Appendix I2

Water Circulation and Water Quality Impacts Memorandum

NOBLE
CONSULTANTS, INC.

PROJECT MEMORANDUM

2201 DUPONT DRIVE, SUITE 830, IRVINE, CA 92612 (949) 752-1530
FACSIMILE (949) 752- 8381

Engineering and Regulatory Support – The Waterfront Development
JN 625-13/1119-01

To:	CDM Smith, Dorothy Meyer, Project Manager
From:	Wenkai Qin
Date:	May 7, 2015
RE:	Water Circulation and Water Quality Impacts
Cc:	

In accordance with our professional services agreement with the City of Redondo Beach and CentralCal Properties, LLC, this memorandum addresses Task Numbers 4.2 and 2.2. Specifically, this memorandum provides water circulation and water quality impacts assessment for the proposed enhancement of the Seaside Lagoon.

Both the existing condition and the proposed project condition are included in our analysis. The proposed project components included in this analysis are shown in **Figure 1**. They consist of conversion of the existing interior swimming lagoon complex (approximately two acres) into a small embayment, Seaside Lagoon, which will be directly connected to King Harbor, a concrete boat ramp, and a 420-foot long rubble-mound breakwater. The conceptual plan of Seaside Lagoon was described in Noble Consultants Inc.'s (NCI) project memorandum dated March 11, 2015[1], and was illustrated in Figure 3 of this memorandum. The boat ramp with the breakwater was proposed by Moffatt & Nichol[2], and the conceptual plan was shown in Figures 1 and 2 of NCI's project memorandum dated January 21, 2015[3].

RMA2/RMA4 Model Description

The two-dimensional hydrodynamic model RMA2 and the water quality model RMA4, both developed by the U.S. Army Corps of Engineers, were used in this water circulation and water quality study. The RMA2 model[4] was developed to compute the water surface elevation and

[1] Noble Consultants, Inc. 2015. Project Memorandum, Seaside Lagoon Enhancement – Wide Inlet Opening Alternative Project Description, Prepared for the City of Redondo Beach, March 11, 2015.
[2] Moffatt & Nichol, 2014. Redondo Beach boat launch ramp facility, feasibility report for the California Department of Boating and Waterways 2015 Grant Cycle. Prepared for the City of Redondo Beach, March 13, 2014.
[3] Noble Consultants, Inc. 2015. Project Memorandum, Joe's Crab Shack Boat Launch Facility Project Description, Prepared for the City of Redondo Beach, January 21, 2015.
[4] USACE, 2003. "Users Guide to RMA2 WES Version 4.5".

horizontal velocity for sub-critical, free-surface flow in two-dimensional flow fields. This model is well suited for and has been extensively applied to the simulation of complex riverine and tidal hydrodynamics of rivers, bays and estuaries.

RMA2 computes a finite-element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. The governing equations of RMA2 include the depth-integrated equations for the conservation of fluid mass and momentum, which are presented as follows:

$$\frac{\partial h}{\partial t} + h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} = 0$$

$$h\frac{\partial u}{\partial t} + hu\frac{\partial u}{\partial x} + hv\frac{\partial u}{\partial y} - \frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2} + E_{xy}\frac{\partial^2 u}{\partial y^2}\right) + gh\left(\frac{\partial a}{\partial x} + \frac{\partial h}{\partial x}\right) + \tau_{bx} + \tau_{sx} + \Omega_x = 0$$

$$h\frac{\partial v}{\partial t} + hu\frac{\partial v}{\partial x} + hv\frac{\partial v}{\partial y} - \frac{h}{\rho}\left(E_{yx}\frac{\partial^2 v}{\partial x^2} + E_{yy}\frac{\partial^2 v}{\partial y^2}\right) + gh\left(\frac{\partial a}{\partial y} + \frac{\partial h}{\partial y}\right) + \tau_{by} + \tau_{sy} + \Omega_y = 0$$

where x, y and t are the Cartesian coordinates and time, h is the water depth, a is the bottom elevation, u and v are the horizontal flow velocity components in x- and y-directions, ρ is the water density, g is the acceleration of gravity, E_{xx} and E_{yy} are the eddy viscosity coefficients in the normal directions on x and y axis surface, E_{xy} and E_{yx} are the eddy viscosity in the shear direction on each surface, τ_{bx} and τ_{by} are the bottom friction components, τ_{sx} and τ_{sy} are the surface wind stress components, and Ω_x and Ω_y are the Coriolis stress components. The bottom friction is defined from the Manning equation. Turbulent energy is represented by an eddy viscosity analogy. Forces generated from wind and Coriolis effects were not considered in this study because they are negligible as compared to the bottom friction.

RMA4[5] is a two-dimensional finite element water quality transport model for simulating depth-average advection-diffusion processes in an aquatic environment. This model has been widely used for investigating the physical process of migration and mixing of a substance in reservoirs, rivers, bays, estuaries and coastal zones. For most applications, RMA4 utilizes the depth-averaged hydrodynamic parameters computed from RMA2.

The depth-integrated equation used in the RMA4 for the transport and mixing process is:

[5] USACE, 2003. "Users Guide to RMA4 WES Version 4.5".

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} - \frac{\partial}{\partial x}\left(D_x \frac{\partial c}{\partial x}\right) - \frac{\partial}{\partial y}\left(D_y \frac{\partial c}{\partial y}\right) - \sigma + kc + \frac{R}{h} = 0$$

where c is the concentration of a given constituent, u and v are the flow velocity components that can be computed from RMA2, D_x and D_y are the constituent diffusion coefficients in the x- and y-directions, respectively, σ is the source/sink of constituent, k is the first order decay of constituent and R is rainfall/evaporation rate.

The RMA4 water quality model has been extensively applied to simulating the concentration of non-conservative substances in an aquatic environment, calculating residence time and evaluating water quality of a harbor or basin.

Criteria for Water Quality Assessment

Two water quality indicators, the water exchange time and the constituent residence time, are commonly used for water quality evaluation. The water exchange time defines the minimum time for the water body in an embayment to be replaced by the ambient water in the ocean. The residence time indicates how long it takes for the concentration of a constituent, if present in the embayment, to drop to a given level.

The water exchange time is defined herein as the ratio of the embayment storage volume at the Mean High Water (MHW) to the average water exchange rate between the ocean and the embayment. Assuming the ocean water is brought into the embayment by the flood tides and stays in the embayment, and only the water originally stored in the embayment is flushed out of the embayment during the ebb tides, the water exchange time is the minimum time that is required for the water in the embayment to be completely replaced by ocean water. A longer water exchange time implies that the water in the embayment is replaced less readily by the ocean water, leading to a potentially less desirable water quality.

The residence time is another important indicator of how fast for the water of an embayment to be renewed, and thus provides a means for assessing the water quality. A typical application to calculate the residence time across an embayment is to hypothetically release a constituent with initially uniform concentration throughout the embayment. The diffusion and advection processes will gradually transport the constituent out of the embayment, and thus the constituent concentration will drop with time. Quantification of the residence time at a given location is typically defined as the time for the constituent concentration to drop to *exp(-1),* or 37 percent of

its initial value. A longer residence time indicates that the water of an embayment is renewed less readily by ocean water, leading to a less desirable water quality.

Finite Element Mesh and Bathymetry for Existing Condition

The area of interest in this water circulation and water quality assessment is King Harbor, including three existing marina basins, and the proposed Seaside Lagoon for the project condition. In order to minimize the unduly influence of the values assigned at the model boundaries on the area of interest, the modeled domain was significantly expanded to cover not only King Harbor, but also the ocean outside of the harbor. The ocean included in the modeled domain extends from the shoreline to approximately 7,000 feet offshore, with an alonshore extent of approximately 8,500 feet. While water surface area of King Harbor is approximately 100 acres, the entire modeled domain exceeds 1,200 acres.

The finite element mesh that was used in the RMA2/RMA4 models for the existing condition is shown in **Figure 2** for the entire modeled domain, in **Figure 3** for King Harbor, and in **Figure 4** for Basin 3 and the proposed project site for Seaside Lagoon. The numbers of finite elements and nodes and the coverage areas are summarized in **Table 1**. The information for the proposed project condition, which will be discussed later of this memorandum, is also listed in this table for comparison.

Table 1. Numbers of Finite Elements and Nodes

Alternatives	Existing condition	Project condition
Number of element (inside harbor)	4,533	5,125
Number of elements (entire domain)	5,155	5,747
Number of nodes (inside harbor)	14,108	15,974
Number of nodes (entire domain)	16,052	17,918
Area (inside harbor)	100	102
Area (entire domain)	1,232	1,232

The existing bathymetry of the modeled domain was developed based on: (1) the January 2015 bathymetric survey conducted by Nearshore and Wetland Surveys for Basin 3, (2) the August

2012 bathymetric survey prepared by Fugro Consultants, (3) the 2004 bathymetric survey prepared by Fugro Consultants, and (4) the NOAA navigational chart (ID: 18744) for the ocean outside of the harbor. For the areas with overlapping coverage, the most recent survey points were used. The existing bathymetry is shown in **Figure 5** for the entire modeled domain, in **Figure 6** for King Harbor, and in **Figure 7** for Basin 3 and the proposed project site for Seaside Lagoon.

RMA2/RMA4 Boundary and Initial Conditions

The boundary conditions required in the RMA2 hydrodynamics simulation include the upstream inflow discharge and the downstream (offshore) water surface elevation. It is assumed that no water flows into the harbor from the landside. The offshore water level boundary condition, which is the driving force for the tidal currents in the modeled domain, was specified based on the measured water level at the NOAA Santa Monica Bay station. The measured water surface elevations of twenty days from January 1st to 20th were smoothed and then used to represent the typical offshore water level boundary condition. The data and the smoothed results are shown in **Figure 8.** A twenty-day period was selected so that the modeling study spanned at least one spring tide cycle and one neap tidal cycle.

The boundary conditions for the RMA4 model include the constituent concentration at the boundaries. It is assumed in our modeling study that the ocean has good water quality. Therefore, the constituent concentration was assigned to zero at the offshore boundary of the modeled domain.

In the RMA4 water quality modeling, the initial constituent concentration was specified as zero for the ocean that is outside of King Harbor, and 100 for the entire King Harbor. This represents the scenario when the entire harbor is initially polluted, while the ocean has good water quality. Due to the water exchange between the harbor and the ocean and the constituent diffusion process, the constituent within the harbor will gradually be transported out of the harbor to the ocean, and thus the constituent concentration within the harbor will drop and the harbor water quality will improve with time. By specifying this initial condition, the temporal variation of the constituent concentration can be modeled, based on which the constituent residence time, a key indicator of the harbor water quality, can be determined.

It is noted that the same offshore boundary condition and initial condition were specified for the existing condition and the project alternative. The differences in model results are thus attributed to the different harbor configurations between the existing and the project conditions.

RMA2/RMA4 Model Parameters

Three major model parameters for the RMA models include the Manning's roughness coefficient (*n*) and the turbulence eddy viscosity (*E*) in RMA2, and the constituent diffusion coefficient (*D*) in RMA4. The values of these parameters were selected based on the values recommended in the RMA documents and on previous project experience.

Water surface elevations were measured at Basin 3 of King Harbor in January 2015. The model results indicate that the water levels in the harbor are virtually the same as the values specified at the offshore boundary, or the tidal muting between the harbor and the ocean is negligible. The difference between the measured data and the model results at Basin 3 is much less than the error of the measurement at Basin 3, and the error of NOAA data measured at Santa Monica Bay that was used as the offshore boundary condition of RMA2. Therefore, the water surface elevation data measure at Basin 3 was not used for determining RMA2 model parameters. The Manning's *n*-values and the turbulence eddy viscosity *E* were thus specified based on the Users Guide to RMA2, and are listed in **Table 2**. Based on the sensitivity tests, the hydrodynamic parameters (water surface elevations and flow velocities) computed with RMA2 were insensitive to changes to the values of *n* and *E*. This is because the temporal fluctuation of water surface elevations in the ocean is the dominant force for governing flow fields in the harbor, while the impact of the bottom friction and the turbulent shear stress is negligible.

The constituent diffusion coefficient used in RMA4 is a measure of the rate at which the constituent disperses. The diffusion coefficient depends on the property of the constituent and the flow turbulent intensity. Based on physical model and filed data obtained by Moffatt and Nichol[6] for Marina del Rey and Huntington Harbor, the diffusion coefficient ranges from 32 ft^2/s for the channel to 540 ft^2/s for the offshore. These values are significantly higher than those recommended in the Users Guide to RMA4, which vary between 0.1 ft^2/s and 10 ft^2/s. The

[6] Moffatt & Nichol Engineers, 2002. "Mandalay Bay Tract 5266 Development Water Quality Model Study". Prepared for Mandalay Parters, LLC.

values adopted in our RMA4 models are between those recommended in RMA4 documentation and those found by Moffatt and Nichol, and are listed in **Table 2**.

Table 2. RMA2/RMA4 Model Parameters

Locations	Manning Coefficient (n)	Eddy Viscosity (E) (lb-sec/ft^2)	Diffusion Coefficient (D) (ft^2/s)
King Harbor basins	0.030	20	10
King Harbor main channel	0.025	50	20
Nearshore outside harbor entrance	0.025	150	20
Ocean	0.020	300	180

Preliminary sensitivity analyses indicated that RMA4 modeling results were sensitive to the diffusion coefficient. A larger diffusion coefficient resulted in faster dropping of constituent concentration within the harbor. It is noted that the diffusion coefficient varies significantly for different constituents. For the same flow condition, some constituents diffuse and get diluted much quicker than the others. The purpose of our analysis is to evaluate the overall water quality in Basin 3 and in the proposed Seaside Lagoon, and a same diffusion coefficient of 10 ft^2/s was assigned for various basins/embayments within the harbor. By doing that, the water quality of Basin 3 and of the proposed Seaside Lagoon can be assessed relative to other basins.

Water Circulation and Water Quality for Existing Condition

Figure 9 and **Figure 10** show the snapshots of the modeled flow fields, including the water depth contours and the flow velocity vectors at a peak flood tide and at a peak ebb tide, respectively. **Figure 11** shows the time series of the water surface elevations at the entrances of King Harbor and the three basins inside the harbor, respectively. **Figure 12** shows the time series of the flow velocities at these representative locations. **Figure 13** shows the time series of the flow discharges. The water surface elevations are virtually the same at these locations, indicating tidal muting is negligible inside the harbor. As shown in **Figure 12**, the peak current

velocity is less than 0.2 feet per second (fps). The maximum flow discharges at the entrance of King Harbor is approximately 2,000 cubic feet per second (cfs), as shown in **Figure 13**.

The water exchange time, defined as the ratio of the embayment storage volume at MHW to the average water exchange rate between the embayment and ambient water outside, was computed for various basins of King Harbor, and is listed in **Table 3**. Also listed in this table includes the results for the project condition, which will be discussed later of the memorandum. The water exchange time is approximately 47 hours for Basin 3, while it is more than 60 hours for Basins 1 and 2. A shorter water exchange time can potentially lead to better water quality.

Table 3. Water Exchange Time

Embayment	MHW area (ac)	MHW storage (ac-ft)	Water exchange time (hour)	
			Existing	Project
Entire King Harbor	100	2,012	71	71
Basin III	3	42	47	47
Basin II	24	456	67	67
Basin I	15	256	61	61
Seaside Lagoon area[1]	3	25	N/A	20

Note: 1-- Area within the proposed breakwater entrance, including Seaside Lagoon and the area that is outside of the lagoon but within the breakwater entrance.

Figure 14 through **Figure 21** show the snapshots of the constituent concentration in the harbor for an eight day period after the initial release of constituent. The time series of the constituent concentrations are shown in **Figure 22** for the locations at the entrances of King Harbor and of the three basins, respectively.

As shown in these snapshots and in **Figure 22**, the constituent concentration near the harbor entrance will decay faster with time than the inner harbor that is further away from the entrance. As an example, the concentration will drop below 30 percent of the initial concentration in two days at the harbor entrance area, including Basin 3 and the site for proposed Seaside Lagoon. But at the same time the concentration will still exceed 70 percent at Basins 1 and 2. The lower

concentration and faster concentration decay in the harbor entrance area are attributed to the stronger constituent advection and diffusion processes due to the stronger water circulation and short distance to the ocean where the concentration was assigned to zero.

The constituent residence time was determined based on the constituent concentration predicted by the RMA4 model, and is shown in **Figure 23.** The residence time is defined as the time for the constituent concentration to drop to *exp(-1),* or 37 percent of its initial value. The residence time is less than 1.5 days for Basin 3 and less than 2 days for the site of the proposed Seaside Lagoon, while exceeds 6 days for Basins 1 and 2. Comparison of the residence time indicates that water quality in Basin 3 and at the site of the proposed Seaside Lagoon is expected to be better than most portions of King Harbor, and will be much better than Basins 1 and 2.

Water Circulation and Water Quality for Project Condition

The RMA2 and RMA4 models for the project condition include three project components: Seaside Lagoon, a concrete boat ramp, and a 420-foot long rubble-mound breakwater. The conceptual plan of Seaside Lagoon was described in Noble Consultants Inc.'s (NCI) project memorandum dated March 11, 2015, and was illustrated in Figure 3 of this memorandum.

The finite element mesh for the existing condition was revised for the project site to incorporate the proposed project components. The revised finite elements at the project site are shown in **Figure 24**, and the bathymetry is shown in **Figure 25**. The finite elements cover the project area up to the elevation at +5', MLLW. The numbers of finite elements and nodes and the areas of coverage are summarized in **Table 1**.

The boundary and initial conditions, and the model parameters used for the project condition are the same as those for the existing condition. The difference in the model results is thus solely attributed to the change to the harbor configuration that is caused by the proposed project components.

A snapshot of the flow field for a peak flood tide predicted for the project condition is shown in **Figure 26** for the entire King Harbor, and the enlarged plot for the project area is shown in **Figure 27**. **Figure 28** and **Figure 29** show the results for a peak ebb tide. **Figure 30** shows the time series of the water surface elevations at the entrances of King Harbor, three basins, and the proposed breakwater, respectively. **Figure 31** and **Figure 32** show the time series of the flow

velocities and flow discharges at these representative locations. The water exchange time for various basins and for the proposed Seaside Lagoon are summarized in **Table 3**.

The results indicate that the proposed project components will have negligible impact to the water circulation within King Harbor. The water exchange time for the area within the proposed breakwater entrance, including Seaside Lagoon and the area that is outside of the lagoon but inside of the breakwater entrance, will be approximately 20 hours, which will be much shorter than the three basins of King Harbor. A shorter water exchange time can potentially lead to better water quality.

Figure 33 through **Figure 40** show the snapshots of the constituent concentrations in the harbor for an eight day period after the initial release of constituent. The time series of concentrations are shown in **Figure 41** for the entrances of King Harbor, the three basins, and the proposed breakwater, respectively. The constituent residence time is shown in **Figure 42**.

The results indicate that the proposed project components will have negligible impact to the overall water quality within King Harbor. The residence time for the project area will be less than 2 days, which will be shorter than most regions of King Harbor.

Conclusion

In summary, the proposed project components will have negligible impact to the overall water circulation and water quality in King Harbor due to the insignificant change to the harbor configuration that will be caused by the project components. The water circulation will be weak in the project area. However, due to the shallow water depth and its vicinity to the harbor entrance, the water quality in the project area will be better than most regions of King Harbor.

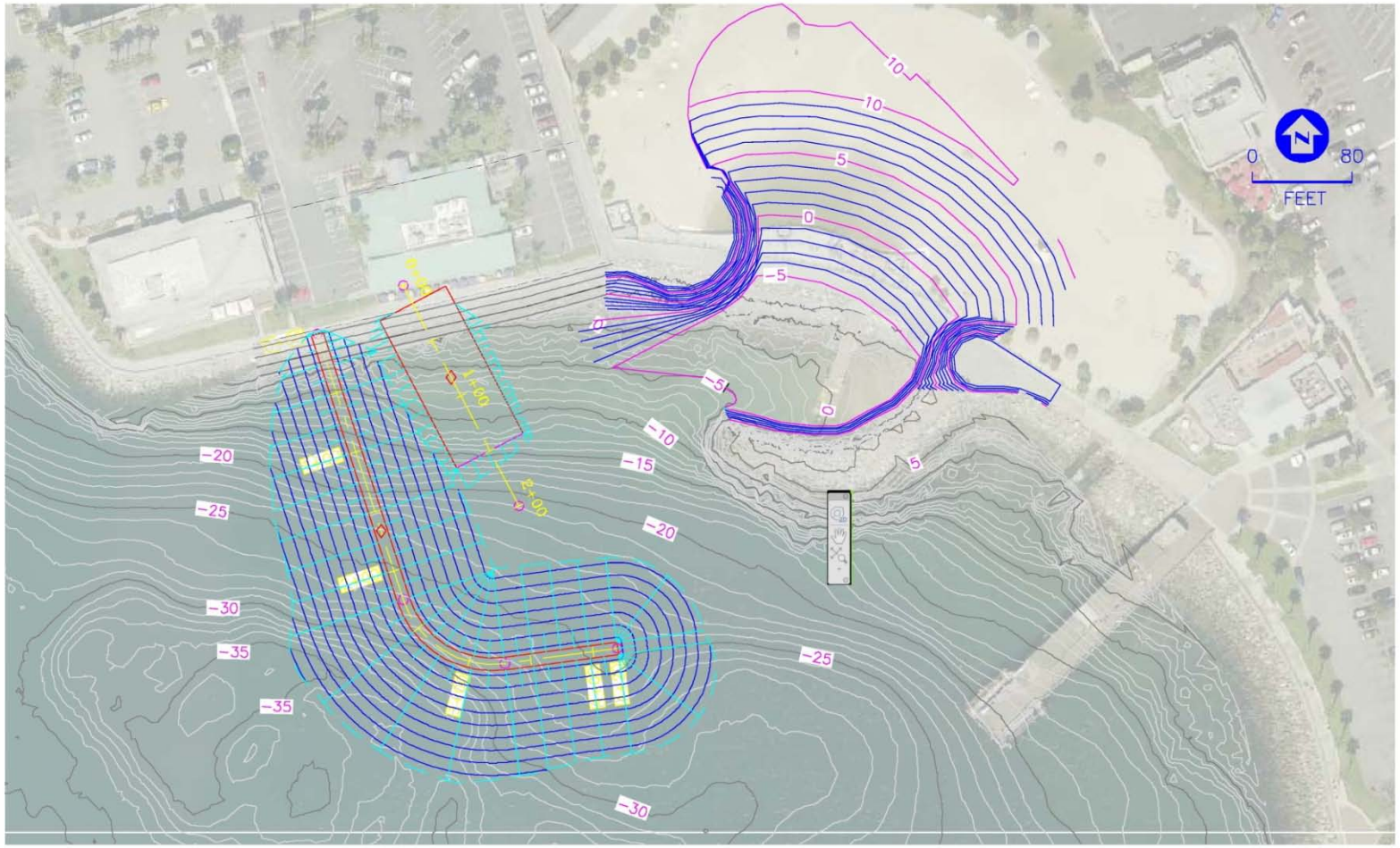

Figure 1. Conceptual Plan for Proposed Project Components: Seaside Lagoon, Boat Launch Facility, and Breakwater

Figure 2. Mesh for Modeled Domain (Existing Condition)

Figure 3. Mesh for King Harbor (Existing Condition)

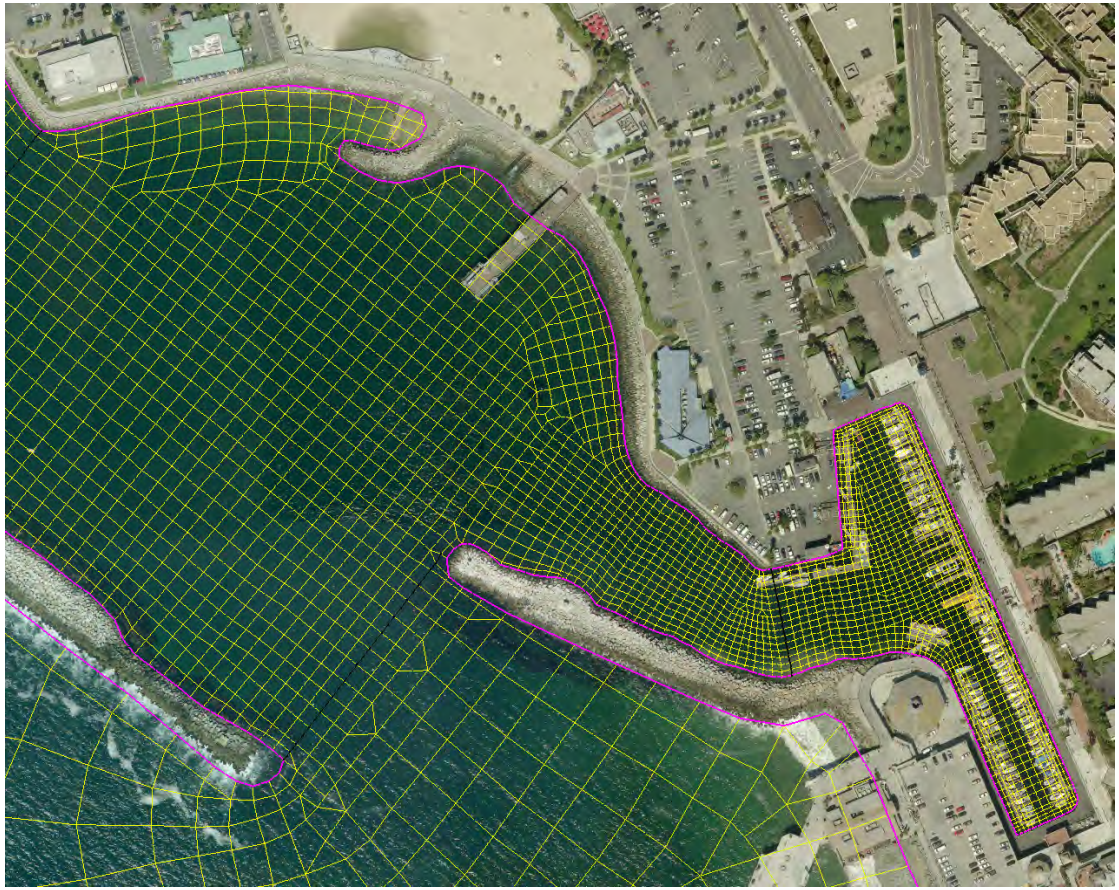

Figure 4. Mesh for Basin 3 and Harbor Entrance Area (Existing Condition)

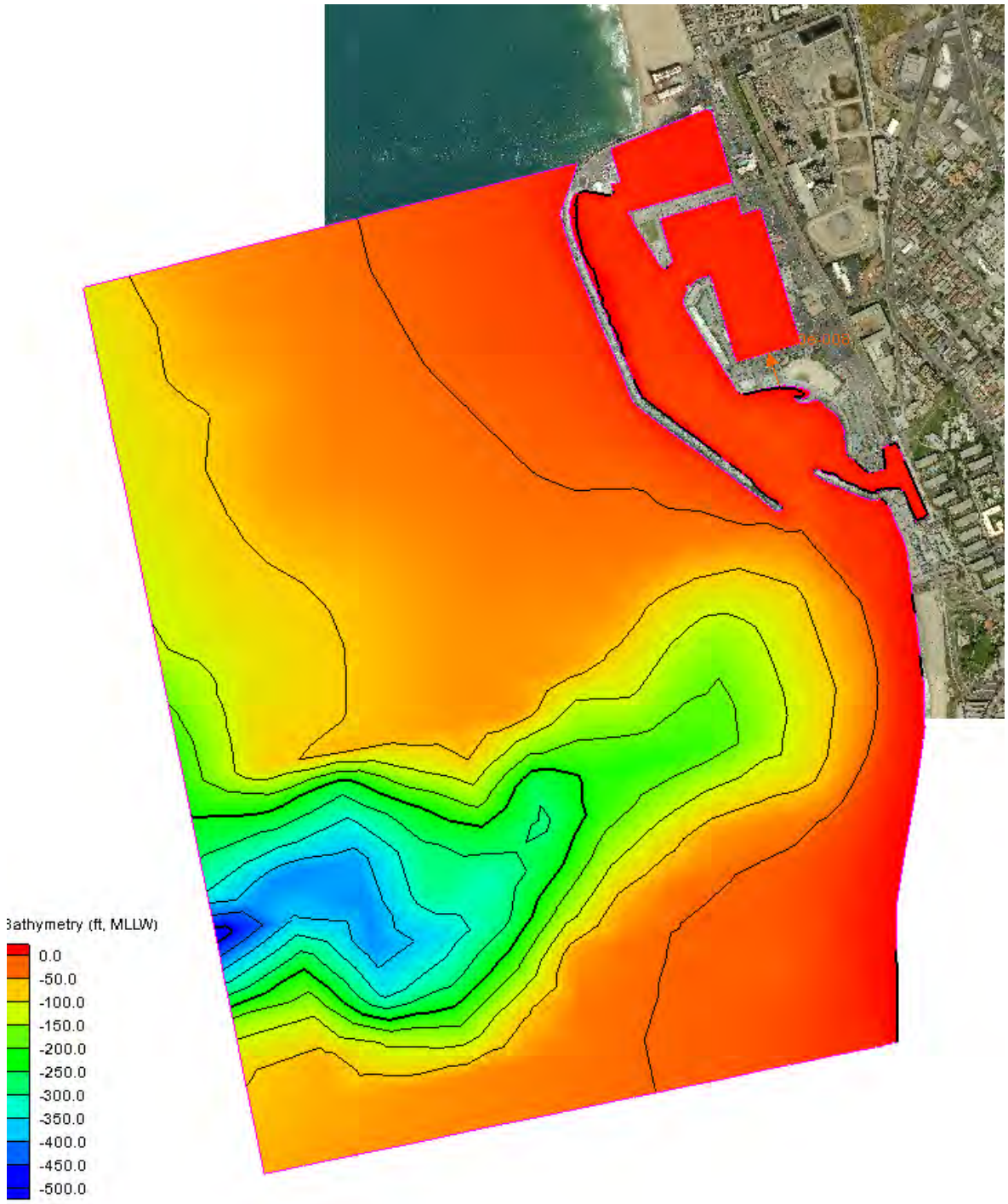

Figure 5. Bathymetry of Modeled Domain (Existing Condition)

Figure 6. Bathymetry for King Harbor (Existing Condition)

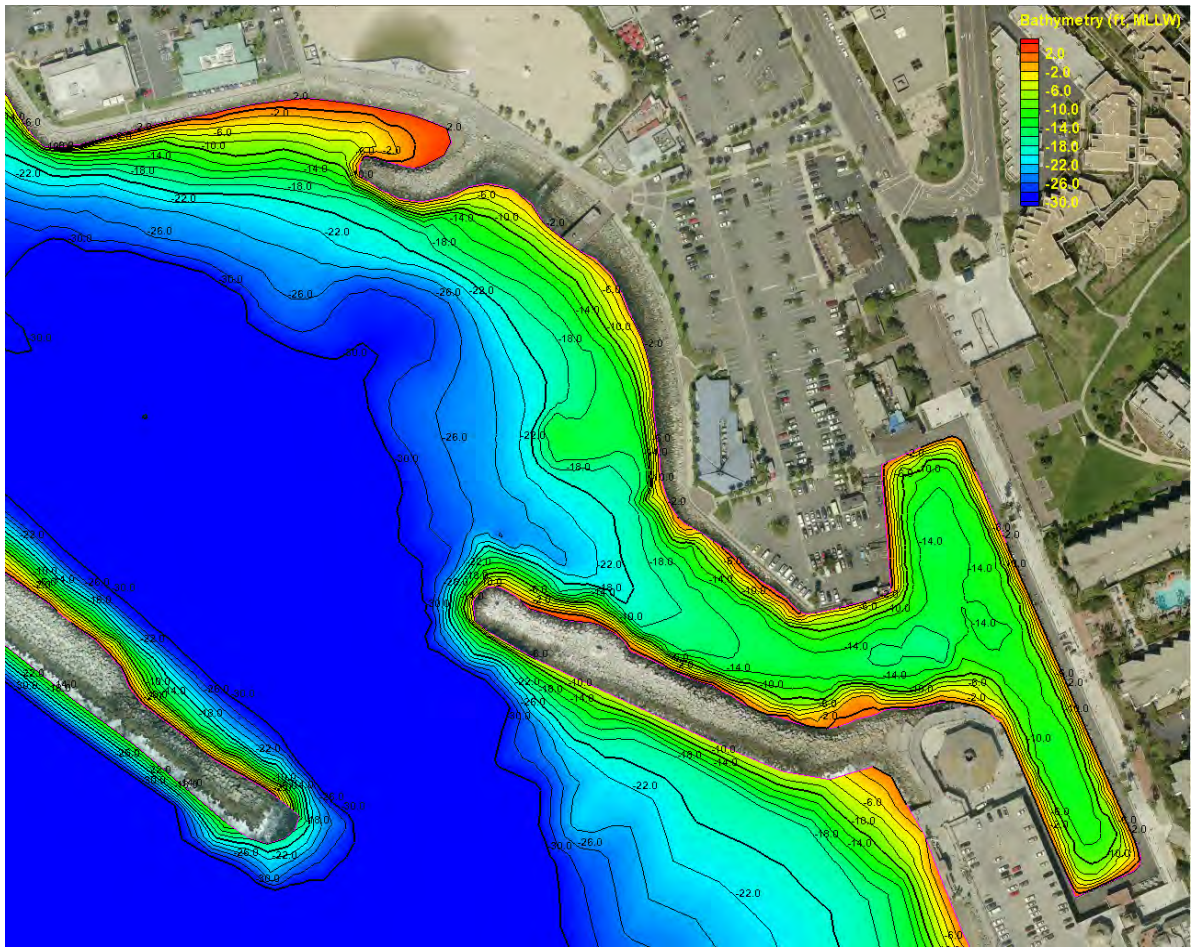

Figure 7. Bathymetry for Basin 3 and Harbor Entrance Area (Existing Condition)

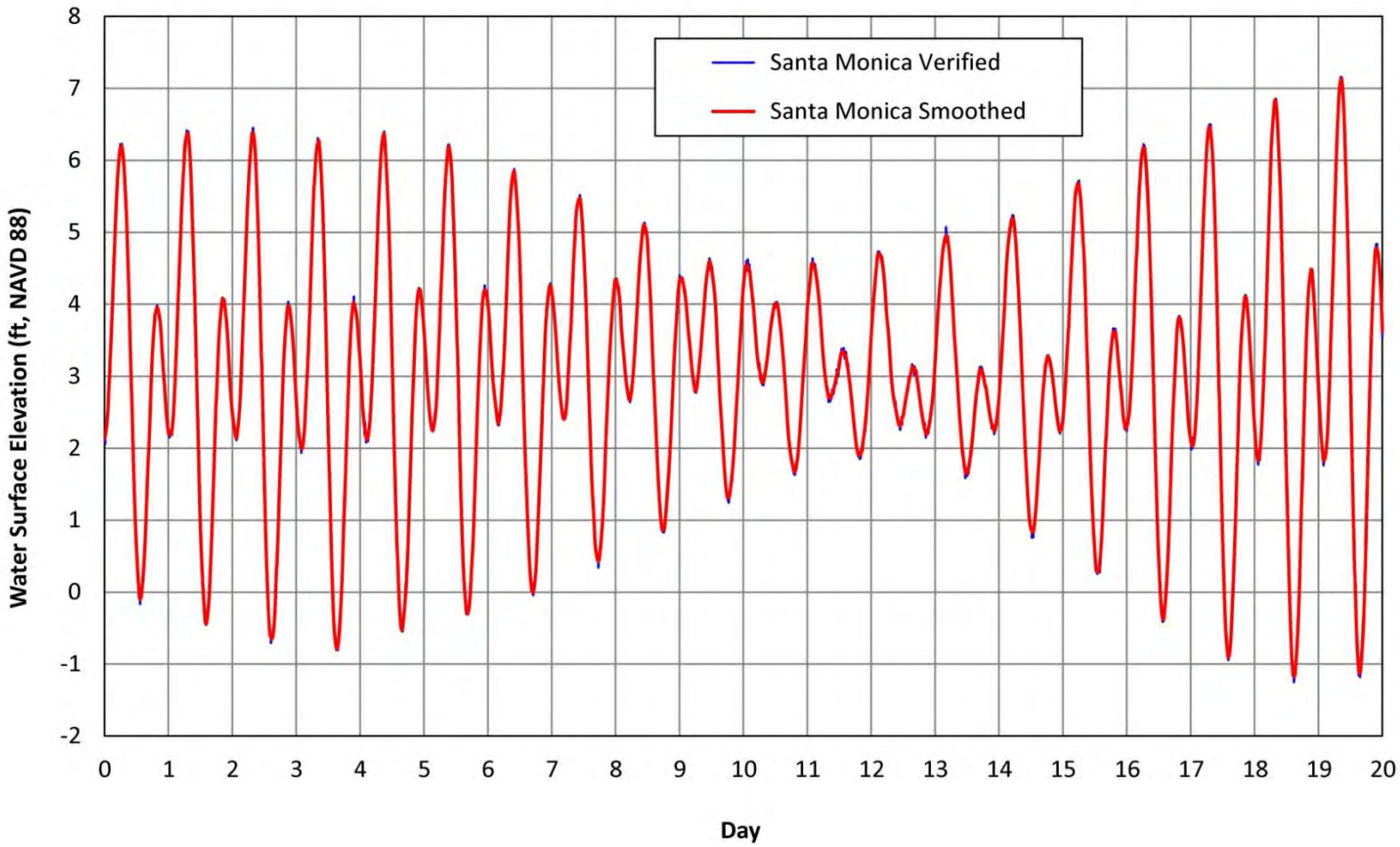

Figure 8. Measured Water Surface Elevations at Santa Monica Used as RMA2 Offshore Boundary Condition

Figure 9. Snapshot of Flow Field for A Peak Flood Tide (Existing Condition)

Figure 10. Snapshot of Flow Field for A Peak Ebb Tide (Existing Condition)

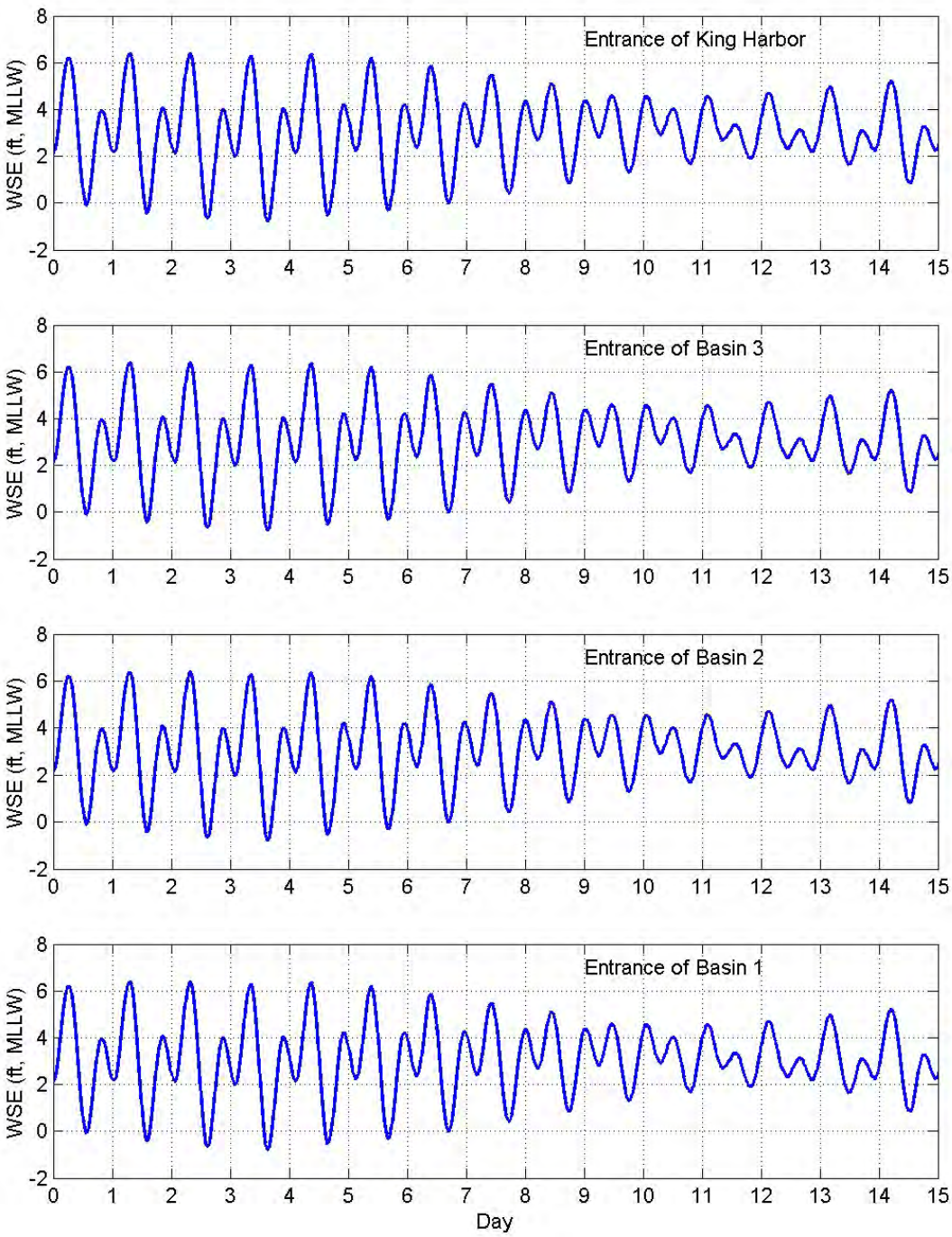

Figure 11. Water Surface Elevations at Entrances of King Harbor and Three Basins (Existing Condition)

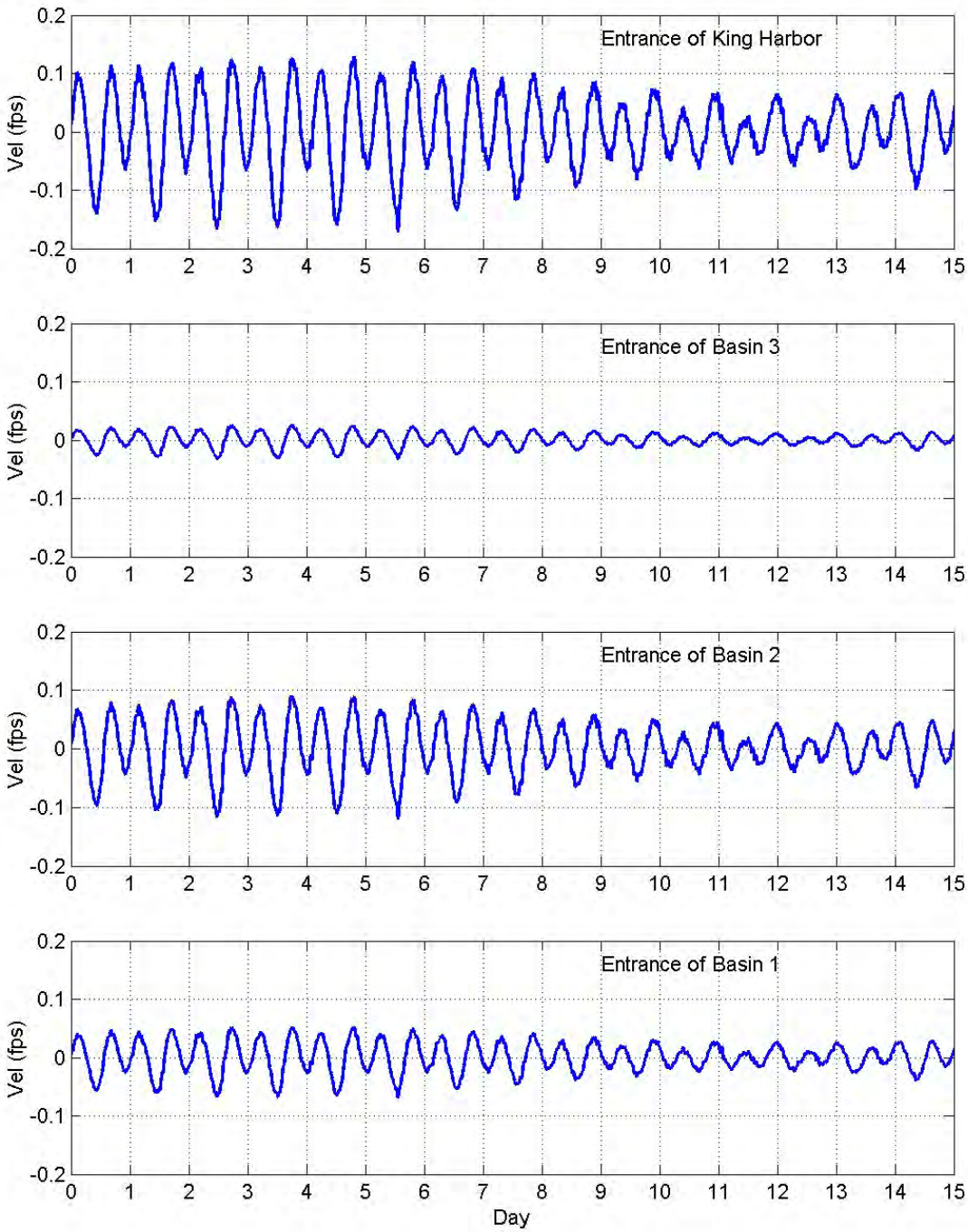

Figure 12. Flow Velocities at Entrances of King Harbor and Three Basins (Existing Condition)

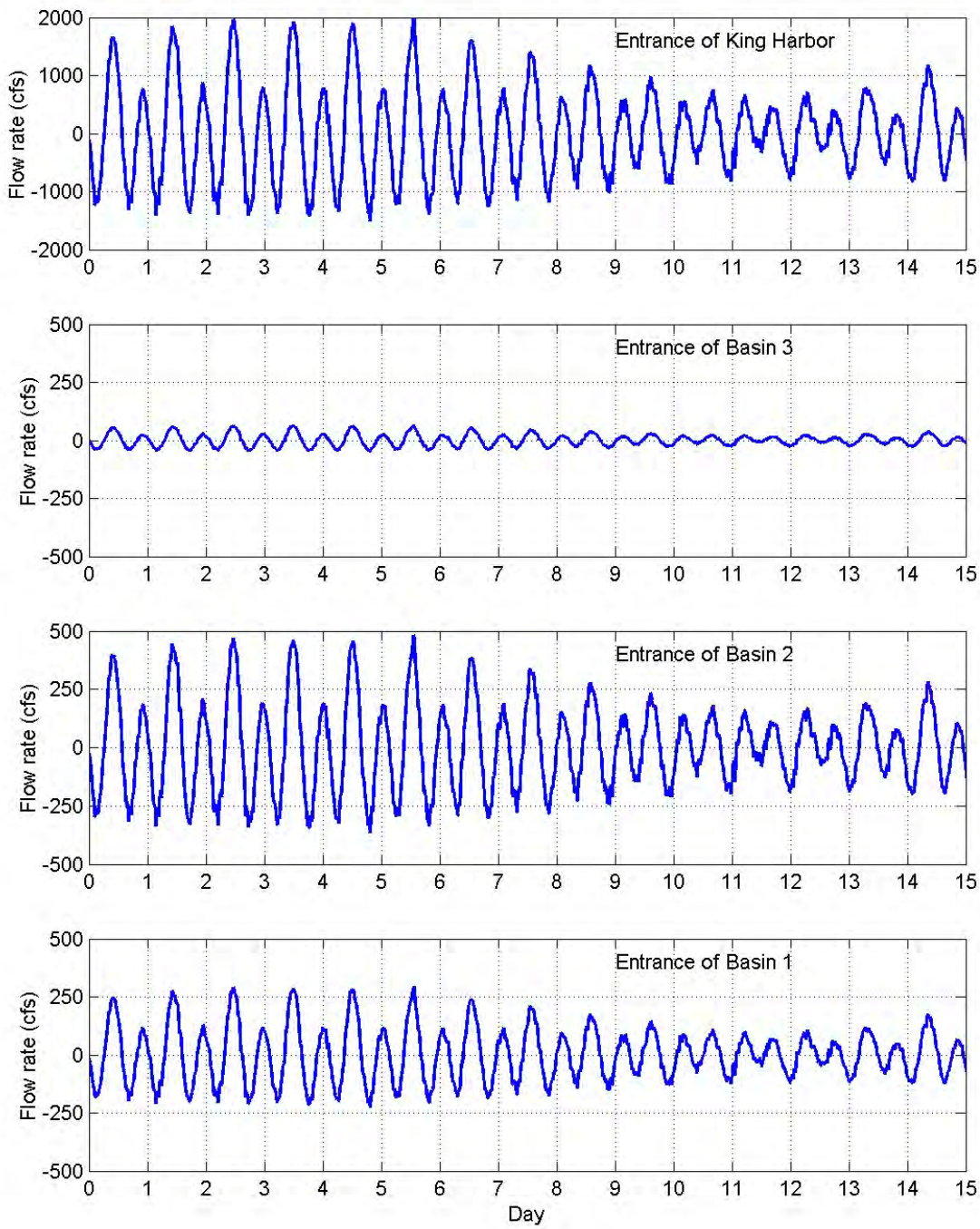

Figure 13. Flow Rates at Entrances of King Harbor and Three Basins (Existing Condition)

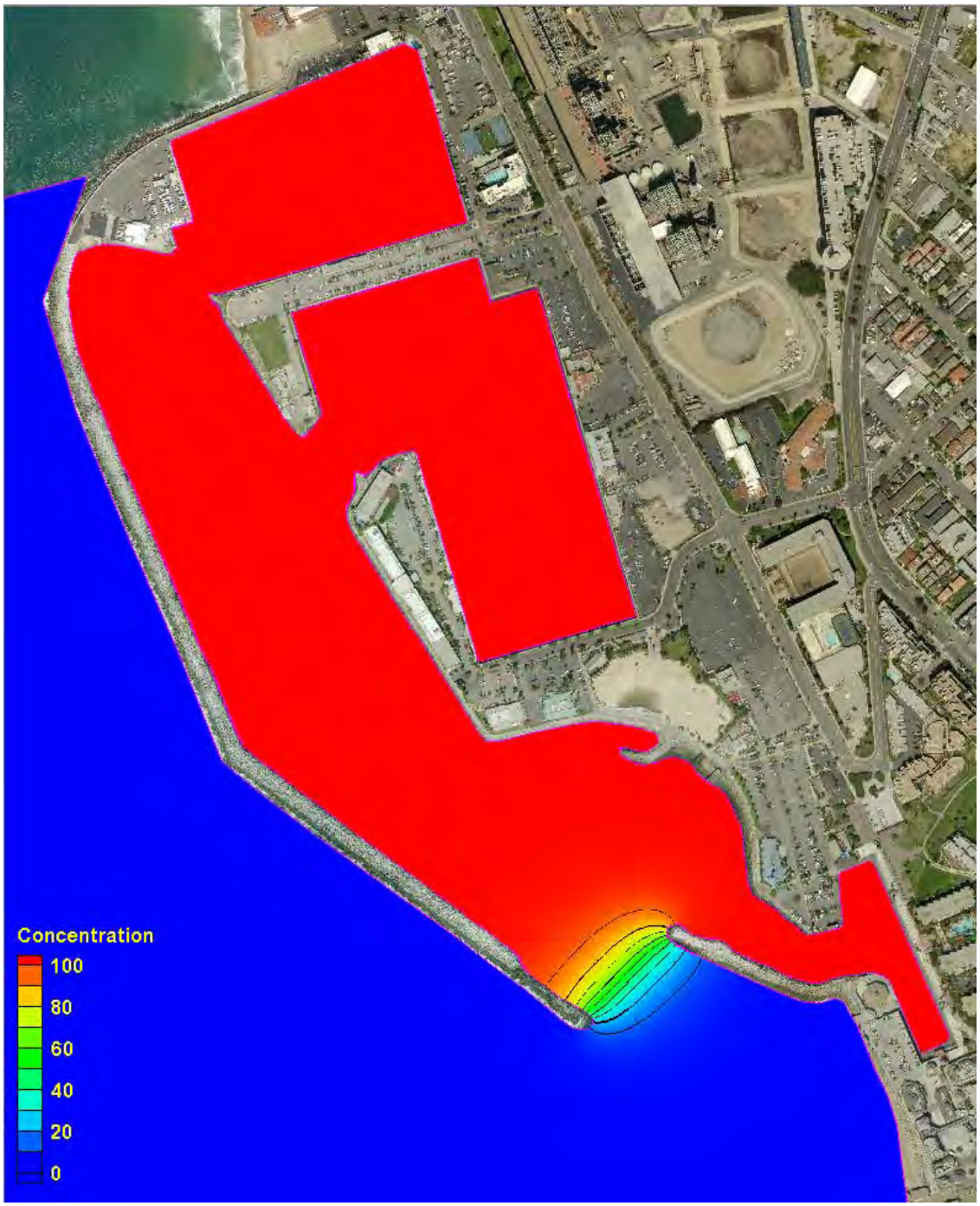

Figure 14. Synthetic Initial Constituent Concentration (Existing Condition)

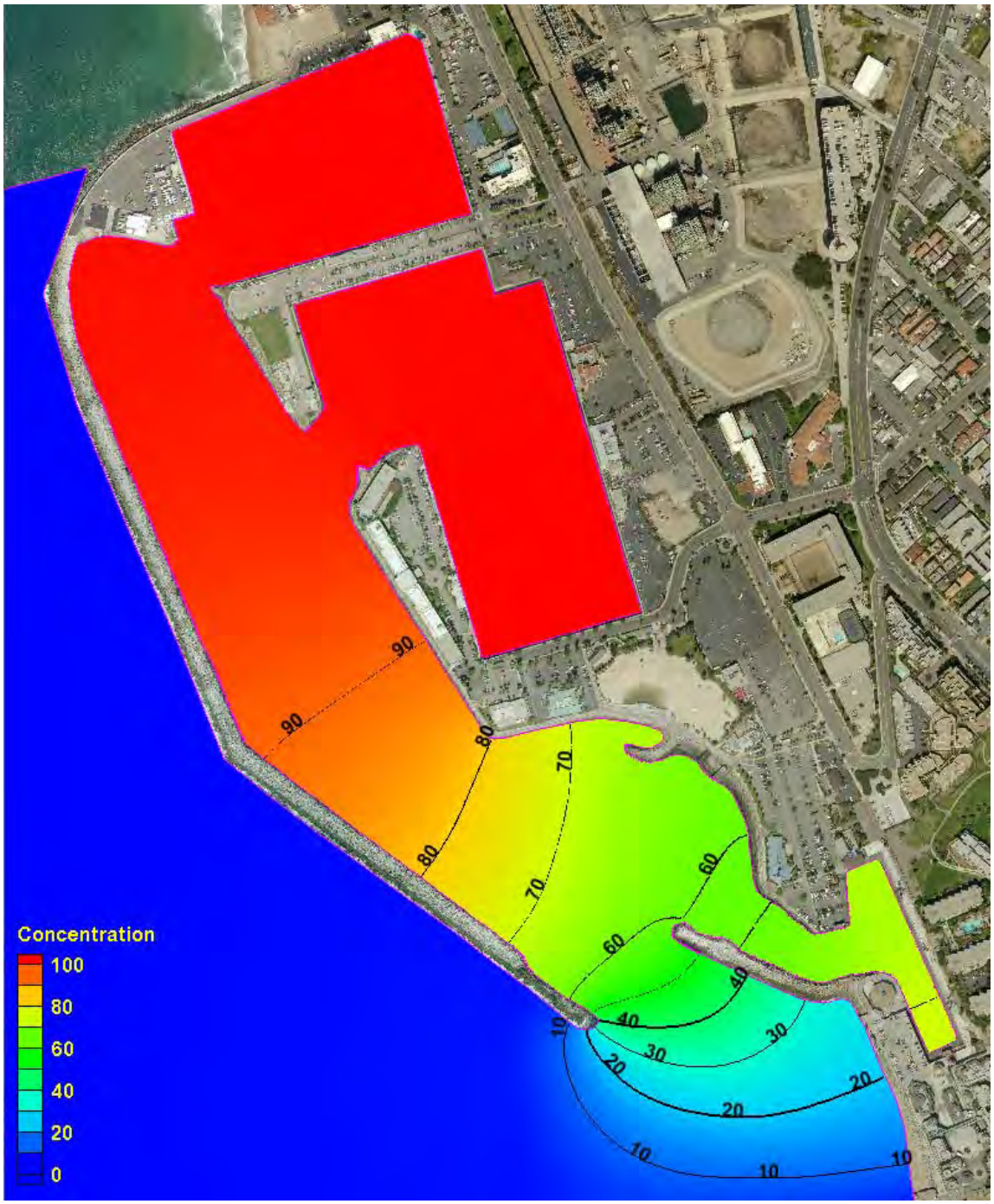

Figure 15. Constituent Concentration in 12 Hours (Existing Condition)

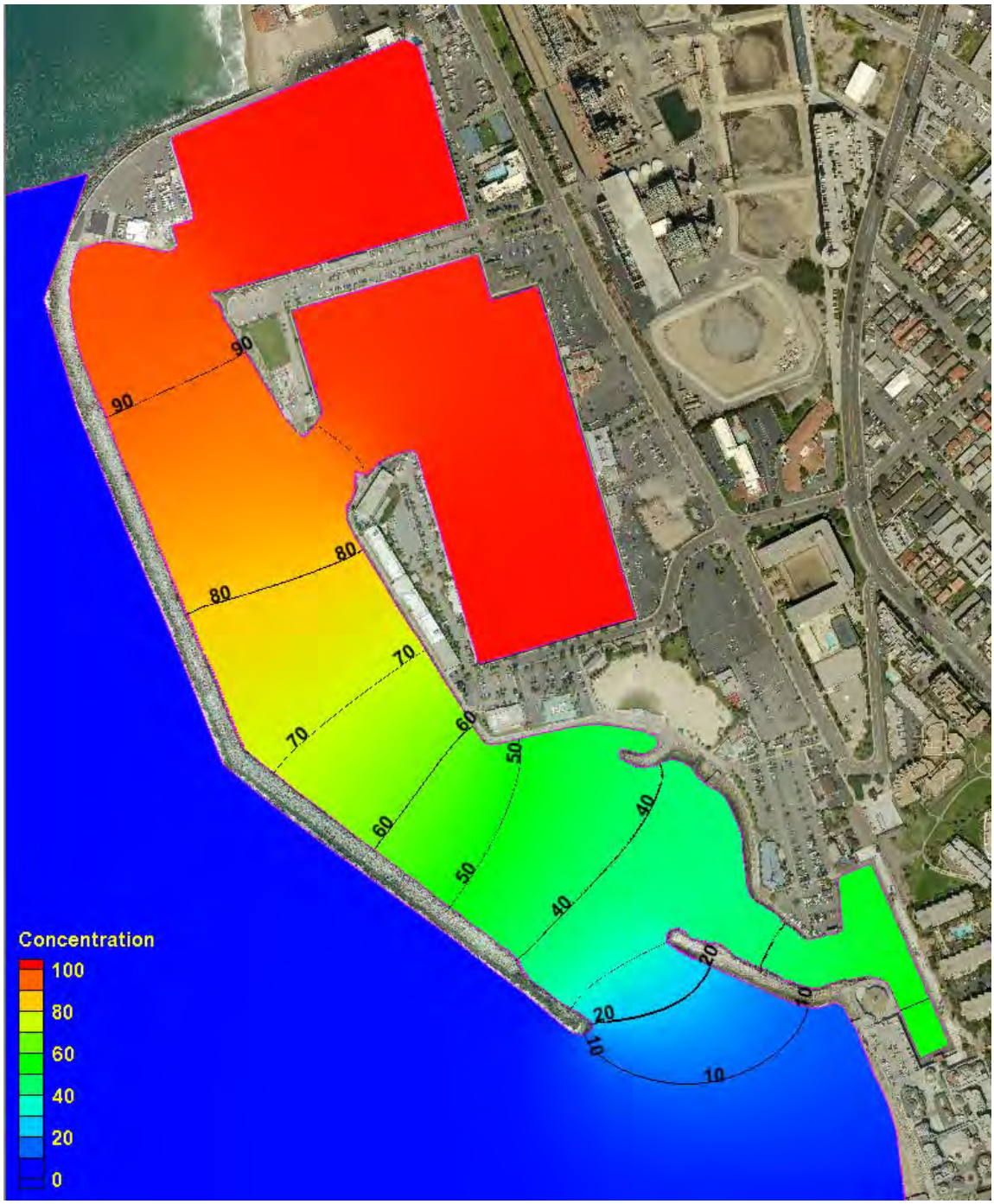

Figure 16. Constituent Concentration in 1 Day (Existing Condition)

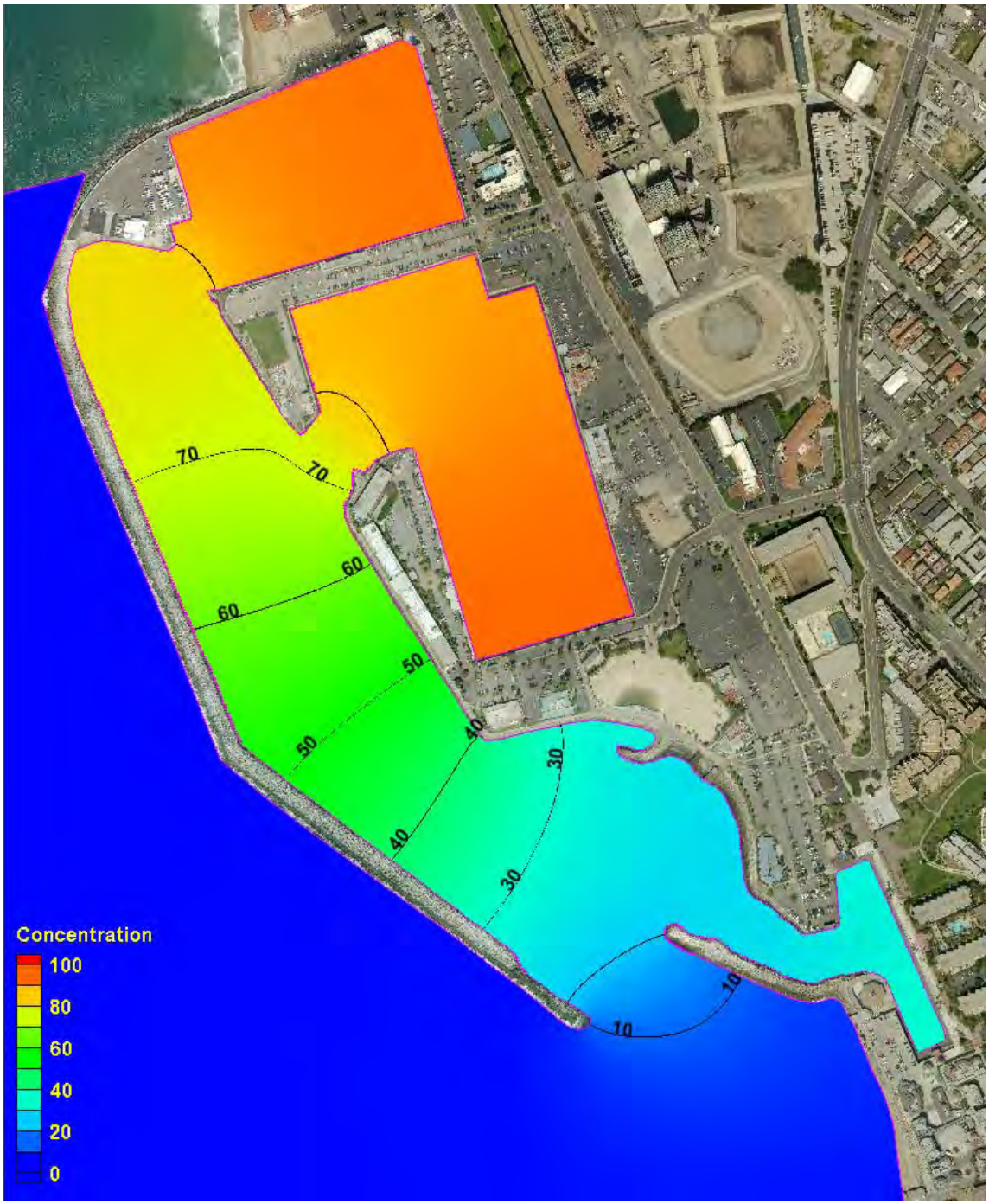

Figure 17. Constituent Concentration in 2 Days (Existing Condition)

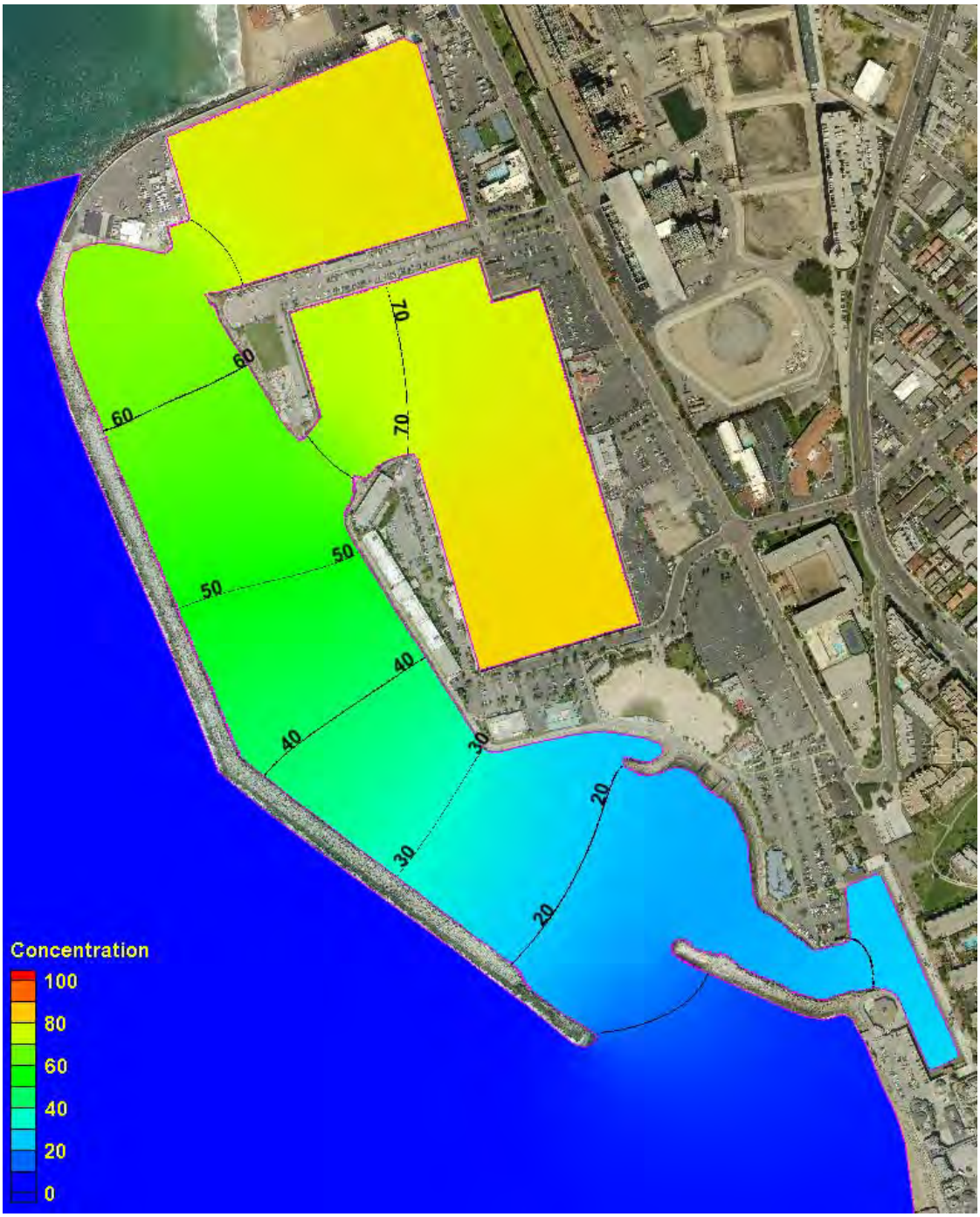

Figure 18. Constituent Concentration in 3 Days (Existing Condition)

Figure 19. Constituent Concentration in 4 Days (Existing Condition)

Figure 20. Constituent Concentration in 6 Days (Existing Condition)

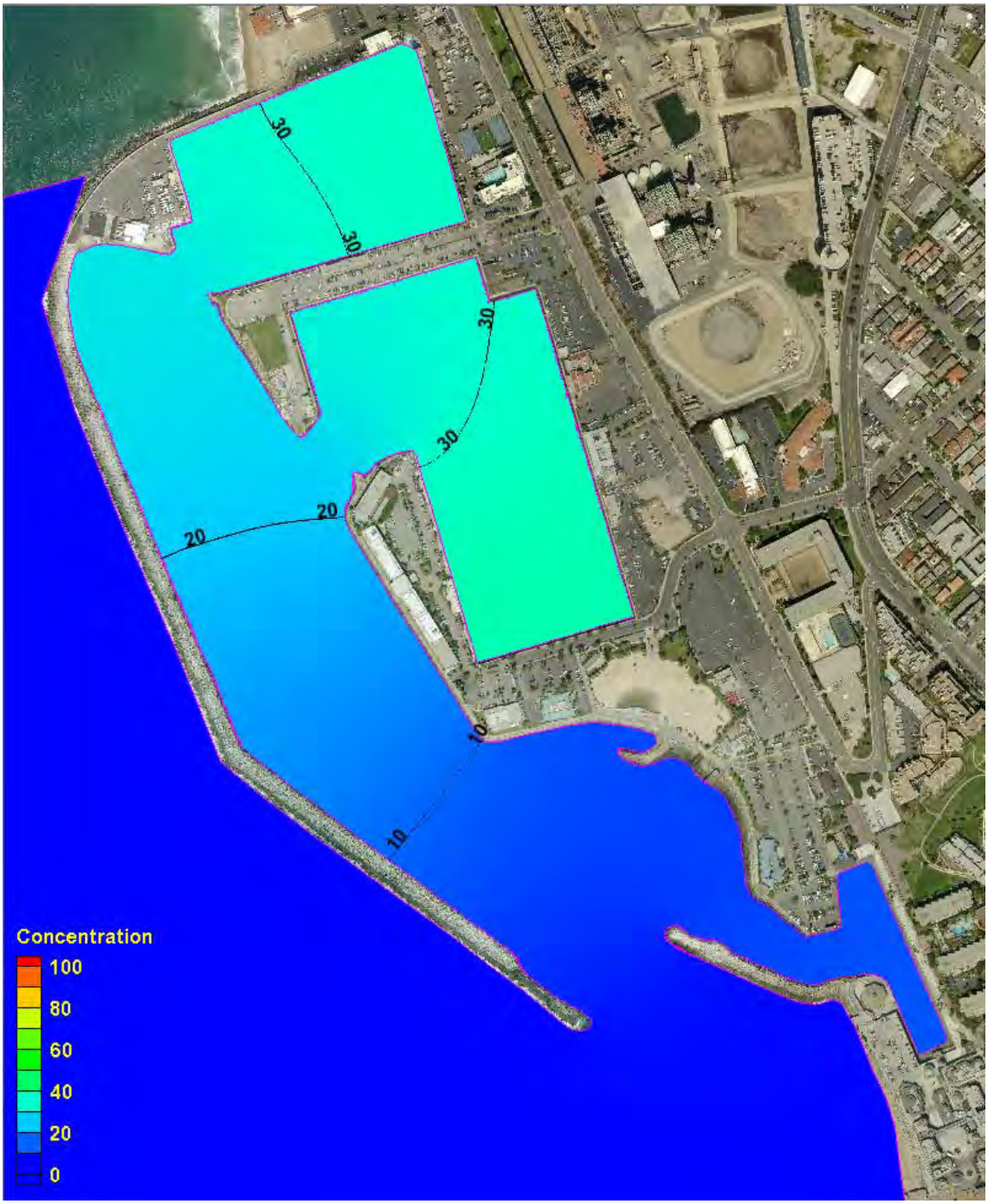

Figure 21. Constituent Concentration in 8 Days (Existing Condition)

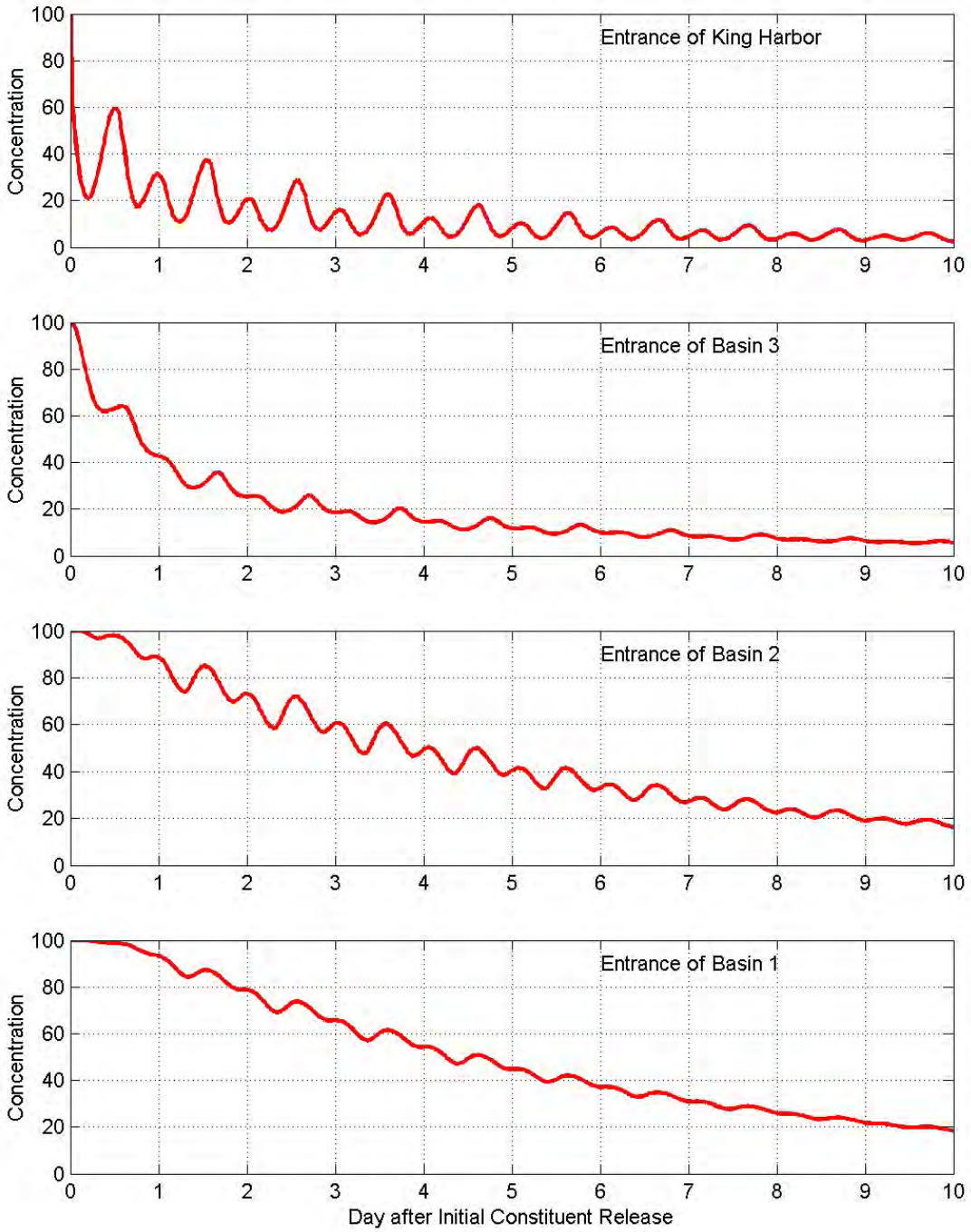

Figure 22. Relative Concentration at Entrances of King Harbor and Three Basins (Existing Condition)

Figure 23. Constituent Residence Time in Days (Existing Condition)

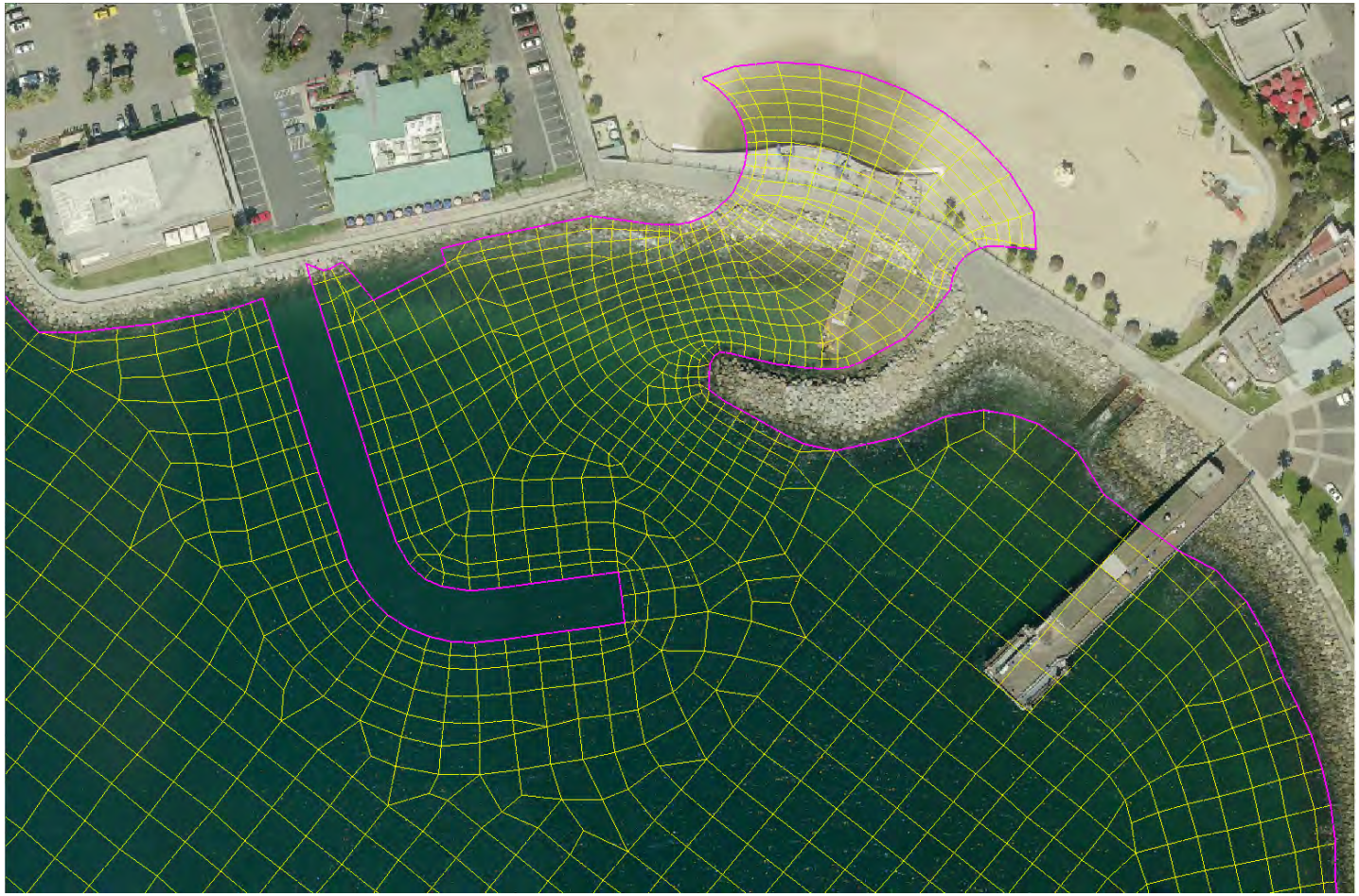

Figure 24. Mesh for Proposed Seaside Lagoon Area

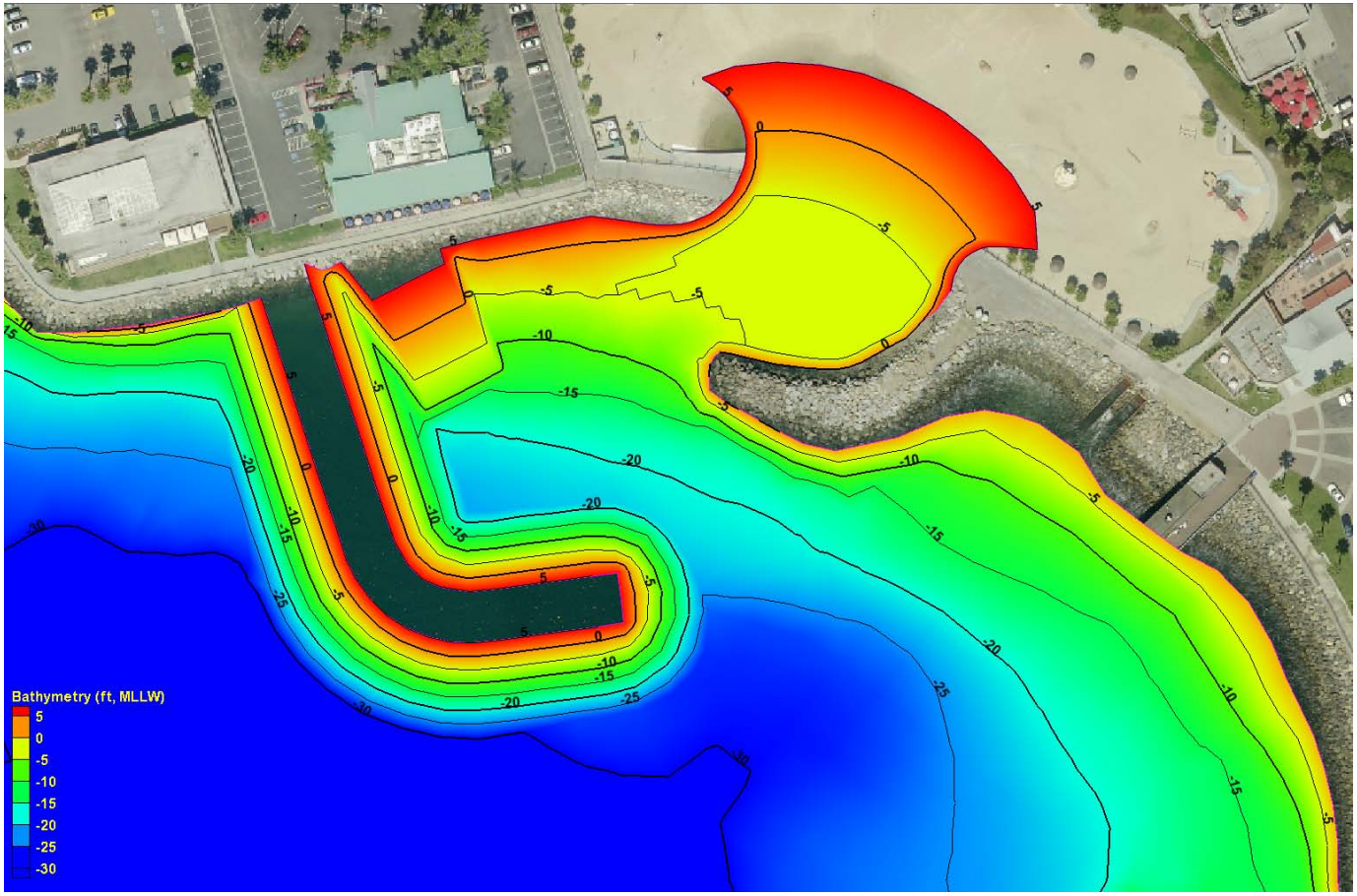

Figure 25. Bathymetry for Proposed Seaside Lagoon Area

Figure 26. Snapshot of Flow Field for A Peak Flood Tide (Project Condition)

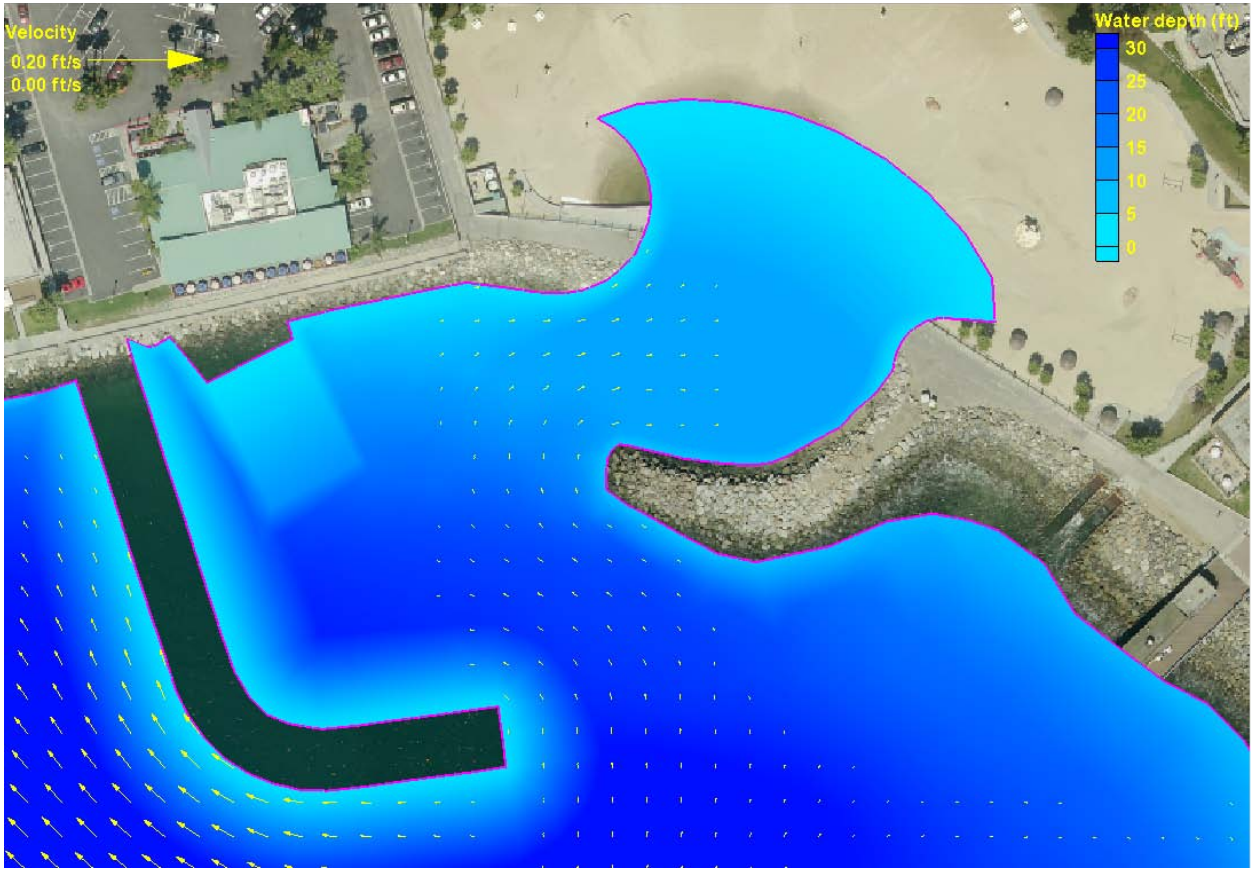

Figure 27. Snapshot of Flow Field for A Peak Flood Tide in Seaside Lagoon Area (Project Condition)

Figure 28. Snapshot of Flow Field for A Peak Ebb Tide (Project Condition)

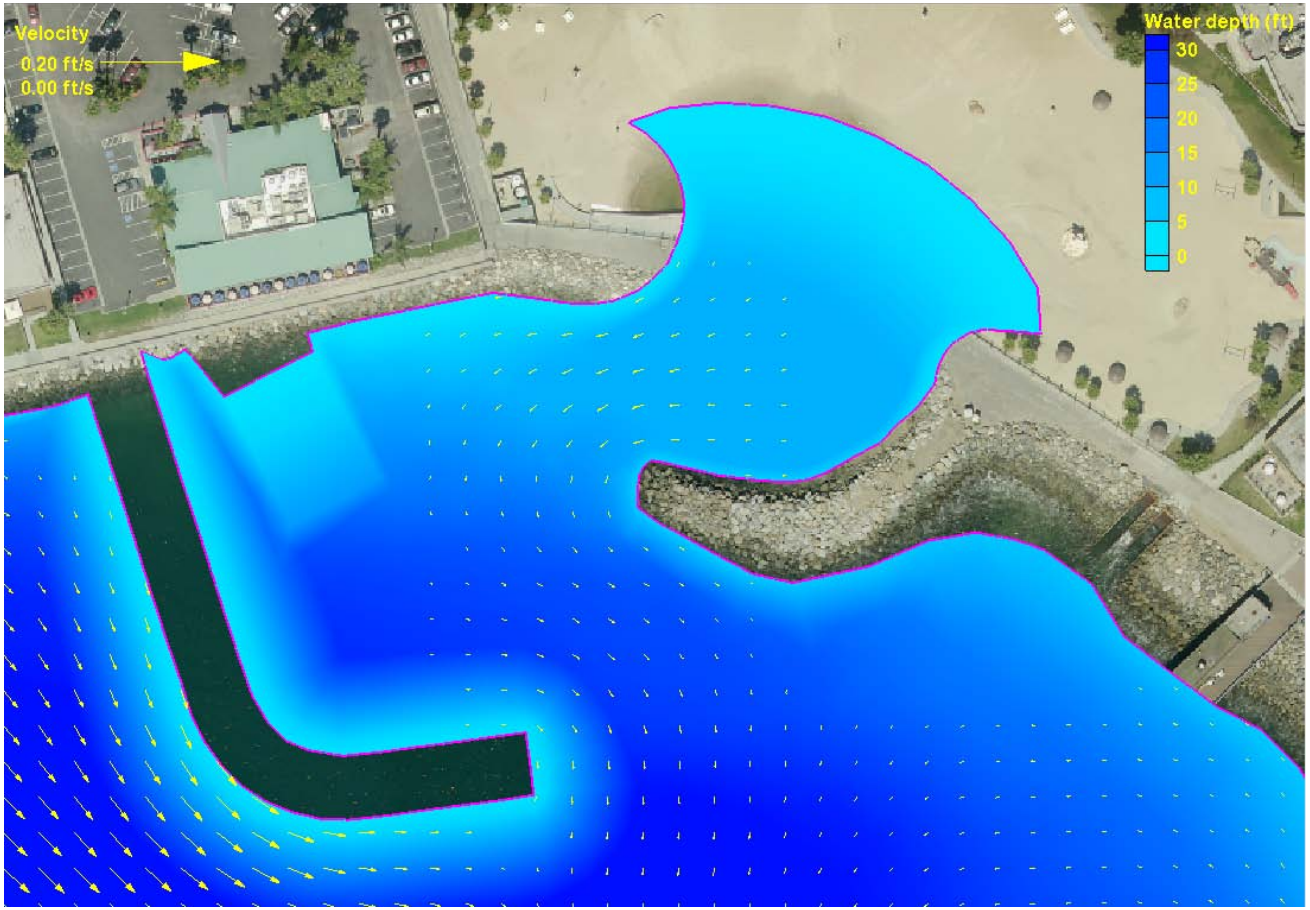

Figure 29. Snapshot of Flow Field for A Peak Ebb Tide in Seaside Lagoon Area (Project Condition)

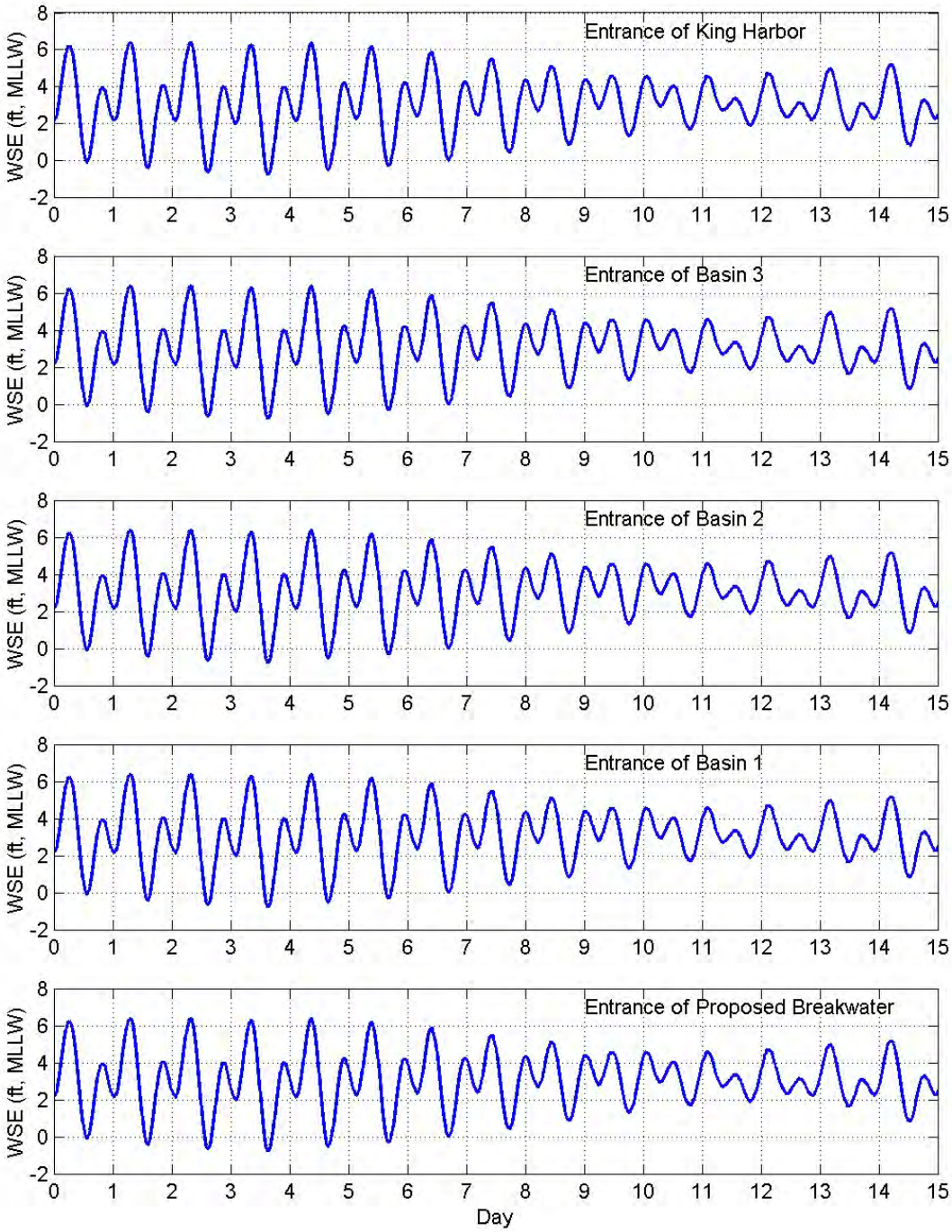

Figure 30. Water Surface Elevations at Entrances of King Harbor, Three Basins and the Proposed Breakwater (Project Condition)

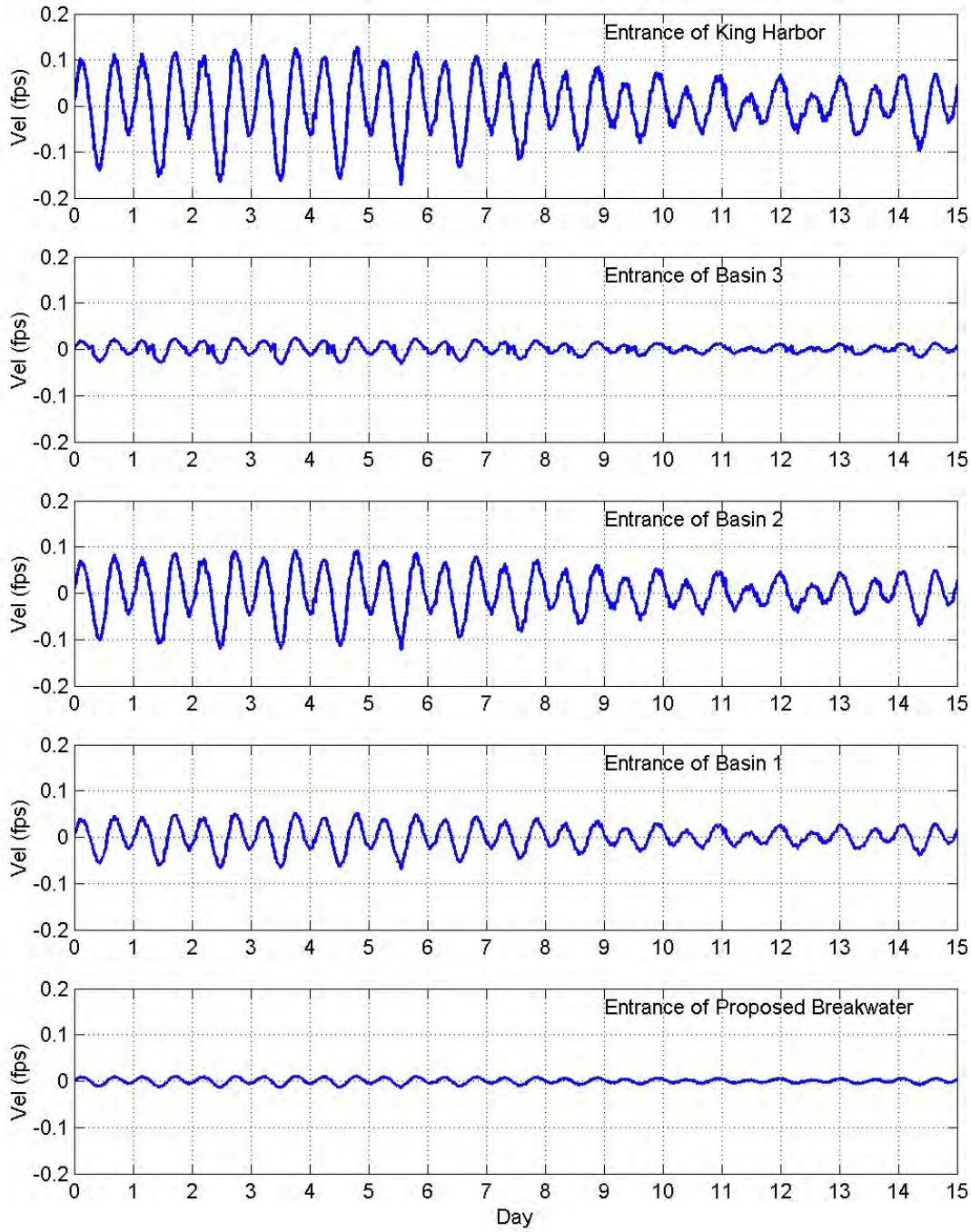

Figure 31. Flow Velocities at Entrances of King Harbor, Three Basins and the Proposed Breakwater (Project Condition)

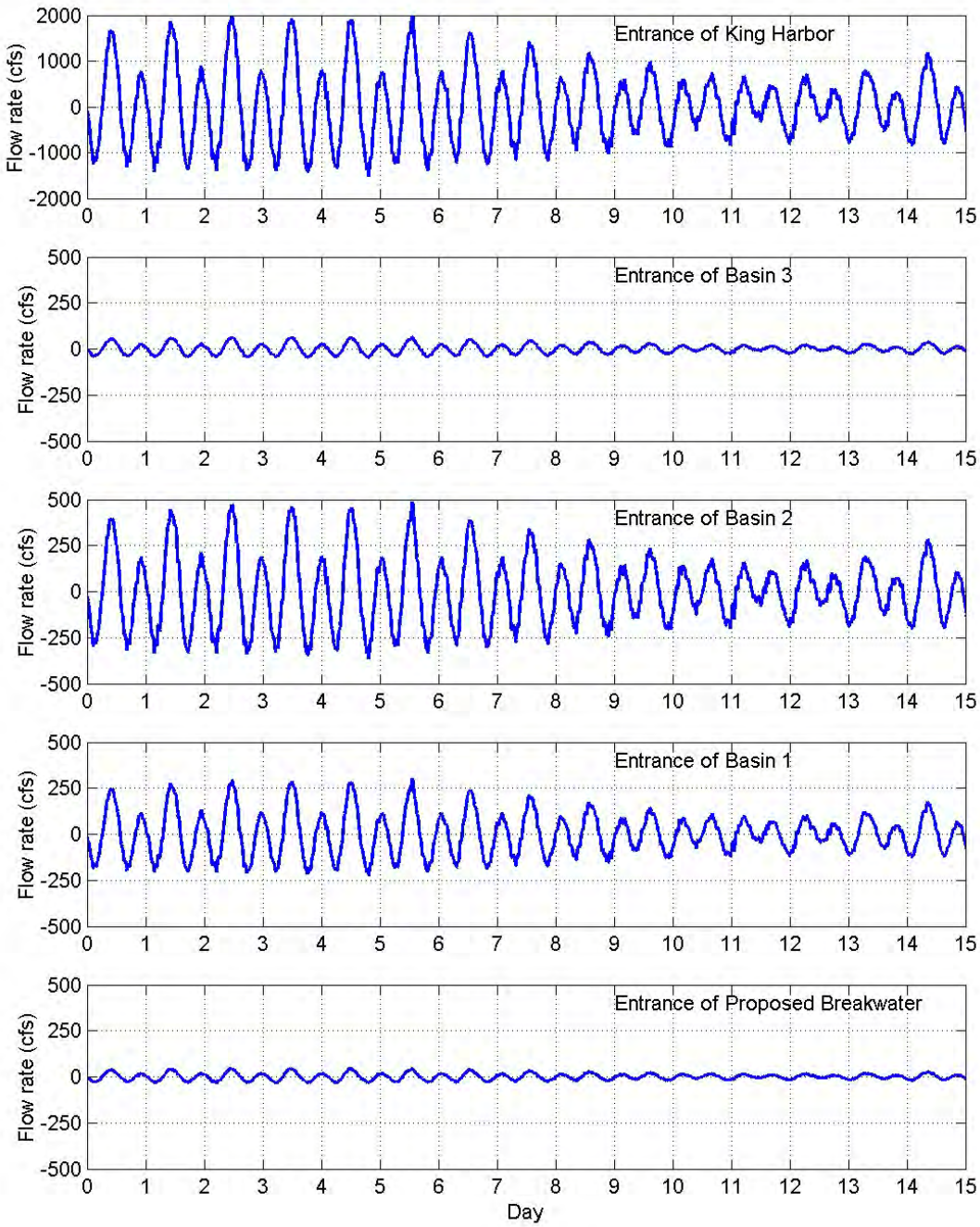

Figure 32. Flow Rates at Entrances of King Harbor, Three Basins and the Proposed Breakwater (Project Condition)

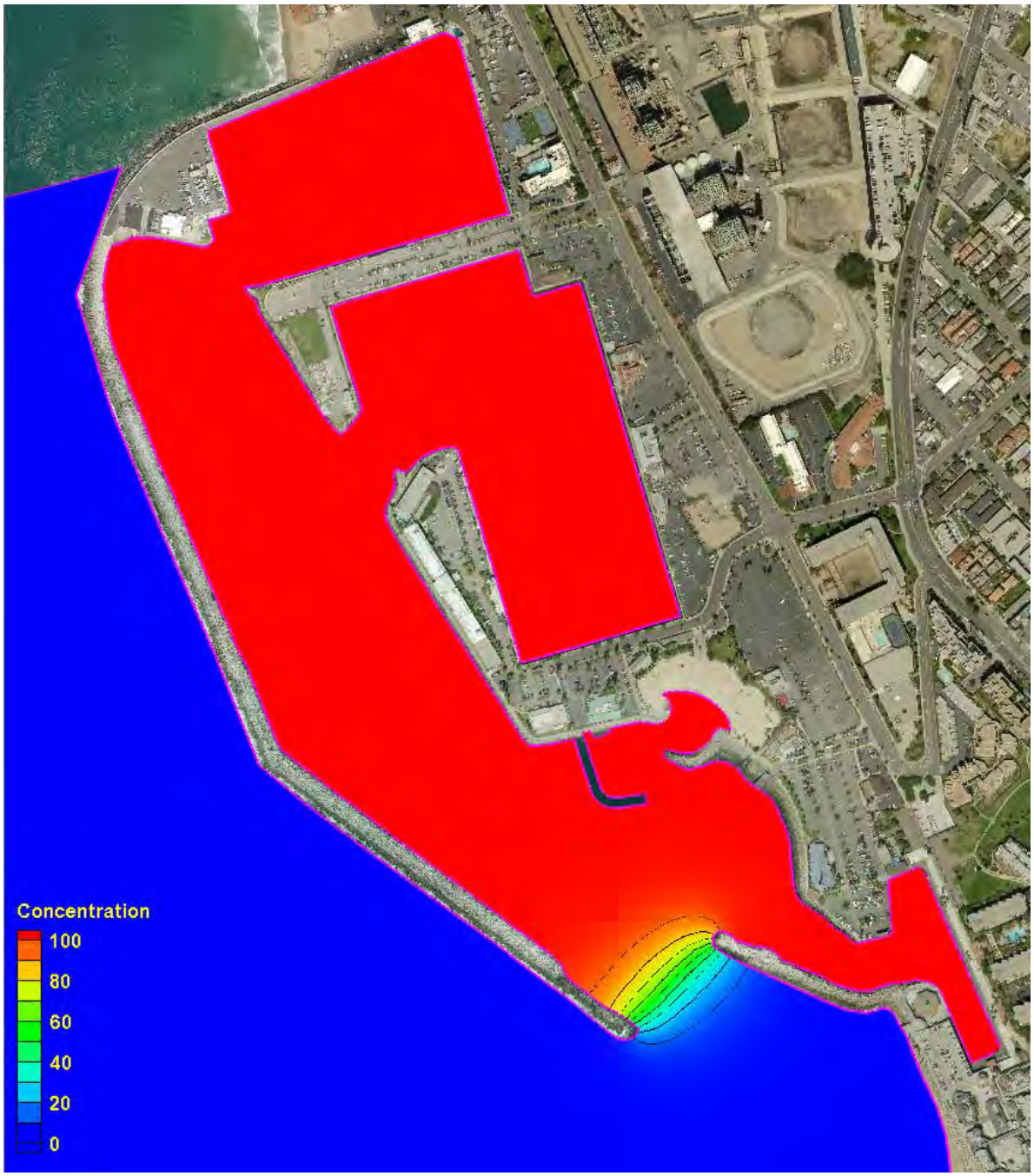

Figure 33. Synthetic Initial Constituent Concentration (Project Condition)

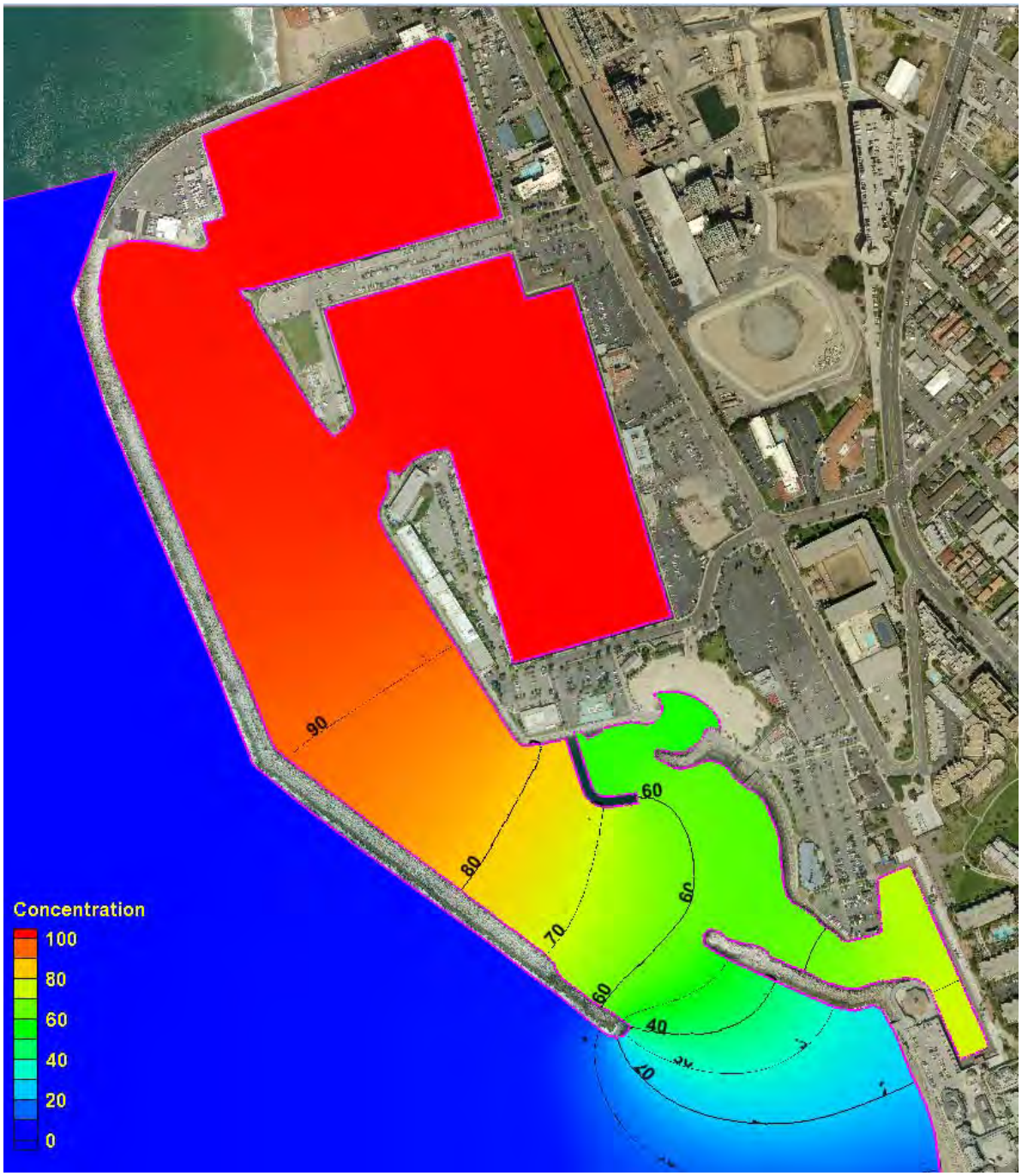

Figure 34. Constituent Concentration in 12 Hours (Project Condition)

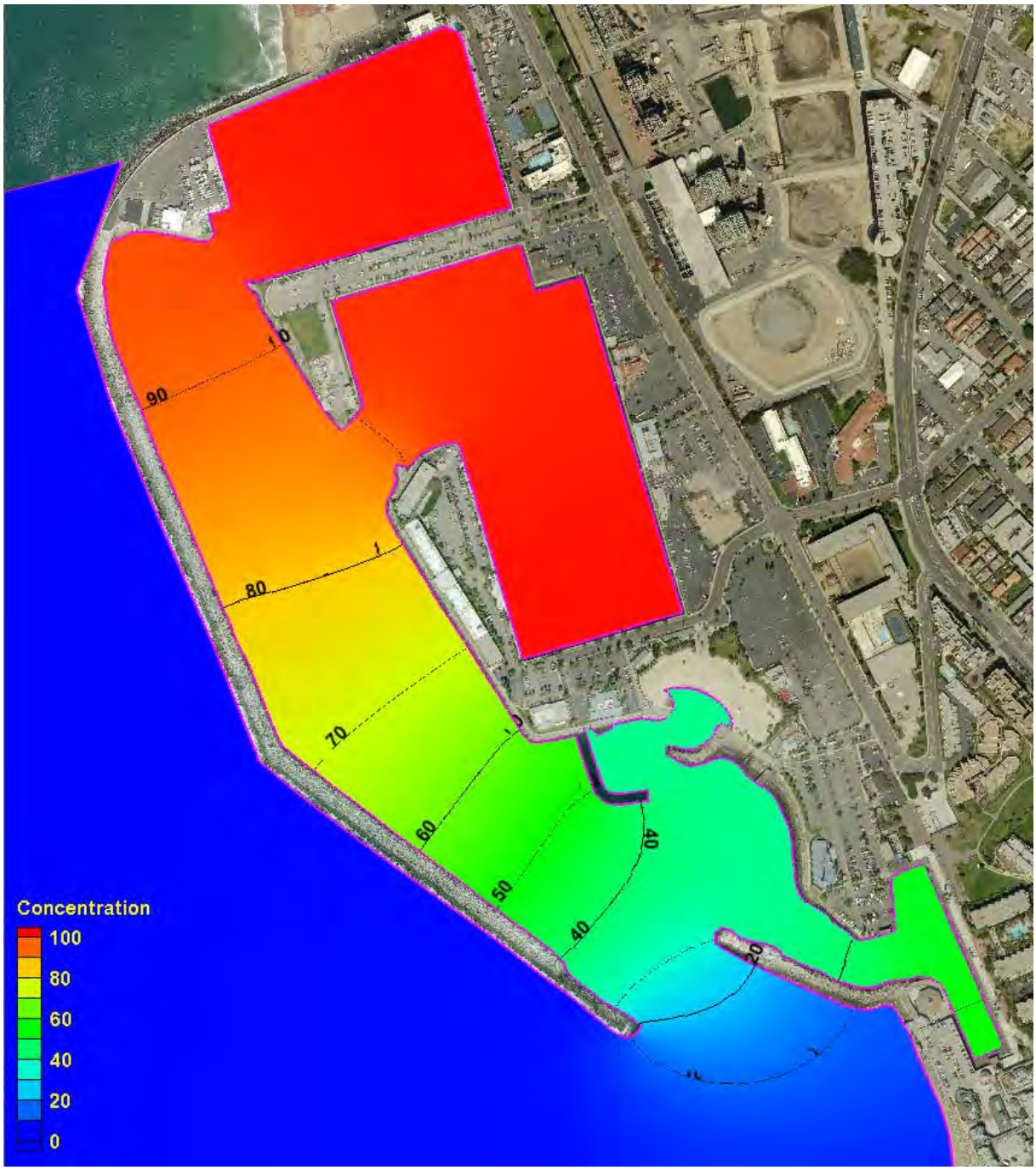

Figure 35. Constituent Concentration in 1 Day (Project Condition)

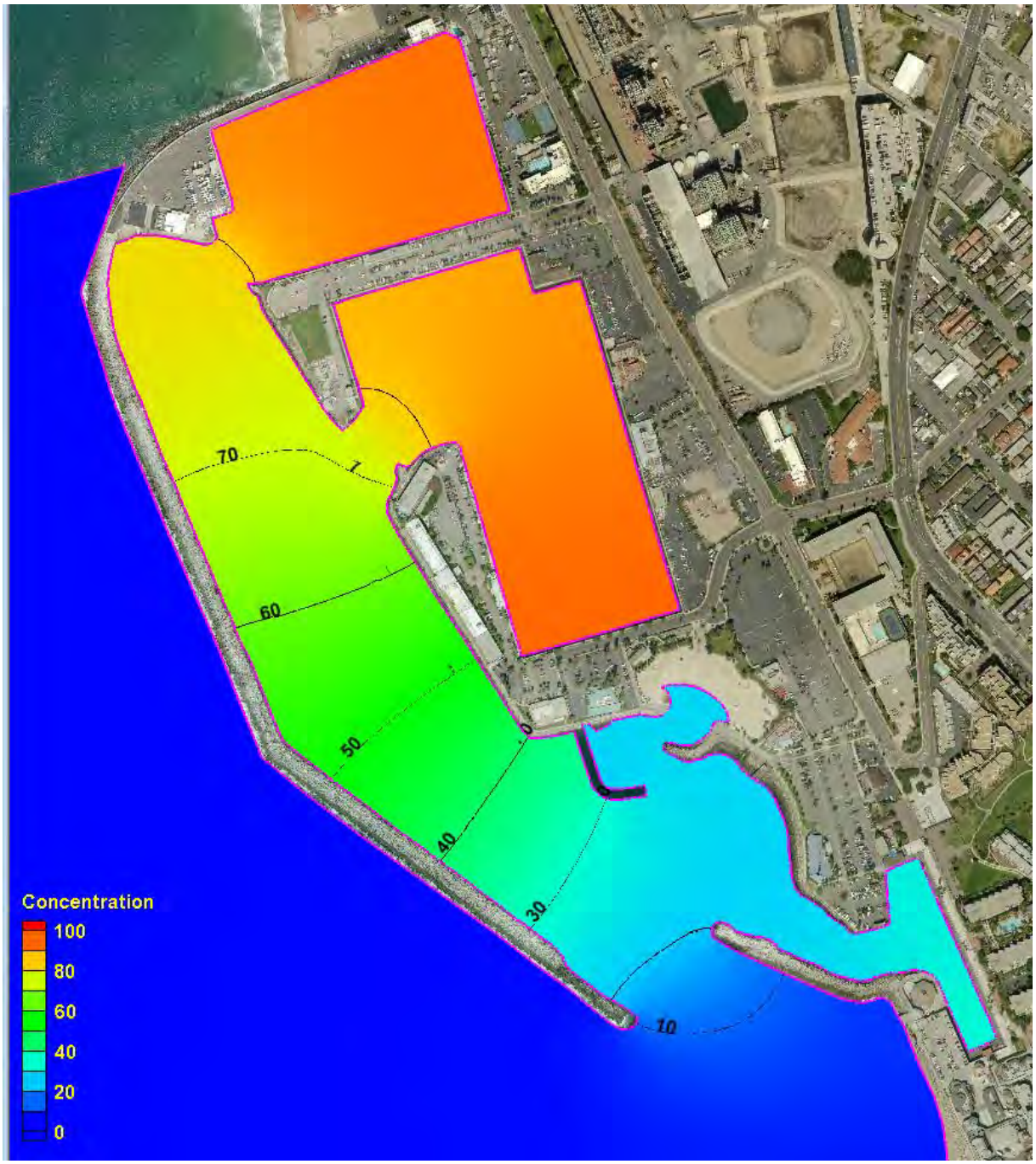

Figure 36. Constituent Concentration in 2 Days (Project Condition)

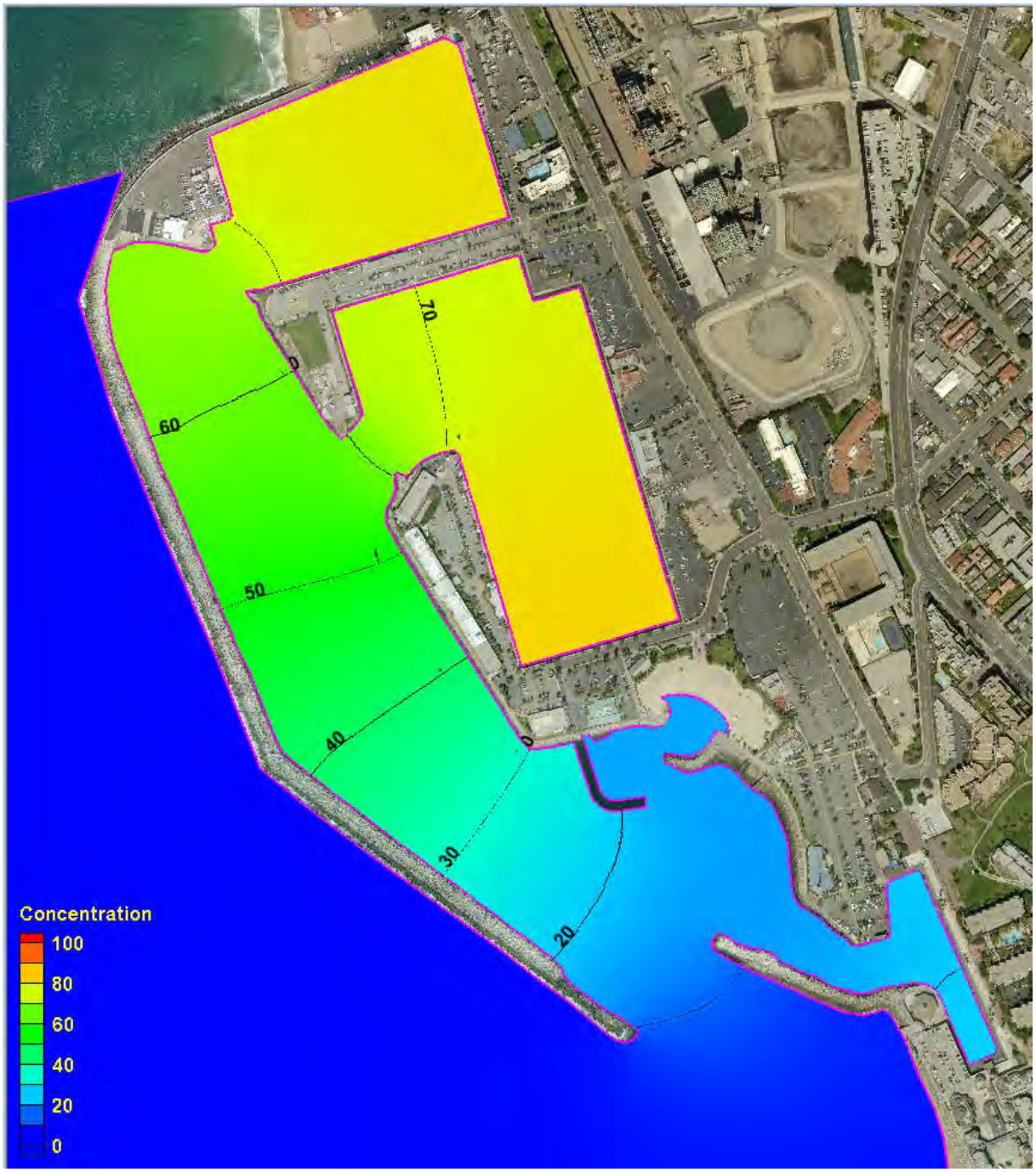

Figure 37. Constituent Concentration in 3 Days (Project Condition)

Figure 38. Constituent Concentration in 4 Days (Project Condition)

Figure 39. Constituent Concentration in 6 Days (Project Condition)

Figure 40. Constituent Concentration in 8 Days (Project Condition)

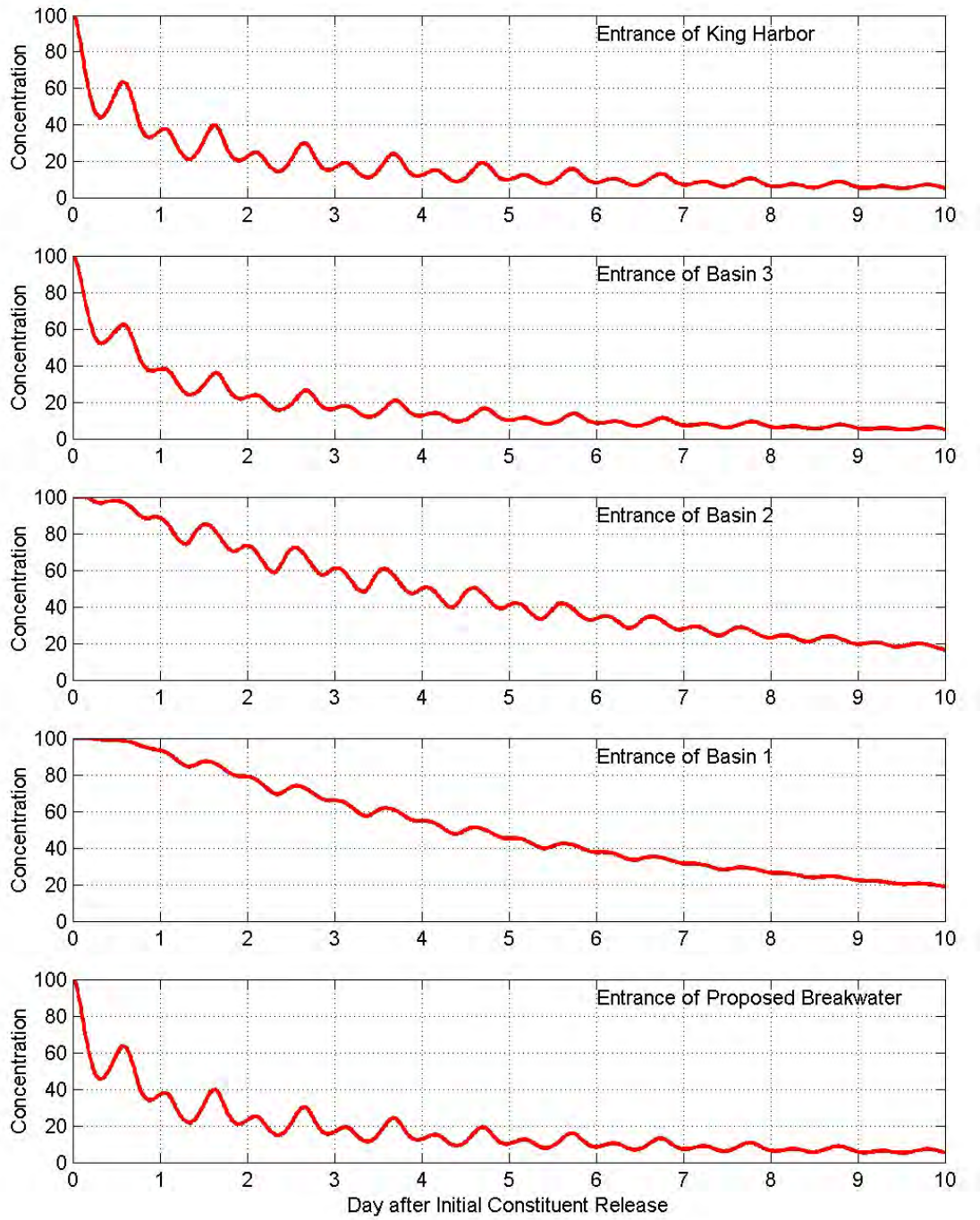

Figure 41. Relative Concentration at Entrances of King Harbor, Three Basins and the Proposed Breakwater (Project Condition)

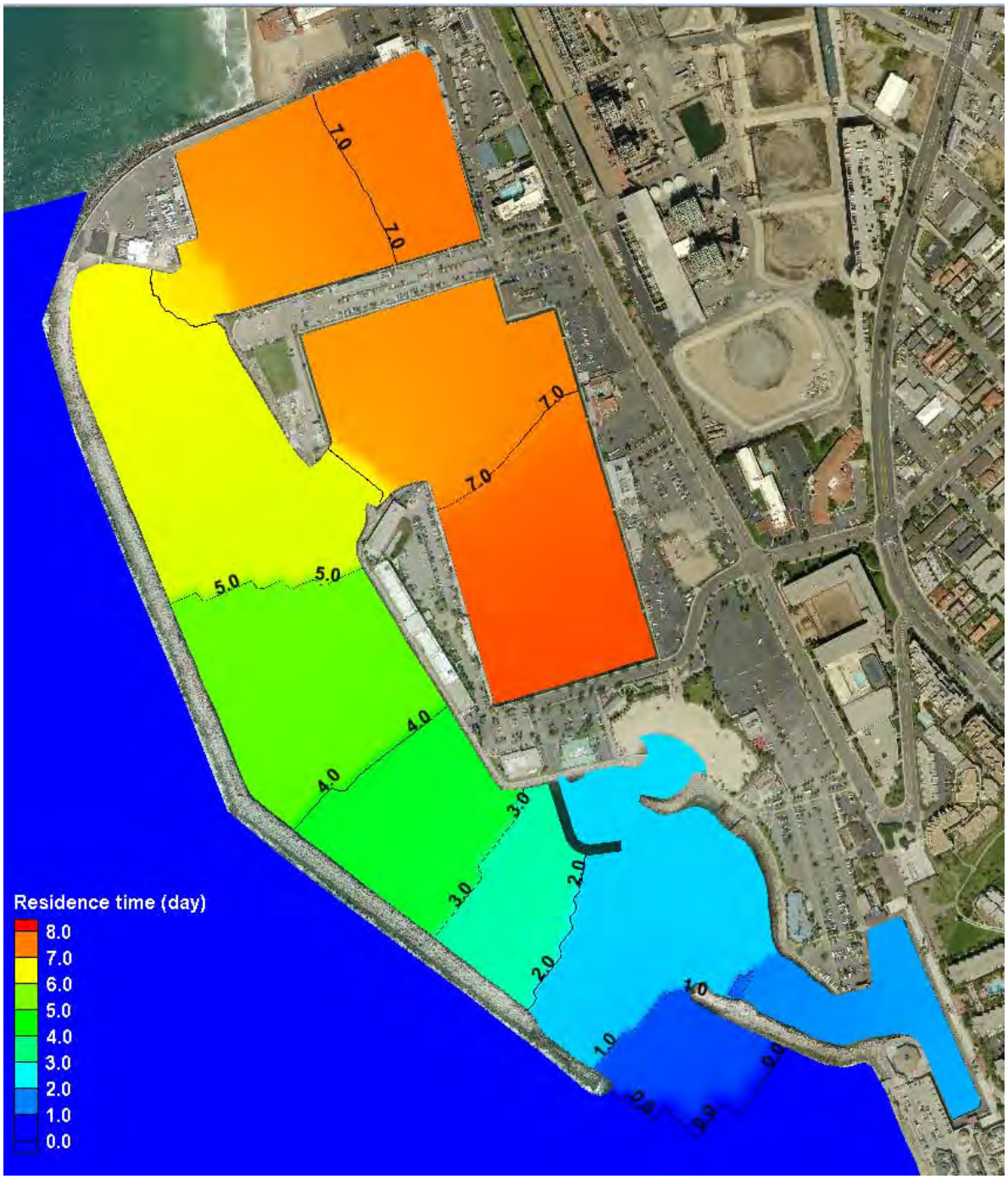

Figure 42. Constituent Residence Time in Days (Project Condition)