An integrated operational forecast system for coastal, fluvial, and pluvial flooding in the San Francisco Bay area

Liv Herdman[1], **Babak Tehranirad[1]**, Cornelius Nederhoff III[2], Li Erikson[1], Greg Pratt[3], Michael Leon[3] and Patrick Barnard[1]

[1]US Geological Survey Pacific Coastal and Marine Science Center, Santa Cruz, California [2] Deltares, Delft, Netherlands [3] NOAA Earth System Research laboratory, Boulder, Colorado

Motivation

Accurate and timely flood and precipitation information is critical for making emergency-response decisions regarding public safety, infrastructure operations, and resource allocation. Accordingly, the California Department of Water Resources has funded the development of a state-of-the-art Advanced Quantitative Precipitation Information (AQPI) system to provide near-term precipitation and flooding forecasts using an integrated observation and modeling framework for the San Francisco Bay area. The main goals of this collaborative project are to detect and track storms, nowcast high-resolution precipitation with cutting-edge radar technology, and forecast watershed and coastal flooding up to 72 hours in advance. This presentation focuses on the most downstream model in the AQPI framework, which is based on the USGS's Coastal Storm Modeling System (CoSMoS: www.usgs.gov/cosmos).

Figure 1. Bay area locations experiencing flooding in the recent past.

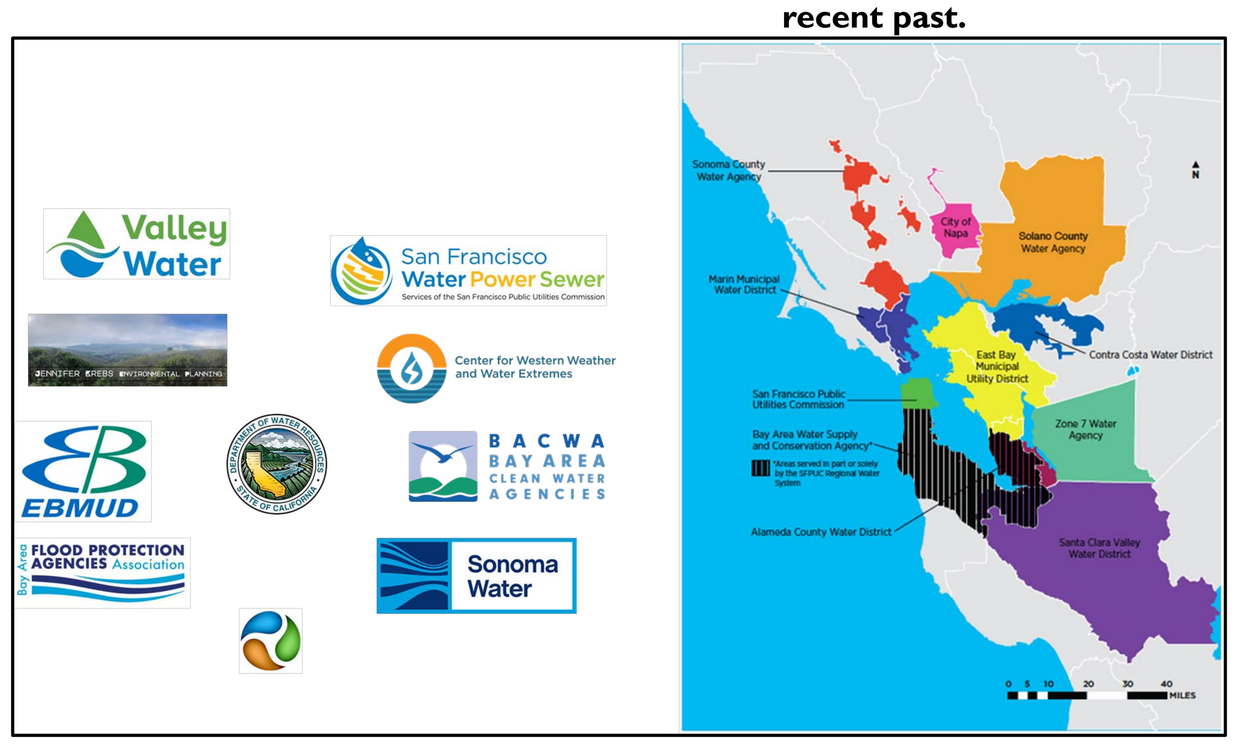

Figure 2. Locations of bay area partners with whom we are partnering in development of AQPI/CoSMoS products.

As part of AQPI, CoSMoS incorporates the nowcast precipitation, winds, and pressure from the NOAA's High-Resolution Rapid Refresh (HRRR) atmospheric model, as well as fluvial discharges from NOAA's watershed model (National Water Model). The coupled model forecasts the start, duration, and maximum water depth of flooding for areas in the zone of coastal influence within the nine counties that comprise the San Francisco Bay area. By integrating this complex set of models and incorporating the best possible observations to create operational forecasts, the AQPI system represents the next generation of forecasting frameworks and will provide demonstrable benefits in the face of hazardous flood conditions to communities across the bay area. Our partnerships with local agencies are the driving force behind the development of the system.

Current operational performance

Model Component	Run time for 18 hours
Atmospheric Model (HRRR)	45 minutes to 1.5 hours
National Water Model	1.5 to 2 hours
DELFT3D –FM	30 minutes
Waves	30 minutes to 1 hour
Effective Coastal forecast length	15 to 16 hours

CoSMoS set up: DELFT3D-FM MODEL

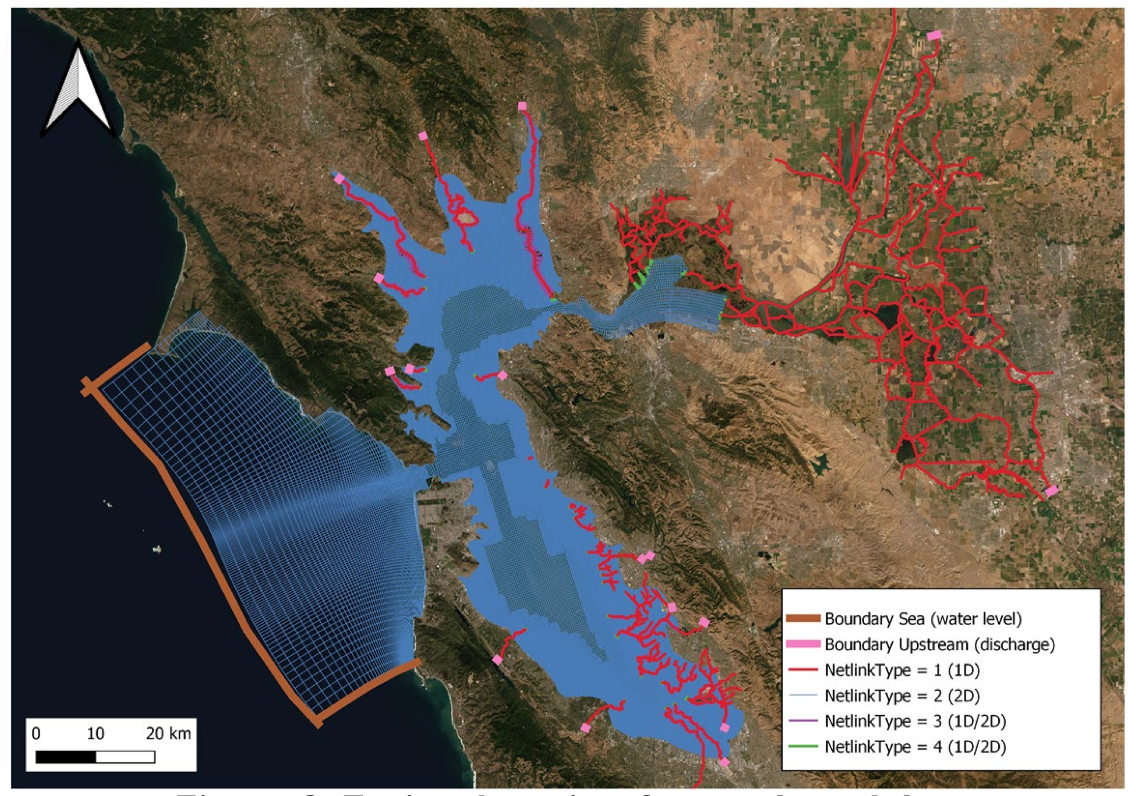

Figure 3. Entire domain of coastal model.

Coupled Water Level (Delft3D-FM) and Wave Model (SWAN)

Offshore Boundary

- Astronomical Tides
- Sea Surface Anomalies from Global Water Level Forecast System (HYCOM)
- Offshore Wave Parameters from Global Wave Model (WaveWatchIII)

Tributaries Inputs

- Discharge Predictions (NWM)

Atmospheric Inputs

- Surface Mean Sea-Level Pressure (HRRR)
- Surface Wind Velocities (HRRR)
- Precipitation (HRRR)

CoSMoS is a physics-based numerical modeling system for assessing coastal hazards from the combined effects of tides, rivers, storm surge, and waves. In particular, the USGS is using the Delft3D-Flexible Mesh Suite, developed by Deltares, that enables 1D/2D coupling and efficient and reliable modeling. Delft 3D –FM, a shallow water flow solver, is implemented in two dimensions on the unstructured grid shown here in blue and in 1 dimension along the channels shown in red. The model domain extends ~20 km offshore of the coast and extends from Point Reyes in the north to Montara in the south. There are 18,4379 2D grid cells and 2,425 1D profiles defined. The forcings applied to the operational model are shown in the list on the right, although the ones in grey are still under development for operations.

On the right, we see a close up of how the 1D/2D coupling is implemented in the mesh.

The 1D channels (Netlink 1, red) are connected to 2D mesh structure (Netlink 2, blue) through either a NetLink 3 (purple) or a Netlink 4 (green). The Netlink 3 is activated when the river water level is higher than the levees or river banks and transmits water out of the channel to capture inland flooding. This Netlink does not transfer momentum. Netlink 4 distributes momentum between the channels depending on the direction of the link and flows bidirectionally between the 2D and 1D mesh.

The results show that the accuracy of this system is as good or better than using only 2D mesh system while saving significant computation time.

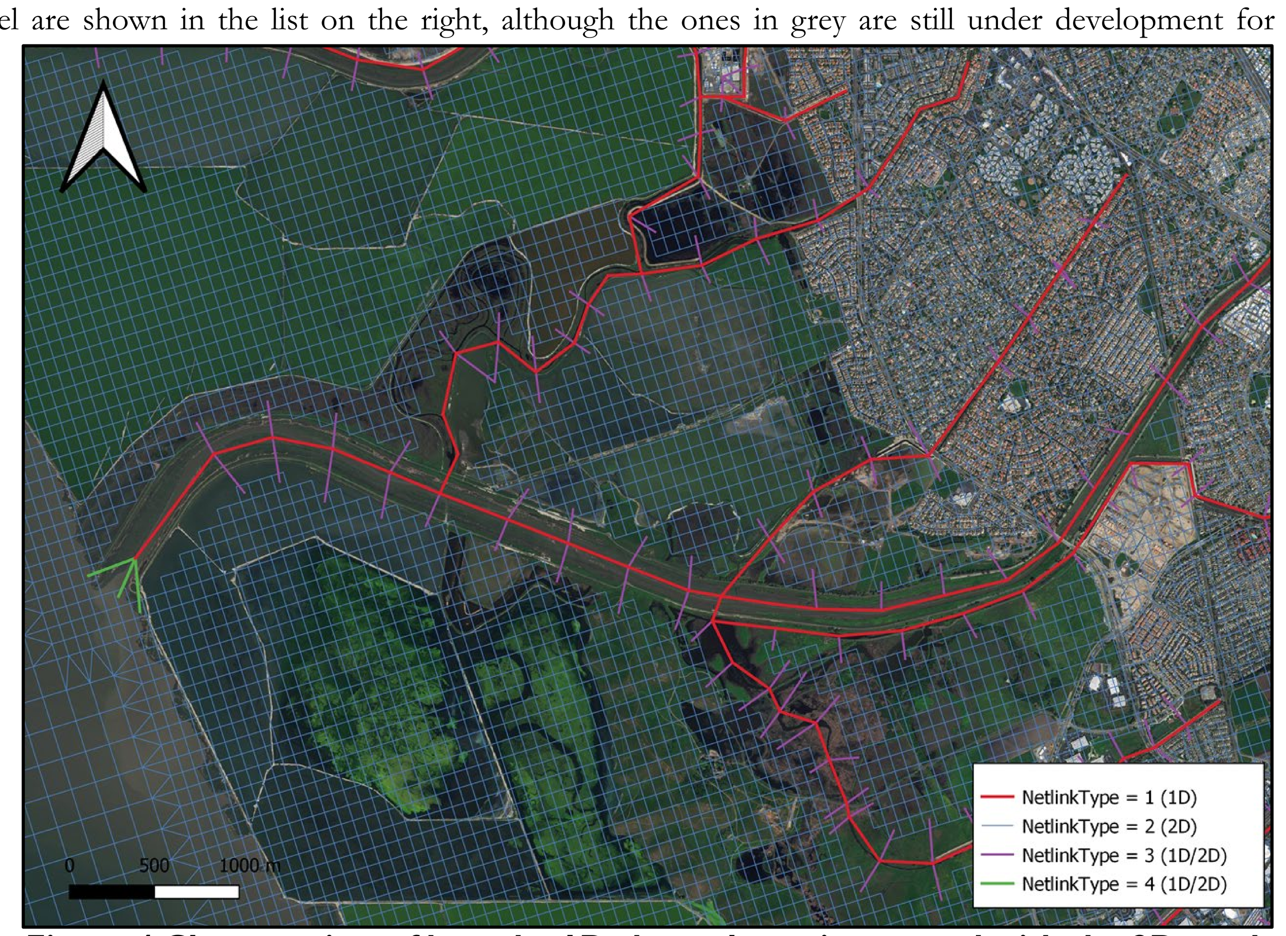

Figure 4 Close up view of how the 1D channels are integrated with the 2D mesh.

CoSMoS Forecast Performance

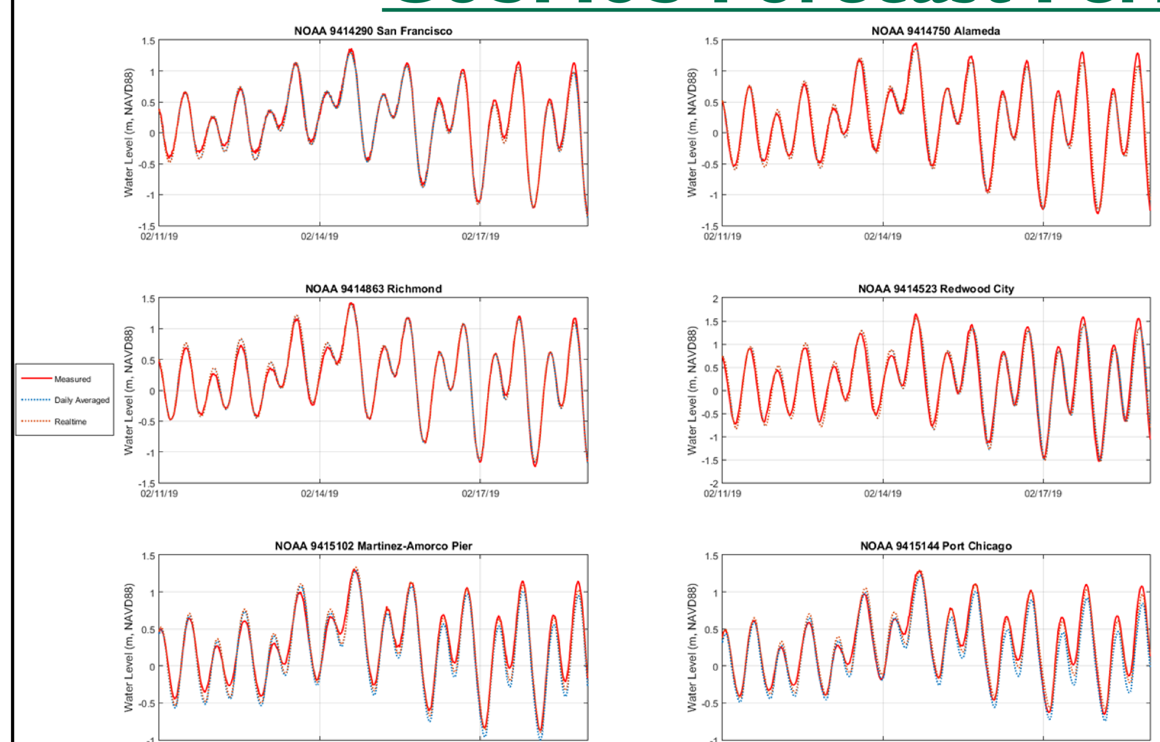

Figure 5 Comparison of observed water levels (red solid line) and model results (dashed lines).

Comparison of the model results to the water level recorded by six different tidal gages during a storm in February 2019 shows that the model captured the storm process well. The set of figures on the left shows the raw water levels as observed and as predicted by CoSMoS. The dashed lines are model results; blue lines show model results forced with historical daily averaged river discharge, and the red dashed lines were forced with forecast 15-minute discharge. The model results are better the closer to the ocean they are, and they are also less sensitive to the discharge forcing. Storm surge is shown in Figure 6.

Fluvial-Coastal Coupling Improves Inundation Mapping

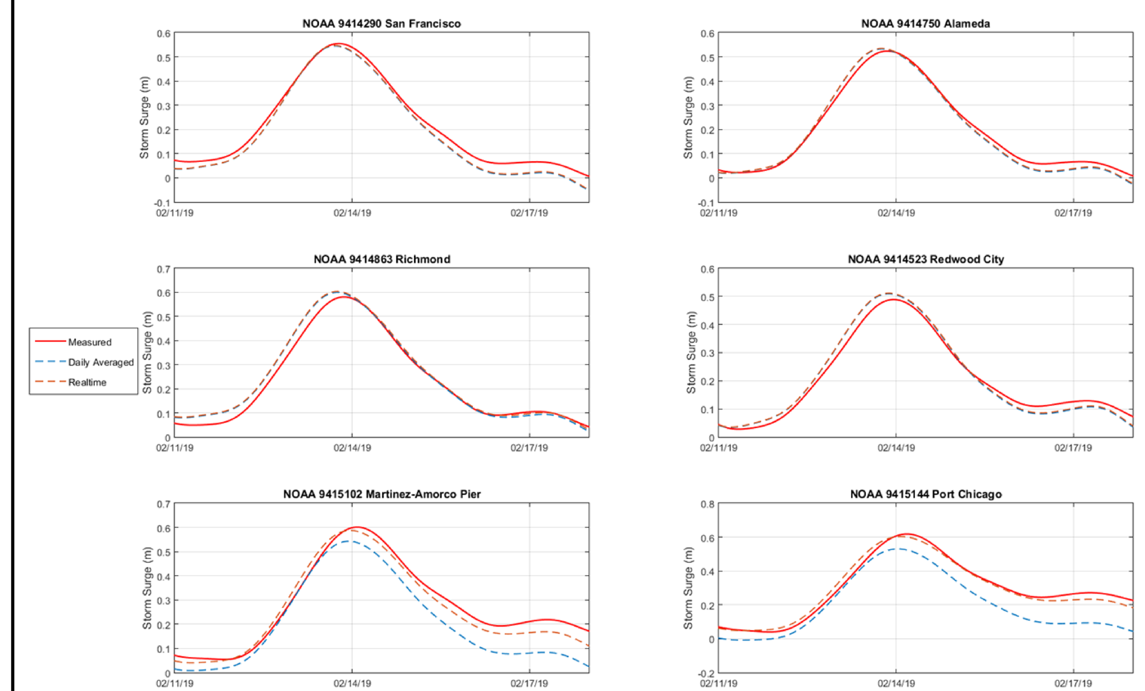

Figure 6. Similar to figure 5, but with tides removed, so the water level shown is the Non Tidal Residual (NTR) for the February 2019 storm.

This forecast model performs well at predicting the NTR throughout the bay. These results show that the model becomes more sensitive to river discharge forcing further away from the ocean inlet (Golden Gate). Therefore, having higher temporal resolution discharge data is essential to predict the NTR accurately near the Delta, highlighting the importance of accurate discharge forecasts.

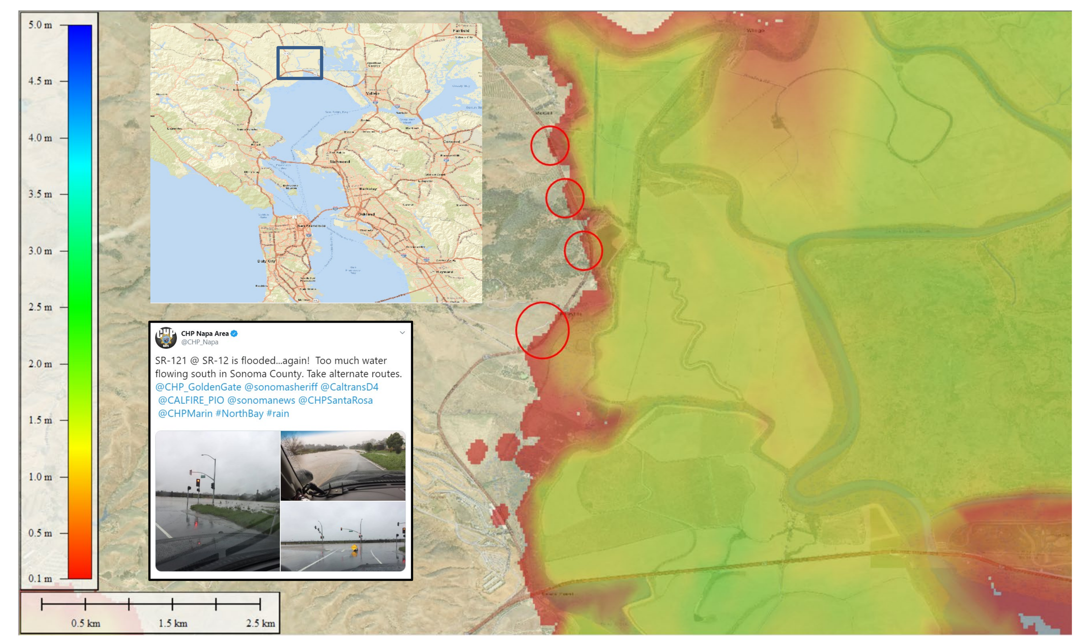

Figure 7. Water depths during a storm event with red circles highlighting the ability of our model to predict road inundation. The road that experienced inundation in our model was confirmed by twitter.

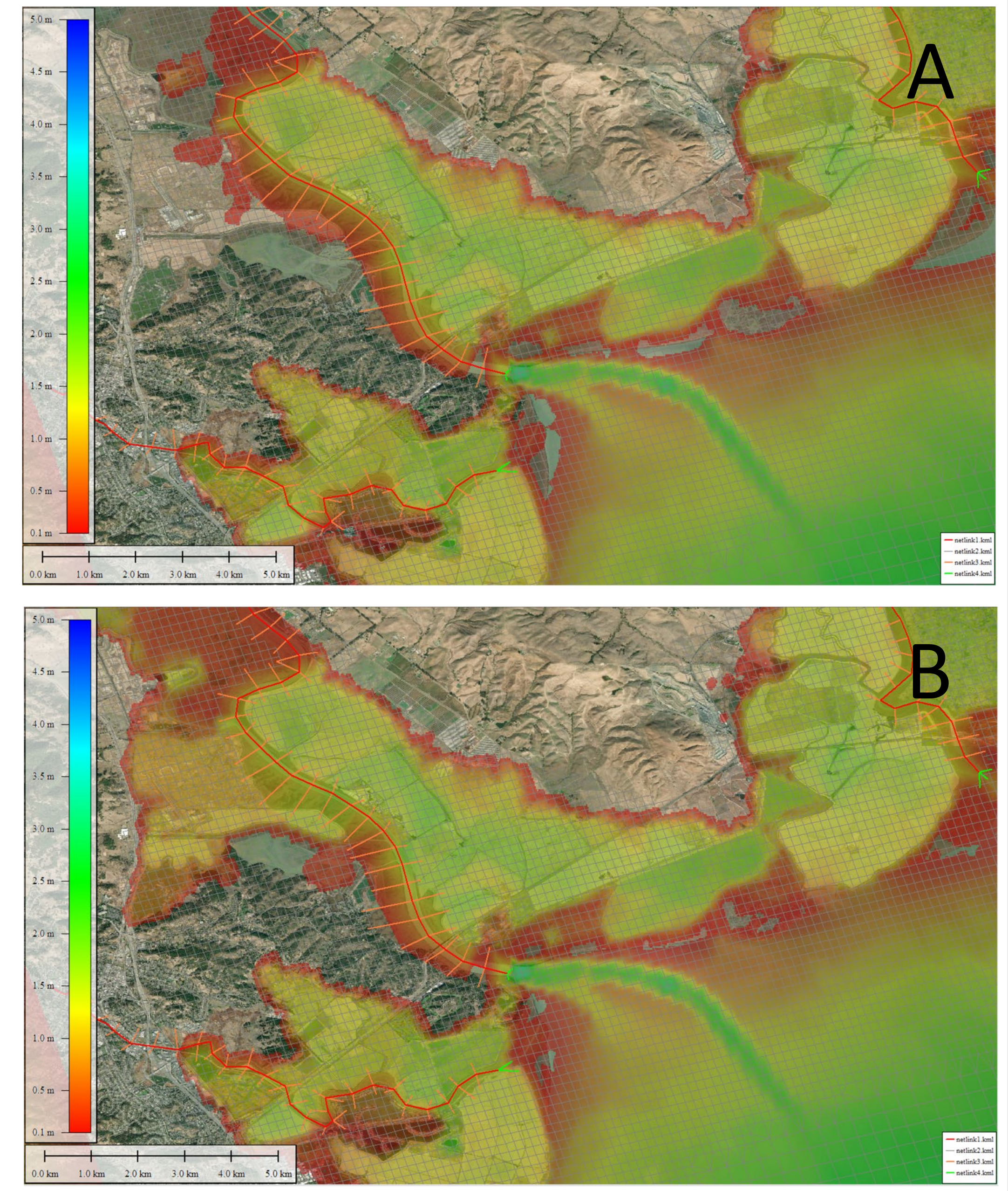

Figure 8. Water depth during a high discharge event where the Petaluma River meets the bay. A) River discharge provided by historical daily averaged values. B) River discharge from forecast 15 minute values.

Accurate discharge peaks and durations are important in predicting not only the water level but also the extent of inundation (Figure 8) The inundation extent is much larger (Figure 8 B) when the peak of the discharge is more accurately represented. Capturing these extents is important for assessing hazards like water level on roads (Figure 7).

Future Work

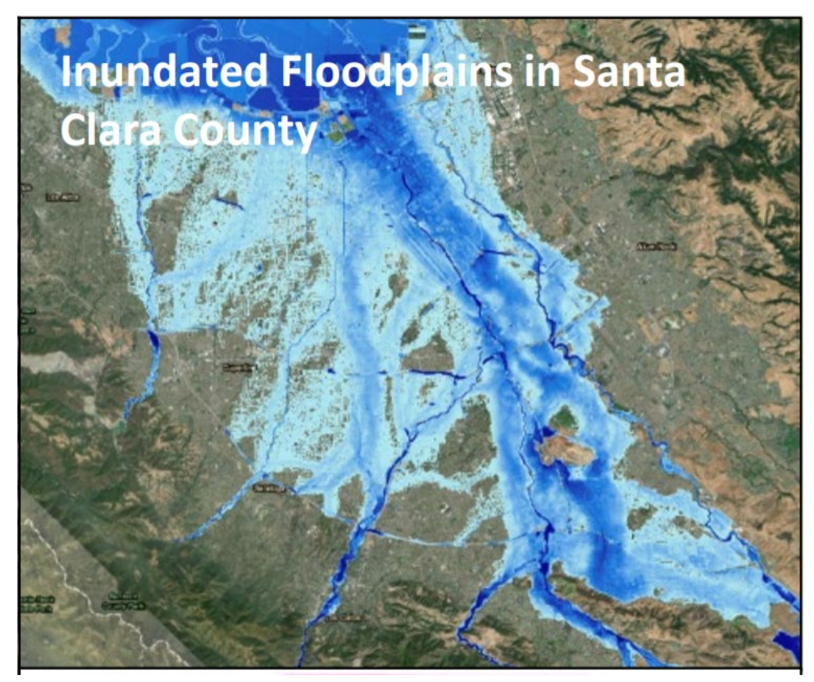

Figure 9. Example of hydrology (watershed) model produced flood plain inundation in upstream areas, from our partner Valley Water.

Our ultimate goal is to create a seamless vulnerability forecast map based on the three processes that can drive flooding: rain, river flow, and coastal water levels. Some of our partners can currently use rain forecasts coming from AQPI to create floodplain inundation forecasts (Figure 9). The National Water Model is currently developing a similar capability. In order to have a comprehensive understanding of vulnerability during an event we need to combine the coastal inundation mapping with the hydrologic model predictions. These can then be combined with important features like the one shown in Figure 10 to understand the potential impact of an event.

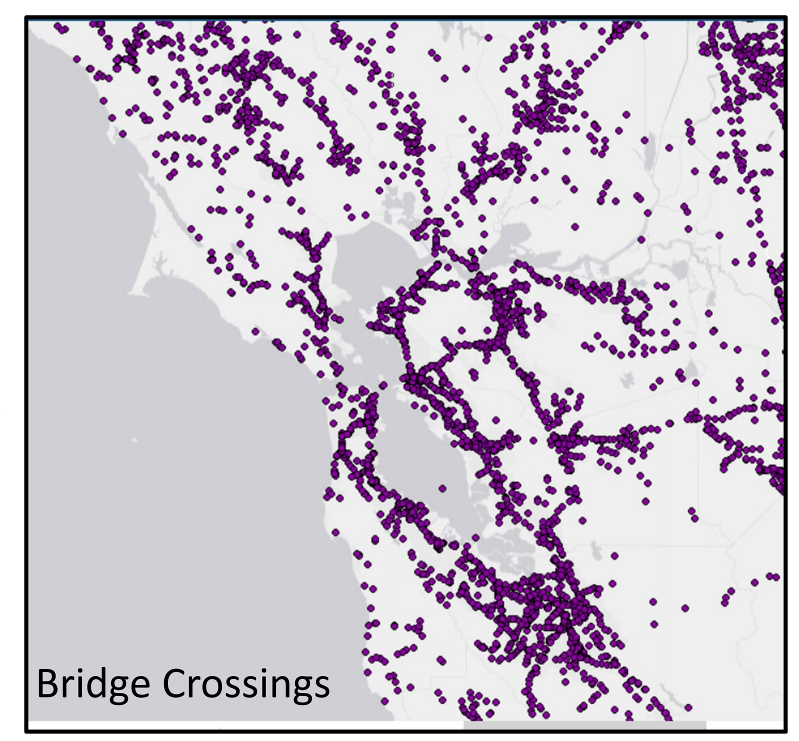

Figure 10. Example of layers necessary for evaluating flood vulnerability.

QUESTIONS?

Further questions can be directed to Liv Herdman lherdman@usgs.gov or Babak Tehranirad btehranirad@contractor.usgs.gov