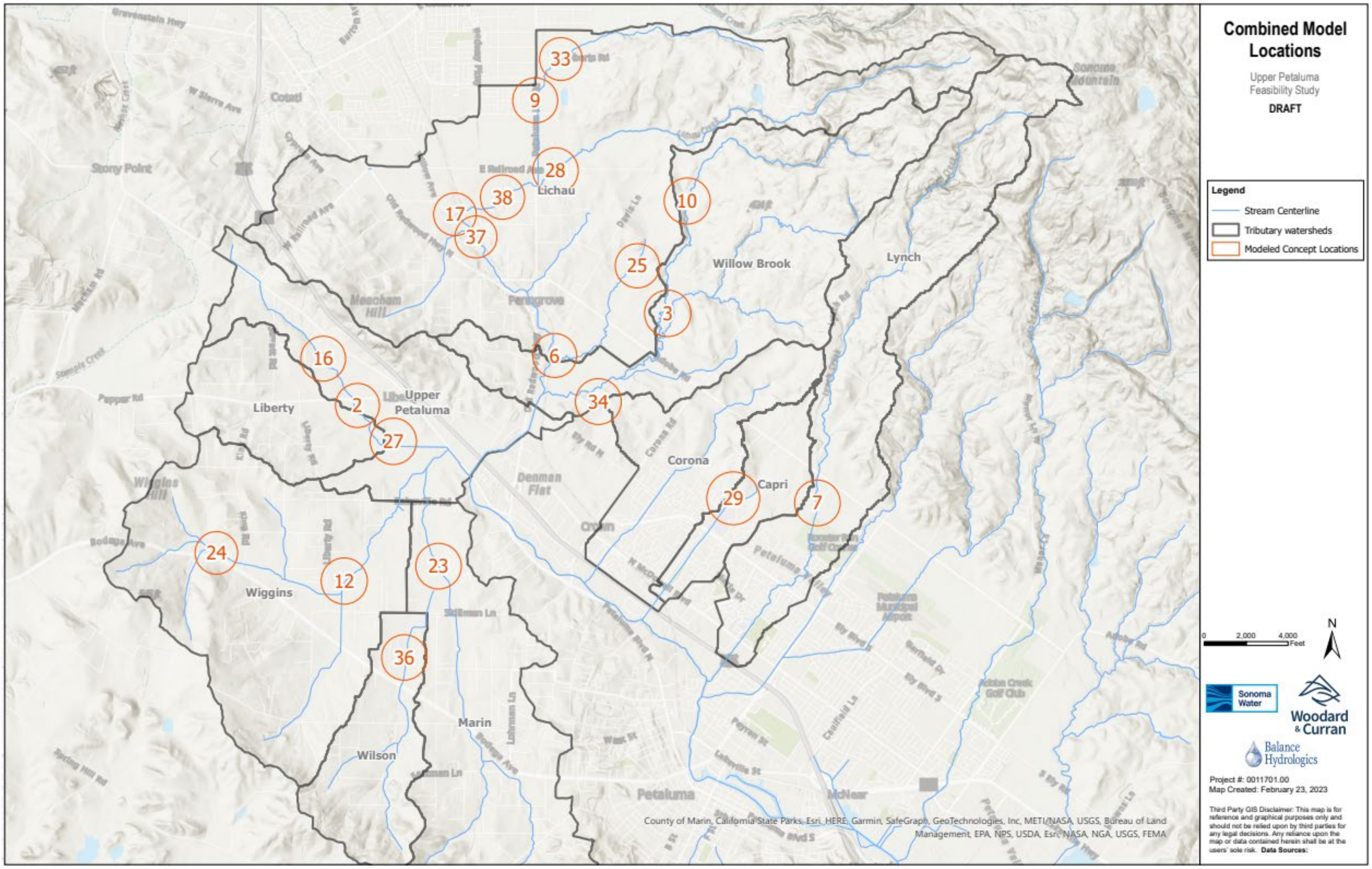


Figure 4: Approximate Modeled Concept Locations

4. HYDRAULIC IMPACTS OF BASIN IMPLEMENTATION

The hydraulic impacts and flood reduction benefits of constructing offline detention basins at the twenty identified locations were analyzed using the HEC-RAS version 5.0.3 two-dimensional (2D) model developed during a previous phase of work as described in the Baseline Model Build TM (Balance Hydrologics, 2019). The existing conditions model was modified to create twenty individual proposed conditions models that each incorporate a single detention basin concept, with a target area of 25 acres and a target depth of four feet (~100 Acre-feet of storage). The resulting flood depth reduction for each individual project was extracted at eight specified locations throughout the Petaluma River watershed. A sum of the flood reduction benefits for all eight locations was computed to provide a basis for comparison between concepts and local flood reduction below each basin was quantified. The following sections describe the existing and proposed conditions model development and model results in greater detail.

4.1. Existing Conditions Model Development

The effective FEMA hydrologic and hydraulic model for the Petaluma River was created using XP-SWMM version 2010 (pre-service pack 1). This model version does not have the capabilities to accurately model the complex channel and floodplain interactions that exist within the Upper Petaluma River Watershed. Balance Hydrologics, Inc. therefore developed a coupled HEC-HMS and HEC-RAS 2D model to better represent the floodplain storage, runoff timing, and inundation extents in the upper watershed. The methodology for developing the existing conditions baseline hydraulics model for the Upper Petaluma River Watershed was documented in the Baseline Model Build TM (Balance Hydrologics, Inc, 2019) and the relationship between models is summarized in **Figure 5**. The hydraulic model simulates the Upper Petaluma River response to the 10-year and 100-year 24-hour storms.

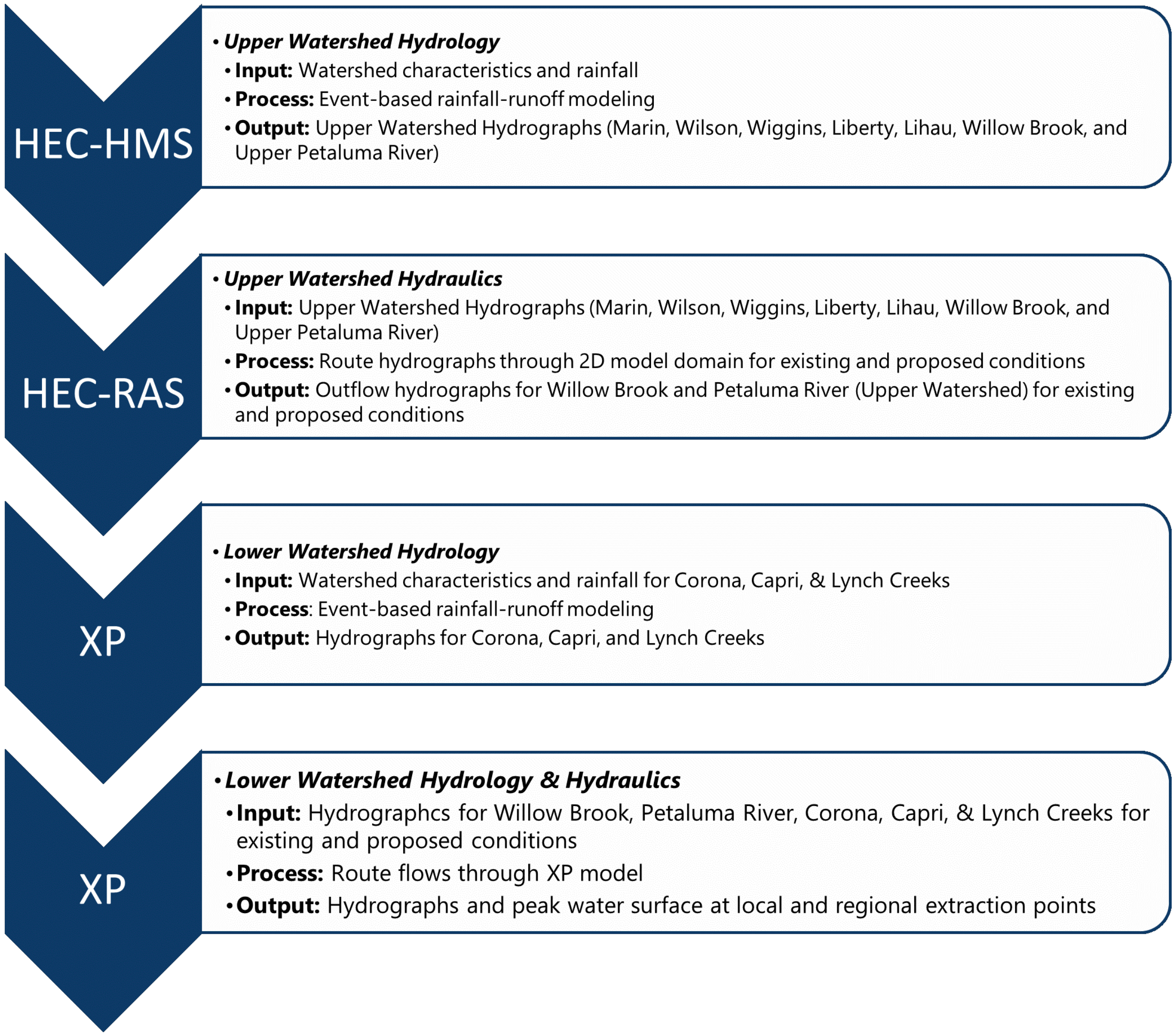


Figure 5: Model Development and Connectivity

To link the upper watershed HEC-HMS and HEC-RAS 2D model to the City's XP-SWMM model Balance Hydrologics removed the upper watershed elements from XP-SWMM and replaced them with a node to input inflows from the HEC-RAS model for Willow Brook Creek and the upstream reach of the Petaluma River, as described in **Figure 5** and shown on **Figure 6**. These nodes were used to input results hydrographs from existing and proposed scenarios from the Upper Petaluma HEC-RAS model to the XP-SWMM model and evaluate flooding in the lower reaches of the Petaluma River. To maintain consistency with the effective model, the HEC-HMS and HEC-RAS models were calibrated to conform with the effective FEMA XP-SWMM model near Highway 101 and Scott Street.

4.2. Proposed Condition Model Development

Twenty proposed conditions model geometries were created to evaluate the impact of constructing offline detention basins in various locations throughout the Upper Watershed. Eighteen model geometries were developed in HEC-RAS version 5.0.3 and two basins were developed in XP-SWMM version 2010 (pre-service pack 1) revised effective model because they are outside of the HEC-RAS model study area.

Initially, a 25-acre footprint was sought at each location. However, basin footprints were drawn to avoid existing infrastructure that was visible in available aerial photography, such as roads and buildings. Therefore, an equally-sized footprint was not possible at all twenty locations due to spatial constraints from existing infrastructure, steep slopes from hills, or existing floodplain areas. These basins may provide less than 100 acre-feet of storage. Some areas could accommodate larger basins (either deeper or larger footprint) during future phases of design. The following sections describe the proposed conditions modeling for each type of model.

All twenty basins fill as water is diverted from the nearest tributary or floodplain. The diversion is typically controlled by a weir along the tributary, although some basins fall along the margin of the natural floodplain such that runoff sheet flows into the basin without diversion structure control. The basins are also modeled with a pipe outfall similarly for each so that the basins drain fully over time. The discharge timing from each basin varies based on numerous factors such as the basin size, basin location, receiving stream elevations, spillway activation, and available grade differential between the basin and stream.

4.2.1. HEC-RAS Models

The existing conditions HEC-RAS models uses a terrain developed from 2014 LiDAR data. The version of HEC-RAS (5.0.3) used for this analysis does not support terrain modification capabilities added to the software after the completion of the existing conditions model. HEC-RAS version 6.1 was therefore used to modify the terrain to incorporate a basin and diversion from the nearest tributary. The new terrain representing each proposed detention basin was then imported into the HEC-RAS version 5.0.3 model for computations.

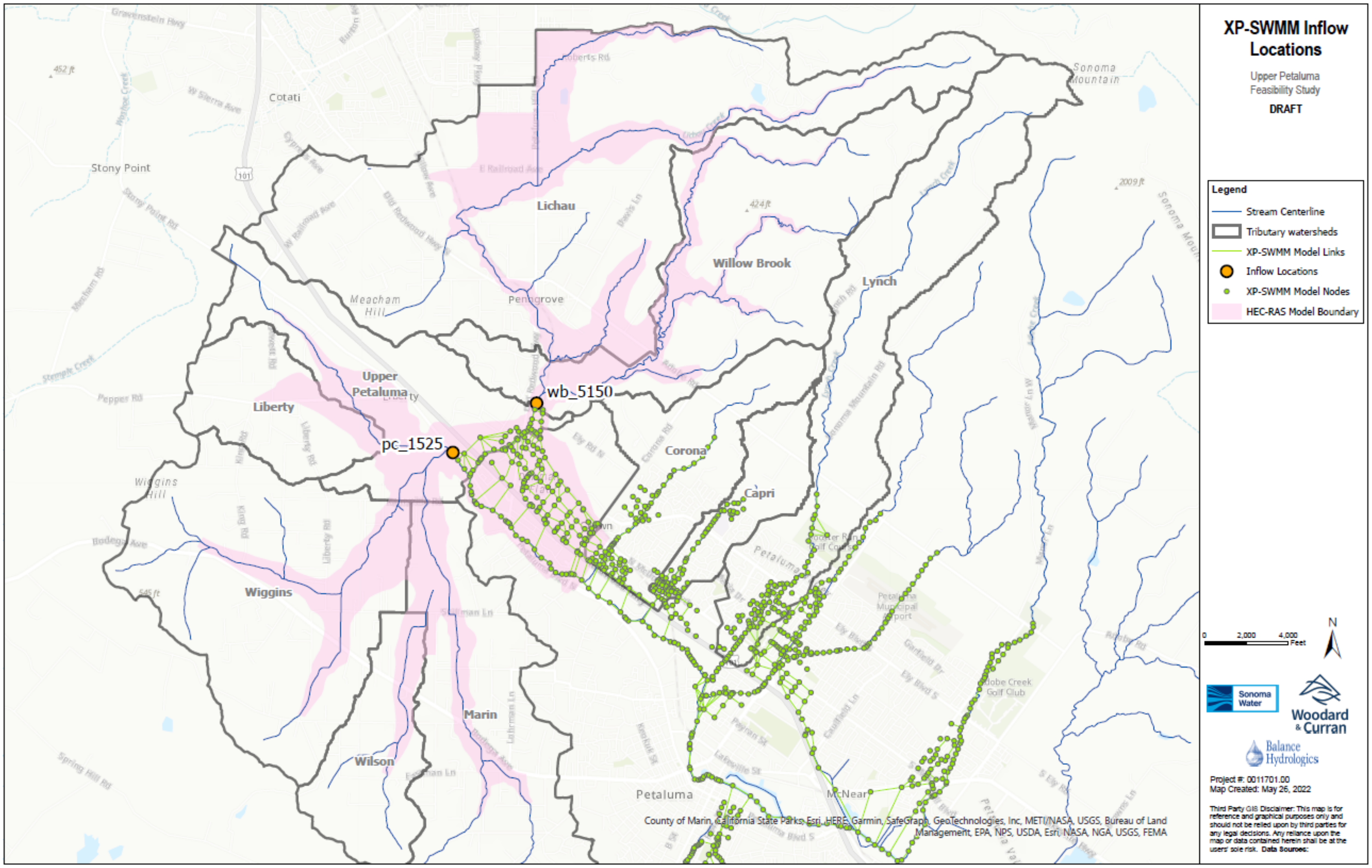


Figure 6: XPSWMM Model Inflow Locations

4.2.2. XP-SWMM Models

The Lynch Creek and Capri Creek basins were modeled using XP-SWMM as they are located downstream of the HEC-RAS model for the Upper Petaluma River Watershed. The basin models created in XP-SWMM use storage nodes to simulate the detention provided for a 100 ac-ft basin. Diversions were included using links from the main channel to the storage area.

4.2.3. Optimization

For the diversions from each tributary, the weir height, location, and widths were adjusted until total diversions approached the target 4-foot depth during the 100-year storm to determine the largest possible capture volume based on the available footprint (targeting 100 ac-ft). The 10-year storm was then simulated with the weir height, location, and widths set based on the 100-yr scenario. Each 10-yr model scenario was inspected to verify the weir heights established by the 100-yr scenario would still divert water into the proposed basin during the 10-yr (more frequent) storm conditions. Future modeling may consider optimizing basin design to the 10-year or other storm event to maximize flood reduction benefits.

For those basins that fall along the margin of the natural floodplain such that runoff sheet flows into the basin, basin geometry and overflow weirs were used to optimize the basins, but basins may provide more or less than the 100 ac-ft of storage as overland runoff is routed through them.

Basin outlets were not used as the primary optimization parameter. These were generally held constant at 18- to 24-inch RCP and had minimal impact on the basin depth and volume.

4.3. Results

Model result extraction locations are shown in **Figure 7,** and include regional and overbank areas. These locations were established during a previous phase of work and were discussed in the Concept Screening TM, as follows:

- Regional extraction points, shown in red on **Figure 7**, were selected to represent downstream reaches including the eastern tributaries (downstream from the confluence of Lichau and Willow Brook Creeks), western tributaries (downstream of the confluence of Liberty, Marin, Wiggins and Wilson Creeks) along the upstream reach of the Petaluma River, and along the downstream reach of the Petaluma River. While the regional extraction points are not directly impacted by projects in each of the modeled tributaries, combined, the four regional extraction points provide a ready comparison of the effects of the concept projects in the upper watershed as well as along the main stem of the river in the City of Petaluma.

- Overbank extraction points at known overbank flood locations, shown in blue on **Figure 7**, were identified to better evaluate flood benefits. Overbank flood data was extracted from the four unique off-channel locations, selected to represent areas that were significantly impacted by flooding during the December 31, 2005 storm event.

The change in water surface elevation between existing and proposed conditions was tabulated and summed for each basin at the eight extraction points along the Petaluma River, as shown in **Table 3 and Table 4.** The total water surface elevation reduction was used as a factor in the location viability scoring task.

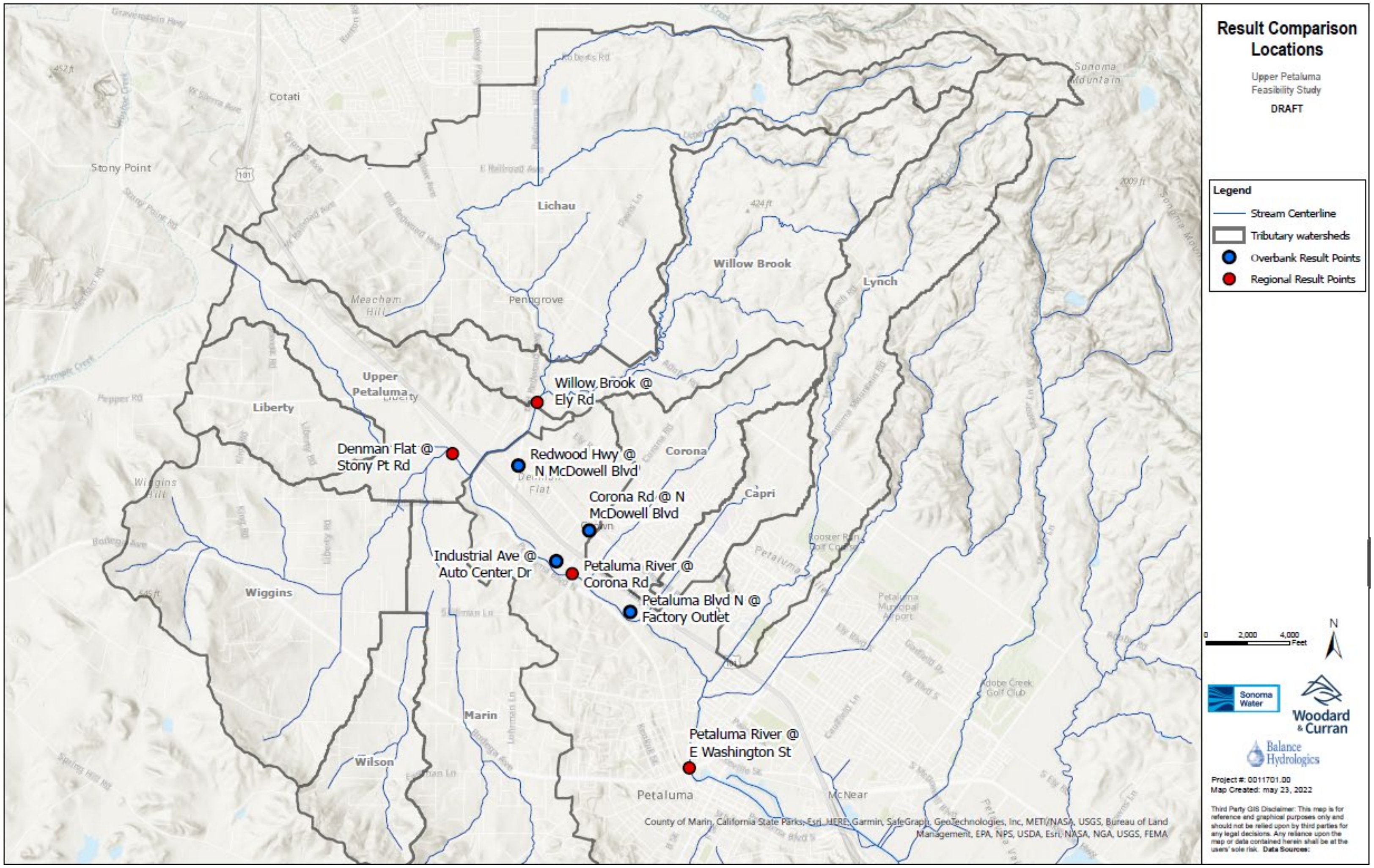


Figure 7: Regional and Overbank Model Data Extraction Points

Table 3: 10-Year 24-hour Project Basin Conditions Depth Reduction (ft) by Basin ID in XP-SWMM Model

Result Point Name/Basin ID	2	3	6	7	9	10	12	16	17	23	24	25	27	28	29	33	34	36	37	38
Willow Brook @ Ely Rd	0.00	-0.18	-0.23	0.00	-0.16	-0.08	0.00	0.00	-0.19	0.00	0.00	-0.11	0.00	-0.04	0.00	-0.15	-0.31	0.00	-0.19	-0.03
Denman Flat @ Stony Pt Rd	-0.08	-0.01	-0.01	0.00	-0.03	-0.01	-0.12	-0.05	-0.02	-0.03	-0.03	-0.02	-0.22	-0.02	0.00	-0.02	-0.01	-0.02	-0.02	-0.01
Petaluma River @ Corona Rd	-0.05	-0.07	-0.06	0.00	-0.12	-0.04	-0.10	-0.03	-0.06	-0.04	-0.02	-0.06	-0.29	-0.07	0.00	-0.09	-0.05	-0.01	-0.06	-0.04
Redwood Hwy @ N McDowell Blvd	0.00	-0.02	-0.02	0.00	-0.02	-0.01	0.00	0.00	-0.02	0.00	0.00	-0.01	0.00	-0.01	0.00	-0.01	-0.03	0.00	-0.02	-0.01
Corona Rd @ N McDowell Blvd	-0.01	-0.21	-0.21	0.00	-0.21	-0.21	0.00	-0.01	-0.21	-0.01	0.00	-0.21	-0.01	-0.21	0.00	-0.21	-0.21	0.00	-0.21	-0.19
Industrial Ave @ Auto Center Dr	-0.06	-0.04	-0.04	0.00	-0.07	-0.02	-0.11	-0.04	-0.05	-0.04	-0.02	-0.04	-0.24	-0.05	0.00	-0.05	-0.03	-0.01	-0.05	-0.03
Petaluma Blvd N @ Factory Outlet	-0.17	-0.22	-0.22	0.00	-0.40	-0.12	-0.33	-0.11	-0.22	-0.12	-0.07	-0.20	-0.81	-0.23	-0.07	-0.30	-0.16	-0.03	-0.22	-0.12
Petaluma River @ E Washington St	0.00	0.00	0.00	-0.03	-0.01	0.00	0.00	0.00	0.00	-0.01	0.00	-0.03	-0.01	0.00	-0.04	-0.01	0.00	0.00	0.00	0.00
Sum of WSE Reductions at all Locations	**-0.37**	**-0.75**	**-0.79**	**-0.03**	**-1.01**	**-0.49**	**-0.67**	**-0.23**	**-0.77**	**-0.23**	**-0.13**	**-0.68**	**-1.57**	**-0.62**	**-0.11**	**-0.85**	**-0.80**	**-0.07**	**-0.77**	**-0.42**

Table 4: 100-Year 24-hour Project Basin Conditions Depth Reduction (ft) by Basin ID in XP-SWMM Model

Result Point Name	2	3	6	7	9	10	12	16	17	23	24	25	27	28	29	33	34	36	37	38
Willow Brook @ Ely Rd	0.00	-0.12	-0.31	0.00	-0.11	-0.07	0.00	0.00	-0.20	0.00	0.00	-0.15	0.00	-0.10	0.00	-0.05	-0.44	0.00	-0.13	-0.08
Denman Flat @ Stony Pt Rd	-0.10	-0.01	-0.02	0.00	-0.02	-0.01	-0.08	-0.07	-0.01	-0.02	-0.04	-0.01	-0.18	-0.01	0.00	-0.02	-0.01	-0.02	-0.01	-0.01
Petaluma River @ Corona Rd	-0.11	-0.03	-0.03	0.00	-0.03	-0.02	-0.10	-0.07	-0.02	-0.03	-0.04	-0.02	-0.24	-0.03	0.00	-0.02	-0.02	-0.02	0.00	-0.02
Redwood Hwy @ N McDowell Blvd	0.00	-0.03	-0.04	0.00	-0.03	-0.02	0.00	0.00	-0.04	0.00	0.00	-0.02	0.00	-0.03	0.00	-0.02	-0.08	0.00	-0.02	-0.02
Corona Rd @ N McDowell Blvd	0.00	-0.10	-0.11	0.00	-0.09	-0.07	0.00	0.00	-0.08	0.00	0.00	-0.06	-0.01	-0.12	0.00	-0.07	-0.20	0.00	-0.05	-0.08
Industrial Ave @ Auto Center Dr	-0.11	-0.02	-0.02	0.00	-0.02	-0.01	-0.09	-0.07	-0.02	-0.03	-0.04	-0.02	-0.22	-0.02	0.00	-0.02	-0.02	-0.02	0.00	-0.01
Petaluma Blvd N @ Factory Outlet	-0.14	-0.15	-0.15	0.00	-0.12	-0.10	-0.15	-0.09	-0.12	-0.05	-0.04	-0.11	-0.41	-0.17	-0.06	-0.09	-0.18	-0.02	-0.02	-0.12
Petaluma River @ E Washington St	-0.18	-0.20	-0.21	-0.12	-0.17	-0.13	-0.20	-0.12	-0.17	-0.08	-0.06	-0.15	-0.44	-0.22	-0.10	-0.14	-0.27	-0.03	-0.05	-0.16
Sum of WSE Reductions at all Locations	**-0.65**	**-0.65**	**-0.88**	**-0.12**	**-0.59**	**-0.43**	**-0.62**	**-0.43**	**-0.66**	**-0.21**	**-0.21**	**-0.55**	**-1.49**	**-0.70**	**-0.16**	**-0.43**	**-1.22**	**-0.12**	**-0.29**	**-0.50**

The greatest total flood reduction (0.81 feet) during the 10-year event resulted from Basin 27 for the Petaluma Boulevard North at Factory Outlet location. During the 10-year event, the greatest overall reduction in total flood depth (1.57 feet) also resulted from Basin 27, as it was able to impact a significant number of extraction points. During the 100-year event, Basin 27 and Basin 34 each resulted in a 0.44-foot reduction in depth at Petaluma River at East Washington Street and Willow Brook at Ely Road, respectively. Basin 27 again produced the greatest total reduction in water surface elevation during the 100-year event, with a total reduction of 1.49 feet across all the result comparison locations.

The hydraulic analysis was intended to identify general areas and tributaries where a detention basin may provide the most effective flood reduction. The results of this analysis do not necessarily represent basins that can or would be constructed within a given area. More detail on constructability considerations is included in **Section 5.2**.

Flood reductions immediately below each detention basin provide additional insight into local benefits not reflected in the regional and overbank extraction point results described above. These localized depth and flow reductions may provide substantial floodplain reduction benefits. Cross sections presenting the change in water surface elevation during the 10-year and 100-year events and hydrographs showing reduction in flow below each basin are presented in **Appendix A**. Additionally, **Table 5** summarizes the local peak water surface elevation reduction below each basin location and **Table 6** summarizes the local peak flow reduction below each basin at the same cross sections shown in **Appendix A**.

Water surface elevation reductions ranged from zero (no local benefit) to 3.1 feet with an average of 0.7 feet of flood depth reduction for the 100-year event. Basin 3 was the highest performing with a local reduction of 3.1 feet and a discharge reduction of approximately 1,000 cfs. Basins 16 and 29 provide a local reduction of 1.4 and 2.6 feet, which correspond to approximately 280 and 460 cfs, respectively. For the 10-year event water surface reductions ranged from zero (no local benefit) to 2.1 feet with an average of 0.79 feet. Basins 29 and 16 were the highest performing with 2.7 and 2.6 feet of flood reduction, respectively.

Table 5. Change in Water Surface Elevation Downstream of Each Basin Location for 10-year and 100-year Events (ft, NAVD88).

Basin ID	10-yr Existing Conditions Peak WSE	10-yr Proposed Conditions Peak WSE	100-yr Existing Conditions Peak WSE	100-yr Proposed Conditions Peak WSE	Change in 10-yr WSE	Change in 100-yr WSE
2	40.4	40.1	40.8	40.4	**-0.4**	**-0.3**
3	93.6	92.0	97.0	93.9	**-1.6**	**-3.1**
6	56.6	55.8	57.4	56.4	**-0.8**	**-1.0**
7	78.6	78.5	79.5	79.4	**-0.1**	**-0.2**
9	126.5	124.6	127.8	127.6	**-1.9**	**-0.1**
10	251.1	250.6	251.6	250.8	**-0.5**	**-0.8**
12	44.9	44.2	45.4	45.3	**-0.7**	**-0.1**
16	66.9	64.4	67.3	65.9	**-2.5**	**-1.4**
17	106.5	105.4	107.3	106.3	**-1.0**	**-1.0**
23	40.3	40.2	41.2	41.2	**-0.1**	**0.0**
24	89.0	88.3	89.8	89.1	**-0.6**	**-0.7**
25	90.5	89.3	91.0	90.4	**-1.2**	**-0.5**
27	39.4	39.1	40.5	40.3	**-0.3**	**-0.2**
28	145.6	145.2	146.1	145.5	**-0.4**	**-0.5**
29	78.8	76.0	78.9	76.4	**-2.7**	**-2.6**
33	141.0	140.9	141.2	141.1	**-0.1**	**-0.1**
34	79.0	78.5	79.7	78.8	**-0.5**	**-0.9**
36	53.2	53.2	53.4	53.4	**0.0**	**0.0**
37	95.8	95.7	96.5	96.5	**-0.1**	**0.0**
38	111.2	110.9	112.2	111.6	**-0.2**	**-0.6**

Table 6. Change in Peak Flow Downstream of Each Basin Location for 10-year and 100-year Events (cfs).

Basin ID	10-yr Existing Conditions Peak Flow	10-yr Proposed Conditions Peak Flow	100-yr Existing Conditions Peak Flow	100-yr Proposed Conditions Peak Flow	Change in 10-yr Flow	Change in 100-yr Flow
2	292	82	589	173	-211	-416
3	1701	1473	2821	1815	-228	-1006
6	572	281	959	330	-291	-629
7	813	716	1807	1579	-97	-227
9	1525	1216	2398	2159	-308	-239
10	500	236	915	278	-264	-637
12	847	430	1536	1273	-417	-263
16	202	15	353	71	-187	-281
17	913	622	1374	943	-291	-430
23	910	852	1571	1547	-58	-24
24	248	14	136	24	-234	-112
25	506	360	905	476	-146	-429
27	1752	1596	2833	2487	-156	-345
28	1122	717	1733	1029	-405	-704
29	276	0	463	1	-276	-462
33	647	509	905	755	-138	-150
34	1634	1228	2194	1460	-406	-733
36	554	527	884	845	-27	-39
37	2230	2150	3389	3392	-81	3
38	1852	1673	2885	2249	-179	-635

While overall depth reduction is an important factor to ranking the basins, the size variability between basins does not allow for a direct comparison. The basins were therefore evaluated using total depth reduction at extraction points per acre-foot of storage provided. This unit comparison helps normalize modeled flood reductions as a measure of effectiveness, or cost-benefit, where the storage is the "cost", and the depth reduction is the "benefit". This total depth reduction noted in **Table 3** and **Table 4** per volume of storage provided is included in **Table 7** and **Table 8** for the 10- and 100-year results.

Similarly, a unit factor of depth reduction versus excavation was also used to evaluate cost-benefit, where excavation represents the "cost" and total depth reduction as the "benefit". This unit factor of depth reduction versus excavation volume is also summarized in **Table 7** and **Table 8** for the 10- and 100-year results.

A unit benefit of the local flow reductions is also included in **Table 7** and **Table 8** showing the flow reduction on the receiving stream listed in **Table 6** per the total storage volume.

Table 7: Unit Benefits of Basin Concepts 10-Year

Basin ID	Total Storage Provided (ac-ft)[1]	Total Depth Reduction/Volume Storage (ft/ac-ft)[2]	Total Depth Reduction / Volume Excavation (ft/ac-ft)2	Local Benefit Flow Reduction / Volume Storage (cfs/ac-ft)
2	105.7	3.5	0.8	2
3	39.5	18.9	2.6	5.8
6	40.8	19.4	2.3	7.1
7	60.5	0.5	0.1	1.6
9	97.5	10.3	3.4	3.2
10	22.1	22.1	2.1	11.9
12	102.5	6.5	4.7	4.1
16	64.4	3.6	0.6	2.9
17	82.2	9.3	3.2	3.5
23	47.5	4.8	3.5	1.2
24	34.2	3.8	0.7	6.8
25	58.1	11.7	1.6	2.5
27	248.4	6.3	2.6	0.6
28	40.1	15.5	1.7	10.1
29	67.5	1.7	0.3	4.1
33	95.2	8.9	2.7	1.4
34	31.2	25.6	3.3	13
36	19.7	3.5	0.6	1.3
37	28.5	26.8	3.9	2.8
38	23.2	18.2	2.6	7.7

1. Total storage volume in acre-feet exceeds the excavated basin volume when backwater floodplain conditions cause the depth to be greater than the basin height (approximately 4 feet). Feasibility of construction in these instances was considered in the final ranking.
2. Factor multiplied by 1,000 for data comprehension and comparisons. Note total depth reduction is the sum of the reduction at each of the 8 locations as listed in **Table 3** and **Table 4**.

Table 8: Unit Benefits of Basin Concepts 100-year

Basin ID	Total Storage Provided (ac-ft)[1]	Total Depth Reduction/Volume Storage (ft/ac-ft)[2]	Total Depth Reduction / Volume Excavation (ft/ac-ft)2	Local Benefit Flow Reduction / Volume Storage (cfs/ac-ft)
2	147.7	2.5	1.5	2.8
3	96.6	7.7	2.2	10.4
6	90.3	8.8	2.6	7
7	100.3	0.3	0.4	2.3
9	98.1	10.2	2	2.4
10	53.2	9.2	1.9	12
12	115.7	5.8	4.3	2.3
16	93.9	2.5	1.1	3
17	88.5	8.6	2.8	4.9
23	51.6	4.5	3.1	0.5
24	58.4	2.2	1.2	1.9
25	99.1	6.8	1.3	4.3
27	289.7	5.4	2.5	1.2
28	98	6.3	2	7.2
29	100.3	1.1	0.4	4.6
33	100.4	8.5	1.3	1.5
34	106	7.5	5	6.9
36	34.1	2	1.1	1.1
37	45.7	16.7	1.4	0.1
38	53.6	7.9	3.1	11.9

1. Total storage volume in acre-feet exceeds the excavated basin volume when backwater floodplain conditions cause the depth to be greater than the basin height (approximately 4 feet). Feasibility of construction in these instances was considered in the final ranking.
2. Factor multiplied by 1,000 for data comprehension and comparisons. Note total depth reduction is the sum of the reduction at each of the 8 locations as listed in **Table 3** and **Table 4**.

5. BASIN LOCATION VIABILITY SCORING

The basin locations shown on **Figure 4** were scored to rank them based on their effectiveness to reduce flood impacts throughout the watershed using the regional and overbank extraction points. Factors considered during the ranking include the sum of the water surface elevation reductions at the eight result comparison locations for each basin, cost effectiveness, and constructability.

5.1. Performance Scoring and Ranking Considerations

The results of the hydraulic analyses, as summarized in **Table 3** and **Table 4**, show the individual project depth reduction at each extraction point as well as the total depth reduction achieved by a given concept at all comparison locations throughout the watershed. The summation of depth reduction at these locations is the first factor used to score the basins because a core objective of the project is to reduce flood depth. Concepts that create more flood reduction provide more benefit. Basins with a higher depth reduction per storage volume and a higher depth reduction per volume of excavation, as noted in **Table 7** and **Table 8**, also scored higher, as they are likely to provide a greater return on investment compared with other project concepts. While local benefit results were not used in scoring and ranking concepts, this information may be very helpful in initiating conversations with interested landowners.

5.2. Design and Constructability Considerations

While the hydraulic model assesses the impact of a project on inundation depth, other factors should be considered when ranking basin locations, such as constructability or the potential for a larger basin. Possible constructability concerns to be further investigated as project feasibility is assessed are as follows:

- Uncontrolled inflow and outflow: Basins located in floodplain overflow areas potentially capture greater than the excavated storage provided. Some potential additional features needed for these areas include:
  - A larger basin footprint to maximize capture of flow for a 100-year event,
  - An overflow route that will not impact downstream facilities, and/or
  - Upstream and downstream improvements to control inflow and outflow and limit local or downstream impacts.
- Limited channel depth or finish grade: Outfall locations need to be verified as some basins in low-lying areas either need to be less than 4 feet deep, have a significantly long outfall pipe, or require pumping after storm events to drain the basins.
- Constructing basins of this magnitude will require significant excavation, and some areas may not be conducive to grading due large amounts of potential cut required.
- Existing easements that may impact the ability to construct.

The Team held a workshop with Sonoma Water staff on March 17, 2022 to discuss the results of the hydraulic analysis and ranking process. The discussion revolved around prioritizing basin effectiveness highlighted in **Table 7** and **Table 8** and constructability considerations. The resulting ranking of potential project locations is shown in **Table 9**.

Table 9: Basin Location Ranking Results

Basin ID	Subwatershed	Basin Area (Acres)	Rank
37	Lichau	14	1
9	Lichau	24	2
6	Lichau	24	3
17	Lichau	22	5
33	Lichau	25	5
34	Willow Brook	26	4
10	Willow Brook	14	8
3	Lichau	24	7
38	Lichau	14	9
27	Liberty	35	10
12	Wiggins	20	13
25	Lichau	25	12
28	Lichau	24	11
23	Marin	8	14
2	Liberty	26	15
16	Upper Petaluma	23	17
24	Wiggins	15	16
36	Wilson	9	18
29	Capri	25	19
7	Lynch	25	20

6. HYDRAULIC IMPACTS OF MULTIPLE BASIN CONCEPTS

Acknowledging that the potential flood reduction impact of multiple basins could be significant, Sonoma Water selected a suite of five highly ranked basin concepts distributed over multiple subwatersheds to analyze as a potential project. A single, combined proposed condition model was created to evaluate the potential flood reduction benefit of a combined project that included basins 6, 9, 12, 27 and 34 (shown on **Figure 8**). As with other proposed conditions modeling (described in greater detail in **Section 4.2**), the combined model was developed using HEC-RAS version 5.0.3. None of the combined model basins were located within the XPSWMM model domain. Results from the HEC-RAS model were, however, used as input to run the XP-SWMM model for the extraction of results at the same eight extraction points shown on **Figure 7**. The resulting total change in water surface elevation at the regional and overbank extraction points for the 10-year and 100-year events are summarized in **Table 9** and **Table 10**.

Table 10: 10-Year 24-hour Combined Model Depth Reduction (ft)

	Combined Basins
Result Point Name/Basin ID	**6, 9, 12, 27, 34**
Willow Brook @ Ely Rd	-0.70
Denman Flat @ Stony Pt Rd	-0.35
Petaluma River @ Corona Rd	-0.49
Redwood Hwy @ N McDowell Blvd	-0.11
Corona Rd @ N McDowell Blvd	-0.21
Industrial Ave @ Auto Center Dr	-0.40
Petaluma Blvd N @ Factory Outlet	-1.30
Petaluma River @ E Washington St	-0.02
Sum of WSE Reductions at all Locations	**-3.56**

Table 11: 100-Year 24-hour Project Combined Model Depth Reduction (ft)

	Combined Basins
Result Point Name/Basin ID	**6, 9, 12, 27, 34**
Willow Brook @ Ely Rd	-1.81
Denman Flat @ Stony Pt Rd	-0.29
Petaluma River @ Corona Rd	-0.47
Redwood Hwy @ N McDowell Blvd	-0.15
Corona Rd @ N McDowell Blvd	-0.45
Industrial Ave @ Auto Center Dr	-0.39
Petaluma Blvd N @ Factory Outlet	-1.02
Petaluma River @ E Washington St	-1.02
Sum of WSE Reductions at all Locations	**-5.60**

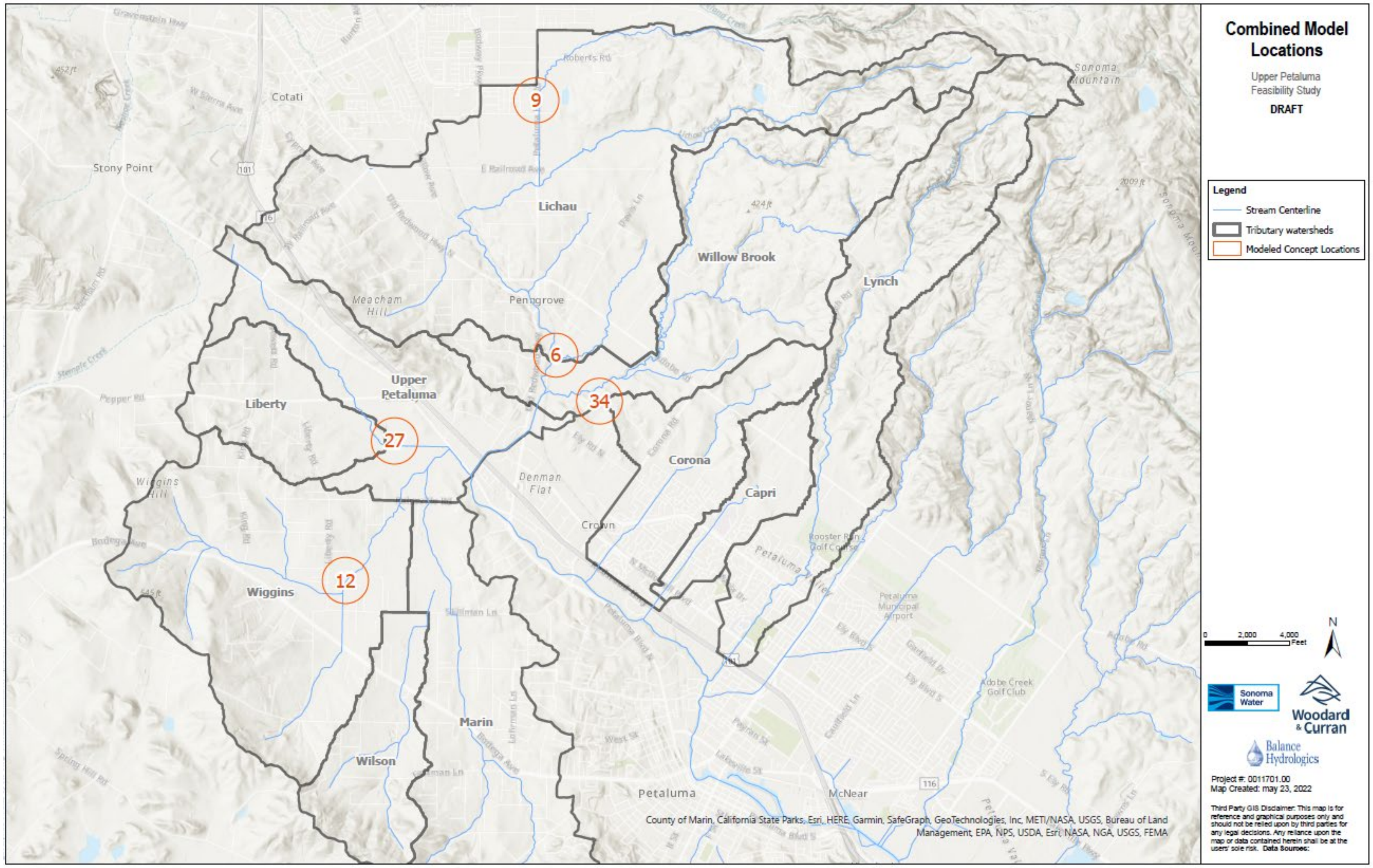


Figure 8: Approximate Modeled Concept Locations – Combined Model

Modeling basins 6, 9, 12, 27, and 34 in isolation and summing the resulting water surface elevation reductions at all extraction locations, as shown in **Table 3** and **Table 4** are different from the result of implementing all five concepts in the same model shown in **Table 9** and **Table 10**. For the 10-year event, this suite of concepts slightly underperforms the result of individual concepts (a reduction of 3.56 feet versus 4.84 feet, respectively) and for the 100-year event, it slightly outperforms (a reduction of 5.6 feet versus 4.8 feet, respectively). The estimated benefits are non-linear and non-additive because the combined basin causes some flows to be coincident which reduced overall effectiveness. Regardless, extraction results from the multi-location scenario demonstrate that flood reductions of up to 1.3 feet for the 10-year event and 1.8 feet for the 100-year event could be expected.

Profiles were created from the XP-SWMM model results and compare the combined model water surface elevations to existing along the Upper Petaluma River, Willow Brook, and overflow flow paths along Old Redwood Highway, McDowell Boulevard, and the Railroad. The profiles are provided for both the 10- and 100-year storms and are included in **Appendix B** with a plan view showing the profile stationing and extents.

As with individual basins analyzed, the hydraulic analysis was intended to identify potential benefits of a suite of detention basins that may provide effective flood reduction. The results of this analysis do not necessarily represent basins that can or would be constructed within a given area. More detail on constructability considerations is included in **Section 5.2**.

7. CONCLUSIONS AND NEXT STEPS

The results of this feasibility analysis confirm that detention basins in the Lichau, Willow Brook, and Liberty Creek tributary watersheds are the most effective at reducing flood depths at the regional and overbank extraction points. Further, favorable locations for capture are identified within each subwatershed, should opportunities arise for landowner participation in these areas. In addition to regional and overbank extraction points, offline detention can reduce local flooding in the tributary watersheds, as noted in **Table 5** and **Table 6**. Basins in Capri and Lynch Creek subwatersheds showed the least potential to reduce flood depths at the regional and overbank extraction points because their peaks are coincident with the Petaluma River and they are downstream of the other tributaries. These basins therefore provide flood reduction for a smaller portion of the watershed than basins in upstream watersheds. While many locations offer potential to meet project objectives, detention basins in the Lichau, Willow Brook, and Liberty Creek watersheds are likely to be the most effective.

As identified in the ranking analyses, in some cases, floodplain modification projects in favorable locations may outperform detention basin projects in less favorable locations. As shown in **Table 1** and **Table 2**, floodplain modification projects on Willow Brook or Lichau are likely to outperform similarly sized detention basin projects on Corona or Capri. As discussed in the Concept Screening TM, optimizing design to maximize benefits during the 10-year event would provide more frequent impact. However, it should be noted that 100-year flood reductions may be more likely to achieve funding, such as that provided through FEMA's Hazard Mitigation Grant Program and therefore, an adaptable design may be sought.

Some individual basins, particularly those on Lichau and Willow Brook, could reduce flood depths at the regional and overbank extraction points as much as 0.88 feet in a single location, or up to 1.57 feet across all result comparison locations. The results of the hydraulic analyses indicated slight depth reductions for most basins at any given result comparison location they impact in the 10-year or 100-year event. Future refinement of project concepts and locations, or the implementation of multiple basins can significantly increase flood reduction benefits, as discussed in **Section 6**.

As an example of the potential impact of multiple basins, the single combined model representing the performance of basins at locations 6, 9, 12, 27 and 34 demonstrated the potential for significant flood reduction benefits, up to nearly five feet of total flood reduction across all result comparison points or a maximum of 1.3 feet for the 10-year and 1.8 feet for the 100-year events. If willing landowners can be identified to partner in further development of projects at highly ranked concept locations, optimization during design will refine understanding of project benefits.

To understand how flood depth reductions would translate to property losses avoided, floodplain mapping provides a helpful communication tool. However, accurate floodplain mapping requires refined topography and consideration of local conditions beyond the level of detail of the current study. Reductions in flood depth of one foot may not produce a reduction in inundated area easily visible at a watershed scale. Furthermore, the purpose of the analysis was to ascertain the most impactful potential project locations in support of landowner engagement. Reduction in floodplain extents were therefore not used to compare existing versus proposed conditions. While the current conceptual results and available data do not support floodplain mapping, future refinement of concepts may result in more significant depth and inundated area reductions once a particular project site is selected conducive to floodplain mapping and submittal of Letters of Map Revision to the Federal Emergency Management Agency.

Offline detention basin storage and flood reductions are feasible in the Upper Petaluma River Watershed. Results of this study provide a basis for initiating outreach to landowners in each area to assess interest in partnerships. The identification of willing landowners will be a key next step in determining feasibility of any project. Once interested parties can be engaged in high-ranking locations, basin concepts should be optimized for performance during the desired flood event. If it is possible to identify landowners of contiguous parcels in favorable locations, a single, larger project opportunity is likely to achieve a more favorable return on investment, as well as greater opportunity for integrated project benefits that will position such a project for future funding opportunities.

APPENDIX A: CROSS SECTIONS AND HYDROGRAPHS DOWNSTREAM OF BASINS

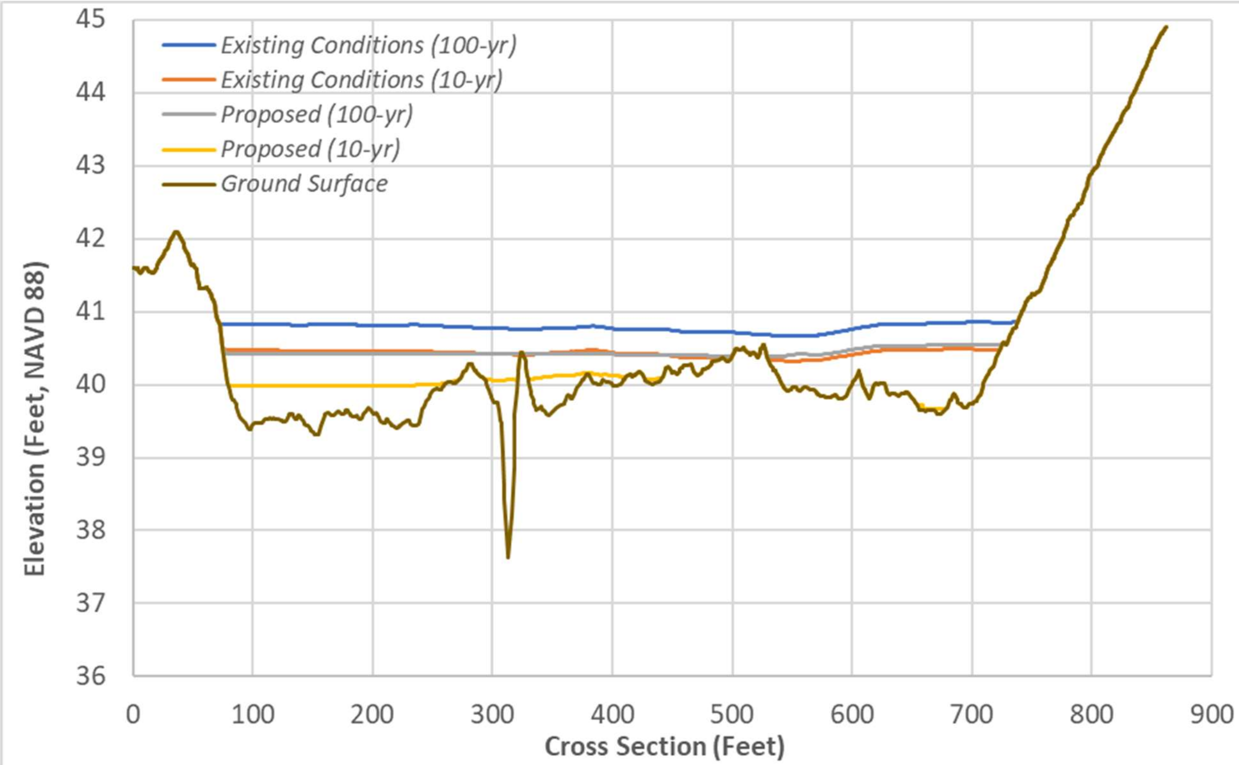


Figure 1: Cross Section on Channel Downstream of Basin 02

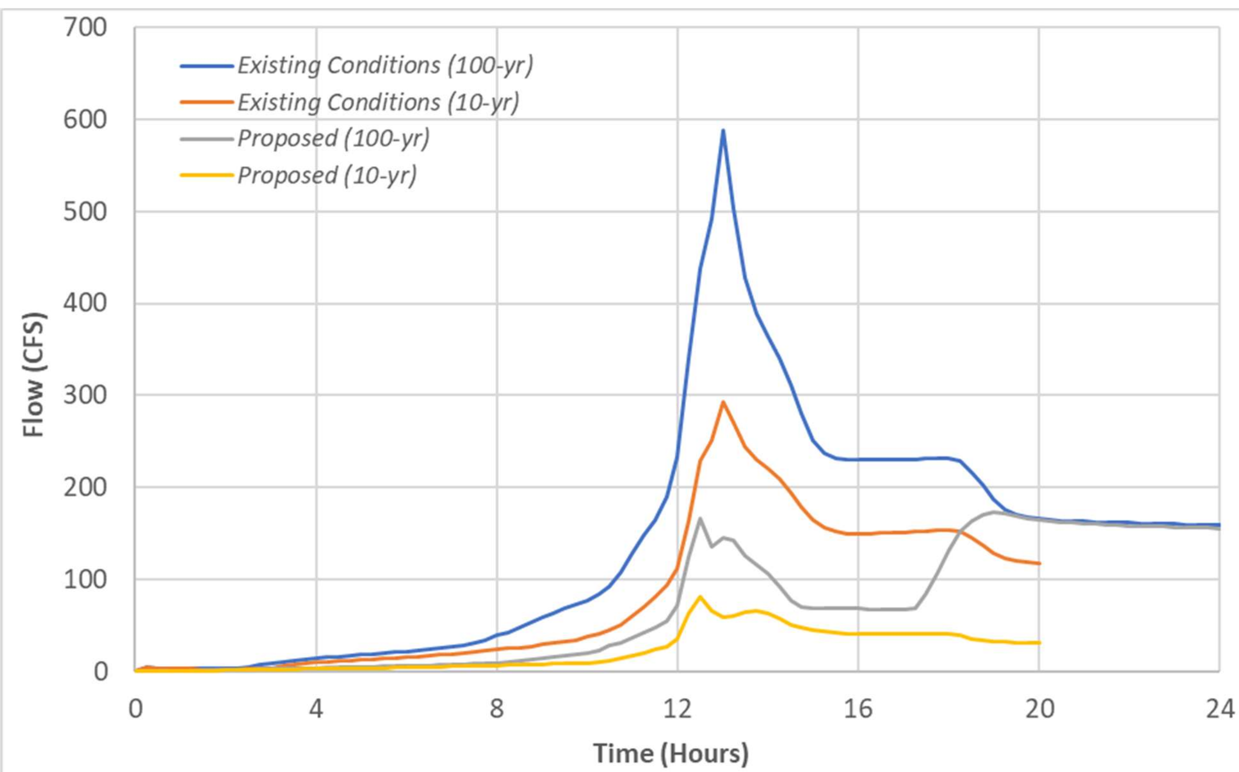


Figure 2: Hydrographs at Cross Section on Channel Downstream of Basin 02

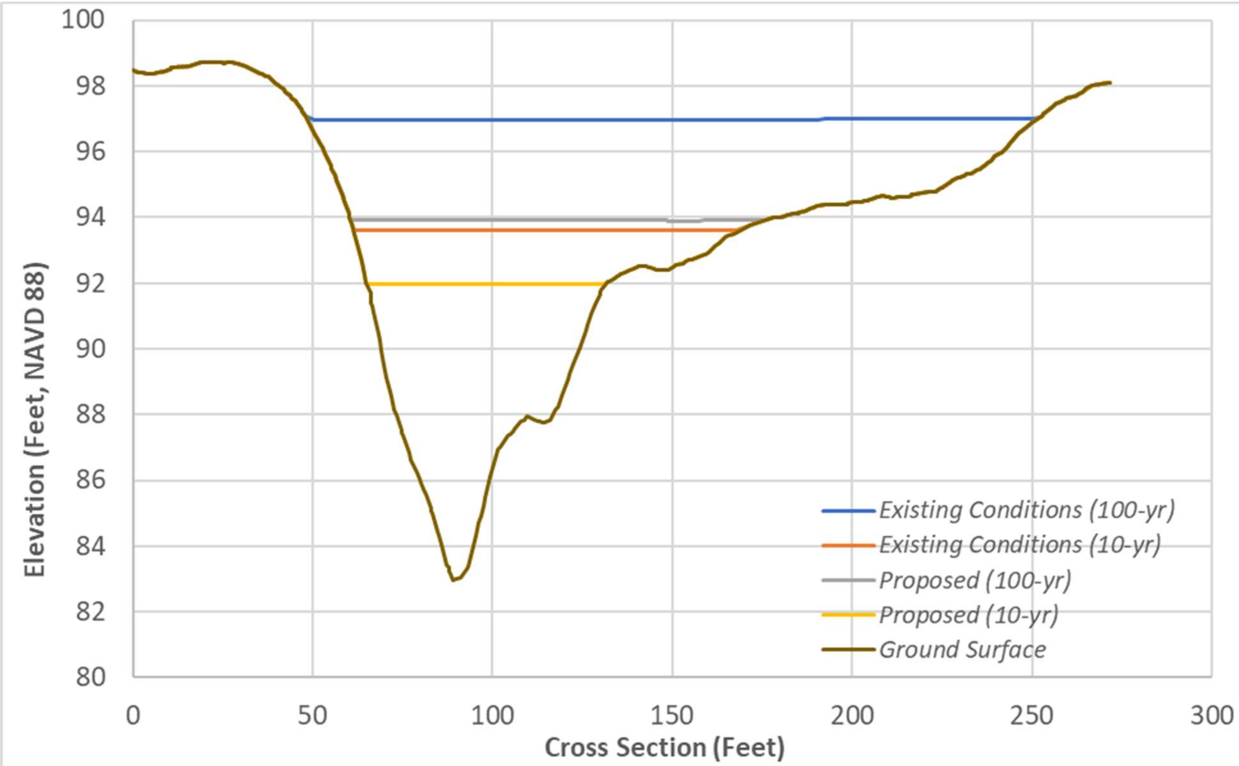


Figure 3: Cross Section on Channel Downstream of Basin 03

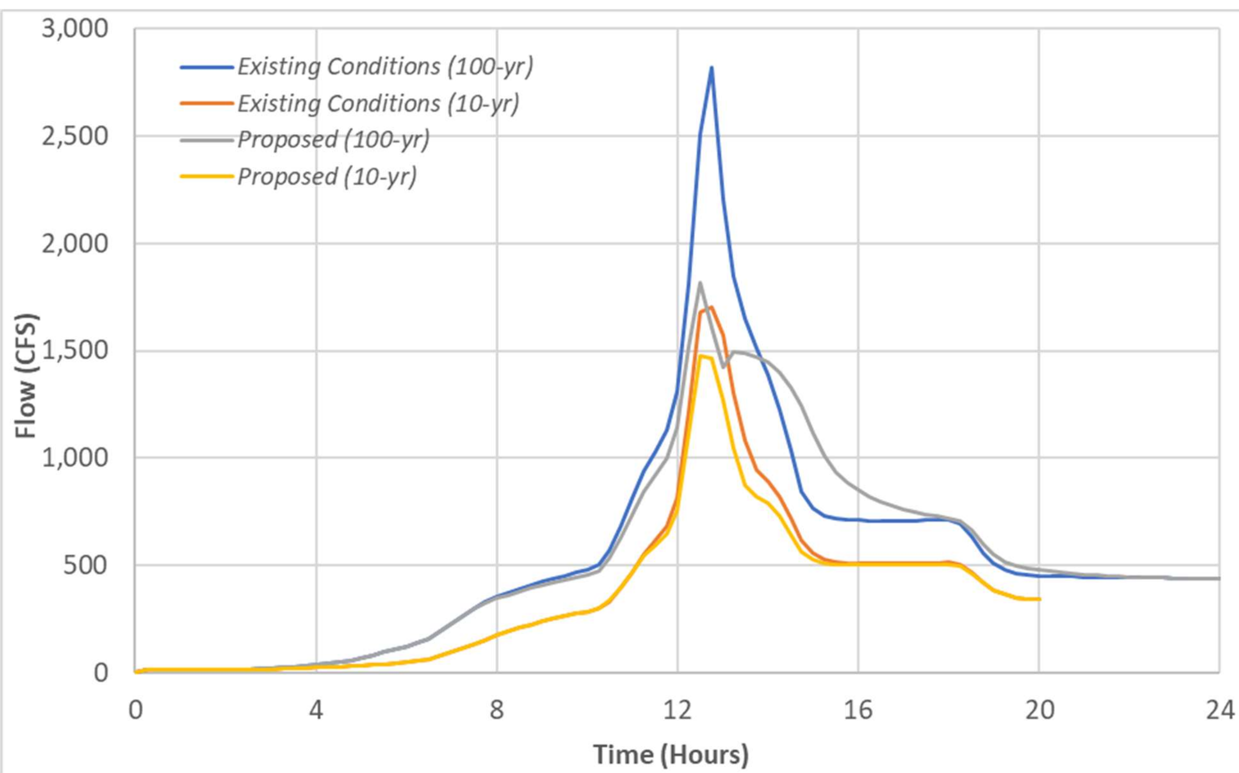


Figure 4: Hydrographs at Cross Section on Channel Downstream of Basin 03

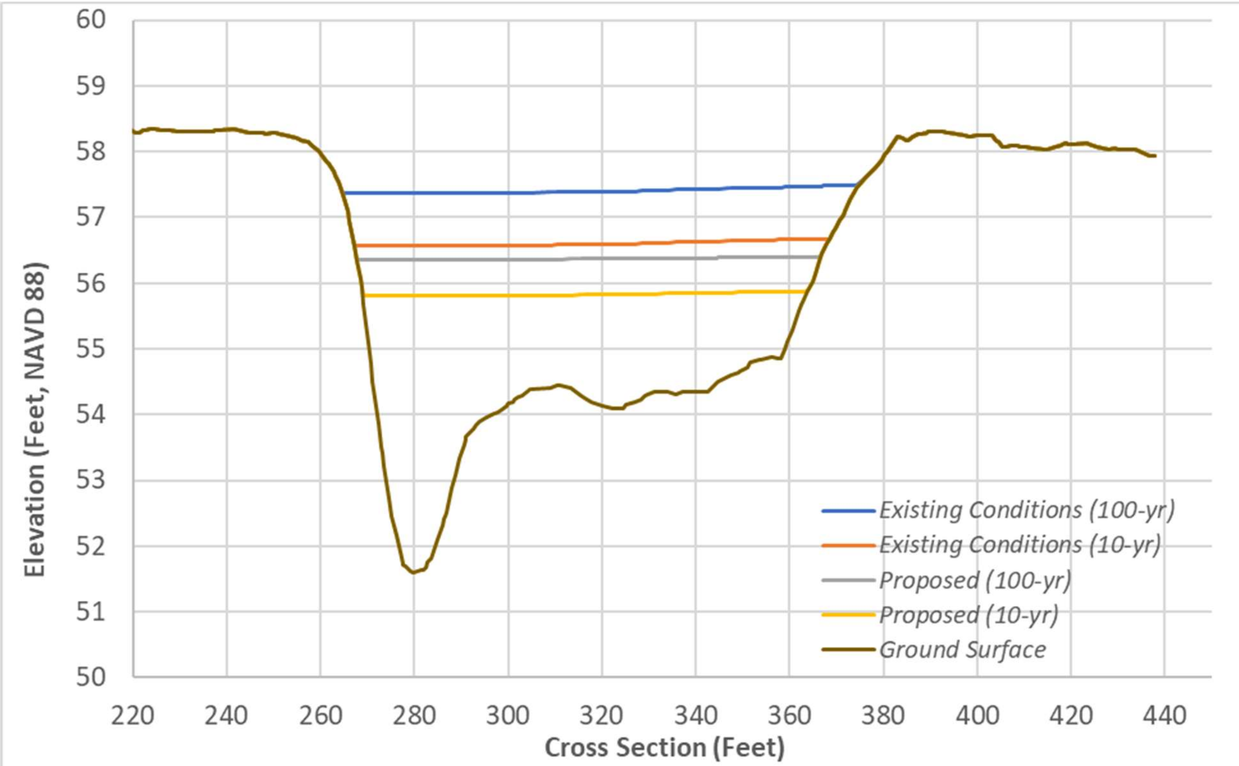


Figure 5: Cross Section on Channel Downstream of Basin 06

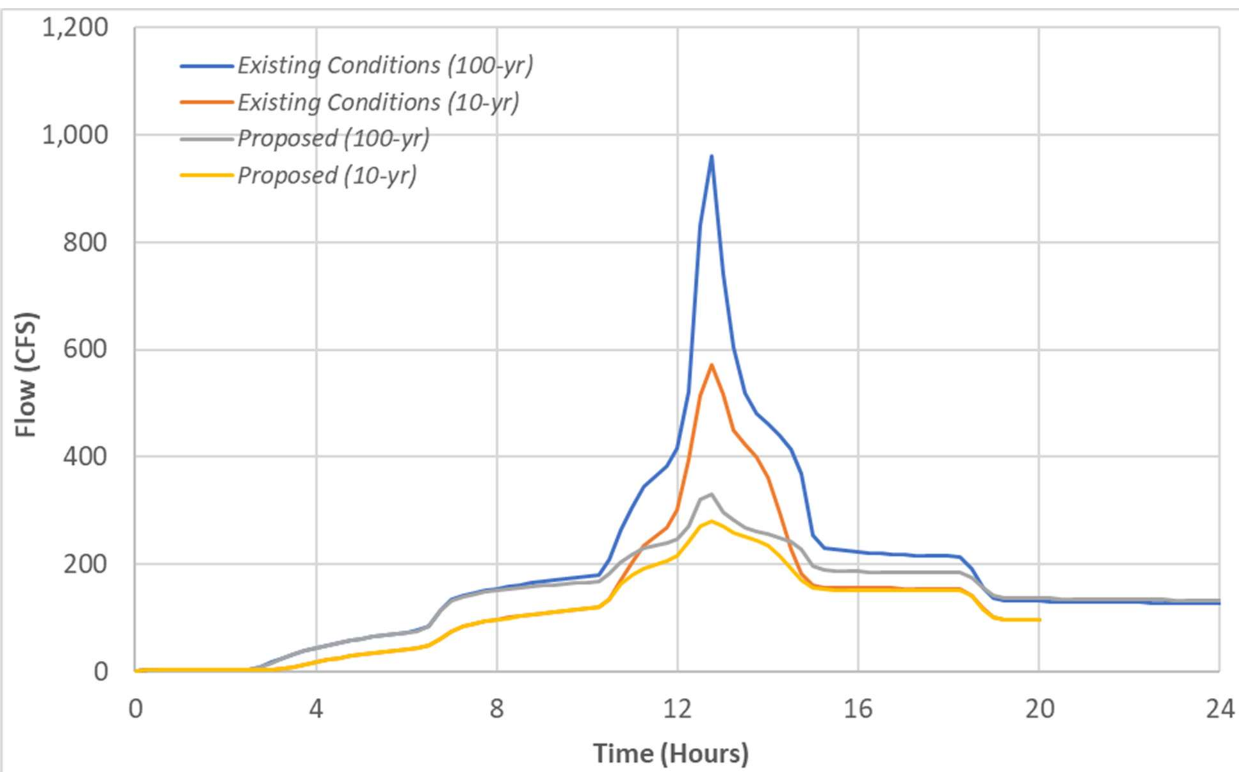


Figure 6: Hydrographs at Cross Section on Channel Downstream of Basin 06

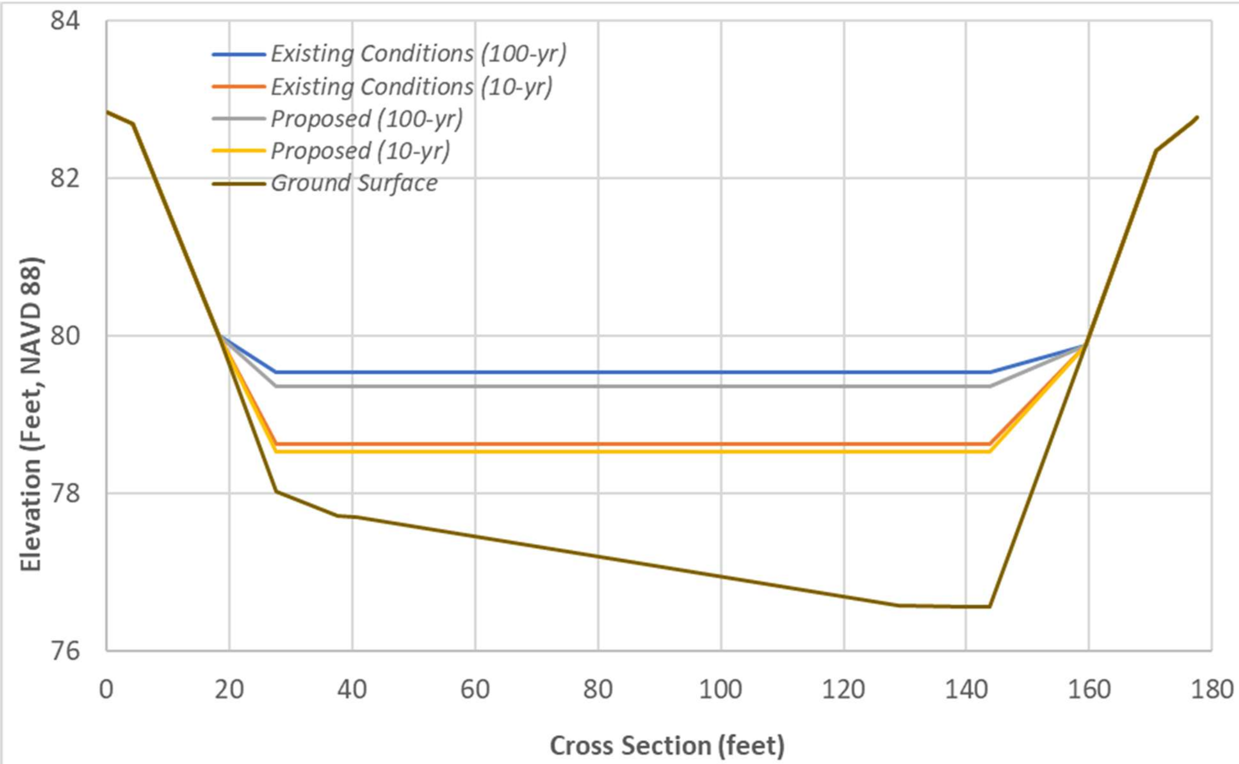


Figure 7: Cross Section on Channel Downstream of Basin 07

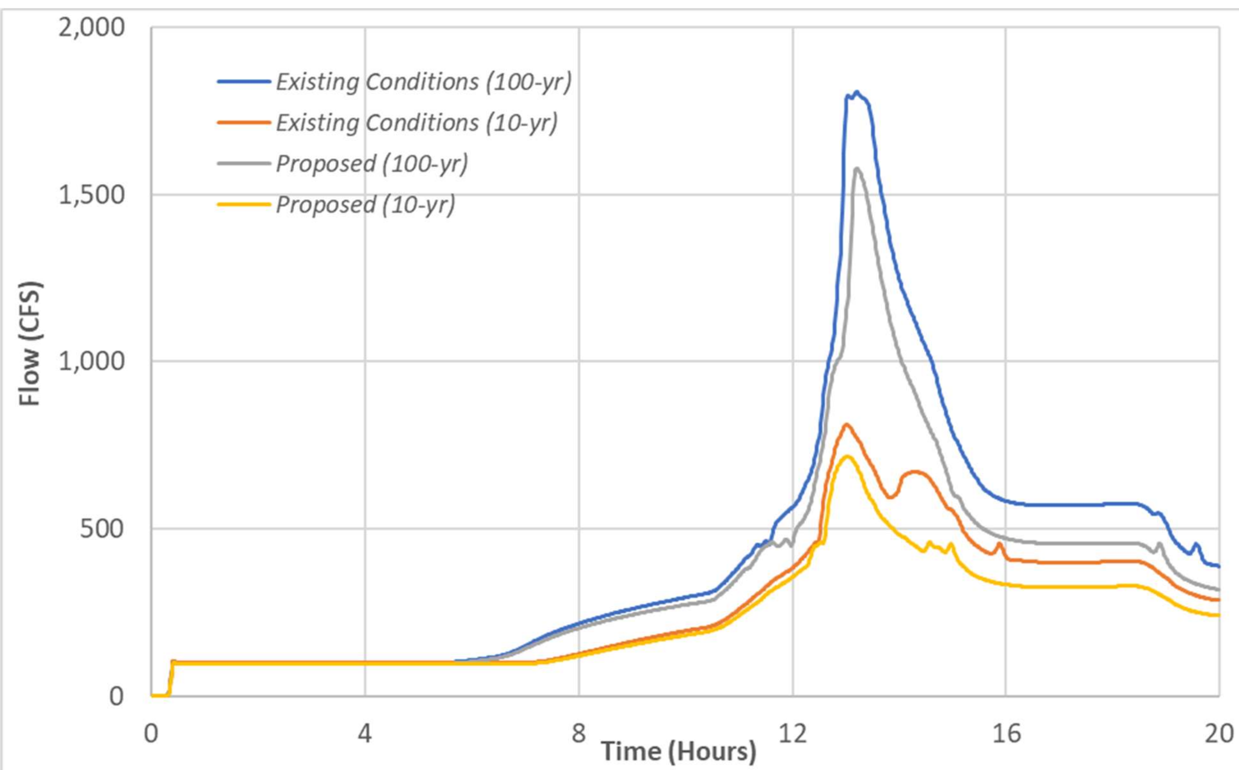


Figure 8: Hydrographs at Cross Section on Channel Downstream of Basin 07

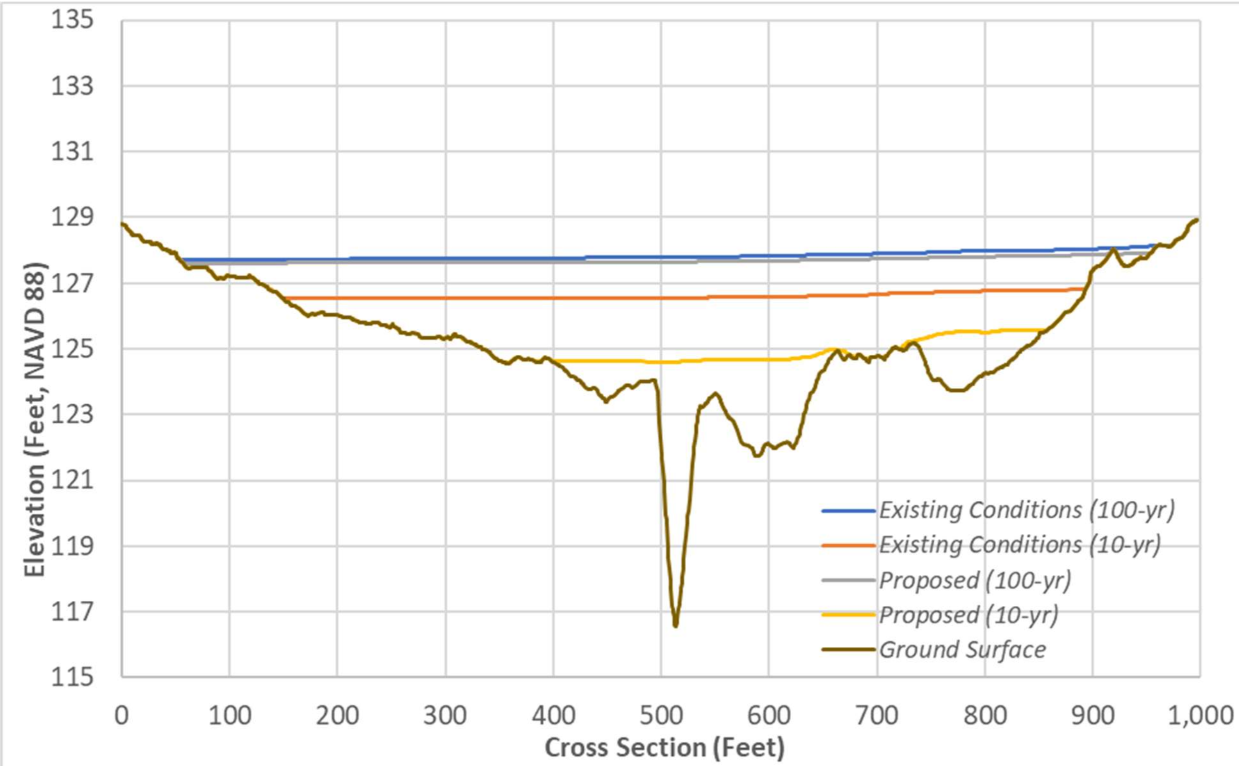


Figure 9: Cross Section on Channel Downstream of Basin 09

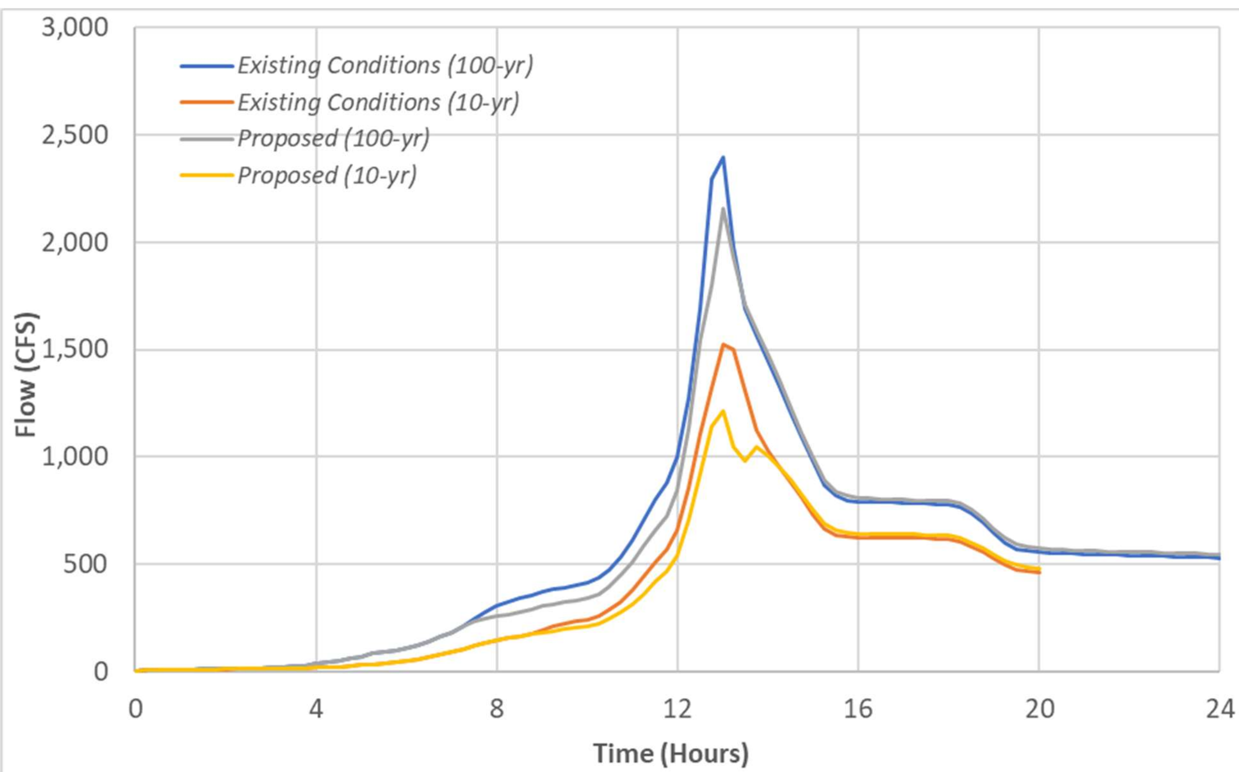


Figure 10: Hydrographs at Cross Section on Channel Downstream of Basin 09

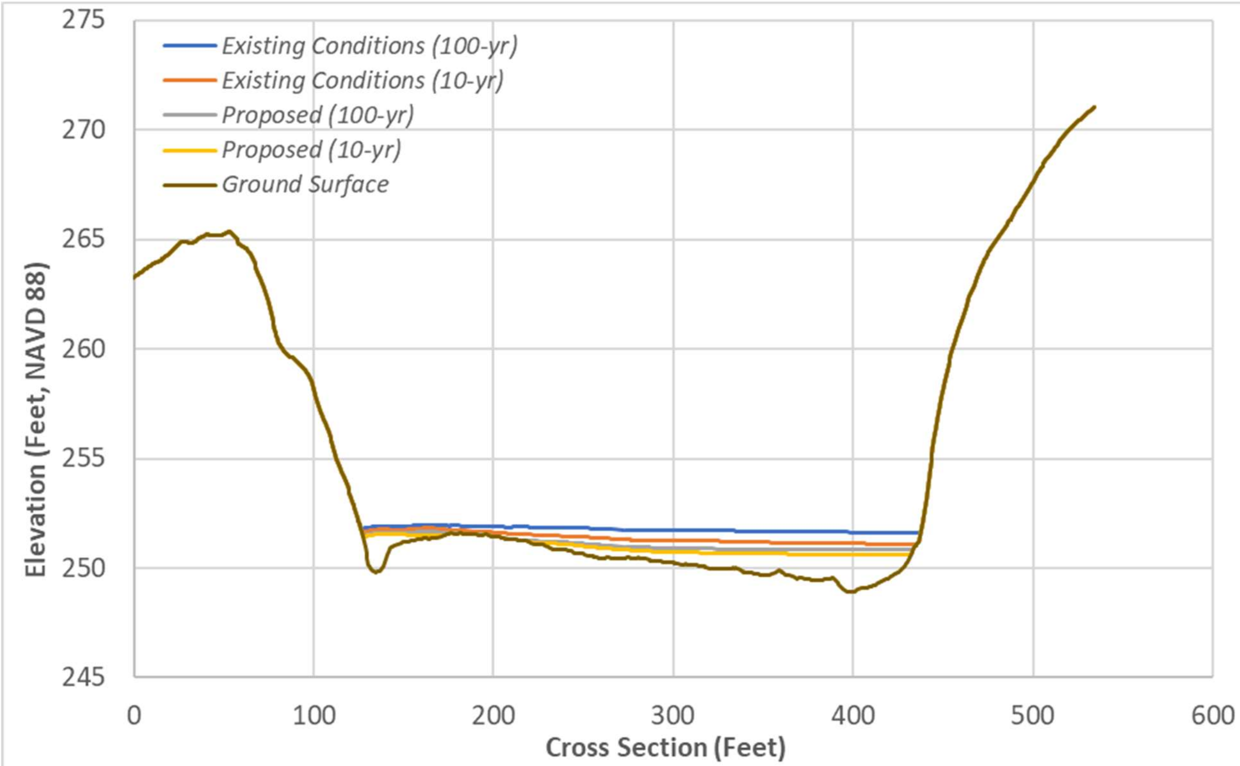


Figure 11: Cross Section on Channel Downstream of Basin 10

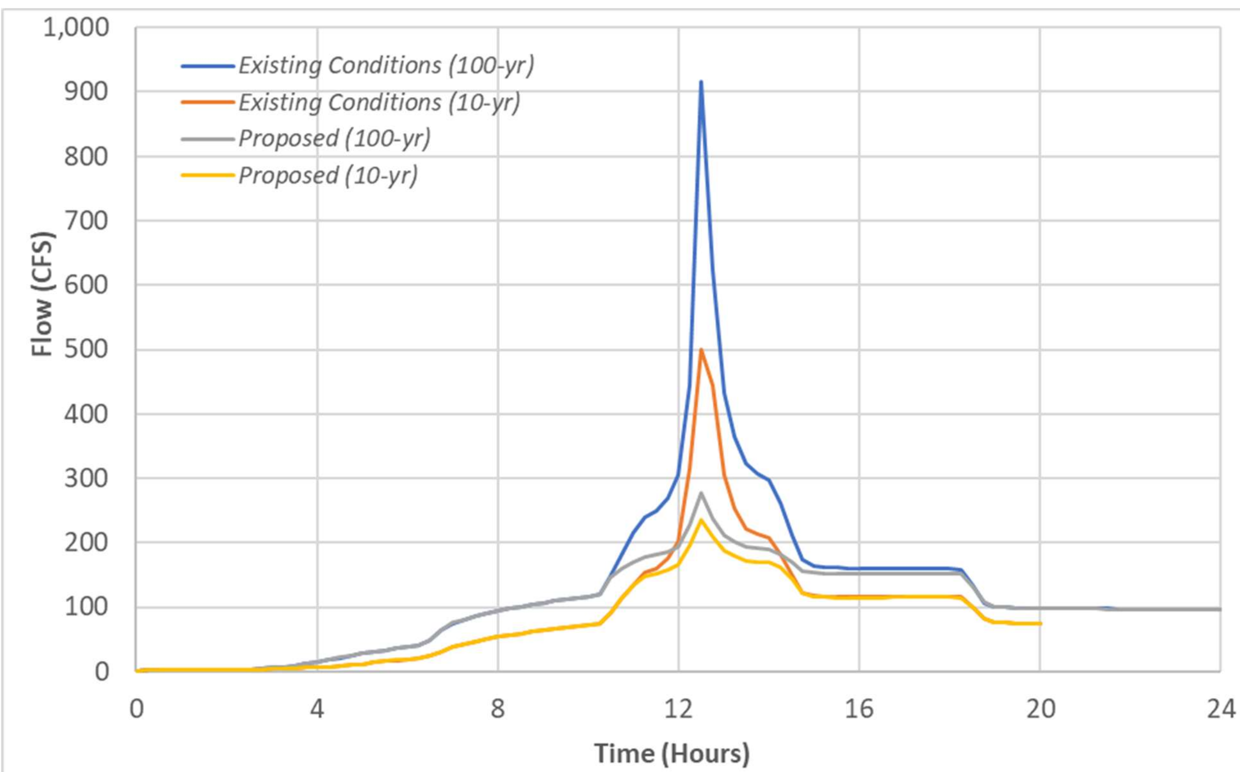


Figure 12: Hydrographs at Cross Section on Channel Downstream of Basin 10

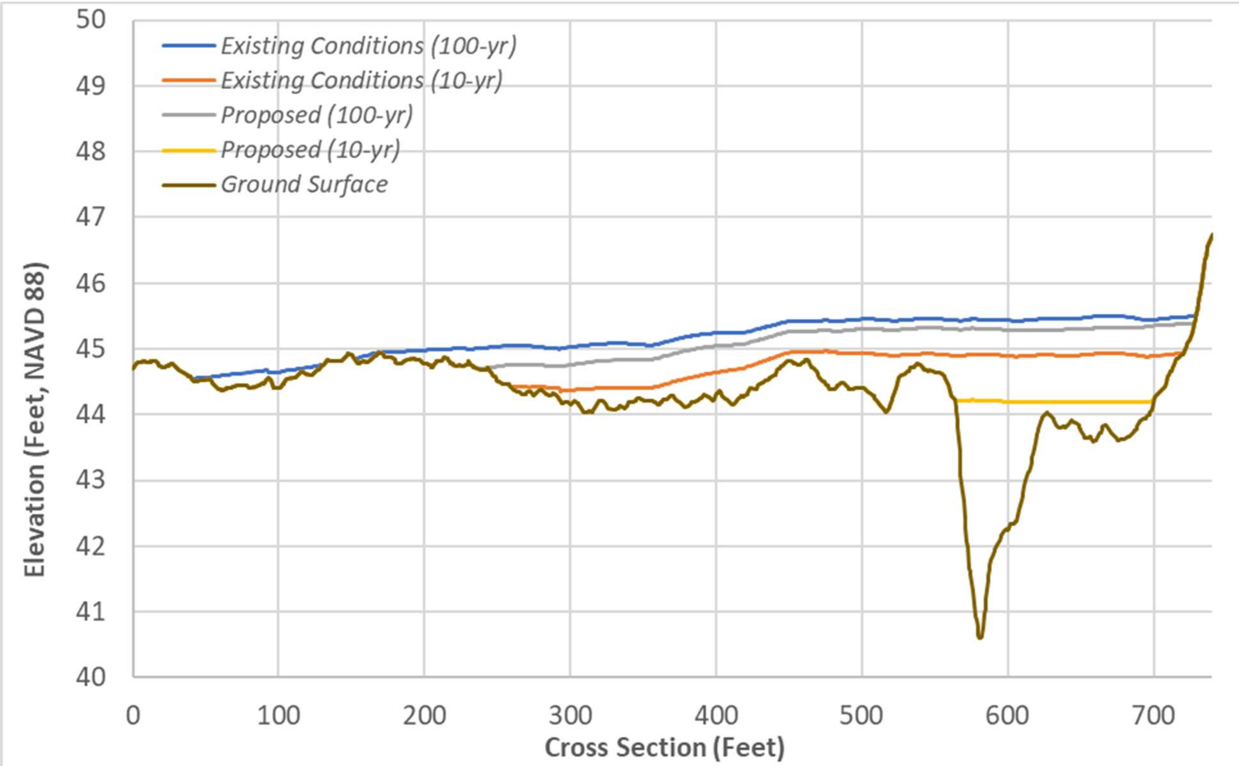


Figure 13: Cross Section on Channel Downstream of Basin 12

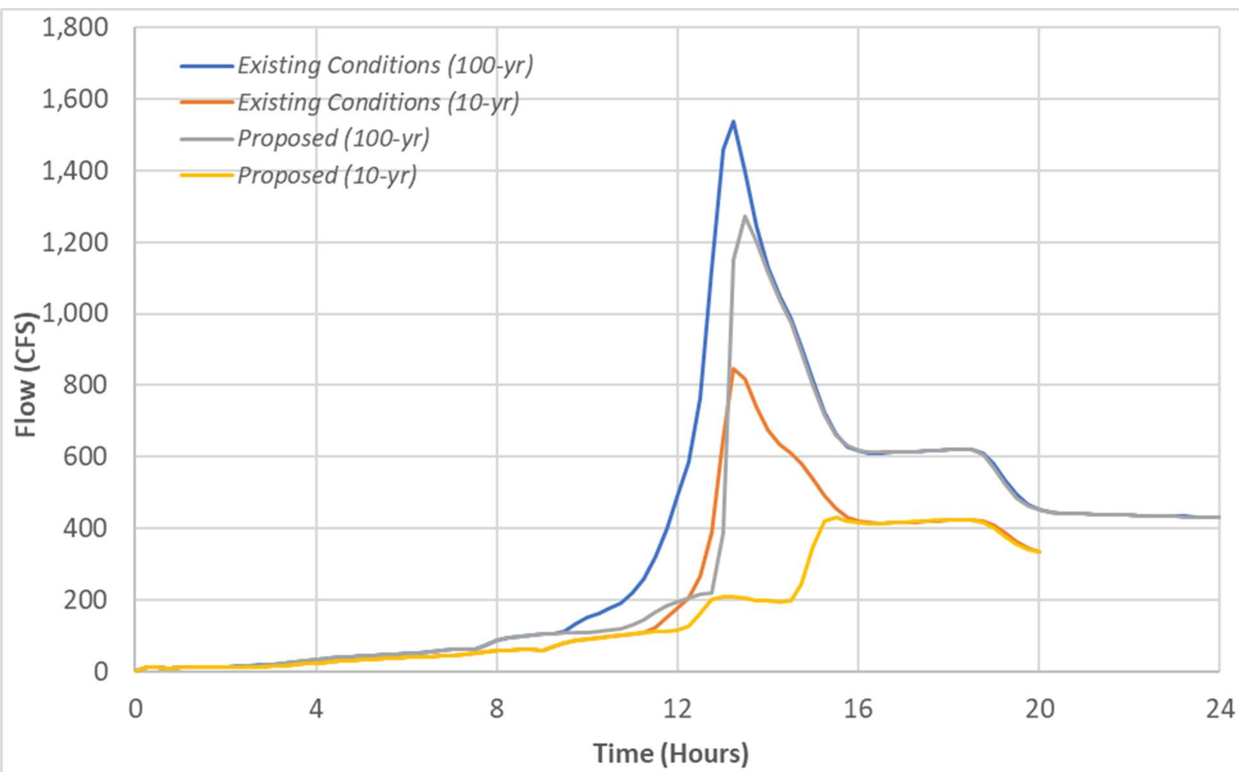


Figure 14: Hydrographs at Cross Section on Channel Downstream of Basin 12

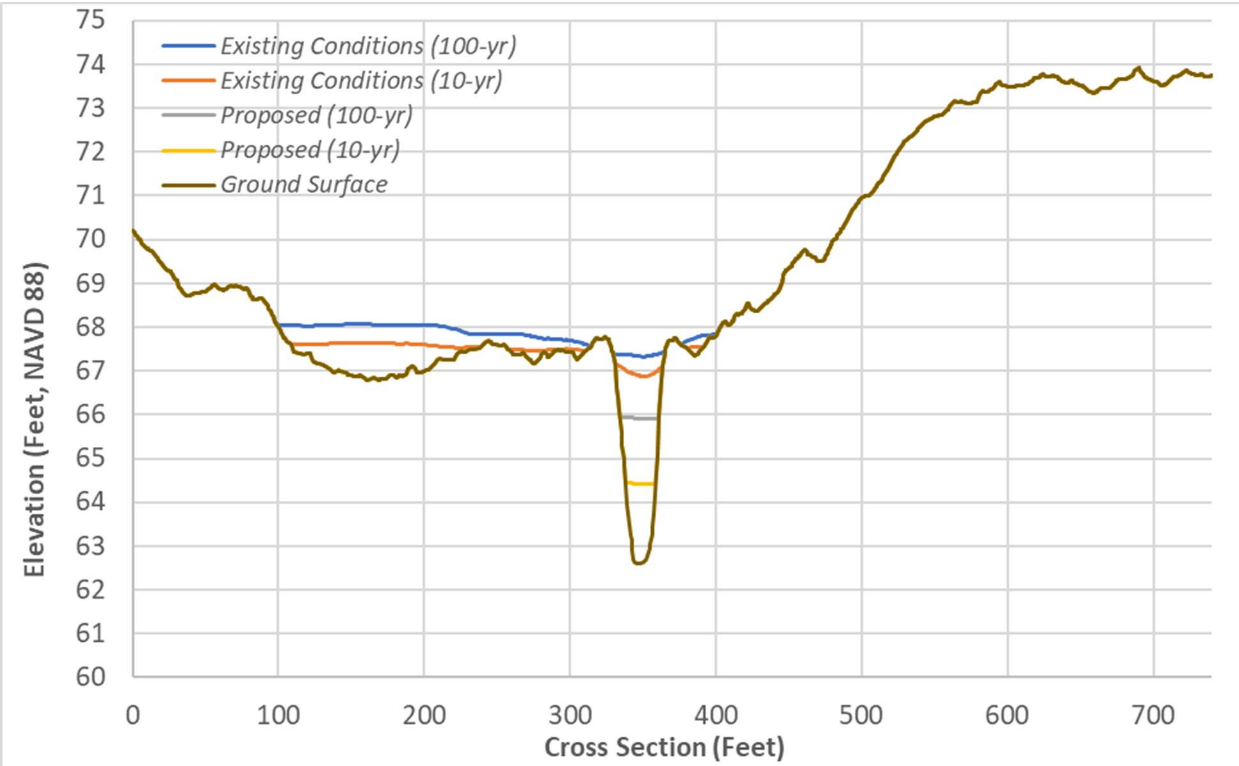


Figure 15: Cross Section on Channel Downstream of Basin 16

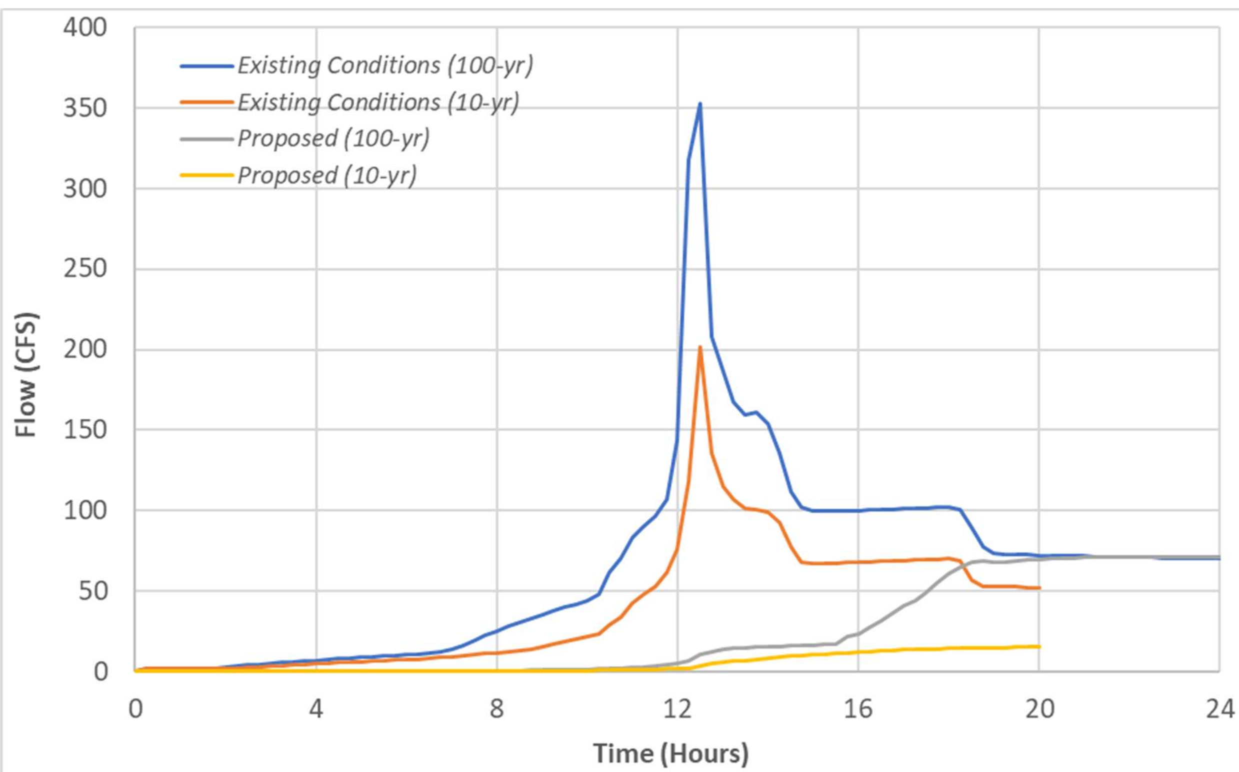


Figure 16: Hydrographs at Cross Section on Channel Downstream of Basin 16

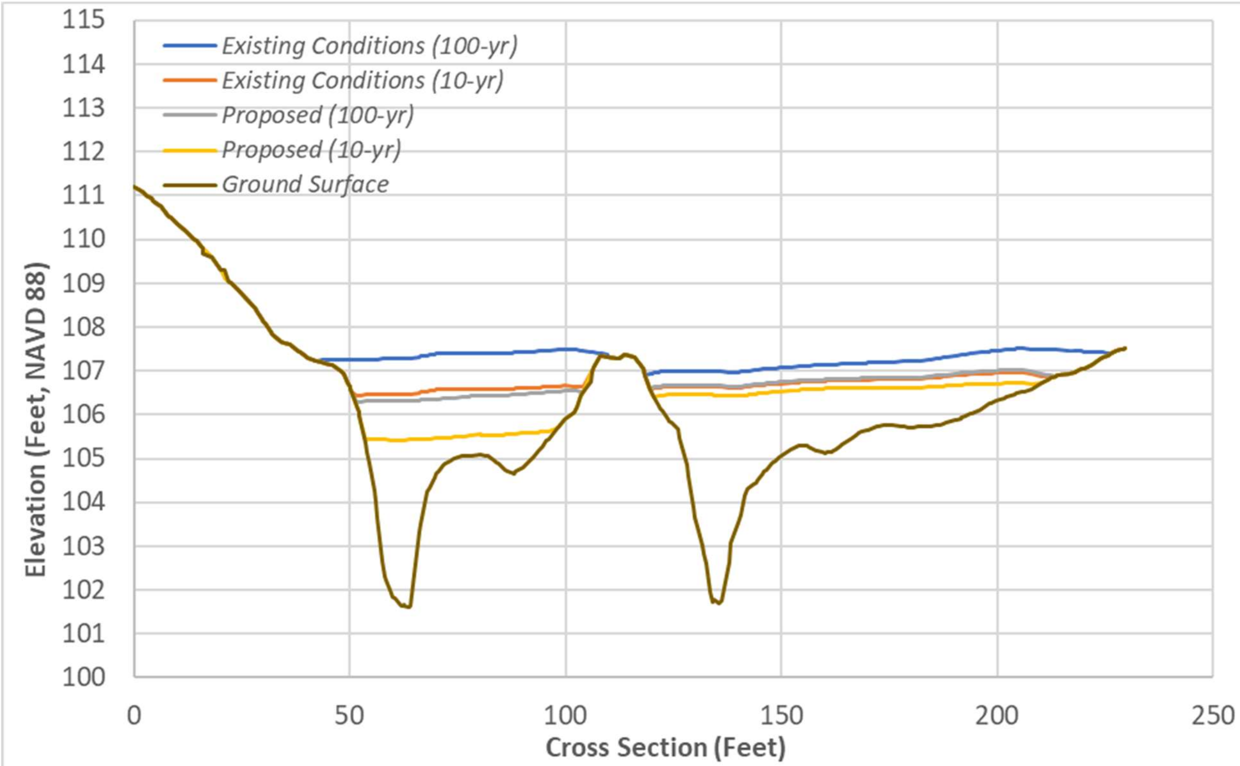


Figure 17: Cross Section on Channel Downstream of Basin 17

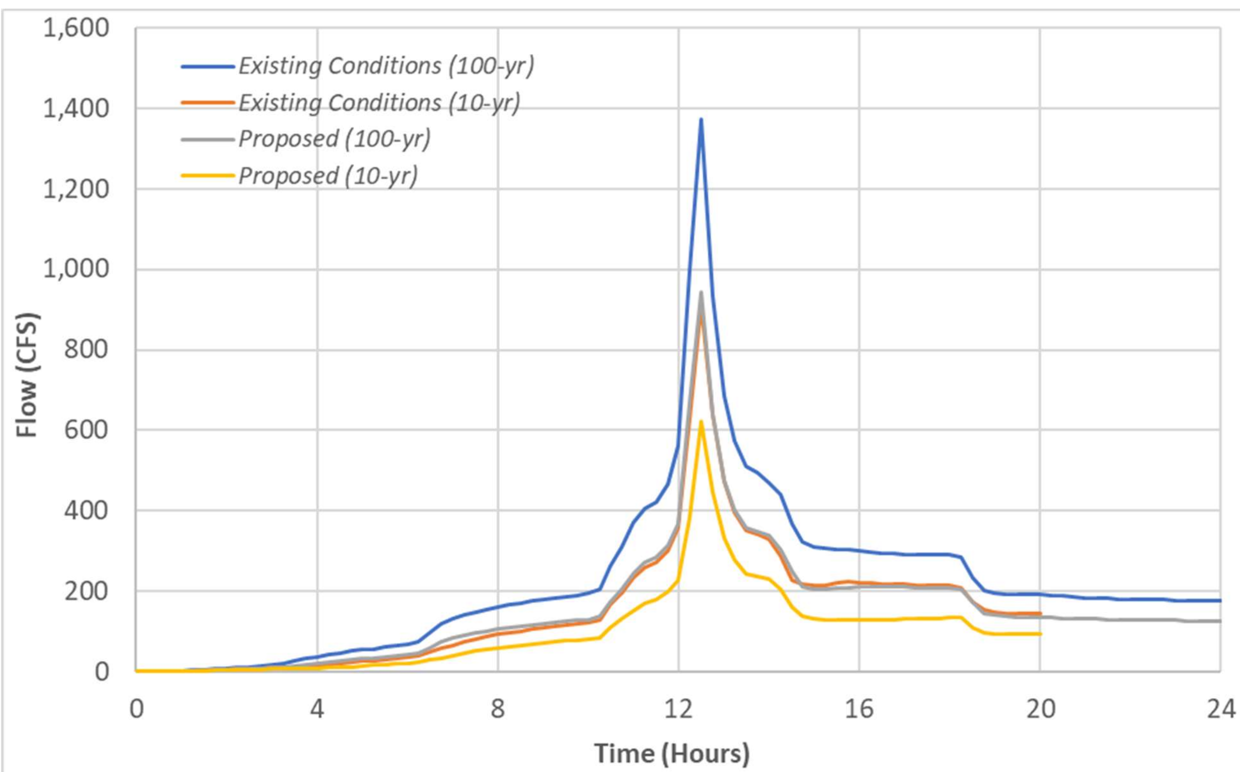


Figure 18: Hydrographs at Cross Section on Channel Downstream of Basin 17

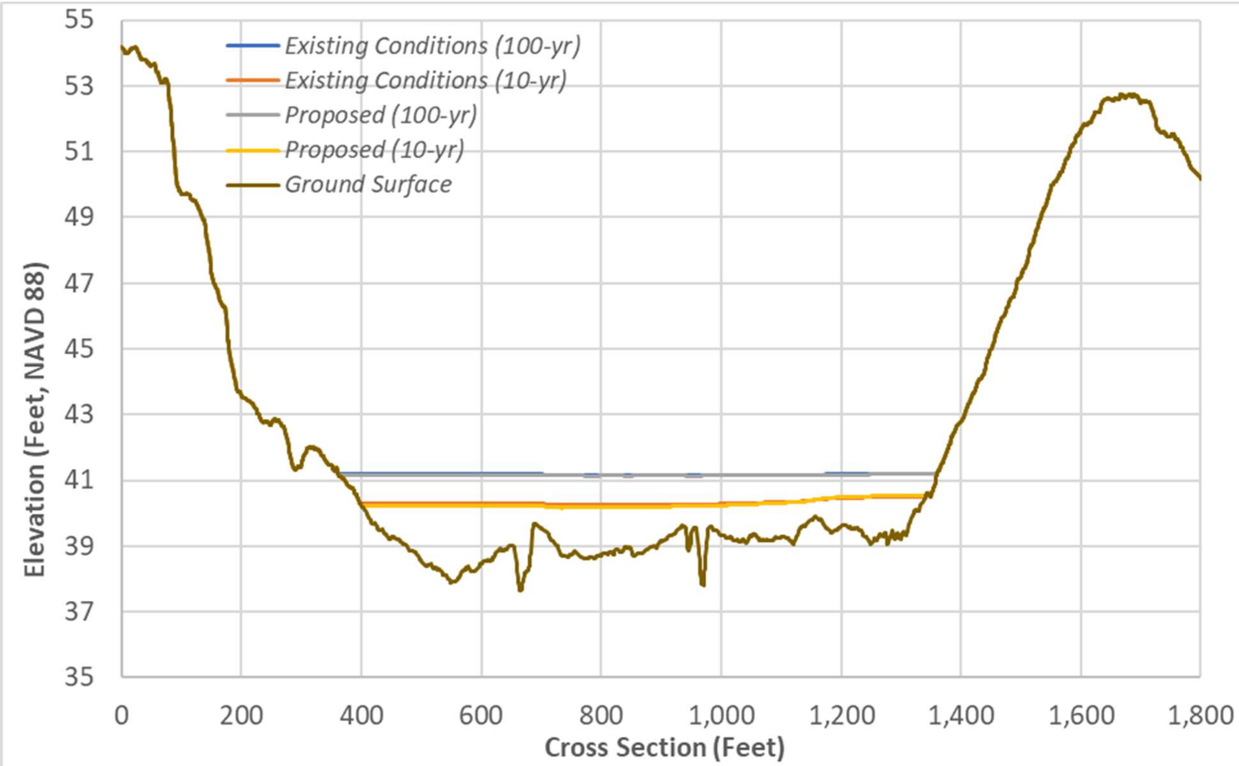


Figure 19: Cross Section on Channel Downstream of Basin 23

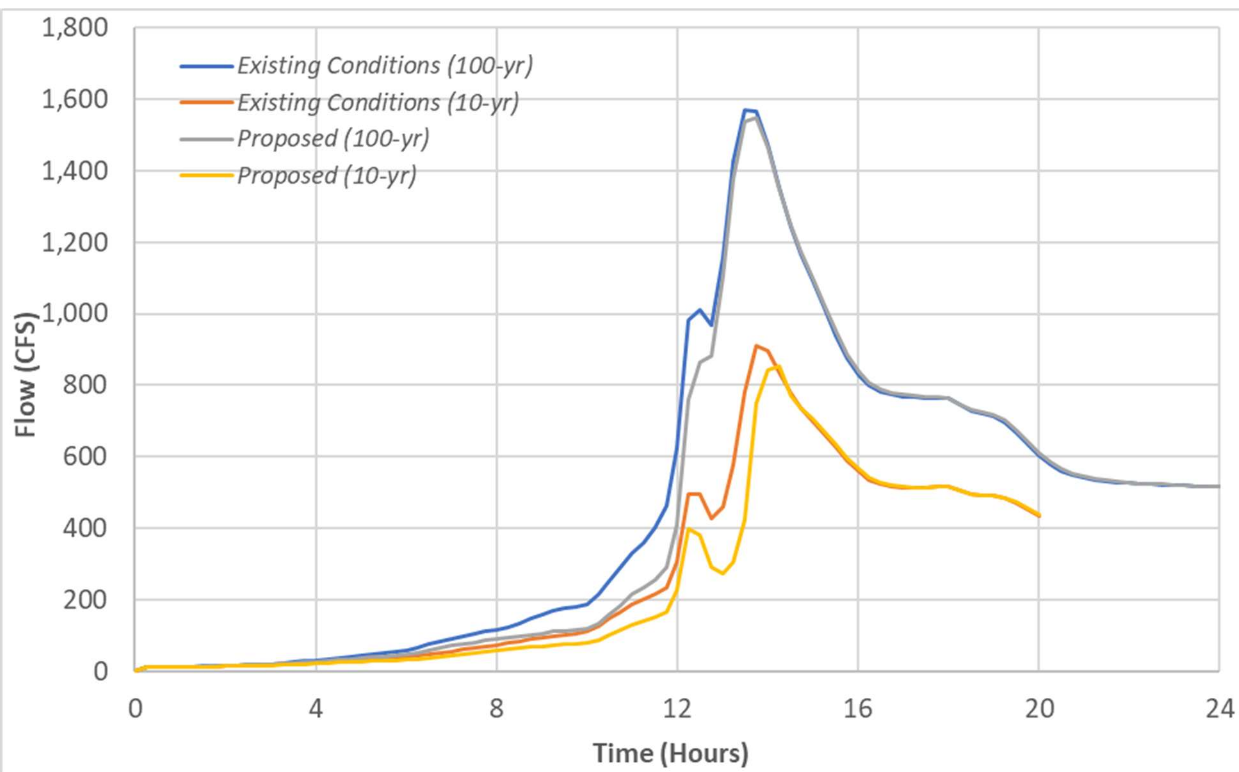


Figure 20: Hydrographs at Cross Section on Channel Downstream of Basin 23

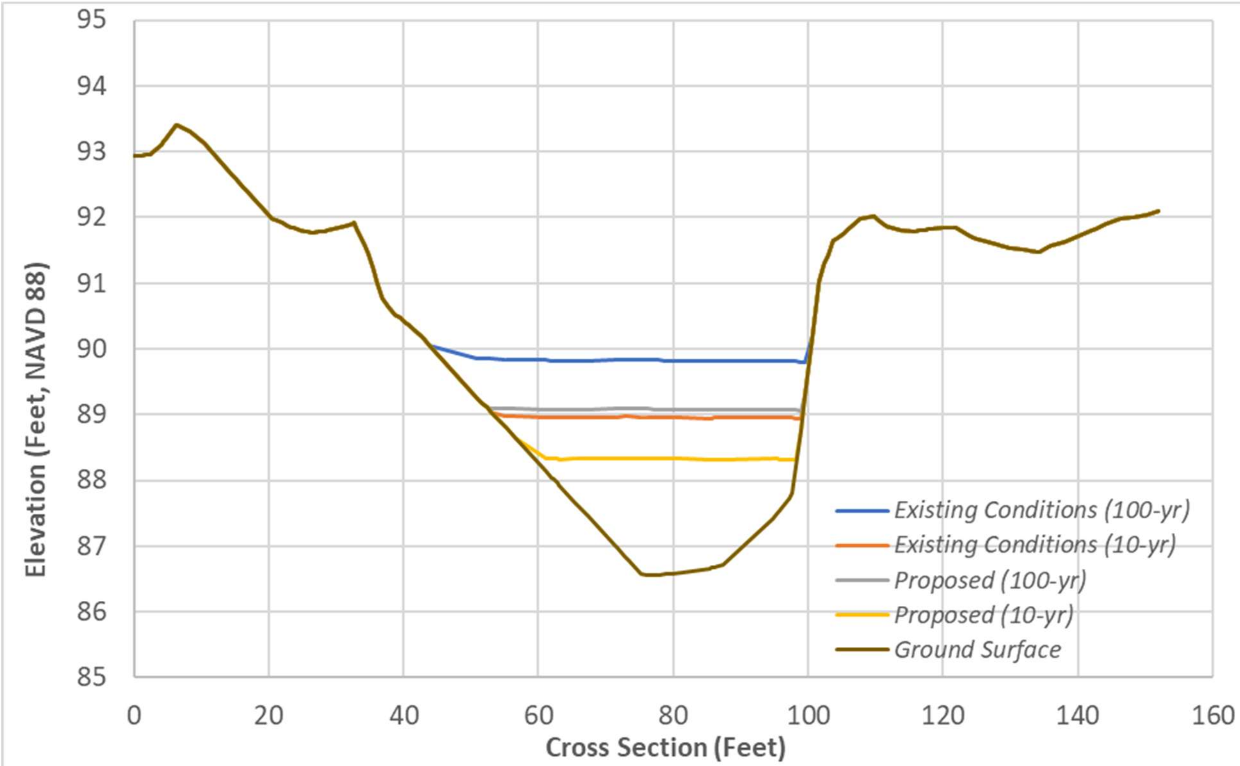


Figure 21: Cross Section on Channel Downstream of Basin 24

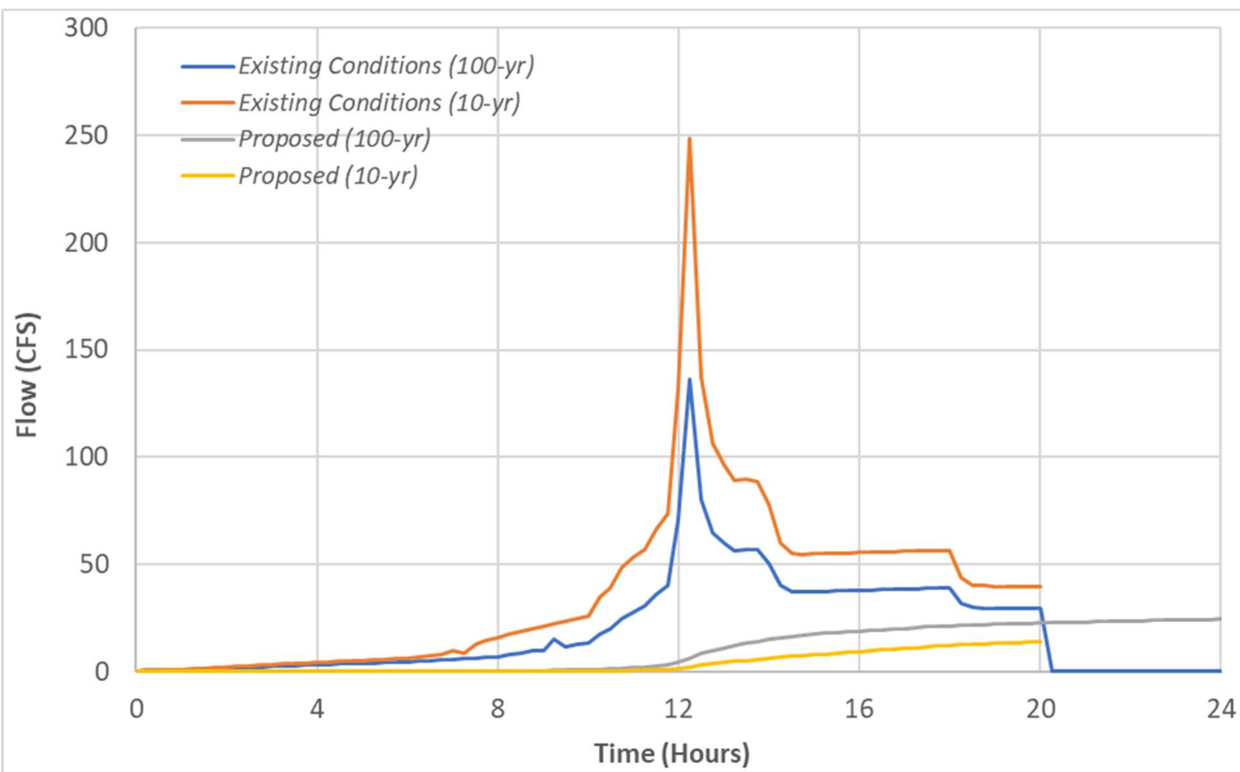


Figure 22: Hydrographs at Cross Section on Channel Downstream of Basin 24

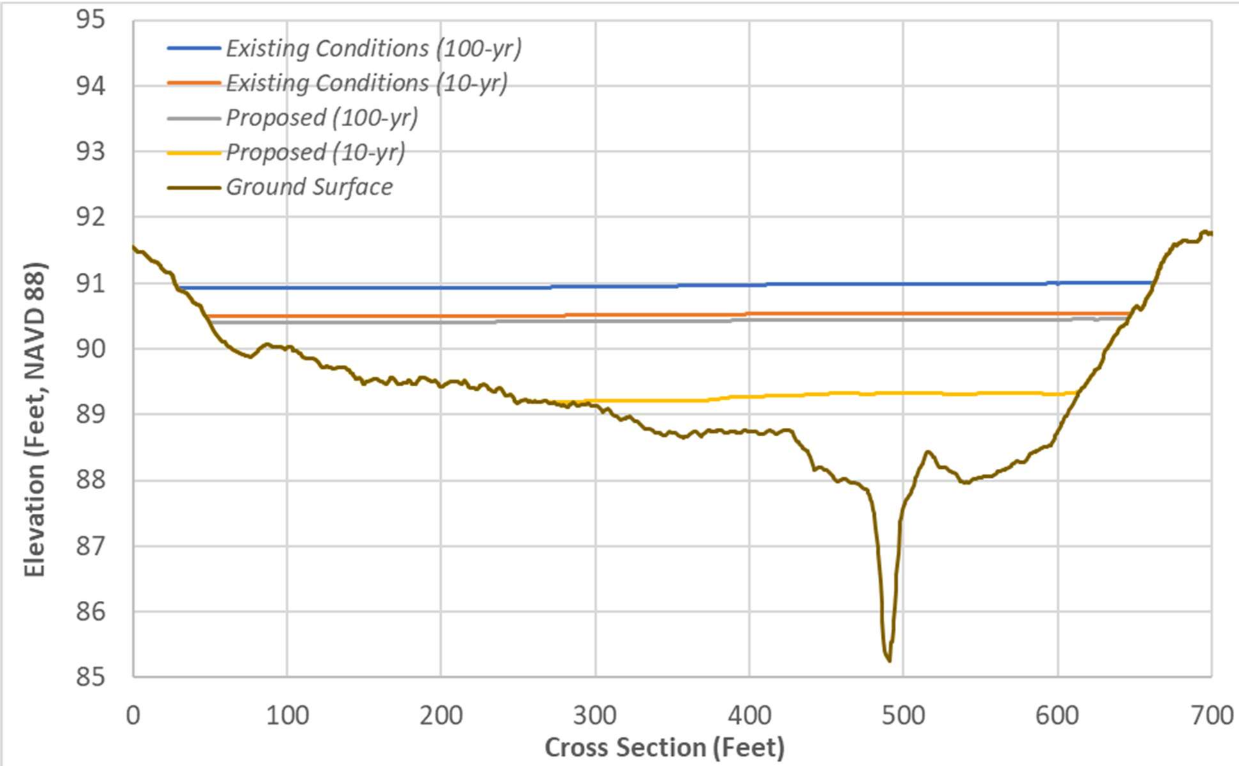


Figure 23: Cross Section on Channel Downstream of Basin 25

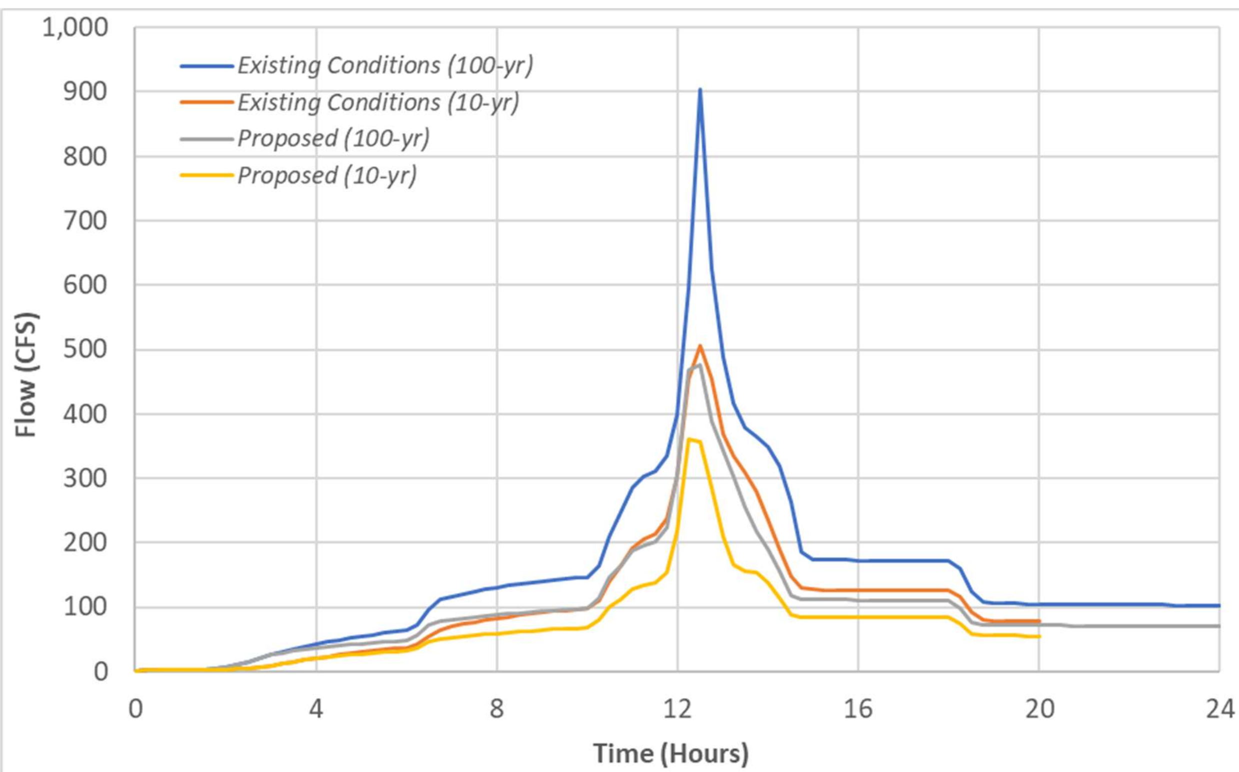


Figure 24: Hydrographs at Cross Section on Channel Downstream of Basin 25

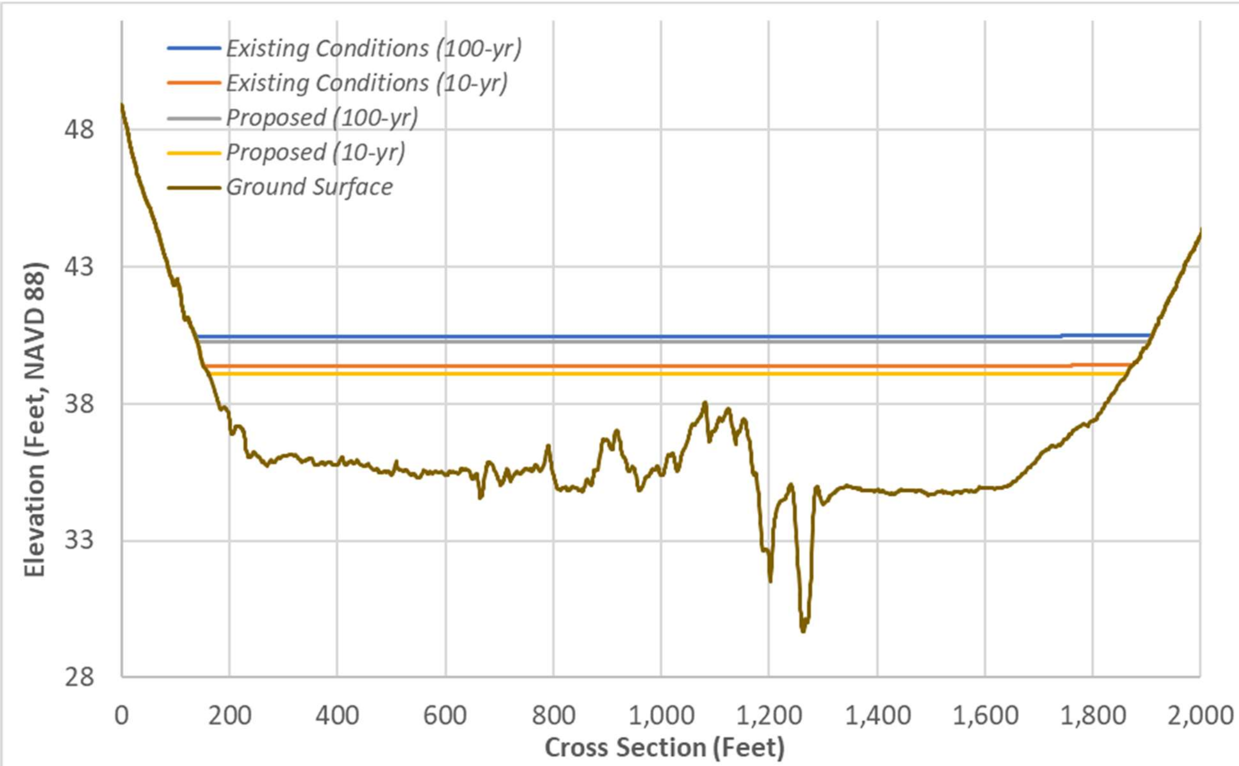


Figure 25: Cross Section on Channel Downstream of Basin 27

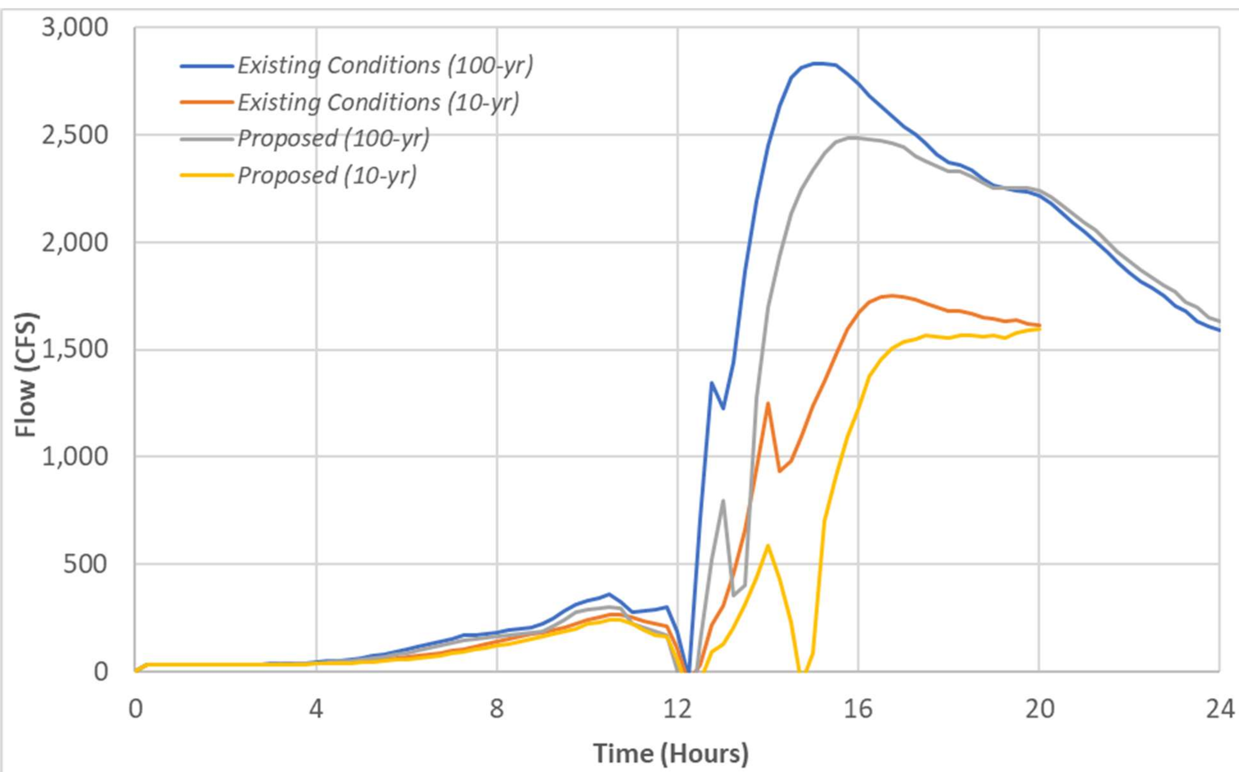


Figure 26: Hydrographs at Cross Section on Channel Downstream of Basin 27

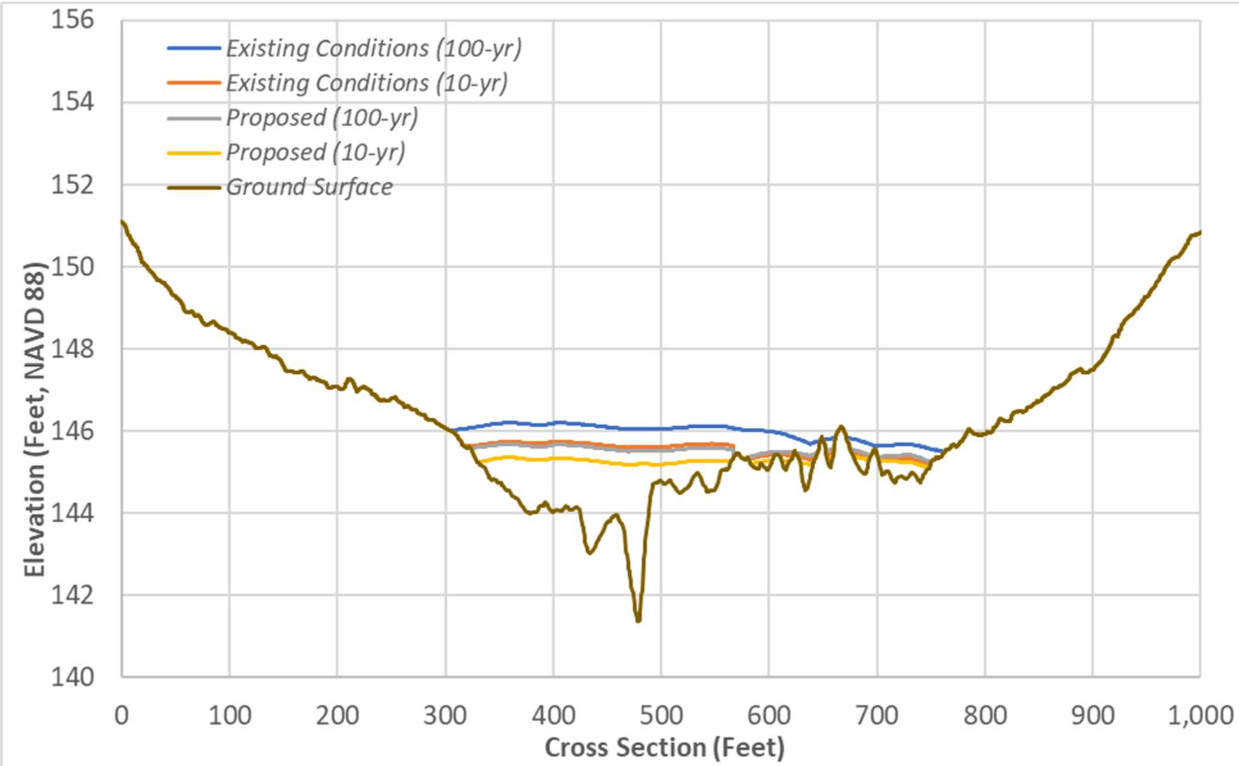


Figure 27: Cross Section on Channel Downstream of Basin 28

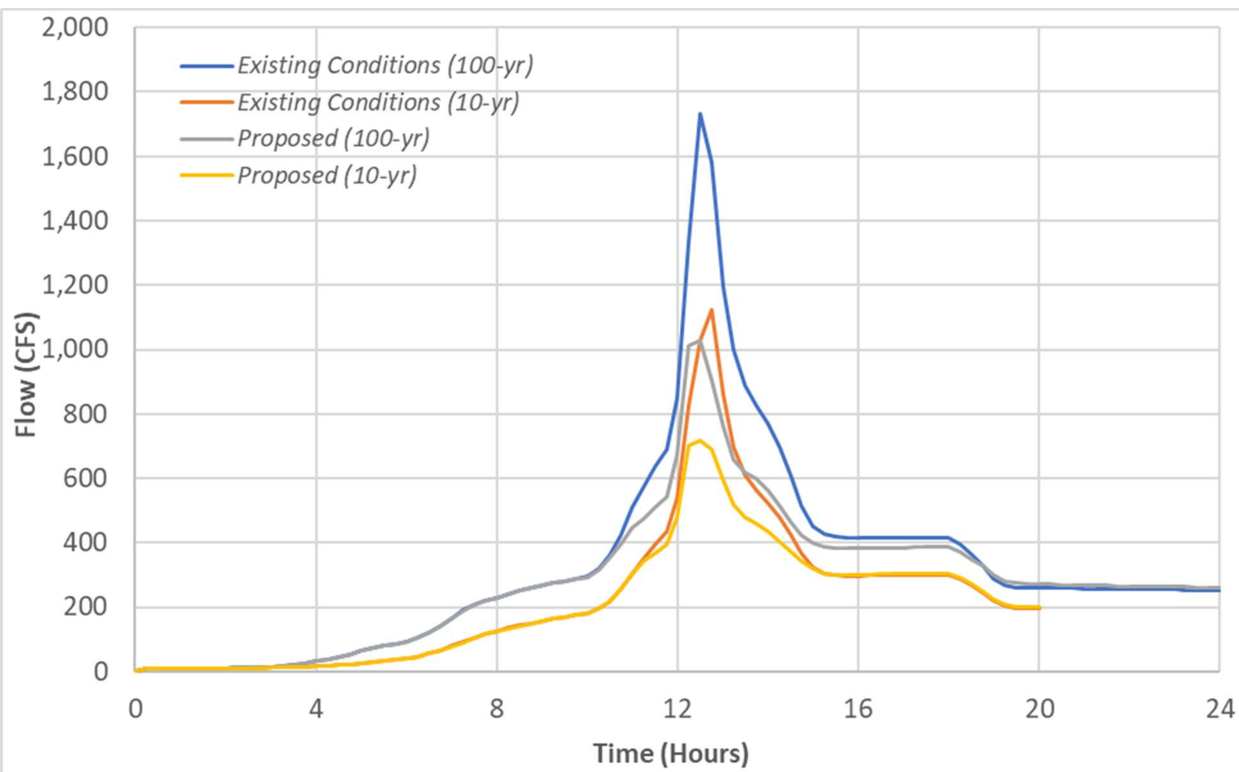


Figure 28: Hydrographs at Cross Section on Channel Downstream of Basin 28

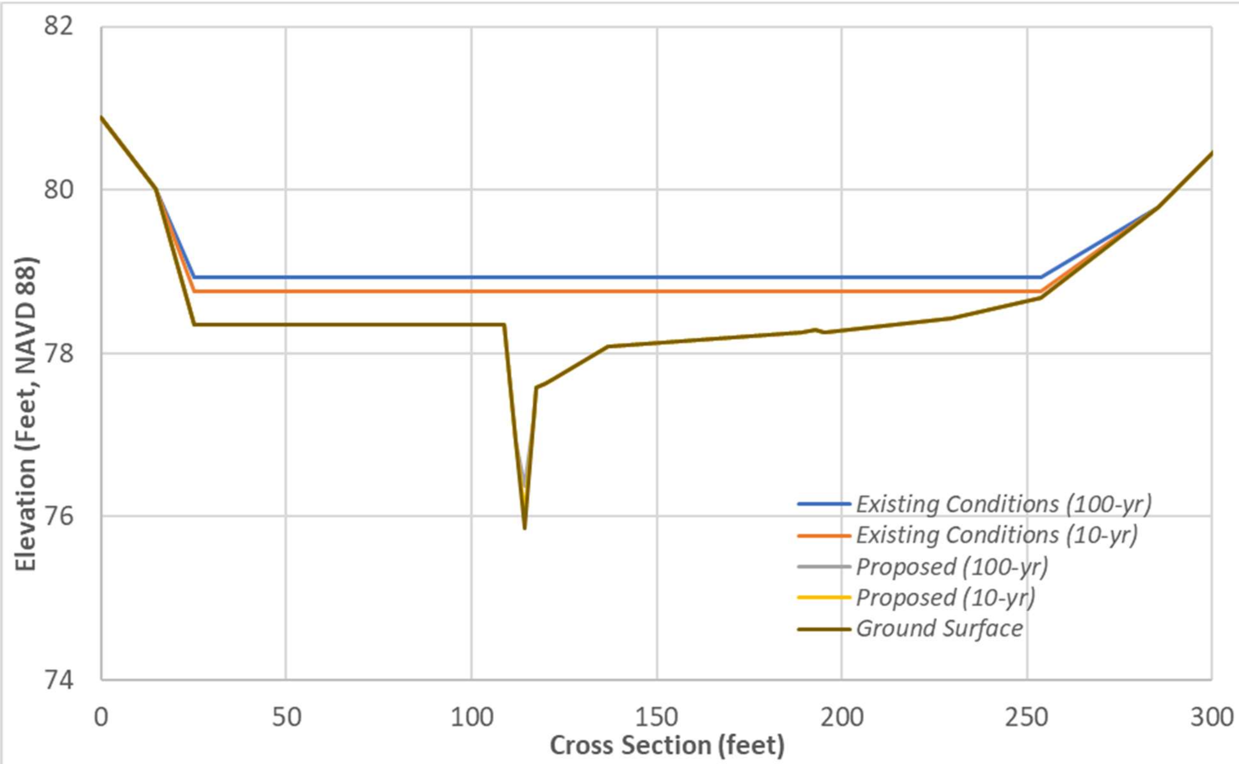


Figure 29: Cross Section on Channel Downstream of Basin 29

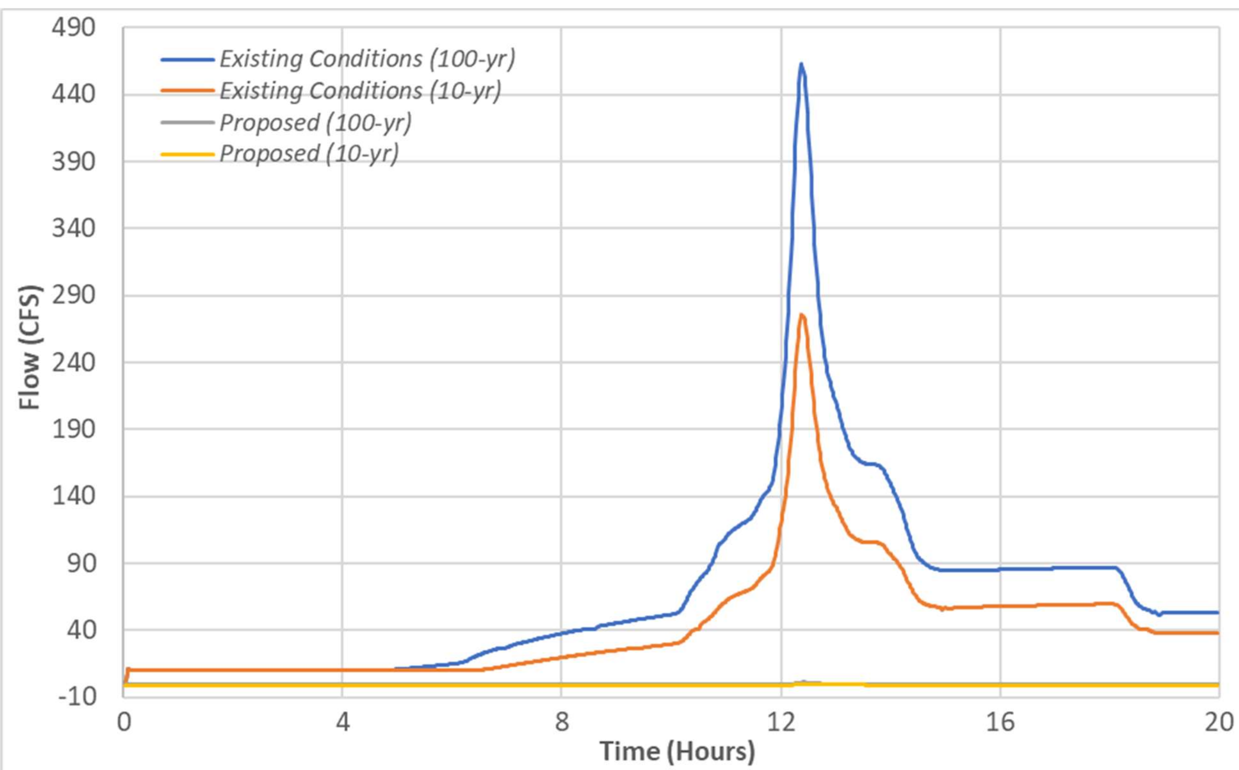


Figure 30: Hydrographs at Cross Section on Channel Downstream of Basin 29

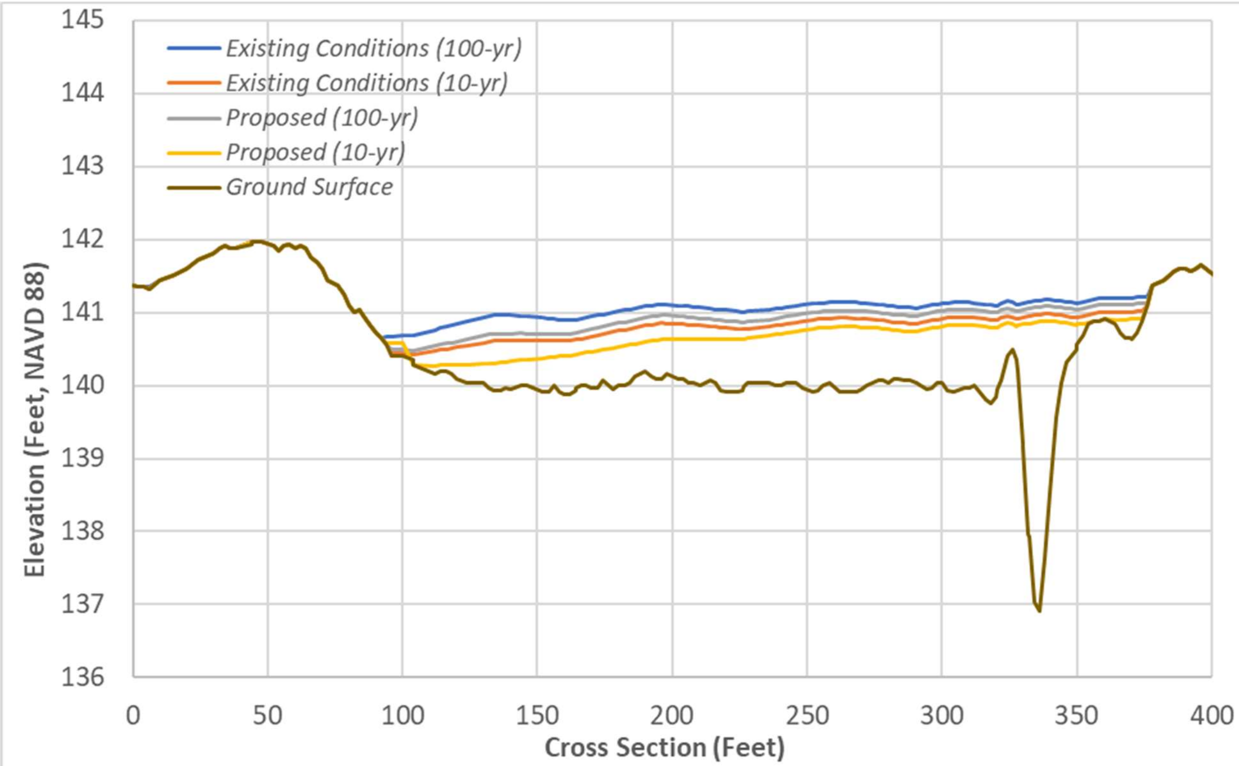


Figure 31: Cross Section on Channel Downstream of Basin 33

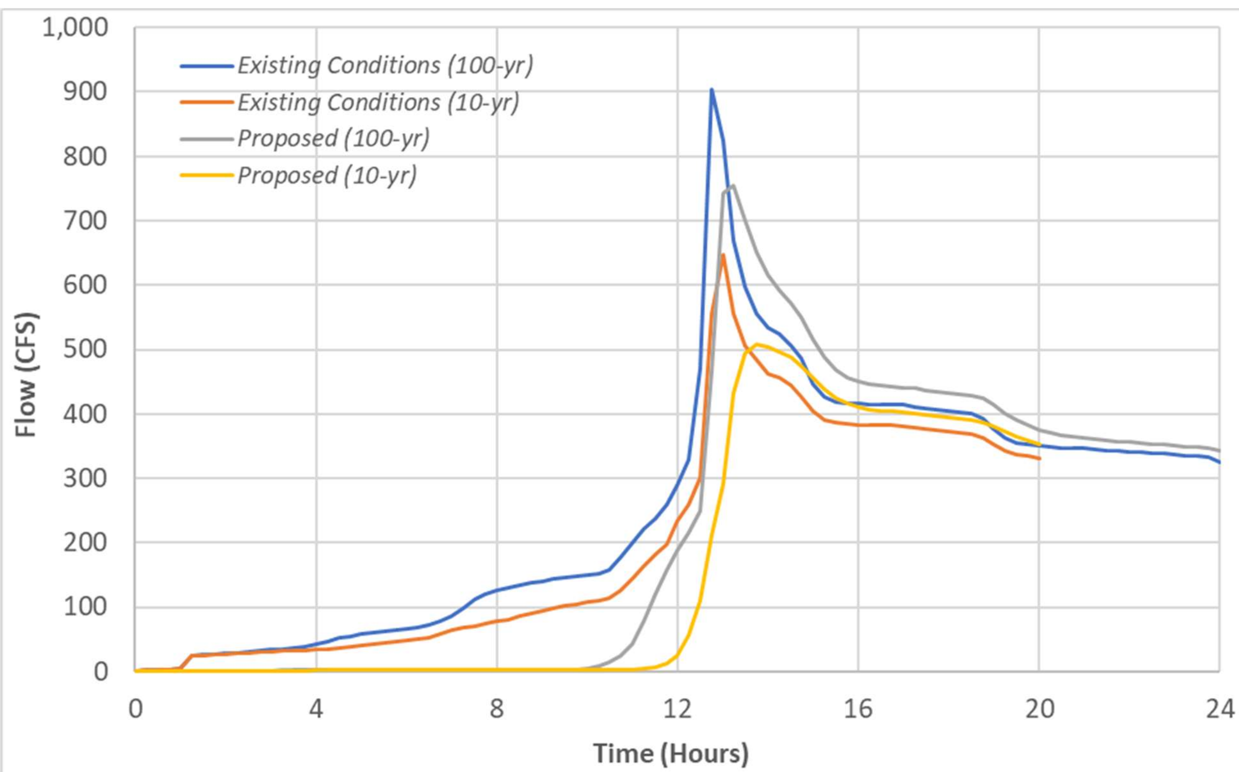


Figure 32: Hydrographs at Cross Section on Channel Downstream of Basin 33

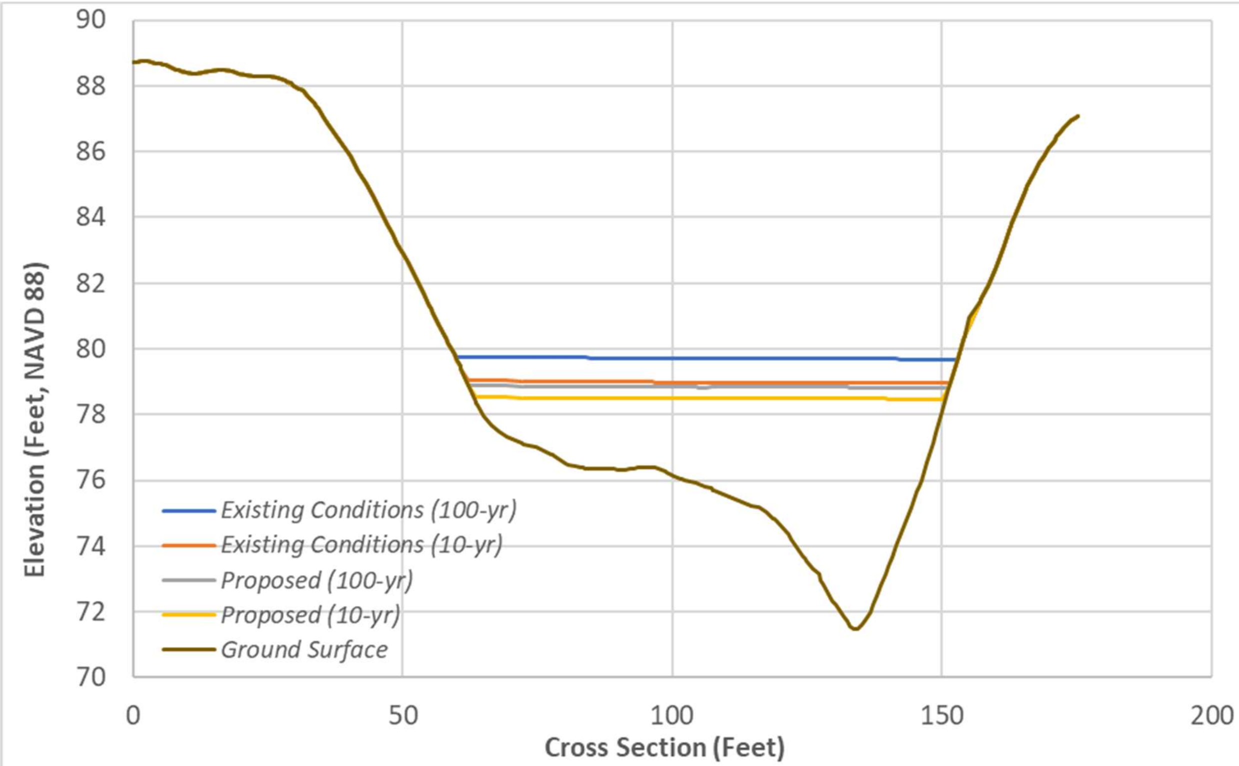


Figure 33: Cross Section on Channel Downstream of Basin 34

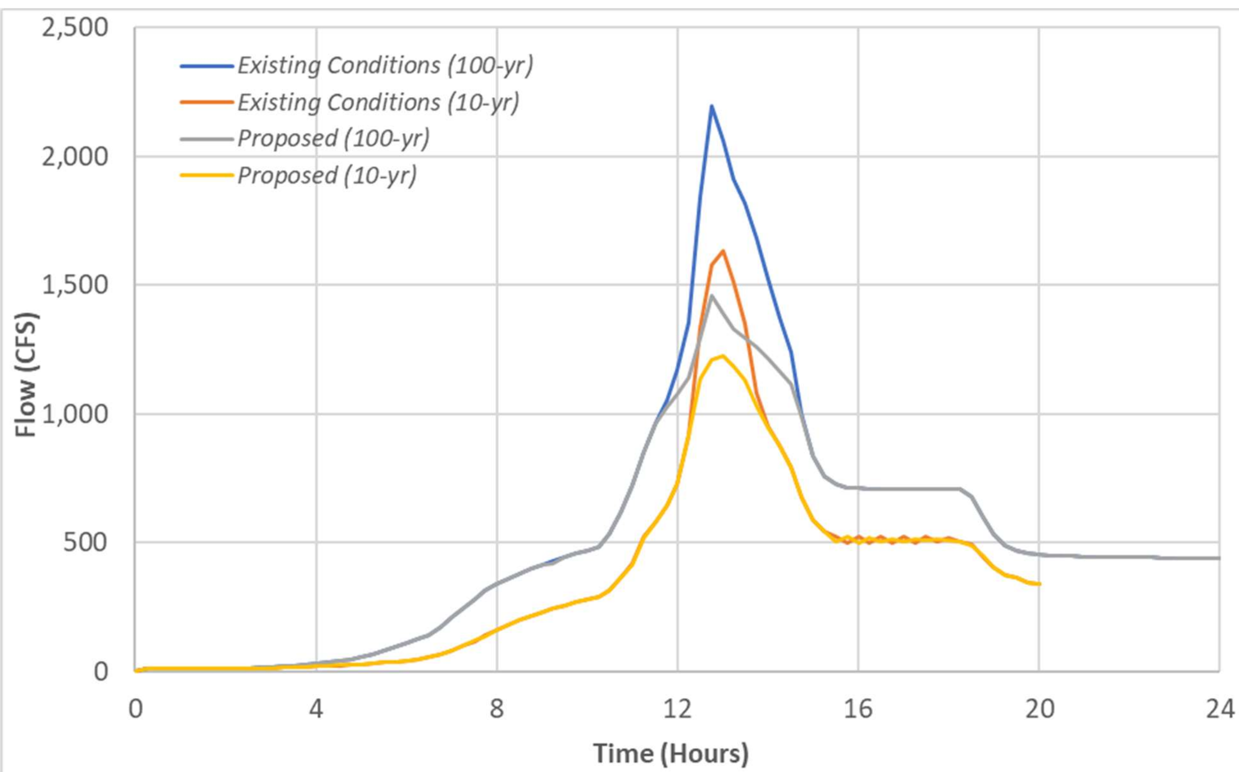


Figure 34: Hydrographs at Cross Section on Channel Downstream of Basin 34

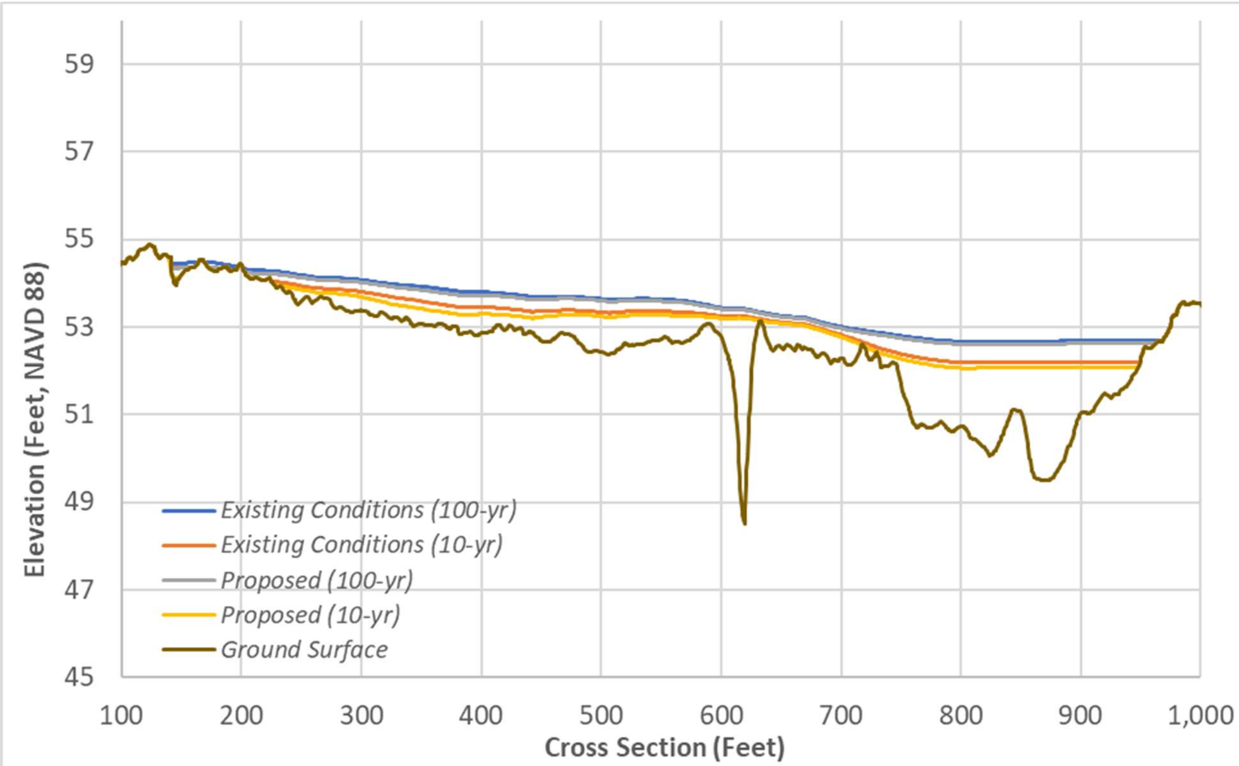


Figure 35: Cross Section on Channel Downstream of Basin 36

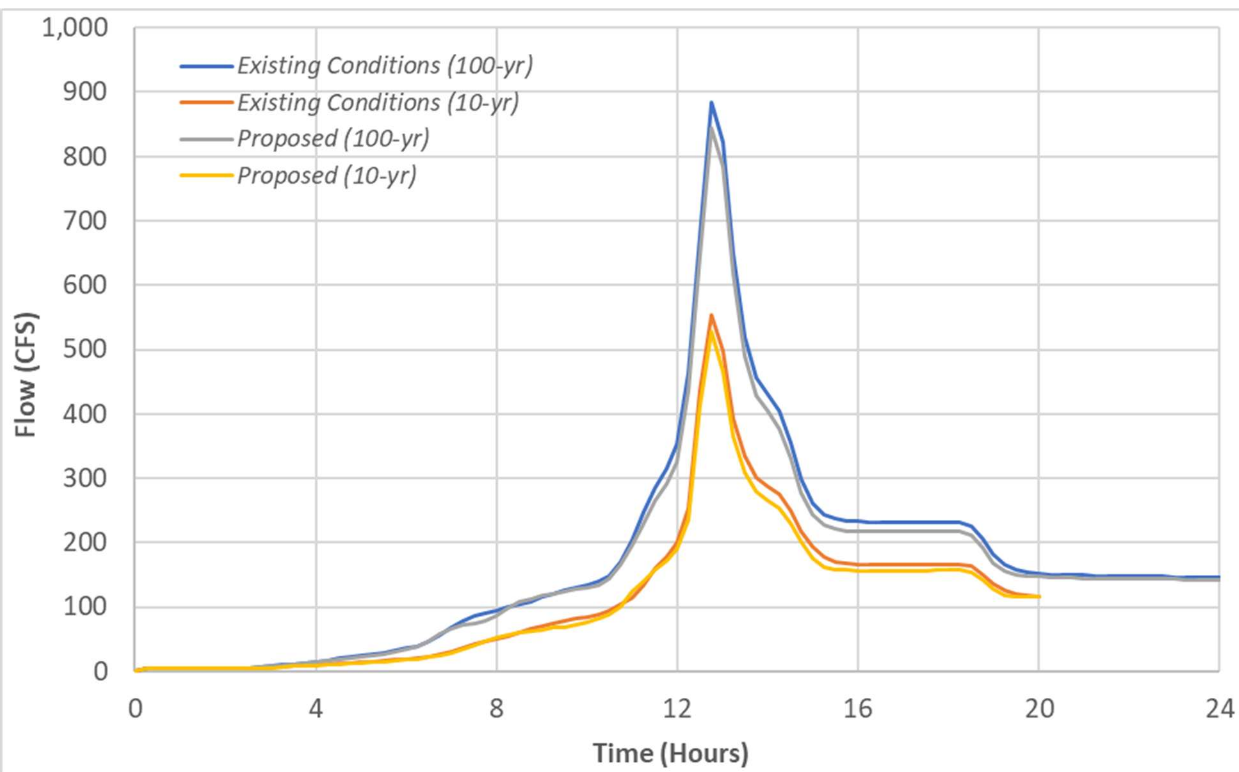


Figure 36: Hydrographs at Cross Section on Channel Downstream of Basin 36

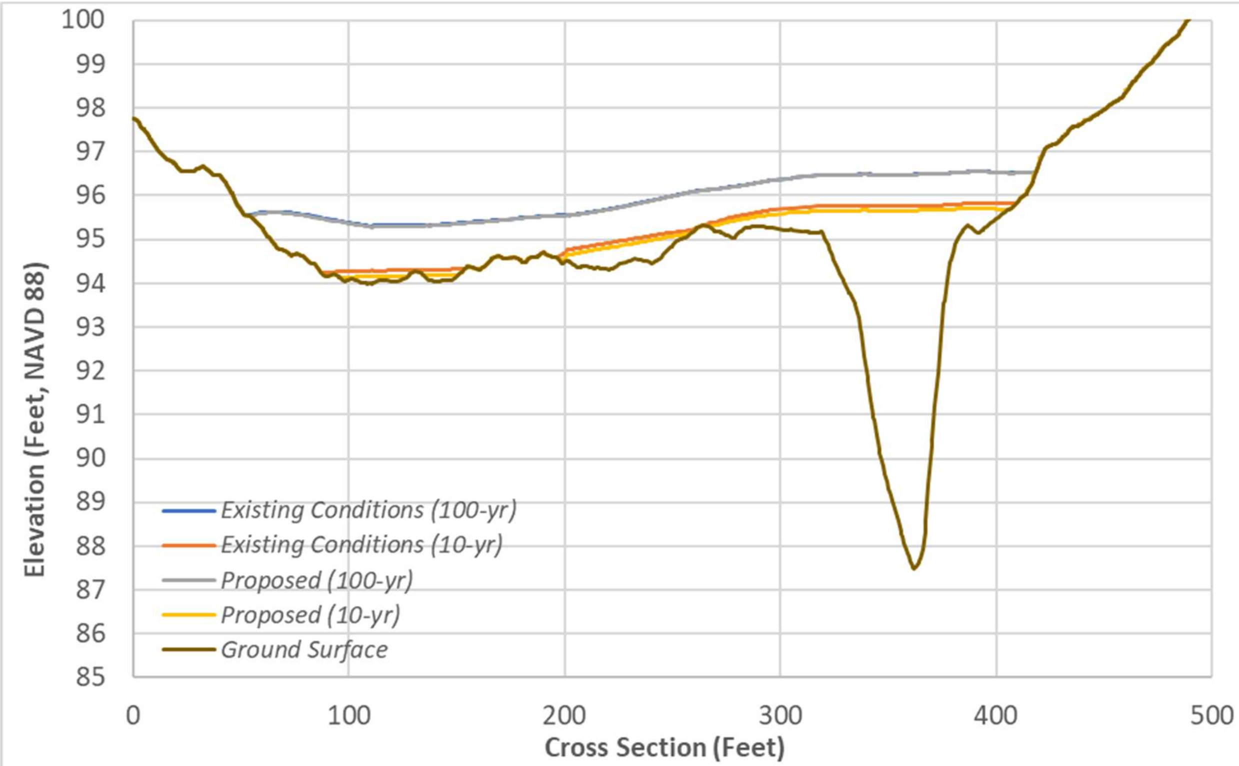


Figure 37: Cross Section on Channel Downstream of Basin 37

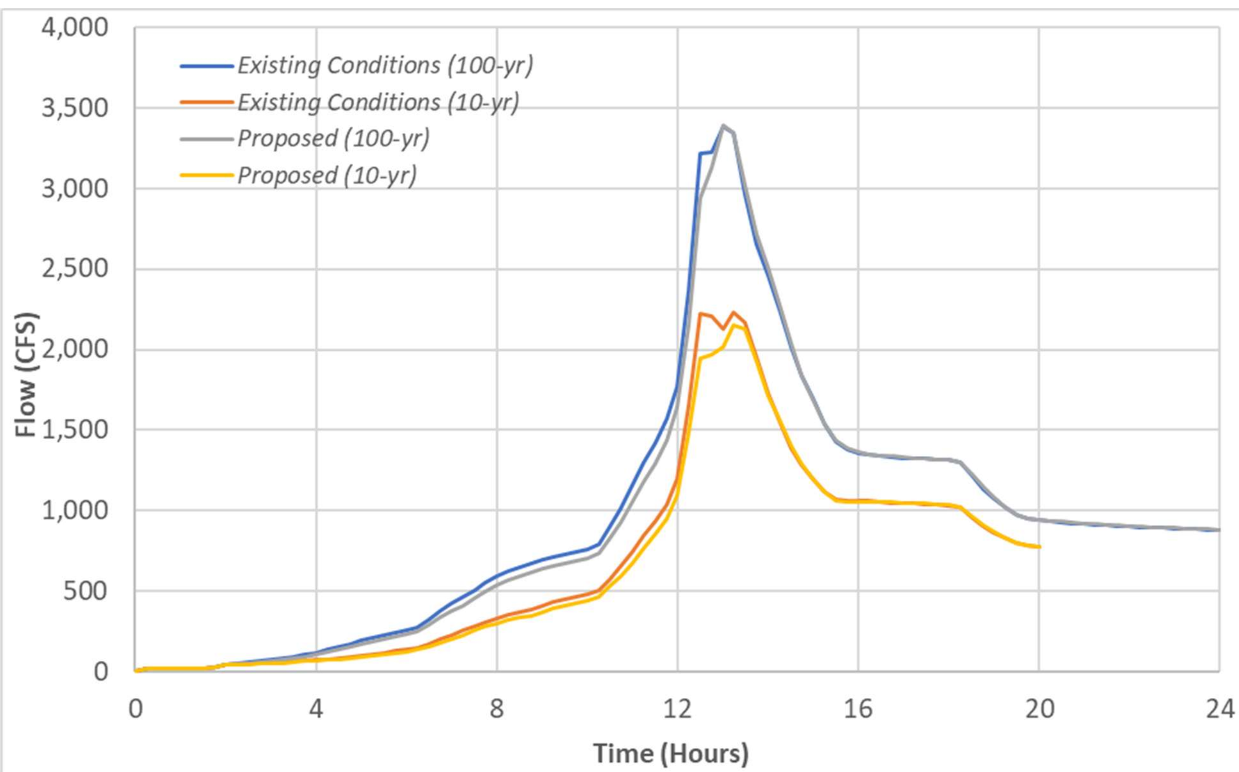


Figure 38: Hydrographs at Cross Section on Channel Downstream of Basin 37

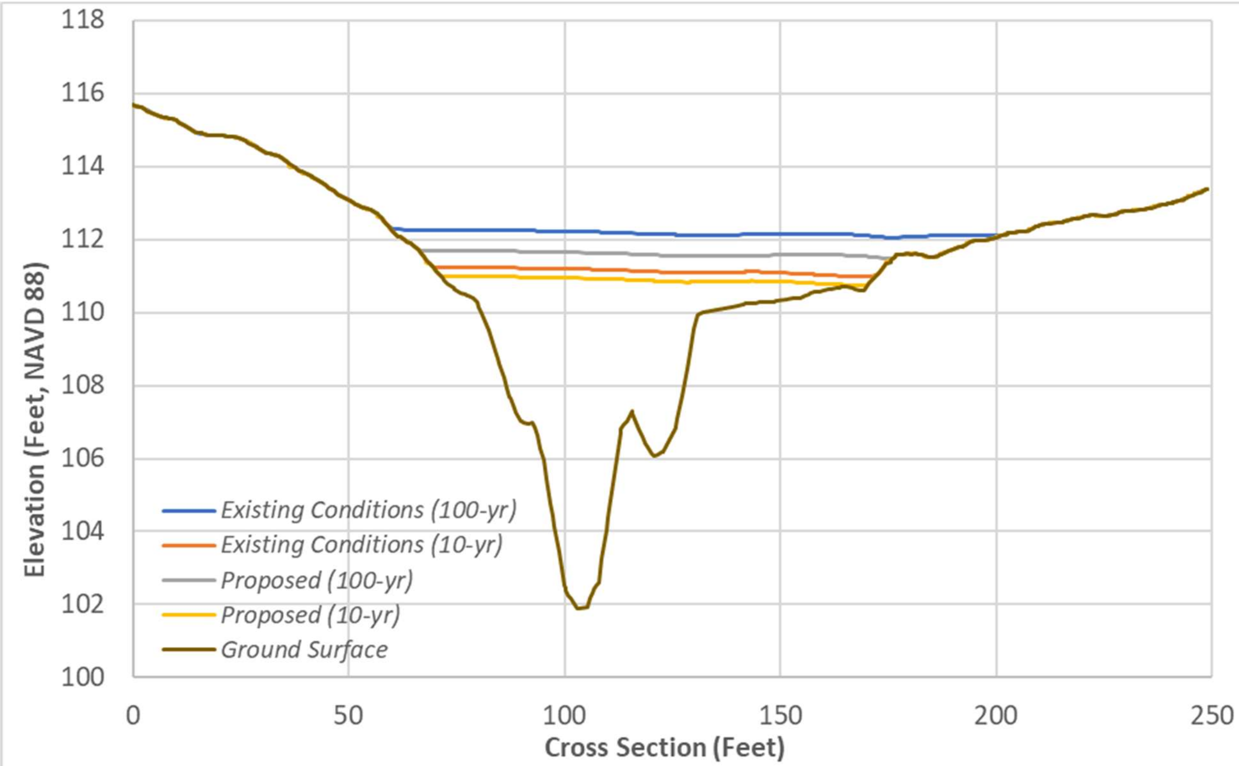


Figure 39: Cross Section on Channel Downstream of Basin 38

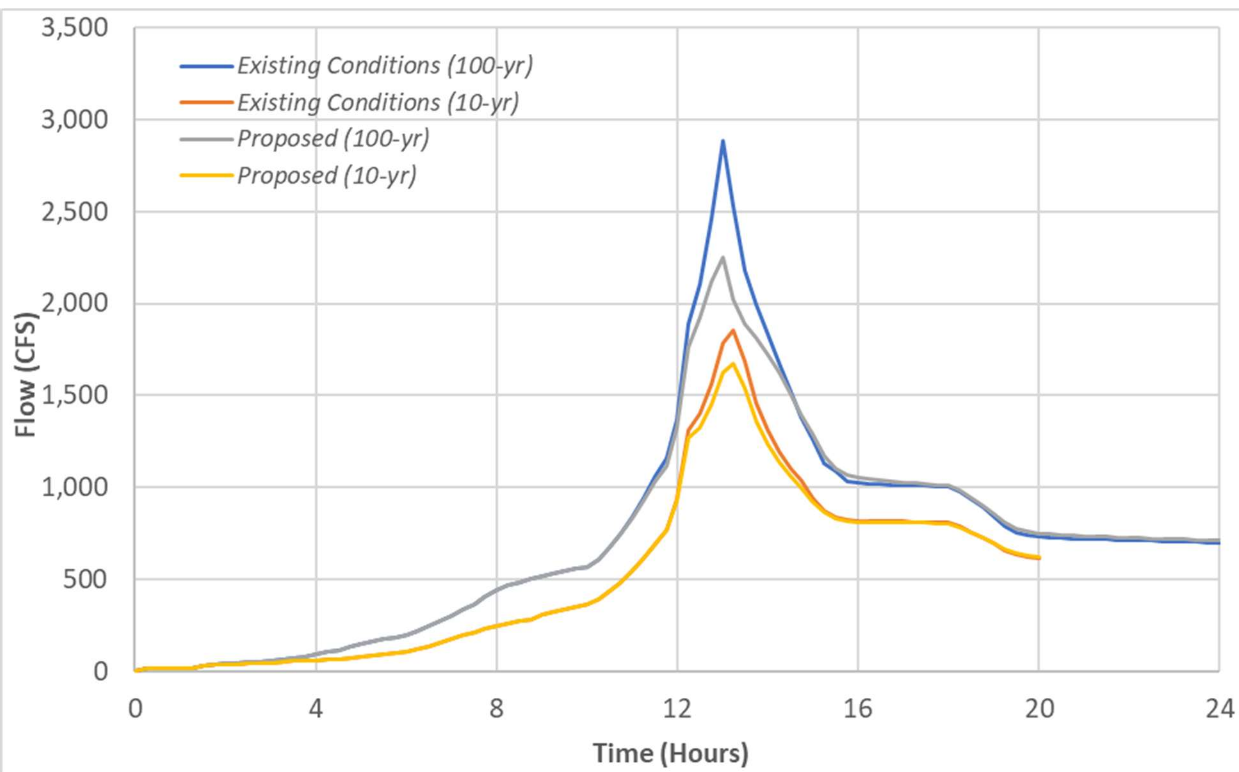


Figure 40: Hydrographs at Cross Section on Channel Downstream of Basin 38

APPENDIX B: COMBINED BASIN XP-SWMM PROFILE RESULTS AND COMPARISON TO EXISTING CONDITIONS

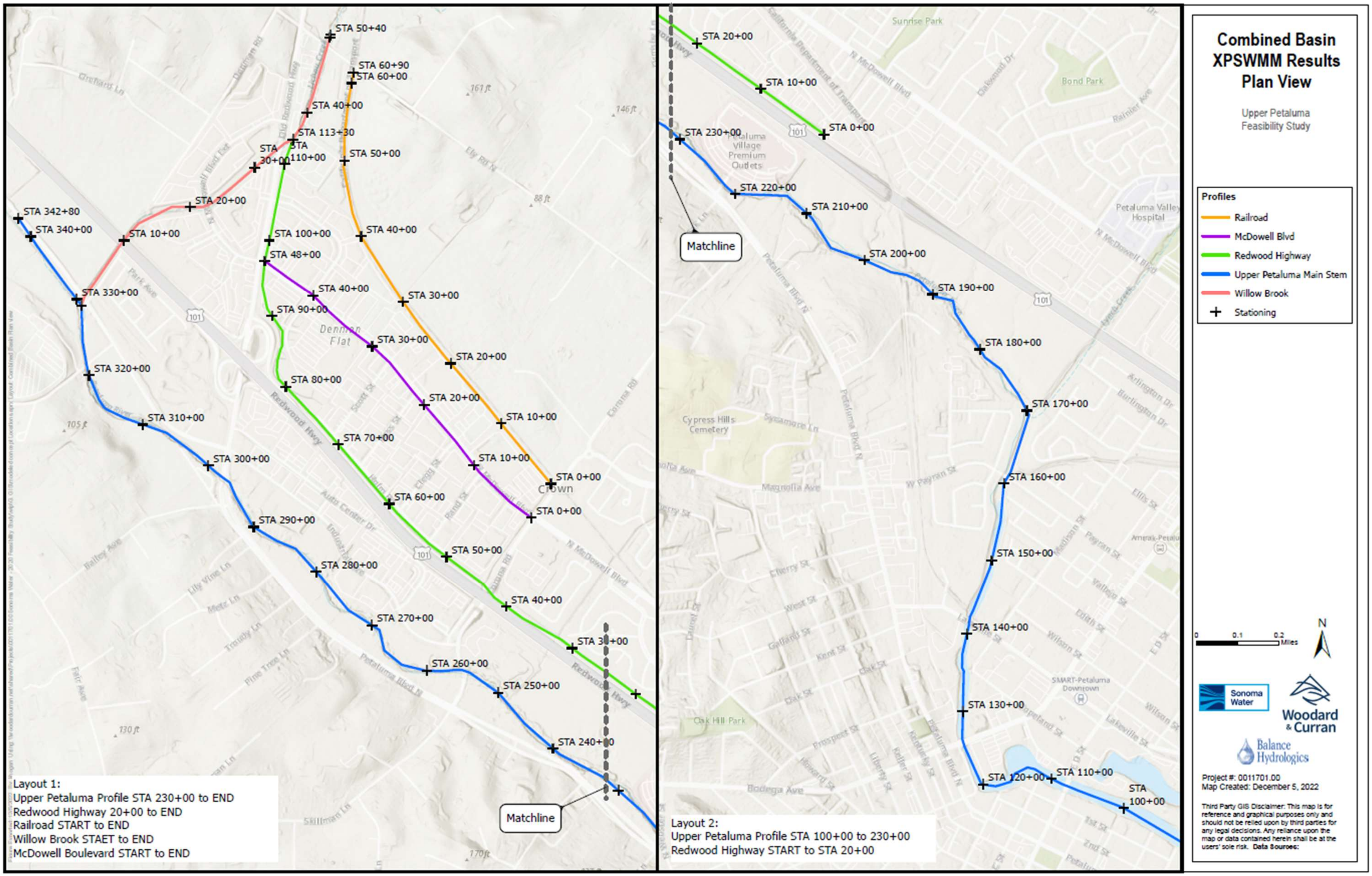


Figure 1: Combined Basin XPSWMM Results Plan View of Model Profiles

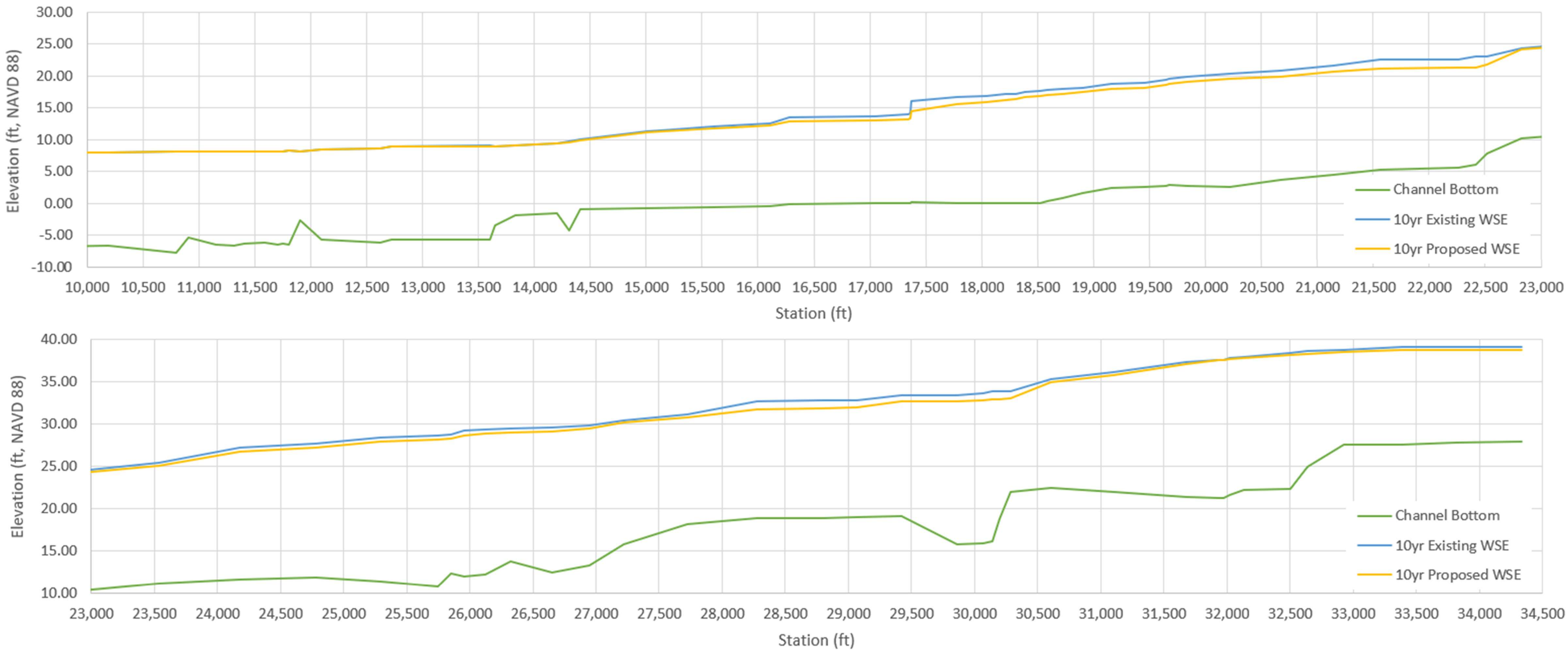


Figure 2: Combined Basin XPSWMM Results Petaluma River Main Stem Model Profile for 10-year Event

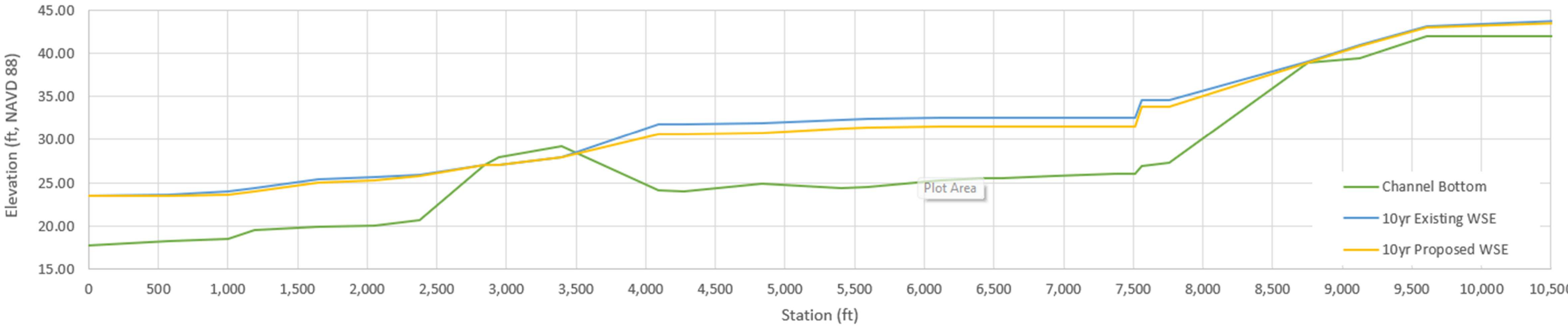


Figure 3: Combined Basin XPSWMM Results Redwood Highway Model Profile for 10-year Event

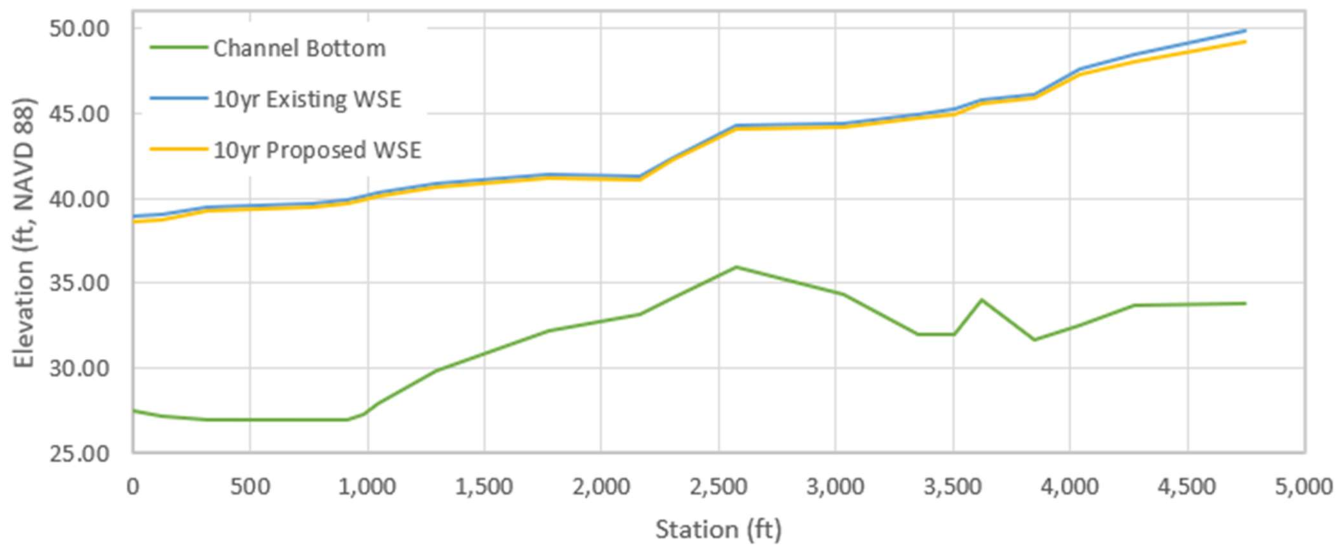


Figure 4: Combined Basin XPSWMM Results Willow Brook Model Profile for 10-year Event

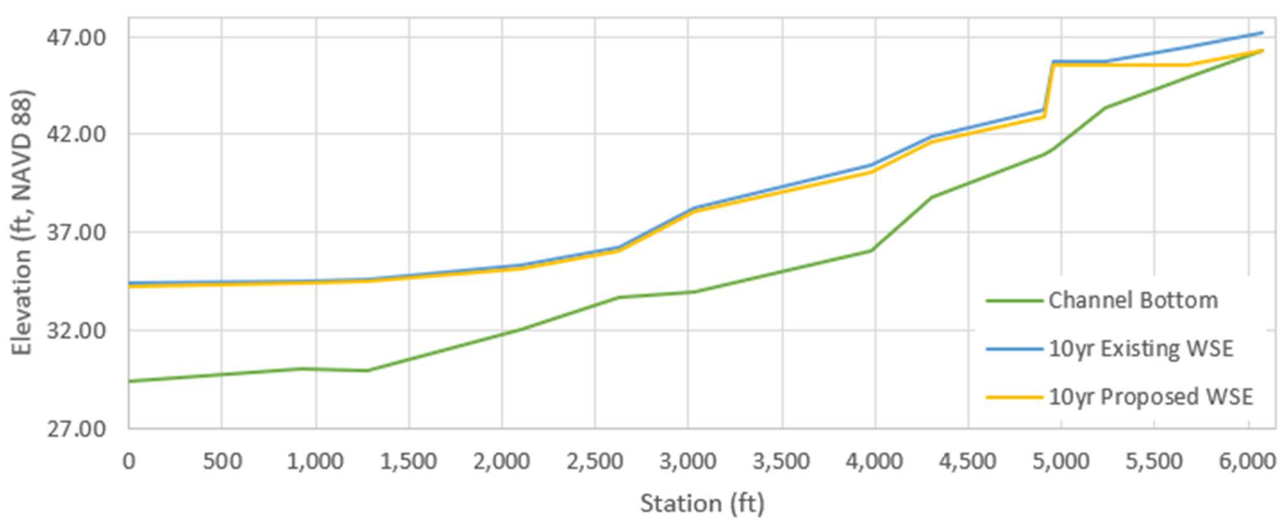


Figure 5: Combined Basin XPSWMM Results Railroad Avenue Model Profile for 10-year Event

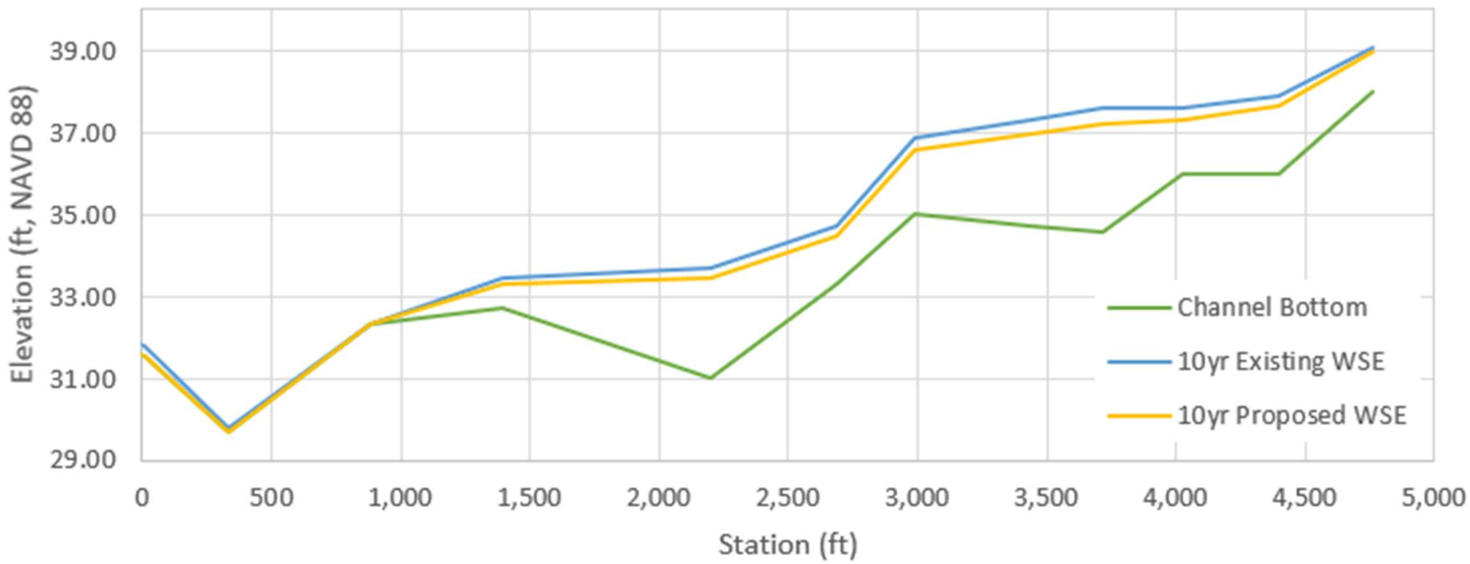
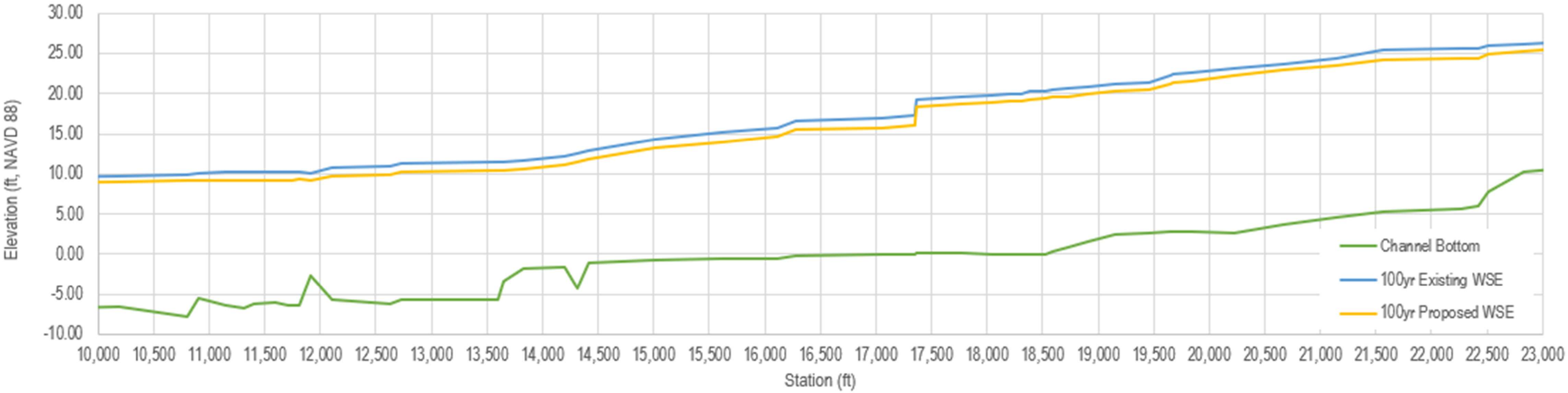


Figure 6: Combined Basin XPSWMM Results McDowell Boulevard Model Profile for 10-year Event



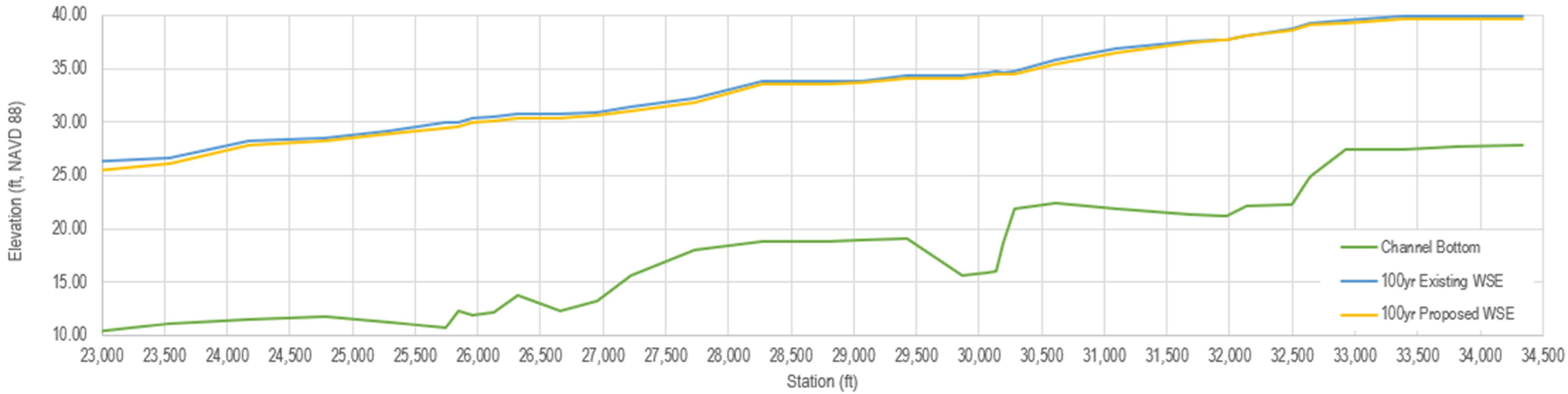


Figure 7: Combined Basin XPSWMM Results Petaluma River Main Stem Model Profile for 100-year Event

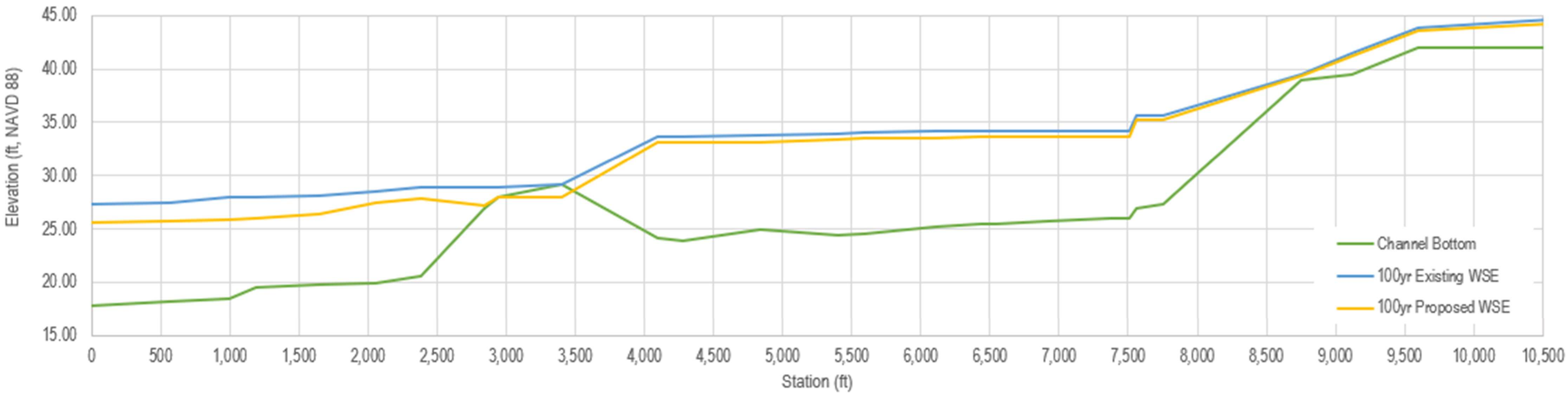


Figure 8: Combined Basin XPSWMM Results Redwood Highway Model Profile for 100-year Event

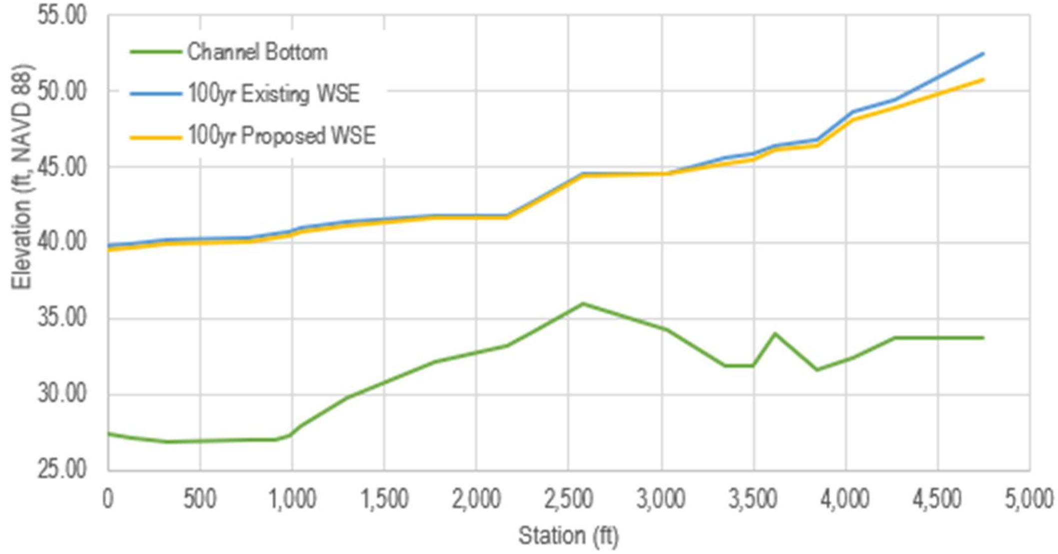


Figure 9: Combined Basin XPSWMM Results Willow Brook Model Profile for 100-year Event

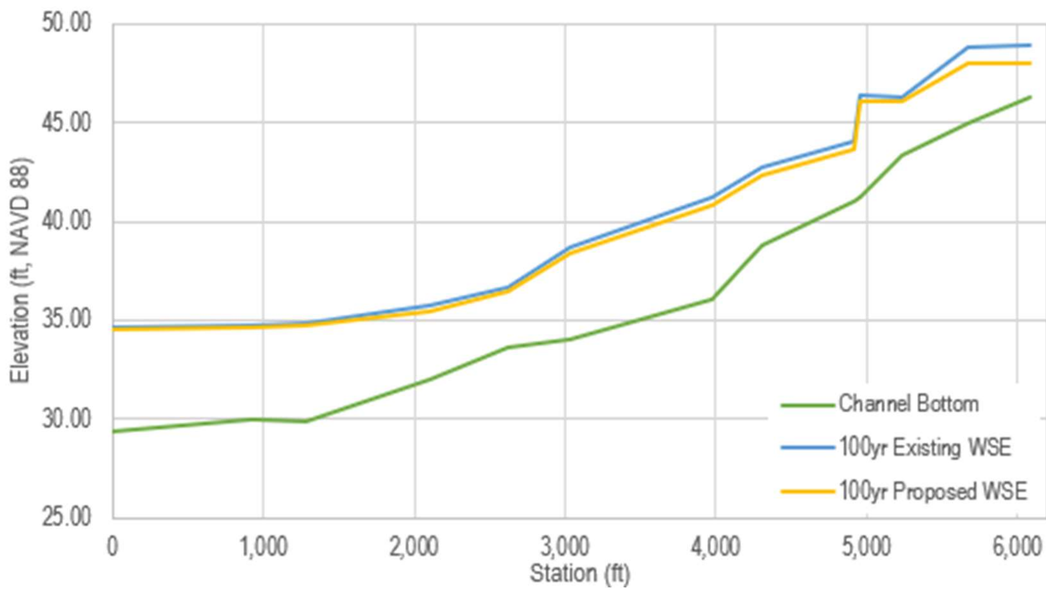


Figure 10: Combined Basin XPSWMM Results Railroad Avenue Model Profile for 100-year Event

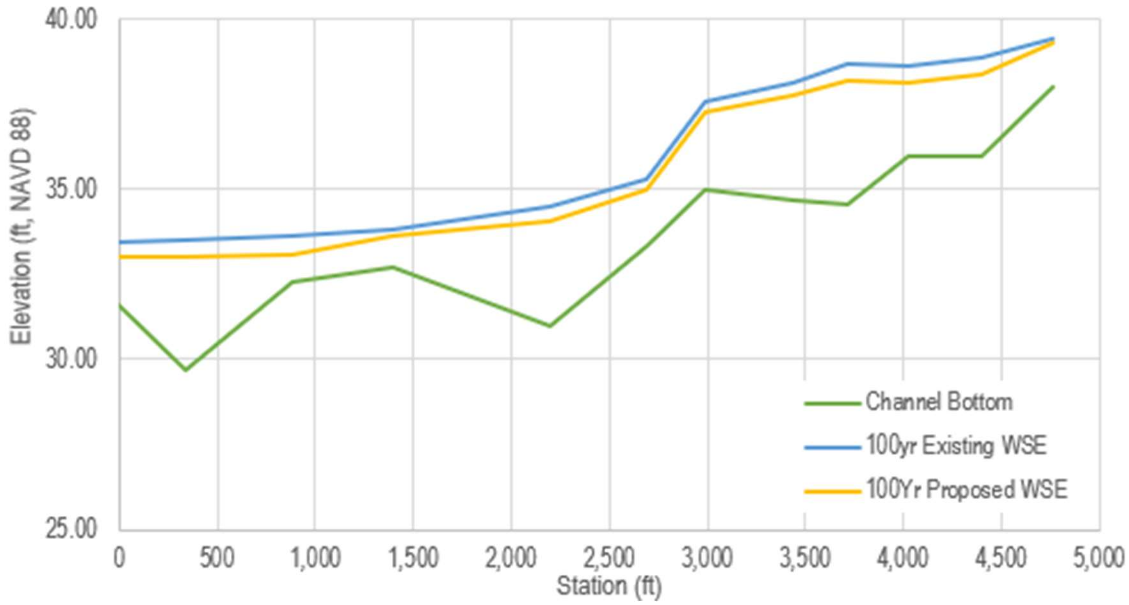


Figure 11: Combined Basin XPSWMM Results McDowell Boulevard Model Profile for 100-year Event