Appendix J

Desalinization and Brine Management Feasibility Assessment

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Preliminary Feasibility Assessment of Desalinization and Brine Management for the South San Diego Bay Salt Ponds Restoration

FINAL REPORT

Prepared for

Ducks Unlimited

Prepared by

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with

DHI Water & Environment

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1. INTRODUCTION

The U.S. Fish and Wildlife Service (USFWS) is currently developing a Comprehensive Conservation Plan (CCP) and Environmental Impact Statement (EIS) for the South San Diego Bay Unit of the San Diego National Wildlife Refuge. This plan includes alternatives to restore and enhance habitat for aquatic and avian wildlife species within the 1,050-acre salt pond complex along South San Diego Bay. Ducks Unlimited (DU) is assisting the USFWS in the planning effort and contracted Philip Williams & Associates, Ltd. (PWA) to carry out a preliminary assessment of salinity reduction and feasibility of a managed brine complex.

The restoration alternatives under development include various levels of tidal wetland restoration within the pond complex and reduction of acreages dedicated to commercial salt harvesting. USFWS and DU selected two specific alternatives for impact analysis that included restoration of many of the ponds fronting the bay to tidal inundation, and a reduced salt production operation (Alternative C Option 4, Figure 1) or complete elimination of salt production in favor of managed open-water and brine ponds (Alternative D, Figure 2). PWA conducted a preliminary technical assessment to answer the following key questions in support of the CCP and EIS process:

- What are the short-term effects on salinity in San Diego Bay that would result from breaching salt pond levees for desalination, and how quickly can these ponds be flushed to ambient salinity levels?

- Is the proposed brine operation feasible, given the flow rates required to maintain suitable habitat in the ponds and the necessary dilution of the hypersaline brine prior to discharge to the bay?

PWA conducted hydrodynamic and salinity transport modeling of two salinity reduction scenarios and applied a simple box model of the brine operations to address the questions above. DHI Water and Environment (DHI) was sub-contracted to develop and apply the numerical hydrodynamic and salinity transport model in support of this analysis.

2. KEY FINDINGS AND MANAGEMENT CONSIDERATIONS

2.1 KEY FINDINGS

PWA conducted hydrodynamic and salinity transport modeling to assess changes in pond and Bay salinities that would result from breaching salt pond levees for salinity reduction. We modeled a phased salinity reduction approach for Alternatives C4 and D. Phase 1 consists of salinity reduction in Ponds 10, 10A, and 11 (Figure 1). Phase 2 includes breaching of Ponds 12 – 15, assuming that the Phase 1 ponds are tidal and at ambient bay salinities (approximately 33 ppt). Alternative D (Figure 2) includes an additional third phase, in which Ponds 23-25 and 28-30 are breached once salinities in the Phase 2 ponds have reached ambient levels. Because of the limited number of model runs contracted for this study, we modeled salinity reduction for only Phases 2 and 3. Pond desalinization in Phase 1 is expected to occur more quickly and with fewer salinity effects to the Bay than in Phases 2 and 3 because of the smaller total mass of salt in the Phase 1 ponds. Key results from numerical modeling of the proposed salinity reduction alternatives include:

- Salinities in the Phase 2 ponds can be reduced to 38 ppt (+5 ppt above ambient levels) within approximately one month. The rate of salinity reduction is initially rapid, then slows over time as the ponds equilibrate to the salinity of the bay. Once salinities decrease to 38 ppt, further salinity reduction is very gradual. Salinity reduction is slowest in Pond 13, the only pond that is not directly adjacent to the Bay.

- The Phase 3 ponds drain almost completely on the first ebb tide and discharge into the Phase 2 Ponds. From there, flushing from the Phase 2 ponds into the bay is similar to the flushing that occurs in Phase 2. Because the bottom elevations of the Phase 3 ponds are above high tide levels, the ponds are not re-flooded in subsequent tide cycles. Isolated "puddles" of high salinity water remain due to the micro-topography of the ponds. Some ditching or grading may be required to drain these puddles for desalinization.

- Within San Diego Bay, salinity increases above 38 ppt (+5 ppt above ambient) are generally limited to areas south of the Chula Vista Nature Reserve and to the first week following breaching for both Phases 2 and 3. As expected, salinity effects are highest in the vicinity of the ponds and immediately after breaching. For Phase 2, salinities in the vicinity of the ponds peak at 50 ppt during the first ebb tide, then decrease to approximately 40 ppt one day after breaching. For Phase 3, salinities in the vicinity of the ponds peak at 120 ppt during the first ebb tide, then decrease to approximately 60 ppt one day after breaching. As expected, salinity in the immediate vicinity of the ponds varies greatly over the tide cycle, with maximum effects observed during low tide, as hypersaline pond water is discharged into the bay.

- Breach widths of approximately 5 meters appeared to provide a reasonable balance between rapidly reducing pond salinities and reducing initial salinity increases in the Bay. Mixing and salinity reduction in Pond 13 during Phase 2 could be enhanced by adding additional breaches to Pond 14 or 15. The breach sizes were selected for the purposes of salinity reduction. Final breach sizes will be selected based on habitat considerations and may be refined in size and location from those used here.

The preliminary feasibility assessment of the brine complex consisted of applying a box model to the proposed configuration of the brine ponds. The brine complex, located in the eastern part of the site, includes Ponds 42, 43, 45, 46, and 47 (Figure 2). We assumed that slightly hypersaline water (40 ppt) water from the managed ponds would serve as the source of inflow to the brine ponds and that the brine ponds would discharge to a mixing basin for dilution with Bay water to near ambient salinity levels (+ 5 ppt) prior to discharge to the Bay. From this preliminary assessment, we conclude the following:

- It appears feasible to manage the brine ponds to simultaneously meet the target salinities for habitat inside the ponds (80 – 120 ppt) and the target salinities for discharge to the Bay (discharge salinities below ambient + 5 ppt) using pumping. Required flow rates into the brine ponds and into the mixing basin for dilution are well within levels that can be accommodated by pumping.

- Flow rates into the brine ponds vary seasonally from about 60 to 170 gpm over the course of a typical year, with the highest rates in the summer due to rapid evaporation. The flows must be managed seasonally to maintain the ponds within the target salinity range. Allowing the pond salinities to vary within the target range allows peak summer flow rates to be reduced below those that would otherwise be required to meet a constant pond salinity target.

- Flow rates through the mixing basin (Pond 41) are much higher than those through the brine ponds, and vary between approximately 300 and 1300 gpm. These higher flow rates are needed to dilute the brine effluent to dischargeable levels and to offset the effects of evaporation in the mixing basin itself. Flushing times vary from 10 to 37 days. The peak flow rates could be reduced to about 830 gpm using flash mixing, in which brine outflow is rapidly diluted in a small basin or canal prior to discharge to the Bay. Flash mixing requires smaller flow rates since the effects of evaporation are negligible. However, dilution operations may need to be managed more closely in flash mixing since any variation in dilution rates would translate more quickly to salinity variations in waters released to the Bay. Despite the modest flow rates, operating costs may be large due to the continuous (or nearly continuous) pumping required.

2.2 MANAGEMENT CONSIDERATIONS

Application of the numerical model is useful for estimating pond desalinization times and characterizing the potential extent and magnitude of salinity effects in San Diego Bay. However, implementation of the salinity reduction program will also require adaptive management to respond to actual conditions during desalinization which may vary from predicted conditions for a variety of reasons. An adaptive management approach would include monitoring during desalinization and identification of adaptive actions, such as closing off the breaches, that could be applied if needed. It may also include staggering the levee breaches so that tidal action is restored to the ponds one at a time. Model limitations and additional management considerations are discussed in Section 4.4.

The brine management box model includes several simplifying assumptions for the purpose of preliminary feasibility assessment. If brine management is carried forward in project planning, these assumptions will need to be assessed in more detail later in the design process. Brine operations must be sufficiently flexible to prevent pond drying and levee overtopping for a range of climatological conditions, to maintain salinities within the target range for habitat, and to avoid hypersalinity and gypsum formation. Sufficient safeguards would be required to avoid high salinity discharges in the event of extreme wet and dry years, pump failure, or other atypical conditions. In addition, further analysis could be useful for identifying lower cost implementation approaches, particularly to reduce the cost of pumping. Model limitations and additional management considerations are discussed in Section 5.4. For the purposes of this study, we have assumed that inflow into the Brine complex is continuous. However, pumping rates that vary in a step-wise manner could be applied to the box model as well.

This study addresses the spatial and temporal extent of salinity changes associated with desalinization and ongoing brine management. This information can be used to assess ecological or other potential impacts associated with the salinity changes. We understand that these issues will be addressed in subsequent environmental review and planning. The salinity reduction and brine management operations may be refined as needed once project impacts have been more clearly defined.

3. MODEL DEVELOPMENT AND CALIBRATION OF EXISTING CONDITIONS

3.1 INTRODUCTION AND MODELING OBJECTIVES

We applied numerical modeling to simulate salinity reduction associated with restoration of the South Bay Salt Ponds. The model is a combined one-dimensional/two-dimensional hydrodynamic and salinity transport model. We used the model to assess the time scales needed to lower salinity in the ponds and the effects on San Diego Bay salinities following the hypersaline discharges.

We developed a Bay-wide numerical model that includes the entire San Diego Bay, the local offshore Pacific Ocean, the South Bay Salt Ponds and the tidal limits of the lower Otay River. The model is capable of predicting both the near-field (local) and far-field (regional) hydrodynamics and salinity impacts of high salinity discharges from breaching the salt ponds.

Application of a depth-averaged 2D model over San Diego Bay and the ponds was assumed appropriate since the shallow water depths in the South Bay will lead to a fairly well-mixed water column. The 1D model was added to simulate the lower Otay River and pond breaches.

3.2 OVERVIEW OF THE NUMERICAL MODELS

The Bay-Wide numerical model uses a combination of DHI's two-dimensional (MIKE 21) and one-dimensional (MIKE 11) modules in order to simulate flows in San Diego Bay, the salt ponds, and the lower Otay River. The MIKE 21 and MIKE 11 components are dynamically coupled at boundary link locations through the MIKE Flood interface. PWA and DHI have successfully applied the MIKE Flood model for desalinization and restoration design modeling of the Napa River Salt Ponds in San Francisco Bay. The Napa River salt ponds are similar in configuration to the San Diego ponds and the model was used to answer similar types of salinity reduction questions.

The numerical simulation of water levels and currents for the bay and ponds was carried out using MIKE 21 NHD (Nested Hydrodynamic) modeling system. Salinity modeling was carried out using the MIKE 21 NAD (Nested Advection-Dispersion) model. The NAD model runs dynamically coupled to the NHD model. The nested model includes the capability of allowing finer (smaller) local grids to be dynamically linked into coarser regional grids.

The MIKE 11 model is used to model the tidal reach of the lower Otay River, and incorporates a river model previously developed by PWA for DU. Breaches are effectively earth weirs and are modeled using control structure weir components of MIKE 11. This allowed breach widths smaller than the grid resolution of the two-dimensional model. The MIKE 21 model is used to simulate the ponds and San Diego Bay.

The MIKE 21 and MIKE 11 models have been dynamically coupled in the Bay-Wide model using the MIKE Flood interface. At each computational time step, momentum and mass are transferred across link points that couple the two modules. For the present applications, link points were specified at each breach location and the at lower reach of the Otay River.

3.3 DEVELOPMENT OF THE NUMERICAL BAY MODEL

The model covers the entire San Diego Bay (Figure 3), and extends offshore from west of Point Loma to upstream of the tidal limit of Otay River. The modeling program consisted of the following steps:

- model setup for existing conditions,
- validation, and
- scenario and production simulations.

The model setup phase involves translating the physics into the mathematical schematization, based on measurements, observations and engineering judgment. Typically, calibration is then conducted to adjust model parameters so that the model prediction compares well with measured data. For this study, since the timeline was short and the San Diego Bay has been extensively modeled in the past, we used published data from existing calibrated models in the initial model setup and proceeded directly to the validation phase. Validation involves using the calibrated model setup for a new period of time on an independent dataset and checking that model predictions compare well to measurements. Model setup is described in this section; model validation is described in Section 3.4.

We relied on calibration data available from Wang et al. (1998), who conducted an extensive hydrodynamic model calibration using measurements from NOAA from 1983. Other datasets were provided digitally from Dr. Ken Richter of Space and Naval Warfare Systems Command (SPAWAR), but time limitations on the project did not allow a treatment of these other sources. The current level of model calibration and validation is considered appropriate for this phase of project planning. See Section 4.4 for a discussion of model limitations.

3.3.1 Model Time Step, Extents and Grids

Model grids were developed from combined bathymetric and topographical databases available for the San Diego Bay area. Surveys by the US Navy on a 50-meter resolution were the main source of bathymetry data for the San Diego Bay. A more detailed description of the bathymetry and topography of the salt ponds complex was provided by DU in an AutoCAD DEM (Digital Elevation Model) (Figure 5).

In order to increase the efficiency of the MIKE 21 model, a 25-meter grid of the Salt Ponds and southern reach of the bay was nested into a 75-meter grid that covered the entire Bay and nearshore zone (Figure 3). Since lower Otay River and the pond breaches could not be resolved in the 25-meter grid, these elements were included in MIKE 11 and coupled to the larger MIKE 21 model using the MIKE Flood interface. Figure 4 shows the location of the MIKE 11 branch and link points as applied in the model.

The hydrodynamic model was setup to run with a time step of 5 seconds, a requirement for numerical stability in the AD (advection-dispersion) model. The exact dimensions and locations of the two-dimensional model are listed in Table 3-1.

Table 3-1. MIKE 21 Grid Specifications

Grid Spacing *(m)*	**Dimension X** *(# points)*	**Dimension Y** *(# points)*	**Origin Longitude** *(degree)*	**Origin Latitude** *(degree)*	**Orientation** *(degree)*
75	281	231	-117.30364	32.58160	-0.163595
25	181	193	-117.13425	32.58392	-0.073158

3.3.2 Hydrodynamics Model: Water Levels and Currents

The main input parameters in the hydrodynamic model are:

- Model geometry, bathymetry (discussed above)
- Bed resistance (Manning's number)
- Eddy viscosity
- Boundary conditions
- Source/Sink input (i.e. power plant intake and discharge)

3.3.2.1 Bed Resistance

A depth dependent Manning n map was developed based on roughness values proposed by Wang et al. (1998) for San Diego Bay. Table 3-2 gives the depth relationship for the Manning's number used in the model and taken from Wang 1998.

Table 3-2. Depth Dependent Manning Numbers

Water Depth (m, MSL)	**Manning's n Values**
0.6 > depth	0.024
2.0 > Depth > 0.6	0.022
6.5 > Depth > 2.0	0.020
12.5 > Depth > 6.5	0.018
Depth > 12.5	0.015

Source: Reprinted from Wang et al. 1998

3.3.2.2 Eddy Viscosity

Experience with similar coastal systems suggests that the eddy viscosity values can be reasonably predicted by $E \cong K \Delta x^2/\Delta t$, where E is eddy viscosity, K is an empirical constant that typically ranges between 0.01 and 0.06 (DHI, 2002), Δx is grid spacing, and Δt is the computational time setup. Although the model was not very sensitive to the eddy viscosity within these ranges of K, final calibrated values were selected to dampen unrealistic eddy patterns in the flow fields. The final values used a K of 0.02 and give:

$E = 22.5\ m^2/s$ (75 meter grid)
$E = 2.5\ m^2/s$ (25 meter grid)

3.3.2.3 Boundary Conditions

As shown in Figure 3, open boundaries exist at the offshore extents of the model domain and require the specification of boundary conditions that drive the tidal flows through the model area. For the present study, a time varying water level derived from astronomical tidal constituents for Scripps Pier was applied along the entire offshore model boundary with no phase or amplitude adjustment made.

3.3.2.4 Source/Sink

In order to account for flows in and out of the nearby power plant, a source-sink was included in the model. A constant recirculating flow was applied at intake and outfalls of the power plant equaling 17.5 m^3/s or approximately 400 million gallons per day (MGD). This value was selected as representative of typical power plant operating conditions at the time that desalinization would occur (winter season), based on data from Jenkins and Wasyl (1996). Historical flow rates vary between approximately 50 and 600 mgd, with most flow fluctuations occurring in the summer and early fall months. Any differences in flow rates from those used in this study may affect the local salinity distributions near the power plant intake and outfall. For example, if actual flow rates during desalinization are larger than those used here, higher salinity waters may extend closer to the intake and further from the outfall. Also, high velocities associated with large outfall flow rates will influence local mixing and stratification is likely to be short lived.

3.3.3 <u>Salinity Transport Modeling</u>

3.3.3.1 Overview and Discussion

The salinity transport modeling was performed using the MIKE 21 NAD (Nested Advection-Dispersion) model running together with the MIKE 21 NHD model, and coupled to the MIKE 11 model of Otay River. For reasons of time and budget constraints, a rigorous salinity calibration was not performed. Instead, DHI relied upon experience in similar environments to select model parameters (dispersion coefficients) related to salinity transport and mixing.

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3.3.3.2 Dispersion Coefficients

Dispersion coefficients are the main parameters specified in the salinity model. Selection of dispersion coefficients can be a difficult process, and requires detailed measurements. Instead of carrying out a comprehensive calibration procedure, the dispersion coefficients applied in the present study have been selected based on the assumption that the dispersion coefficients are dependent upon the grid spacing and time step of the model. The dispersion coefficients have been estimated through the relation:

$$D = K \bullet \Delta x^2 / \Delta t$$

where D is the dispersion coefficient, K is a proportionality constant, Δx is the grid spacing, and Δt is the computational time step. Based on our experience in similar systems, the constant K typically ranges from approximately 0.01 to 0.06. We selected a value of 0.02 for this study as the typical mid-range value from experiments, and has been found to provide reasonable mixing characteristics in similar model studies. From this relation above, the dispersion coefficients used in the modeling were:

D = 22.5 m^2/s (75 m grid)
D = 2.5 m^2/s (25 m grid)

3.4 MODEL VALIDATION

Results from the hydrodynamic model were compared to measured water levels and currents around the Bay. Measurements of water level and currents were available from various sources, and data collected by NOAA/USGS/US Navy from 1983 were used.

3.4.1 Water Level Validation

For the validation period, three tide level gauges were available for comparing against model predictions. Figure 6 shows the locations of these stations (SSD, SD, and BP). The time period used for the water level measurement validation was 9/6/83 to 10/6/83.[1] Table 3-3 compares the modeled versus measured tidal constituents for the main 4 constituents that represent the bulk of the tidal forcing due to the attraction of the moon and sun on surface waters of Earth. For mixed tides such as those in San Diego, the main semi-diurnal tidal constituents are M2 (principal lunar) and S2 (principal solar), and the main diurnal forcing from the K1 (luni-solar declination), 01 (principal lunar) constituents. The constituent harmonic analysis is based on a least squares method, using DHI's tidal analysis package (Foreman, 1977 and DHI, 2001). The results of the constituent analysis indicate that modeled water levels match well with measured water levels throughout San Diego Bay.

[1] The effects of sea level rise since 1983 are small and are expected to be within the range of error of the modeling.

3.4.2 Current Validation

For the validation period in 1983, eight mechanical current meters were identified as useable for comparing against model predicted currents. Figure 6 shows the locations of these current meter stations. The time period used for the water level measurement calibration was 9/6/83 to 10/6/83. Table 3-4 compares the modeled versus measured tidal current constituents for the main tidal constituent, M2. The constituent analysis is based on a least squares method as previously described in Section 3.4.1. Generally the comparison is quite good. Discrepancies are most likely attributable to the fact that there were reportedly some problems with the mechanical meters, and the fact that these point measurements may not be representative of depth-averaged conditions simulated by the model.

Table 3-3. Comparison of Modeled Versus Measured Water Levels Tidal Constituents

Results	M2		K1		O1		S2	
	Amp	Phase	Amp	Phase	Amp	Phase	Amp	Phase
	(cm)	(deg)	(cm)	(deg)	(cm)	(deg)	(cm)	(deg)
Tides at Ballast Point (BP)								
Model	51.7	271.8	33.2	86.4	20.5	81.2	20.7	258.2
Field Data	51.6	270.1	33.6	87.3	21.9	81.2	20.4	256.2
Difference	0.1	1.7	-0.4	-0.81	-1.4	-0.0	-0.3	2.0
Tides Downtown (SD)								
Model	54.4	273.6	33.5	87.4	20.7	82.3	21.9	260.2
Field Data	54.0	271.7	33.7	87.8	21.4	80.8	22.4	260.5
Difference	0.4	1.8	-0.2	-0.4	-0.7	1.5	-0.4	-0.4
Tides at South San Diego Bay (SSD)								
Model	57.3	276.6	33.9	89.0	21.0	84.1	23.2	263.8
Field Data*	57.0	273.9	34.5	87.8	21.6	82.0	24.0	264.2
Difference	0.3	2.6	-0.6	1.2	-0.5	2.0	-0.8	-0.4

*Field data available only from 1993 and analysis performed on this data.

Field data constituents reprinted from Wang, et al. (1998)

Table 3-4. Comparison of Modeled Versus Measured Current Speed, for Tidal Constituent M2

Station	Model Results, 1983				From Measurements, 1983			
	Major	Minor	Inclination	Phase	Major	Minor	Inclination	Phase
	(m/s)	(m/s)	(deg)	(deg)	(m/s)	(m/s)	(deg)	(deg)
Constituent M2								
N1	0.085	0.004	92.1	247.8	0.102	0.009	91.6	258.3
N2	0.063	-0.001	86.9	242.9	0.097	0.000	92.9	263.3
N4	0.121	0.002	86.1	242.1	0.106	-0.008	94.3	224.0
N5	0.171	0.0000	134.0	253.2	0.167	0.010	135.7	246.7
N8	0.387	-0.001	128.8	250.4	0.325	0.018	136.4	238.9
N10	0.233	0.001	26.1	67.4	0.265	0.005	27.1	59.0
N12	0.201	0.000	167.9	250.4	0.179	-0.015	163.0	244.0
N13	0.213	0.000	133.8	249.4	0.206	-0.005	139.3	246.0

Note: Inclination is the direction of the major axis of tidal current ellipse, in degrees and counterclockwise from x-axis (east-west axis). Major/minor is the speed of the dominant/weaker tidal current. Phase is a measure of the relative time reference

4. SALINITY REDUCTION MODELING

4.1 INTRODUCTION

The linked 1D-2D model described in Section 3 was applied to simulate tidal hydrodynamics and salinity transport within the Bay, ponds, and lower Otay River. In particular, the modeling effort assessed changes in pond and Bay salinities that would result from breaching salt pond levees for salinity reduction. This approach to salinity reductions relies on tidal mixing through the breaches to flush hypersaline water from the ponds. We modeled phased salinity reduction for Alternatives C4 and D, per discussions with DU and USFWS.

Results from the modeling effort are presented in two forms. Contour maps of salinity in the ponds and south San Diego Bay at various stages after breaching were generated in order to illustrate the magnitude and extents (spatial and temporal) of increases in Bay salinities. Since these contour plots show only "snapshots" at particular times, we also present continuous time series of salinities in the Bay and ponds for selected locations over the simulation periods.

Although no precise discharge criterion has been established for release of saline waters to the Bay, increases of 5 ppt above ambient conditions were selected as an initial target level. Prior to project implementation, acceptable discharge criteria will need to be selected in conjunction with regulatory agencies such as the Regional Water Quality Control Board and will need to consider impacts to species and existing ecology. Salinity levels in San Diego Bay can be quite variable. Surface salinities in San Diego Bay were monitored during a five-year fish study conducted between July 1994 and April 1999 (Allen 1999). Salinities in the bay were generally higher than in the ocean, with bay-wide average salinities ranging from 32 ppt to 39 ppt during the course of the study. Salinities were generally highest in October and in the south bay, where they reached highs of 40 ppt in October 1996.

4.2 ALTERNATIVES CONFIGURATION

The configurations of Alternative C Option 4 and Alternative D are shown in Figure 1 and Figure 2. We modeled phased salinity reduction for Alternatives C4 and D, per our discussion with DU and USFWS. For both alternatives, Phase 1 consists of desalinization of Ponds 10, 10A, and 11. Desalinization may occur through breaching or by routing the water from the Phase 1 ponds into other ponds. We assume that the Phase 1 ponds would be tidal and at ambient salinities (approximately 33 ppt) prior to initiating Phase 2. In Phase 2, Ponds 12-15 would be breached. Alternative D includes an additional third phase, in which Ponds 23-25 and 28-30 are breached once salinities in the Phase 2 ponds have reached ambient levels. In each phase, ponds breached and desalinated in previous phases were modeled as tidally active and at ambient salinity levels.

Because of the limited number of model runs contracted, we modeled only salinity reduction for Phases 2 and 3 in this study. Pond desalinization in Phase 1 is expected to occur more quickly and with fewer salinity effects to the Bay than in Phases 2 and 3 because of the lower salinities and total mass of salt in the Phase 1 ponds (see Table 4-1 for pond salinities).

We used the existing pond topographies from DU, modified to include the proposed supra-tidal nesting areas, as shown in Figures 1 and 2. Pond topographies were not modified to include final grading (cuts and fills) for cordgrass and tidal marsh creation, per instruction from DU (S. Carroll, pers. comm.). Therefore, we assume for this study that any grading would occur after desalinization. The exception is the inclusion of the nesting fills, which were incorporated into the model before the decision to maintain the existing pond grades had been made and these remained in the model. These fills do not significantly change the results or conclusions of this study.

We selected initial pond salinities and water levels representative of late September to mid-February conditions. Pond breaching would be conducted during this time of year to avoid impacts during the nesting season. Therefore, initial salinities were calculated by taking the average of measured salinities occurring between September and mid-February. The seasonally-averaged salinities are given in Table 4-1. Ambient salinity was assumed to be 33 ppt and was applied uniformly over the ocean, the bay and the Otay River for initial model startup. Water surface elevations were provided by DU and are shown in Table 4-1.

Salinity reduction was simulated over a two month period, using measured tide data from 9/4/1983 to 11/6/1983 to drive the model at the offshore boundaries. The hydrodynamic model was allowed to spin-up for two days prior to breaching the ponds, which occurred at slack high water during the peak of the spring tide cycle. Pond breaches were modeled as broad-crested weirs with crest elevations of time varying crest elevations which start at a high elevation (closed) and drop to the existing elevations of the pond bed at each location. The breaching process (lowering of the weir crest) was scaled over a 6-hour period. This scaling represents the time over which the breaches would be constructed and prevents model instabilities associated with sudden changes in system bathymetry.

For Phase 2, we used breach widths of 5 meters on all the ponds. A 5-meter width was found to provide a good balance between being large enough for rapid desalinization of the ponds, yet small enough to reduce the spike in bay salinities immediately after breaching. Breach widths of 10 meters, 15 meters, and 2.5 meters were also tested at a cursory level. Results from the 10- and 15-meter runs indicated a larger spike in the bay salinities immediately after breaching, but with no significant benefits in terms of more rapid desalinization times. Results from the 2.5-meter breach did not reduce these short-term impacts in the bay appreciably beyond those simulated by 5 meter breaches. A 5 meter breach width exhibits slight tidal damping compared to 10 meters width which was found to provide full tidal exchange with no damping. For Phase 3, we assume that 5-meter breaches connect the Phase 3 Ponds (Ponds 23, 24, 25, 28, 29 and 30) to Ponds 13 and 15. Breaches from the Phase 2 Ponds to San Diego Bay are assumed to have enlarged to widths of 10 meter in response to tidal action.

Breach sizes were selected for salinity reduction only. Breach locations were provided by USFWS and DU (Figures 1 and 2). Final breach sizing and locations will be based on habitat restoration objectives (e.g., full tidal exchange in the short and long-term, channel shape similar to natural channels), and will likely differ from those used here.

Table 4-1. Initial Conditions: Pond Water Surface Elevations and Salinities Prior to Breaching

POND NUMBER	Elevation (ft, NAVD)	Elevation (m,NAVD)	Elevation (m,msl)	Salinity (ppt)
Phase 1 Ponds				
10	5.8	1.77	1.06	33*
10A	5.8	1.77	1.06	33*
11	5.8	1.77	1.06	33*
Phase 2 Ponds				
12	5.5	1.68	0.97	61.0
13	5.2	1.58	0.88	76.7
14	5.2	1.58	0.88	90.7
15	5.0	1.52	0.82	92.6
Phase 3 Ponds				
20	11.4	3.47	2.77	111.5
21	11	3.35	2.65	114.7
22	8.5	2.59	1.89	142.8
23	8.4	2.56	1.86	214.3
24	8.3	2.53	1.83	262.4
25	8.2	2.50	1.80	268.0
28	7.0	2.13	1.43	281.0
29	9.3	2.83	2.13	290.4
L	7.0	2.13	1.43	NA
30	9.1	2.77	2.07	278.0

* Assume already breached in Phase 1 and restored to ambient salinities.

4.3 RESULTS

4.3.1 Phase 2

4.3.1.1 Salinity Reduction in the Ponds

Figure 7 shows a time series plot of the salinity variation inside the Phase 2 ponds. Note that the salinity values are averaged over the entire pond volume. Figure 8 through Figure 10 show the depth-averaged instantaneous salinity fields of the ponds at selected periods for 1 day, 7 days and 28 days after breaching, both at low and high tides.

Ponds 12, 14 and 15 reduce in salinity to nearly equal levels fairly rapidly, and after approximately 7 days have dropped below 38 ppt or 5 ppt above ambient levels. After 1 month they have reduced to about 35 ppt, or 2 ppt above ambient levels. Salinity reduction in Pond 13 is slightly slower due to the fact that it is not directly breached to the bay, and relies on tidal action in Pond 12 for flushing power during Phase 2. Also, the bed elevation of Pond 13 is higher in the tide frame and much of the pond is dry during low tide, which reduces the overall mixing capacity of the pond. Pond 13 is reduced to 38 ppt after 24 days.

4.3.1.2 Salinity Increases in San Diego Bay

Figure 8 through Figure 10 show the depth-averaged instantaneous salinity fields of the lower South Bay at selected periods for 1 day, 7 days and 28 days after breaching, both at low and high tides. Salinities at various locations in San Diego Bay (shown in Figure 11) are plotted as time series in Figure 12. The plots show that salinity impacts are most significant near the ponds, and are fairly well reduced by the time the plume reaches Location C. Salinities at all locations are significantly reduced and approach ambient conditions by 28 days.

4.3.2 Phase 3

4.3.2.1 Salinity Reduction in the Ponds

The existing elevations in the Phase 3 Ponds, as shown in Figure 5, are above mean tide level (MTL), with a majority above mean higher high water (MHHW). Due to the existing topography, these ponds are rarely tidal, except for ponds 25 and 28 which are partially tidal. Although these high-elevation ponds do not drain completely due to the micro topography of the bed surface, most of the water is discharged over just 6 hours, which corresponds to the duration of the first ebb tide. Therefore, salinity reduction in Phase 3 Ponds is very short, expect for localized areas where the hypersaline water is not able to completely drain.

4.3.2.2 Salinity Increases in San Diego Bay

Figure 13 through Figure 15 show near-field impacts to San Diego Bay 1, 7, and 28 days after breaching of the Phase 3 ponds at corresponding low and high tides. After 1 day, the greatest impacts to the bay salinity are mostly contained to the south of the power plant causeway, and are about 40 ppt above background levels. Note that salinities in the Phase 2 Ponds are even higher, and act to dampen the short-term impacts to the bay. After 7 days, the impacts north of the causeway are less than 5 ppt above background. Numerical results indicate that after 28 days, impacts to the bay are negligible.

Figure 16 plots time series of salinities at the points throughout the bay shown in Figure 11. Although these results are qualitatively similar to the far-field impacts for Phase 2, bay salinities following discharges from the Phase 3 Ponds are much higher. The results presented in Figure 16 show that salinity impacts are most significant near the ponds, and are fairly well reduced by the time the plume reaches Location C. Additionally, the impacts are only appreciable in the short-term, with bay salinities dropping to below the +5 ppt threshold shortly after 7 days.

4.4 MODEL LIMITATIONS AND MANAGEMENT CONSIDERATIONS

Application of the numerical model was useful in quickly developing estimates of flushing time in the ponds as well as increases in Bay salinities. However, the following items should be considering when interpreting the numerical results:

- The model provides estimates of the magnitudes and time scales of salinity impacts to the bay, and provides a basis for comparison between alternatives that is appropriate for preliminary feasibility assessment. It can be used to screen various salinity reduction alternatives. If the breaching salinity reduction alternative is carried forward in project planning, we recommend that the model be refined. This approach of using an initial screening level model and subsequent refinement was used in planning for the Napa Salt Marsh Restoration Project. Refinements would include additional calibration, validation, and sensitivity assessment, plus additional details of the restoration plan once these are developed. A more thorough calibration, validation, and sensitivity assessment would help to define and narrow the uncertainties in the modeled results.

- If more a refined analysis is required for alternative analysis during later stages of the planning effort, we recommend re-visiting the selection of the dispersion with a more complete dataset of measured salinity. This would reduce uncertainties associated with the incomplete calibration. Salinity measurements needed for a complete calibration of the advection-dispersion model were not available within the time frame dictated by the project schedule, and we relied on our experience with similar systems to construct the model. The choice of dispersion coefficient affects the size and magnitude of salinities in the bay. Large values of the dispersion coefficient will increase the spatial extent and lessen the magnitude of salinity increases (mass of salt is conserved). The converse is true for small values of the dispersion coefficient. The results of desalinating the ponds probably are not that sensitive to changes in dispersion coefficients, since the flushing of these ponds is driven by advection processes and due to the breach size and bed elevation of the ponds relative to the tide range.

- Breach sizes and locations are preliminary, and are expected to be refined based on habitat objectives later in project design (Section 4.2). Breach timing is also preliminary and may be refined based on detailed consideration of construction feasibility. Simultaneous breaching was assumed in the salinity reduction alternatives, resulting in hypersaline discharges from multiple ponds at the same time. Management of the actual salinity reduction program may include staggering the levee breaches so that tidal action is restored to the ponds one at a time. This would lessen the magnitude of salinity increases in the Bay, but extend salinity reduction of the complex. Adaptive management of the desalination program for the complex could be aided by monitoring salinity levels in South San Diego Bay to reduce the possibility of unanticipated adverse impacts to wildlife.

- The modeling assumes a certain set of initial pond salinity and water level conditions. The plan will need to include sufficient flexibility for actual conditions that vary annually.

- Application of the 2D MIKE model should be limited to systems without appreciable stratification. According to the literature (Wang et al 1998), San Diego Bay can be treated as well mixed, except during infrequent periods of freshwater inflow from the Sweetwater and Otay rivers. These rare stratifications could persist for a few days during low tide energy periods (neap tides). Stratification may also occur when warm water discharges from the South Bay power plant flow over more dense saline Bay water. The effect of this stratification on salinities would be strongest near the power plant discharge, although large velocities at the outfall wound tend to mix effluent throughout the water column. During desalination of the salt ponds, stratification may also develop if density differences between the effluent and receiving water outweigh the vertical mixing in the Bay. Therefore, the Estuarine Richardson Number (Fischer 1979) was computed using modeled results to asses the likelihood of stratification due to salinity reduction. This non-dimensional number is a measure of the stabilizing power of density differences to the mixing power in the Bay. The computed Richardson number is at the lower end of the range at which strongly stratified flow could be expected, suggesting that the depth-averaged model is appropriate for this level of analysis. Additionally, wind-waves were not included in the numerical model and would increase the vertical mixing in the shallow portions of South San Diego Bay.

- Dissolution of precipitated salts was not taken into account in the present modeling exercise, and may affect the time required to reduce pond salinities to ambient levels. However, we do not expect the dissolution process to significantly affect the short-term changes in Bay and pond salinities presented above. Uptake of precipitated salts and salinity in the underlying soils is likely a rate-limited process, with time scales longer than the flood-ebb tidal cycle.

5. BRINE FEASIBILITY

Alternative D contains a brine management component, shown in Figure 2. Brine ponds would be managed to create habitat for brine shrimp and brine flies, and foraging areas for waterfowl and shorebirds. PWA created a simple box model to assess the feasibility of maintaining the proposed brine operation in terms of the flow rates required to maintain suitable habitat in the ponds and to dilute the hypersaline brine prior to discharge to the Bay. This analysis was carried out at a conceptual level. No numerical modeling was performed in this initial assessment.

5.1 CONFIGURATION OF THE BRINE COMPLEX

As shown in Figure 2, the brine complex is located at the easternmost extents of the project area, and includes Ponds 42, 43, 45, 46, and 47. To ensure proper habitat for brine shrimp and brine flies, the target salinities in the brine ponds range between 80 and 120 ppt. Per our discussions with the planning team, we assume that new hydraulic structures would be installed to convey the required water and that pumps would be used as necessary to move water through the system. A preliminary criteria for release of water into San Diego Bay was +5 ppt. As per the salinity reduction discussion in Section 4, actual discharge criteria for the project will need to be agreed upon between the project sponsors and relevant agencies.

A number of management scenarios are possible for the brine complex. A source of inflow to the brine ponds is required to offset evaporation and maintain suitable conditions in the ponds. Due to the elevated salinity in the brine complex, discharges from these ponds must be diluted prior to release into San Diego Bay. The basic components of brine management are: a source of inflow to the brine ponds; a source of water, referred to as make-up water, to dilute the brine pond outflow; a mixing basin in which to combine the brine outflow and make-up water; and discharge to the Bay.

The assumed route for flows through the brine ponds is shown in Figure 17. We assumed that inflow to the brine ponds would be supplied from the managed ponds, since this water would already be at slightly elevated salinity levels and it makes more sense to route it to the brine ponds rather than discharging it to the Bay. Based on our experience with ponds managed for water fowl and shorebird habitat at the Napa River salt ponds in San Francisco Bay, we assumed that these managed ponds would have salinities of approximately 40 ppt. Several ponds would be suitable as mixing basins. We considered Ponds 41 and 48, since they are adjacent to the brine ponds. Pond 41 is shown as the mixing basin in Figure 17. Make-up water to the mixing basin is assumed to come from Bay water. This could be supplied from any of the tidal ponds, preferably as far from the eventual brine discharge point as possible. Salinities in the mixing basin would be maintained at ambient salinity +5 ppt. The diluted effluent could then be discharged into the canal west of Ponds 41 and 30. If pond 48 is used as the mixing basin, some grading and levee construction would be required to connect Pond 48 with the canal.

5.2 THE BOX MODEL

PWA developed an analytical mass-balance model to track salinity and water volumes in the brine complex and mixing basin. The brine ponds were considered one unit in order to simplify the analysis. Figure 18 shows a schematic of the box model structure. A mass balance of salt and water is applied to the brine complex, which receives inflow at 40 ppt from the managed ponds and discharges to the mixing basin. A second mass balance is applied to the mixing basin, which uses make-up water from the Bay to dilute the hypersaline (80 – 120 ppt) discharges from the brine ponds. Make-up water for the mixing basin is assumed to come from the Bay or tidal ponds at 34 ppt[2], and, as noted above, salinity in the mixing basin is limited to 39 ppt. Both the brine ponds and mixing basin are subject to freshwater losses and gains due to evaporation and precipitation.

Mean monthly rates of evaporation and precipitation were collected from readily available sources. Published mean monthly data collected by the National Weather Service (NWS 2002) at Chula Vista from 1960 – 1990 were used to establish typical rates of precipitation. Evaporation rates were determined based on data from the California Department of Water Resources (DWR). As shown in Figure 19, evaporation barely outpaces precipitation during the winter but is much more intense in the summer. Essentially, it is the net evaporation, along with the flow rates through the system, which determine the salinity and water volumes in the ponds.

The simplicity of the box model allowed PWA to quickly screen various configurations and management scenarios at a cursory level. Table 5-1 summarizes the model set up for each of the five screening runs analyzed by PWA. Based on the results of the screening runs (Table 3-1), we selected Run 4 for further consideration. Run 4 consisted of prescribing an intake flow rate from the managed ponds into the brine complex (Q_{IN}), and using the box model to estimate the resulting salinity. Management of the brine complex was then optimized by minimizing the peak summer pumping rate (Q_{IN}) while keeping the brine ponds in their target salinity range (80 – 120 ppt). The box model was then applied to calculate the make-up flow rate (Q_{MUP}) required to maintain the mixing basin at a constant 39 ppt. The intake and make-up flows were seasonally-varied in order to stay within the range of target brine salinities and were optimized within the constraints of the configuration to reduce the peak summer pumping rates.

5.3 RESULTS

Results for Run 4 are discussed below.

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[2] Ambient salinity levels for the brine analysis were assumed to be 34 ppt since make-up water will be drawn from the southernmost reach of the Bay. Measurements from the Port of San Diego show seasonally-averaged salinities in this area to be slightly higher than the central and northern sections of the Bay.
(Data source: http://www.portofsandiego.org/sandiego_environment/bay_water_sampling.asp)

5.3.1 Brine Ponds

Results from the brine complex are shown in Figure 20, which plots the flow rates and salinity through these ponds. The results show that, under typical metrological conditions, the brine ponds delineated in Alternative D can be maintained between 80 – 120 ppt with modest pumping rates. Pumping into the brine ponds varies from approximately 60 gpm in the winter to 170 gpm during the summer months. Peak salinity levels in the ponds lag the peak pumping by about three months, with the highest salinities (approximately 120 ppt) occurring in late autumn. During the late winter and early spring months, salinity in the brine ponds drops to 80 ppt. Peak salinities lag peak pumping rates by three months because of evaporation and the pumping strategy employed in the model. The pumping strategy shown in Figure 20 was to “prime” the brine ponds by reducing their salinity early in the summer, when it was relatively easy to outpace evaporation. Then during the summer, the brine ponds are not near the upper-limit of acceptable salinity and can accommodate increases in salinity. If salinities were not “primed” (i.e., lowered) at the beginning of the summer, it would be more difficult to outpace intense summer evaporation, there would be less management flexibility, and peak pumping rates would probably be higher.

Water levels in the brine ponds varies seasonally and, for the configuration modeled, levee improvements may be required to prevent overtopping in Pond 42. A uniform water surface elevation was assumed across the brine ponds and average bed elevations were used to convert the water volume computed by the box model to the depths plotted in Figure 21. Water levels in the brine ponds are inversely related to salinity, with a maximum depth in mid-March and minimum in late autumn. It may be possible to avoid levee improvements, using different brine pond management strategies. For example, it may be possible to limit water levels in Pond 42, but allow higher water levels elsewhere in the brine complex.

5.3.2 Mixing Basin

As described above, the box model was applied to Pond 41 to estimate how much make-up water is required to maintain the mixing basin (Pond 41) at 5 ppt above ambient levels for the brine discharges plotted in Figure 20. As shown in Figure 22, the flow rate of make-up water into the mixing basin peaks at about 1330 gpm. Approximately 900 gpm (68 % of the total) is needed to dilute the brine effluent to discharge levels, and the remaining 420 gpm (32 % of the total) is required to offset the effects of evaporation within the mixing basin. These results suggest that the required pumping rates are feasible, assuming continuous pumping. Discharges to the Bay range between 330 and 1330 gpm (Figure 22).

The pumping rates could be reduced by diluting the brine discharges with flash mixing, in which brine outflow is rapidly diluted in a small basin or canal prior to discharge to the Bay. Flash mixing requires smaller flow rates since the effects of evaporation on a small pond surface area are negligible. Flash mixing reduces peak flows to approximately 800 gpm (from 1330 gpm). Make-up flows with flash mixing are shown as the green line in Figure 22. The canal west of Ponds 30 and 41 provides a possible location for flash mixing. An alternative solution may include a passively-managed, gravity-driven system that relies on tidal flushing. Such a system, however, would require grading (excavation) of Pond 41 since its bed elevation is currently above high water levels (see Figure 5).

The resulting flushing time[3] varies from approximately 10 days when the make-up flow rate is maximum, to about 37 days during periods of low flow (Figure 23). Flushing times greater than a month may lead to deteriorated water quality, and the low pumping rates during these periods could be increased to alleviate these concerns.

5.4 MODEL LIMITATIONS AND MANAGEMENT CONSIDERATIONS

The box model suggests that management for brine habitat is feasible from a physical processes perspective. The box model includes several simplifying assumptions for the purpose of preliminary feasibility assessment. If the brine management component is carried forward in project planning, these assumptions will need to be assessed in more detail later in the planning and design process. In addition, further analysis could be useful for identifying lower cost implementation approaches, particularly to reduce the cost of pumping.

Brine operations should include flexibility in management of flows. Management considerations include: pond drying or levee overtopping, climatic variations (discussed further below), maintaining brine salinities within the target range for habitat, potential for gypsum formation if salinities exceed approximately 150 ppt, water quality in the ponds, and potential for temporary pump failure.

The box model considers the brine ponds as one large, well-mixed pond with uniform water levels. In reality, salinities and water levels will vary between the ponds, with the extent of variation dependent on the exact pond configuration.

The model assumes average monthly rainfall and evaporation conditions. Daily and annual (wet and dry year) variations will affect the amount of pumping required for brine management and dilution. These variations could also affect brine salinities and the potential for pond drying and levee overtopping. Brine management scenarios for wet and dry years should be considered during future planning stages prior.

The modeled brine configuration assumes a seasonal-varying supply of 40 ppt water from the managed ponds. Managed pond operations have not been modeled and we did not evaluate the feasibility of meeting the assumed inflows to the brine ponds. However, given the high evaporation rates in South San Diego Bay, it is likely that a significant amount of flow through the managed ponds will be required to maintain suitable salinities in those ponds. Additionally, it would be possible to meet the brine pond target salinities even if Bay water (at approximately 34 ppt) were needed to augment the inflow from the managed ponds. This would affect flow rates in the brine pond and mixing basin flow, as well as residence times. Operations for the brine complex will need to be coordinated with those for the managed ponds in later project planning.

Intake and make-up flows were fit to the shape of a sine wave for ease in modeling seasonal variations.

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[3] Flushing Time = Pond 41 Volume / Make-up Flow Rate = V / Q_{MUP}

In reality, brine operations are likely to use stepped or discontinuous flow/pumping rates. Therefore, actual operations may require higher pumping rates than those modeled here. For stepped pumping, differences from the peak modeled flows are expected to be minor. For discontinuous pumping, peak flow rates will be several times the modeled rates, but still within the range of typical pumping operations (e.g., pumping one day out of seven yields increases peak flow rates from 2.9 to 20 cfs). More detailed brine runs could be conducted to optimize the pumping rates. Additional cost reduction may be possible by modifying the management configuration to use gravity-driven flows for brine inflow and/or dilution.

Table 5-1. Run Catalog for Box Model

	Brine Complex			Mixing Basin				Comments
	Volume	Salinity	Intake Flow	Pond	Volume	Salinity	Make-up Flow	
Run 1. Constant brine salinity	Prescribe as constant	Constant (100 ppt)	Calculated	48	Constant	Constant (39 ppt)	Calculated	Flow into the brine complex and mixing basing peak at 209 gpm and 1200 gpm, respectively.
Run 2. Constant brine intake flow	Calculated	Calculated	Prescribe as constant	48	Constant	Constant (39 ppt)	Calculated	Constant flow into brine ponds of 110 gpm cannot maintain salinity within the target range of 80 – 120 ppt.
Run 3. Varying brine salinity and intake flow	Calculated	Calculated	Prescribe as time-varying	48	Constant	Constant (39 ppt)	Calculated	Flow into the brine complex and mixing basin peak at 170 gpm and 1036 gpm, respectively. Brine salinity in 80 – 120 ppt range.
Run 4. Same as Run 3, but with Pond 41 as mixing basin	Calculated	Calculated	Prescribe as time-varying	41	Constant	Constant (39 ppt)	Calculated	Make-up flow into mixing basin increases to 1326 gpm due to greater surface area of Pond 41.
Run 5. Same as Run 4, but allowing mixing basin salinity and volume to vary	Calculated	Calculated	Prescribe as time-varying	41	Calculated	Calculated	Prescribe as time-varying	Make-up flows similar to Run 4.

Note: “Calculated” means that this parameter was determined from the box model.

6. LIST OF PREPARERS

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With:

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FIGURES

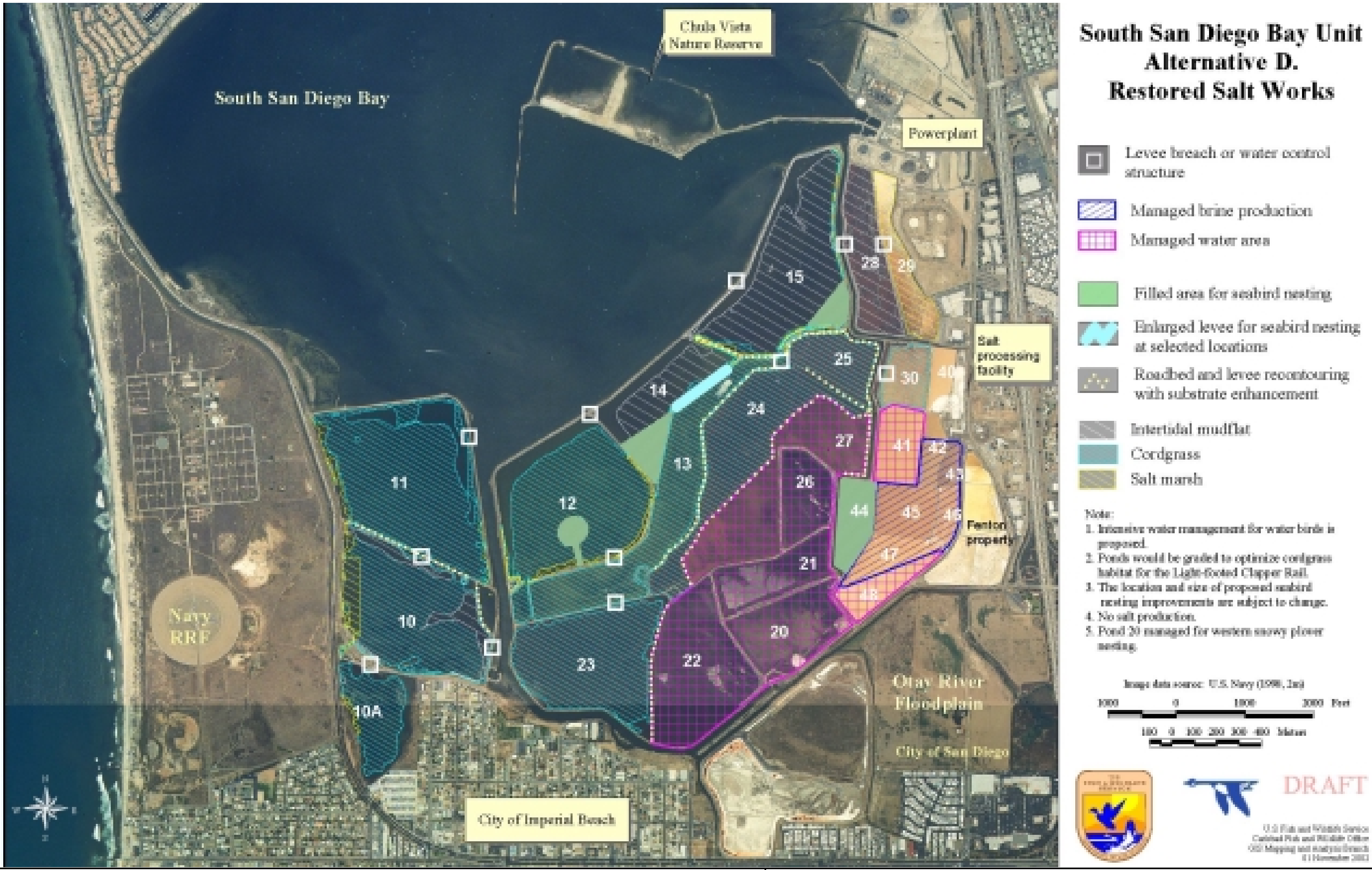
Source: USFWS

figure 1

South San Diego Bay Salt Ponds

Configuration of Restoration Alternative C Option 4

PWA Ref 1631



Source: USFWS

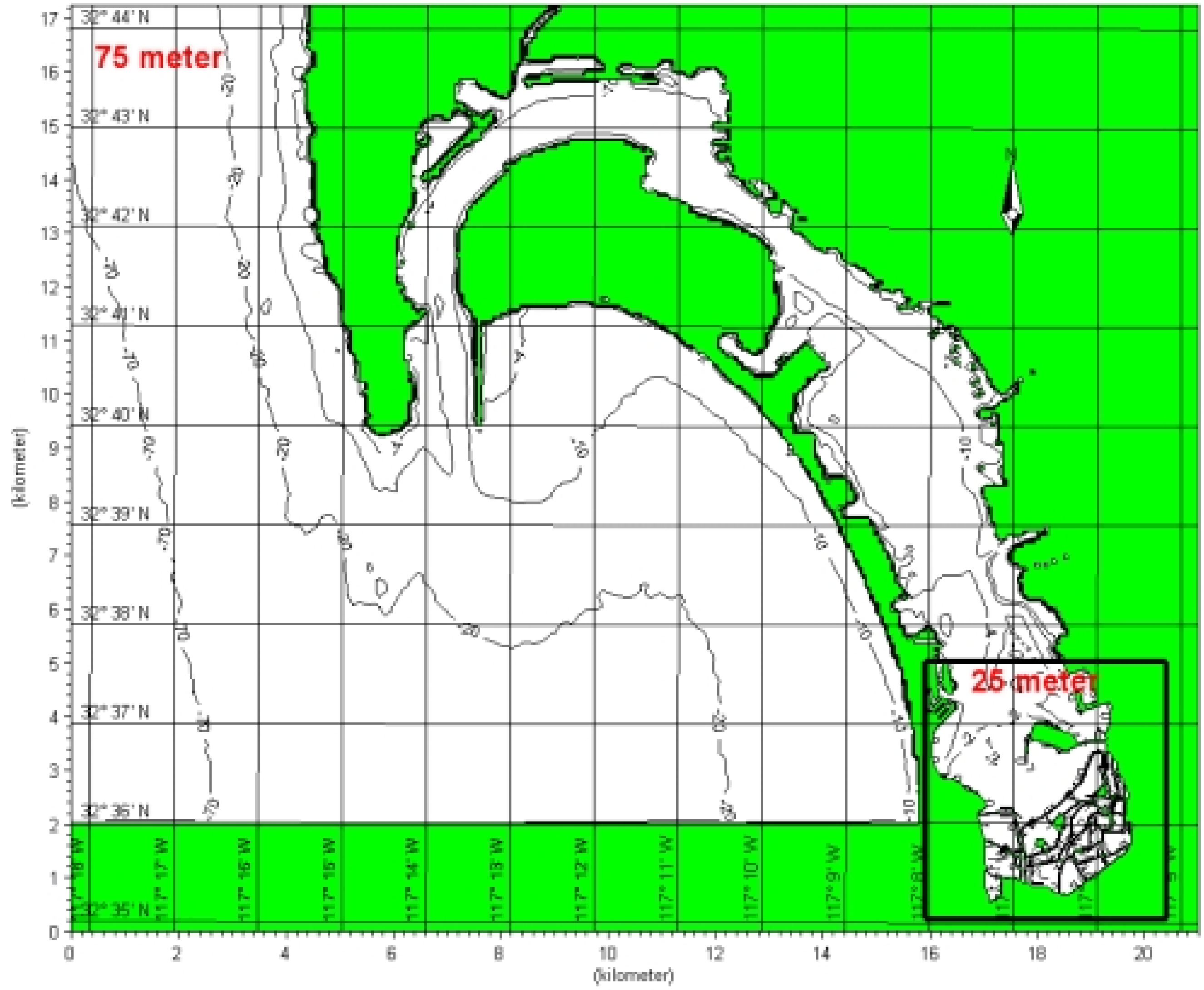
figure 2

South San Diego Bay Salt Ponds

Configuration of Restoration Alternative D

PWA Ref 1631

PWA



f igure 3

South San Diego Bay Salt Ponds

Extent of MIKE 21 Nested Model Grids

PWA Ref 1631

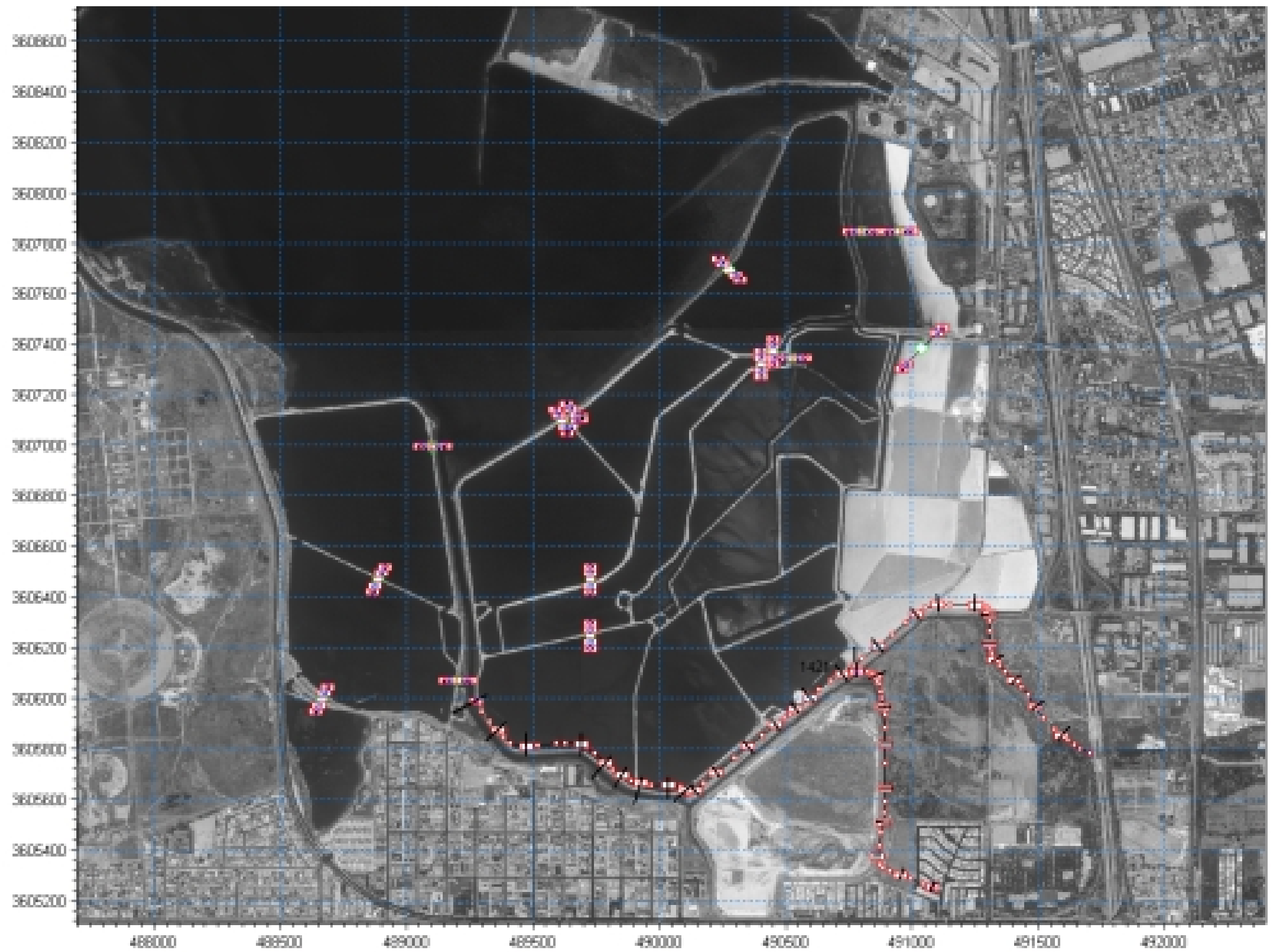


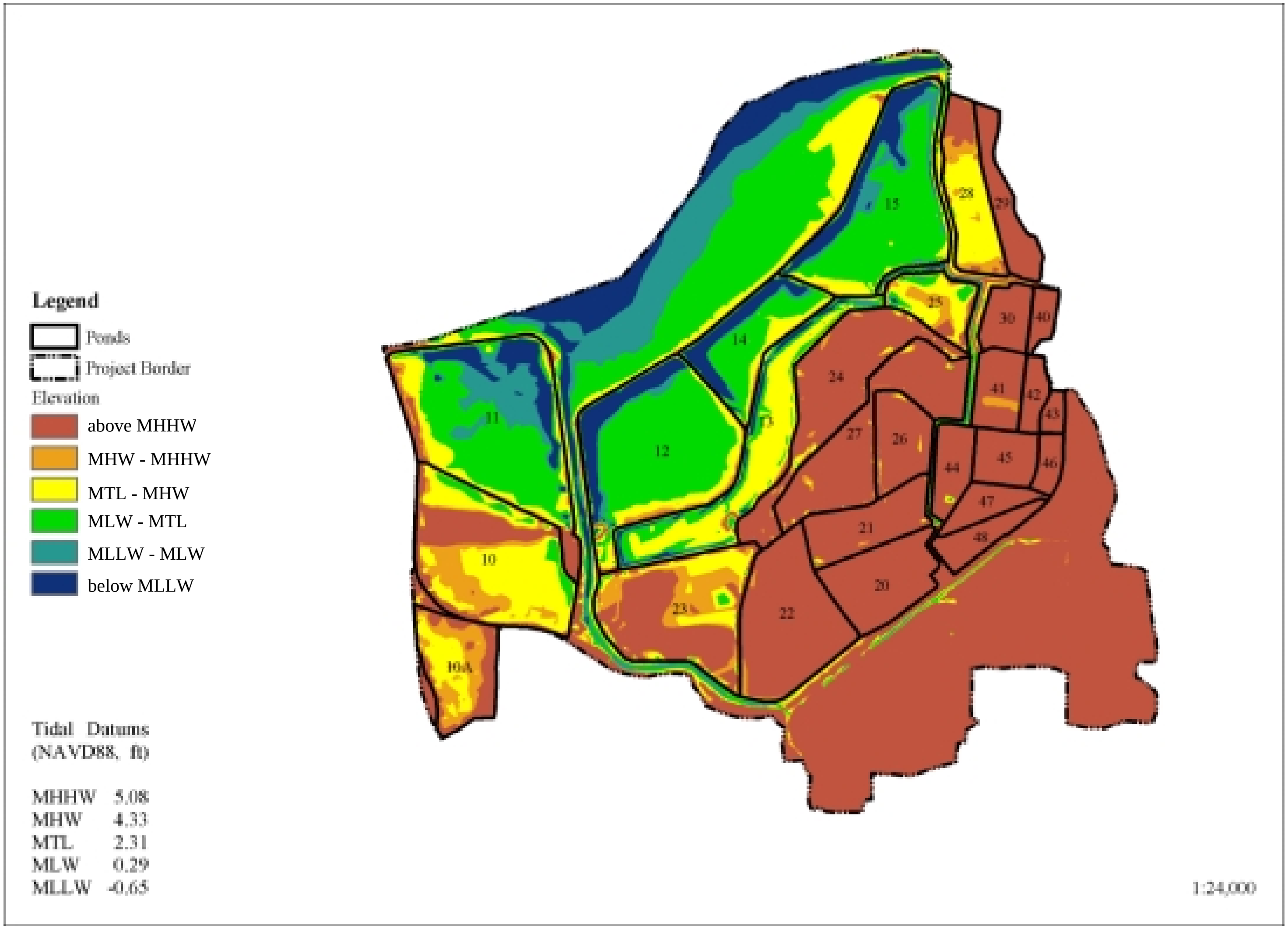
figure 4

South San Diego Bay Salt Ponds

Location of MIKE 11 Otay River and Breaches

PWA Ref 1631

PWA



Source: DTM from DU

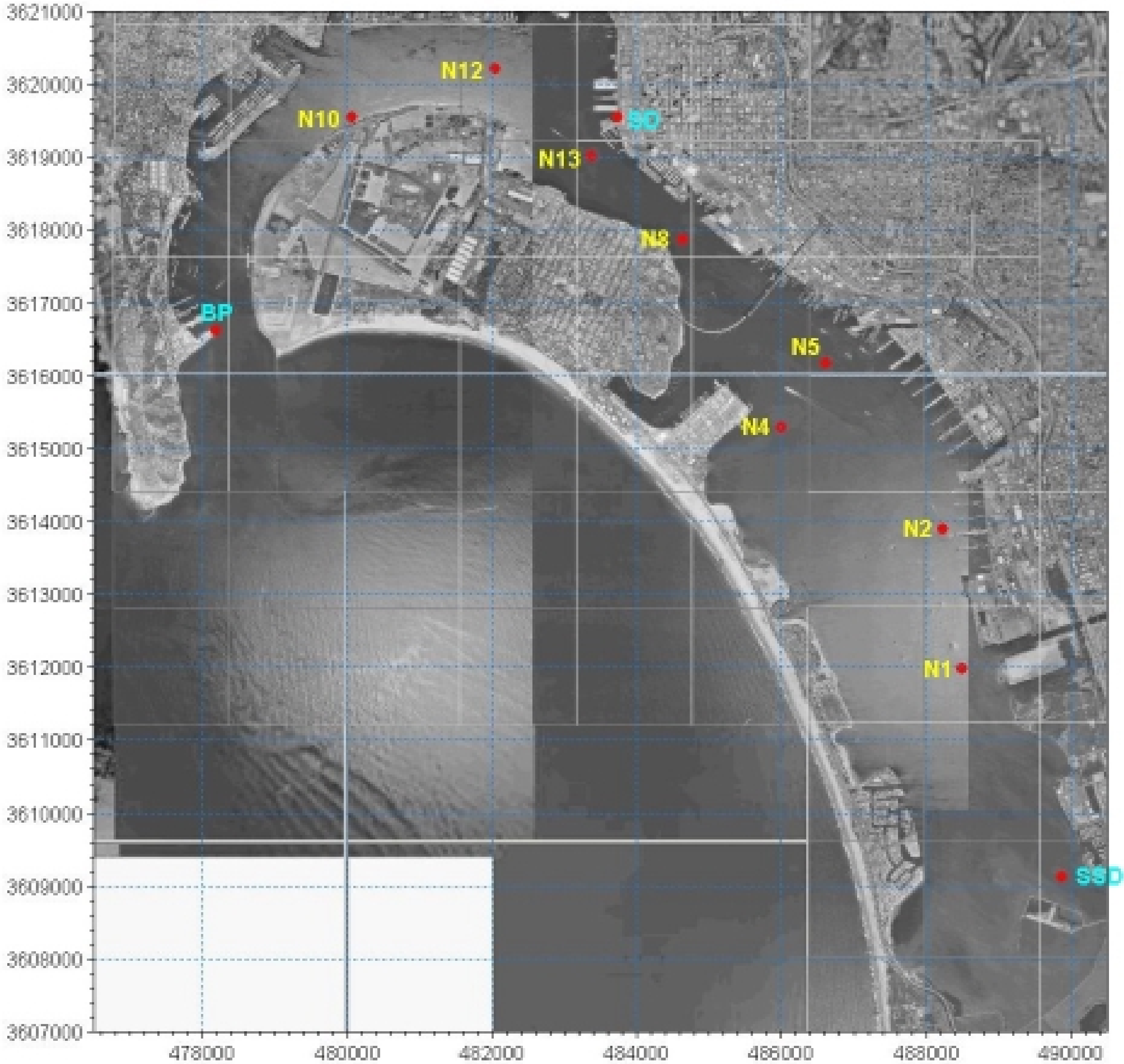
figure 5

South San Diego Bay Salt Ponds

Bed Elevations for Salt Ponds

PWA Ref 1631

PWA



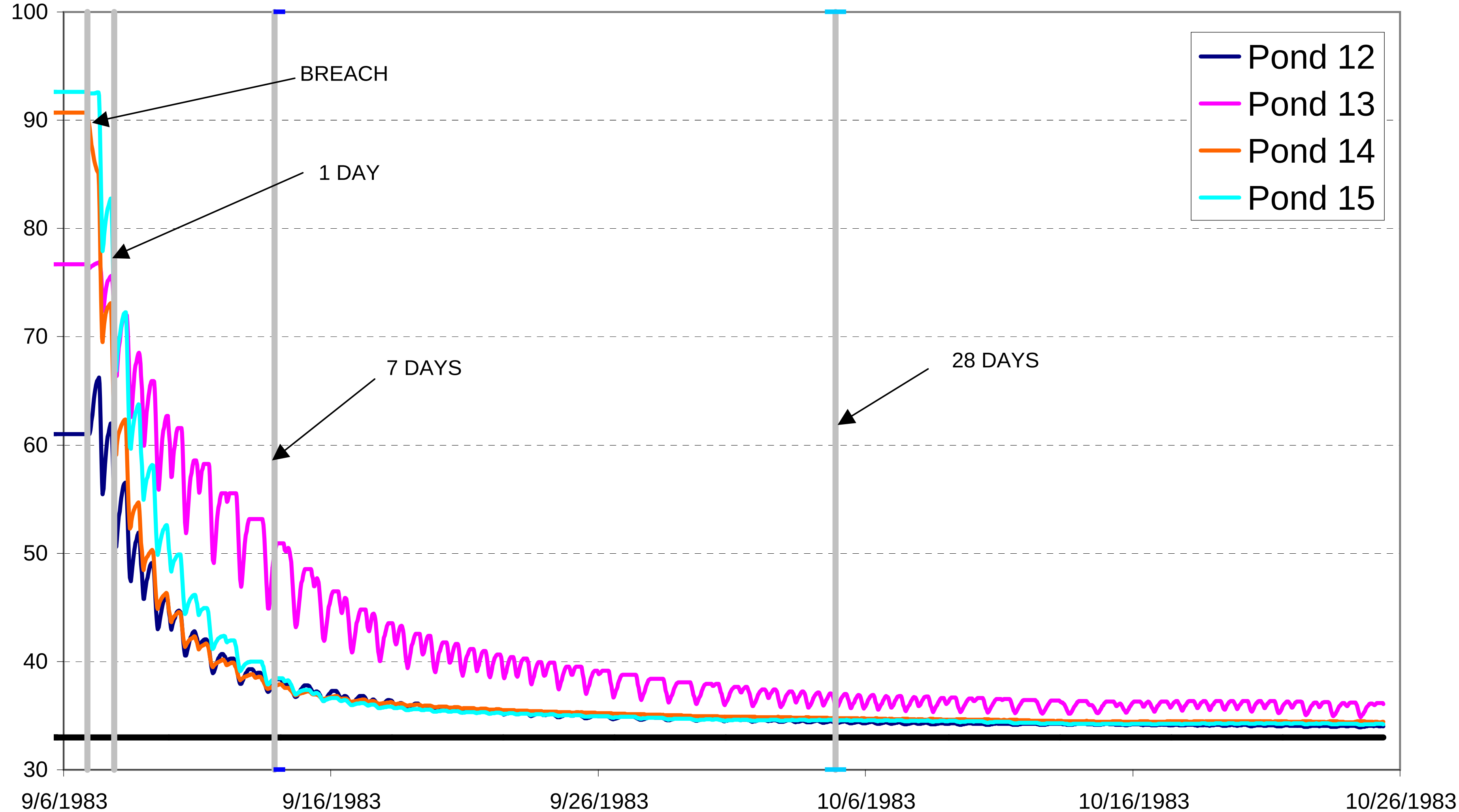
Source: NOAA Measurements from 1983

figure 6

South San Diego Bay Salt Ponds
Locations of NOAA Current Measurements
during the 1983 Measurement Period

PWA Ref 1631

PWA



Notes:
Salinities in Ponds are weighted average concentrations over the entire pond.

Black bar represents ambient salinity (33 ppt).

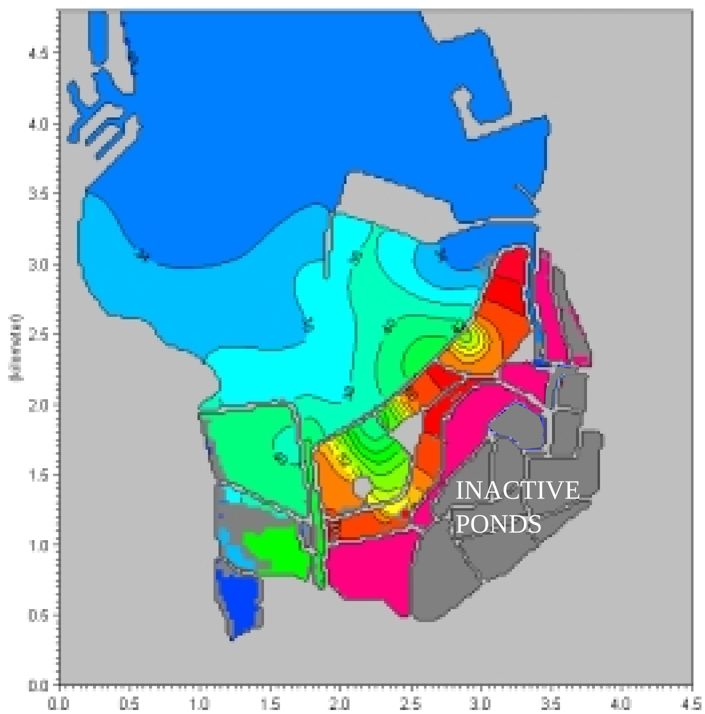
figure 7

South San Diego Bay Salt Ponds

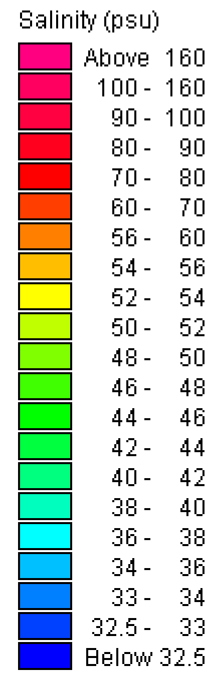
Pond Salinity Time Series, Phase 2

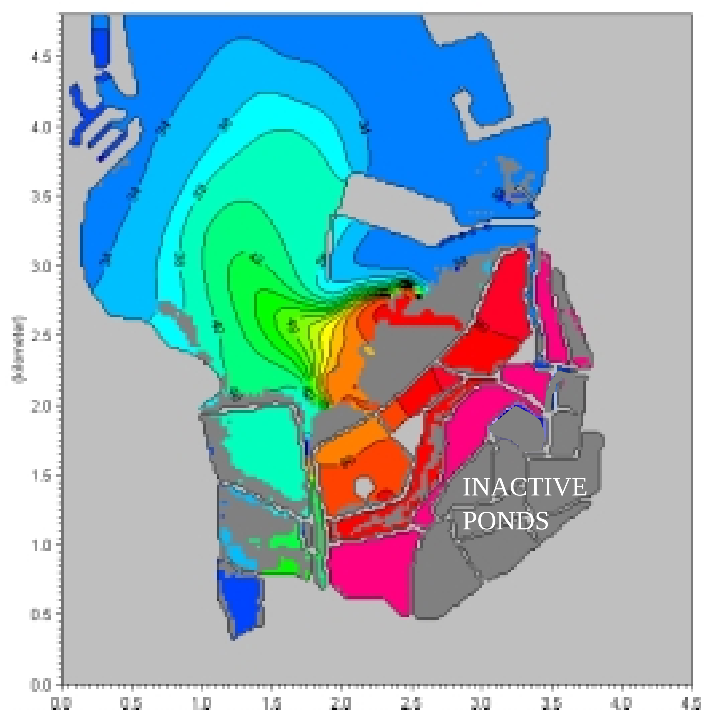
PWA Ref 1631

PWA



Salinity
Distribution in
South San Diego
Bay at *high tide*
1 day after breach.





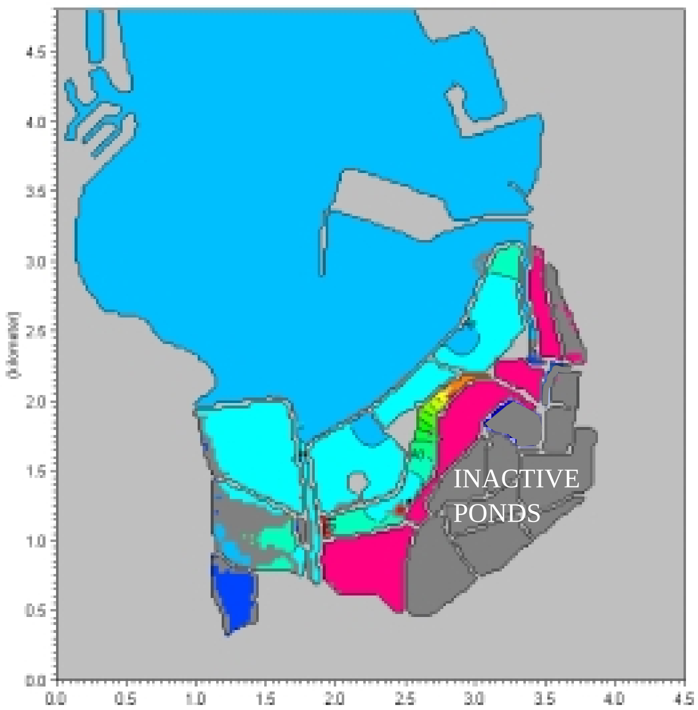
Salinity
Distribution in
South San Diego
Bay at *low tide*
1 day after breach.

Notes: Simulated salinities at low and high tides, 1 day after breach of Alternative C Option 4.

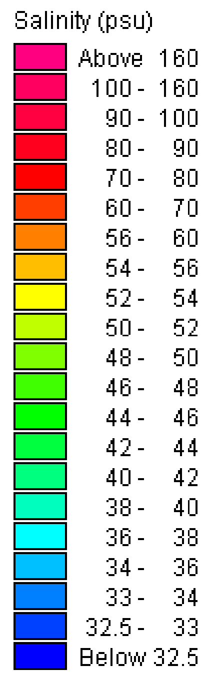
figure 8

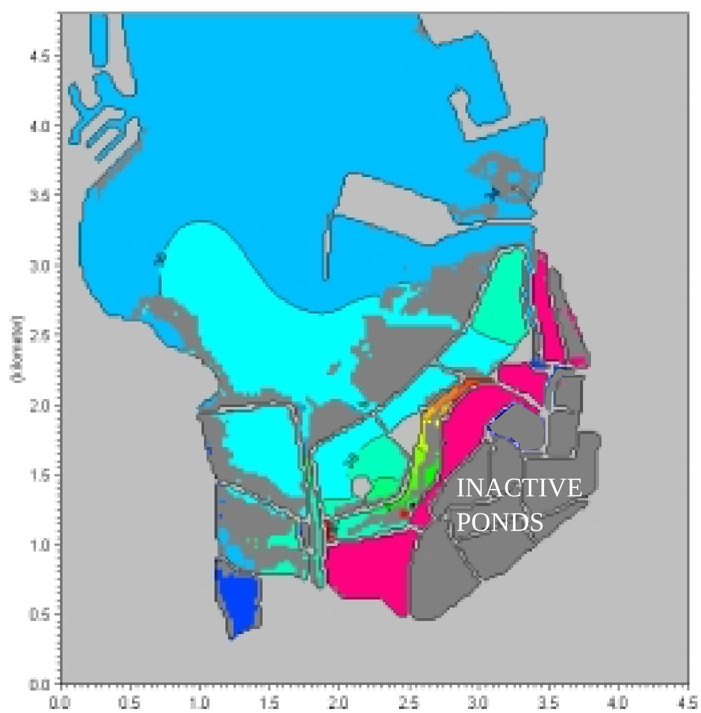
South San Diego Bay Salt Ponds
Salinity Distribution in the South Bay & Ponds,
Phase 2 , 1 Day After Breach

PWA Ref 1631



Salinity Distribution
in South San Diego
Bay at *high tide*
7 days after breach.





Salinity Distribution
in South San Diego
Bay at *low tide*
7 days after breach.

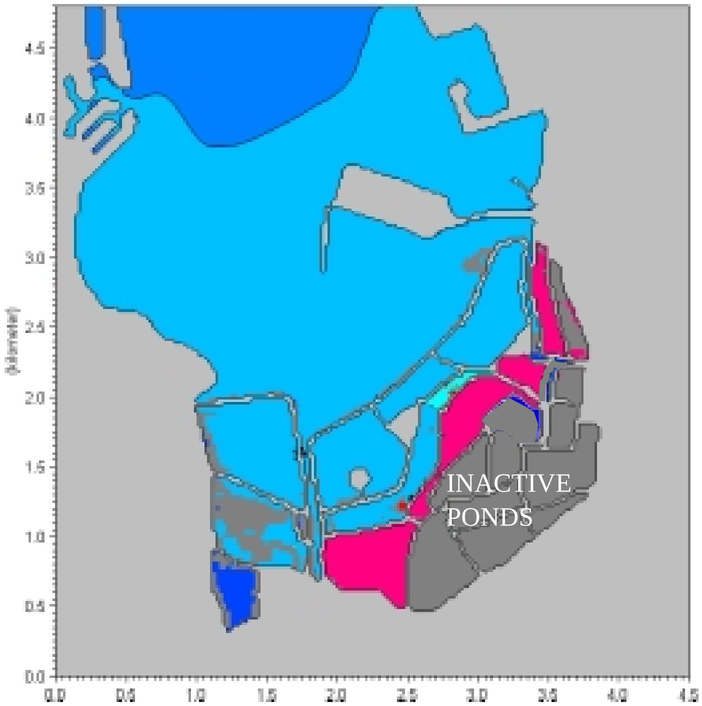
Notes: Simulated salinities at low and high tides, 7 days after breach of Alternative C Option 4.

f igure 9

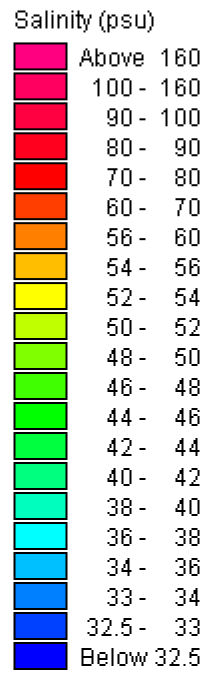
South San Diego Bay Salt Ponds
Salinity Distribution in the South Bay & Ponds
Phase 2 , 7 Days After Breach

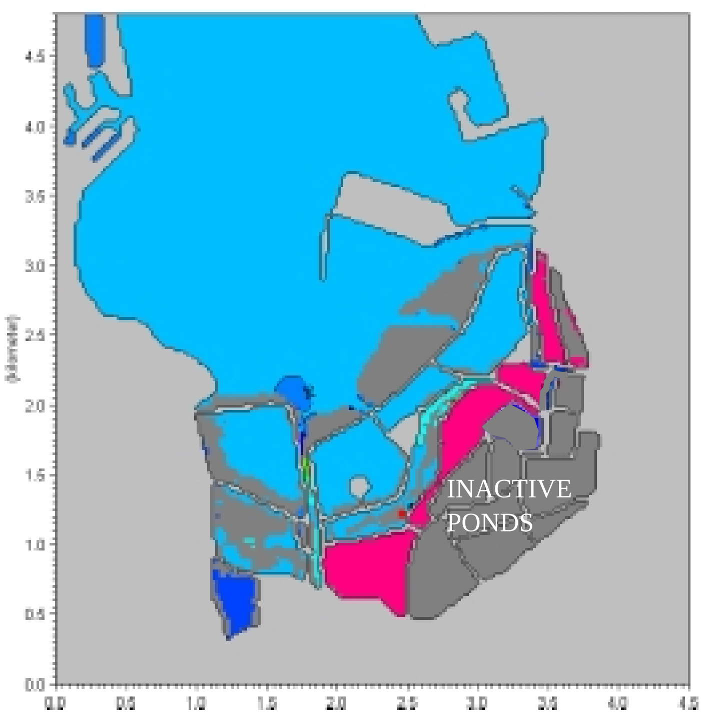
PWA Ref 1631

PWA



Salinity Distribution in South San Diego Bay at *high tide* 28 days after breach.





Salinity Distribution in South San Diego Bay at *low tide* 28 days after breach.

Notes: Simulated salinities at low and high tides, 28 days after breach of Alternative C Option 4.

figure 10

South San Diego Bay Salt Ponds

Salinity Distribution in the South Bay & Ponds, Phase 2 , 28 Days After Breach

PWA Ref 1631

PWA

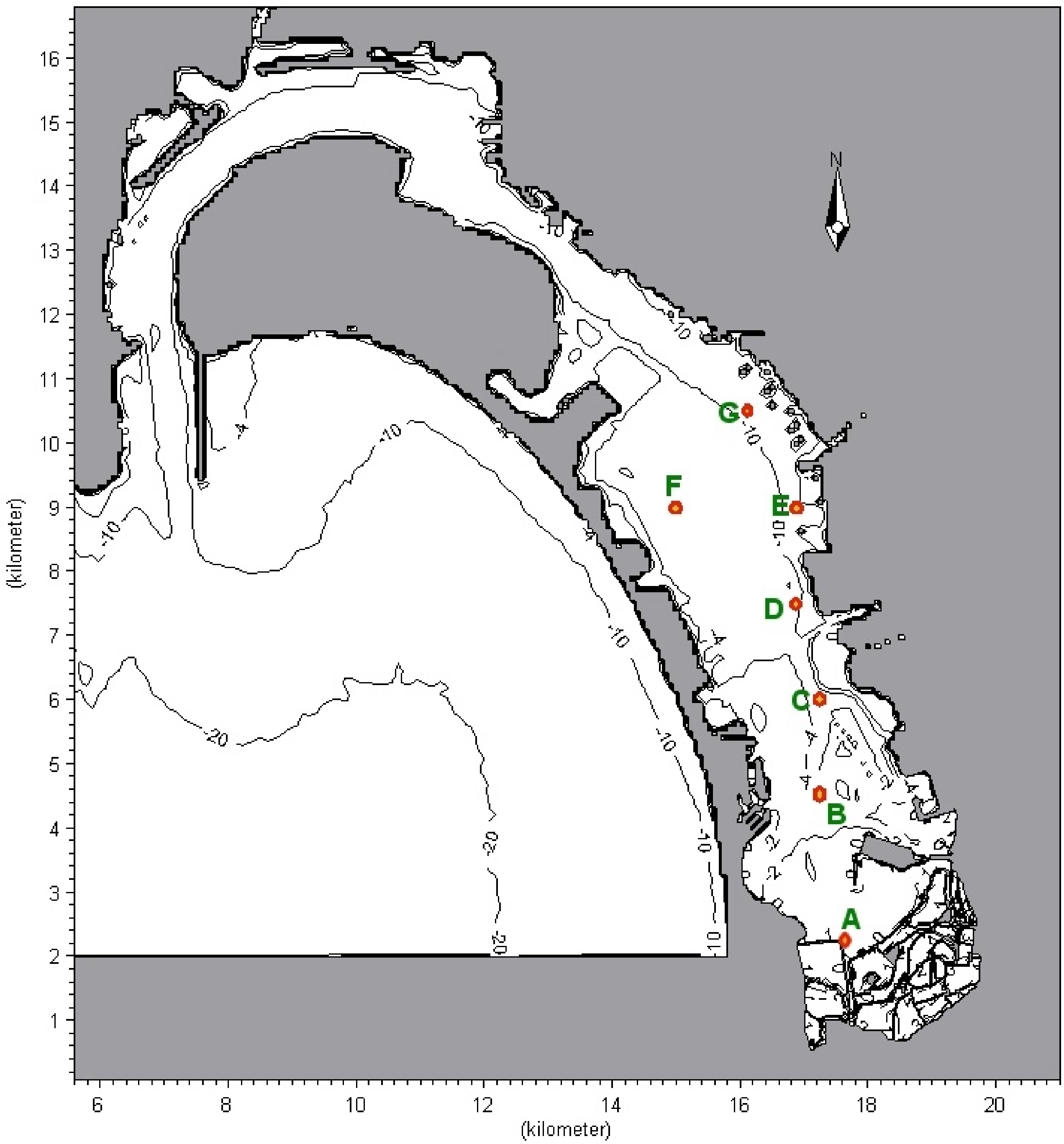
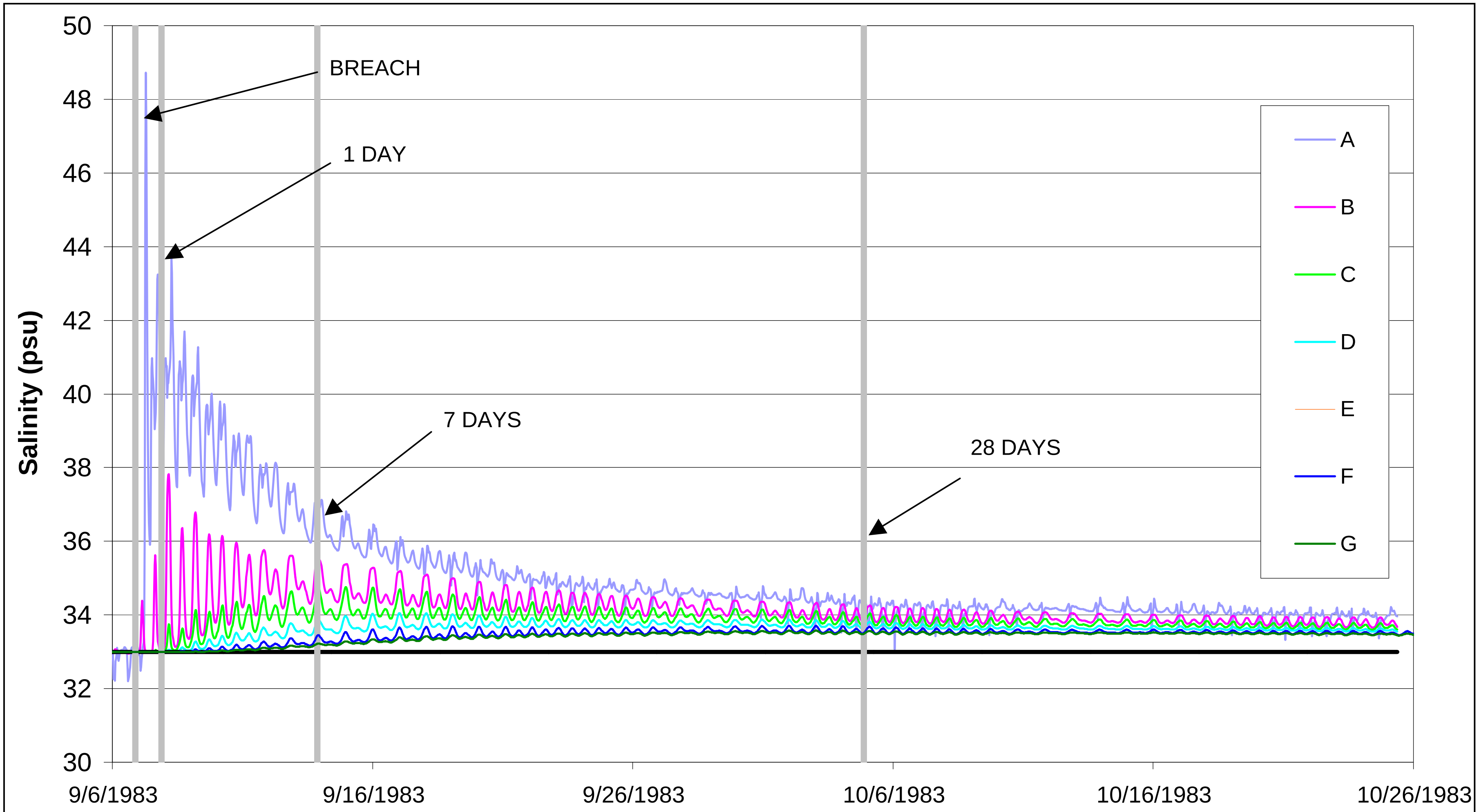


figure 11

South San Diego Bay Salt Ponds

San Diego Bay Salinity Point Locations - Alternative C Option 4

PWA Ref 1631



Notes: See Figure 4.6 for location points A through G

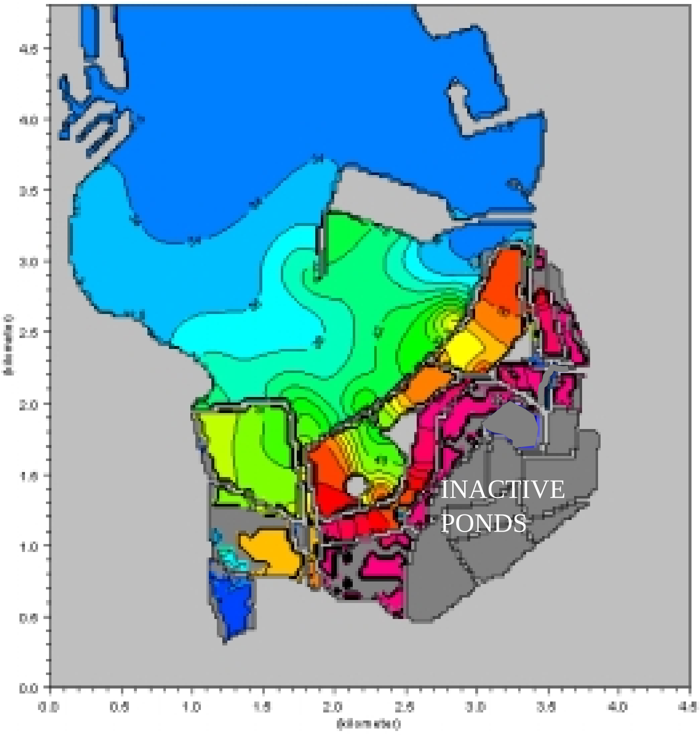
figure 12

South San Diego Bay Salt Ponds

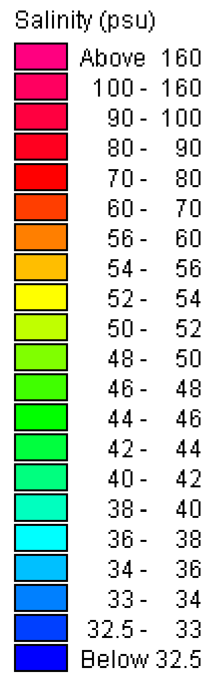
San Diego Bay Salinity Time Series , Phase 2

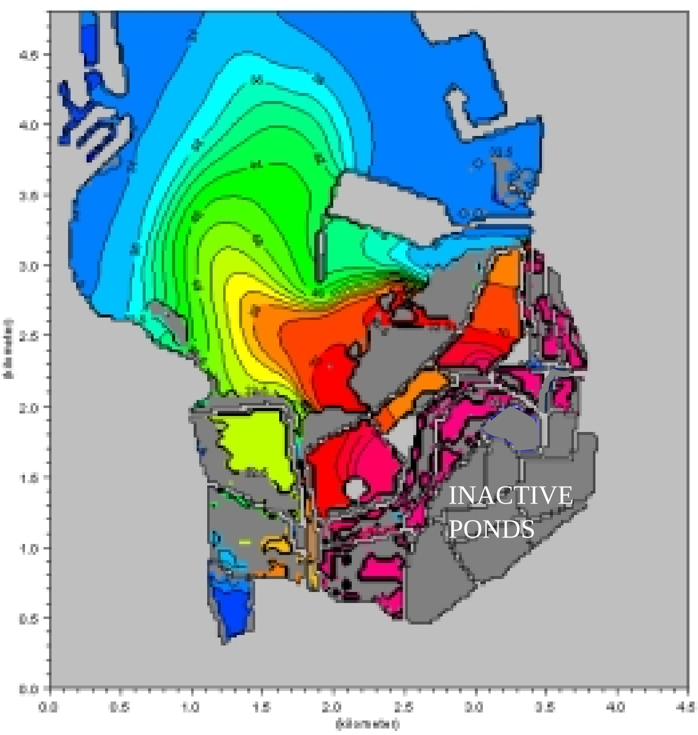
PWA Ref 1631

PWA



Salinity Distribution in South San Diego Bay at *high tide* 1 day after breach.





Salinity Distribution in South San Diego Bay at *low tide* 1 day after breach.

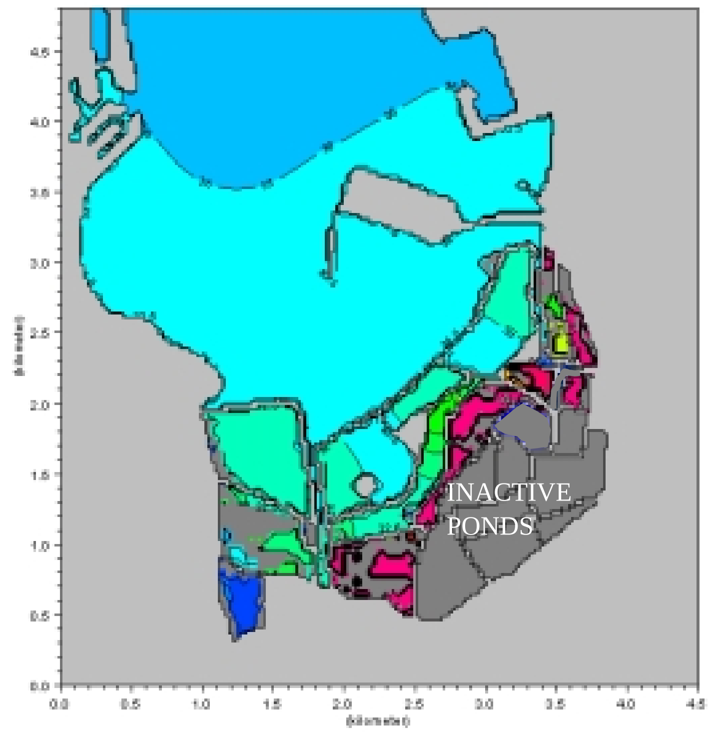
Notes: Simulated salinities at low and high tides, 1 day after breach of Alternative D.

figure 13

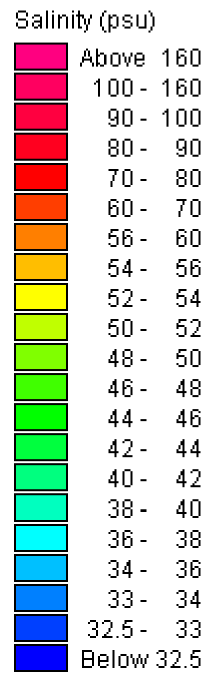
South San Diego Bay Salt Ponds
Salinity Distribution in the South Bay & Ponds, Phase 3, 1 Day After Breach

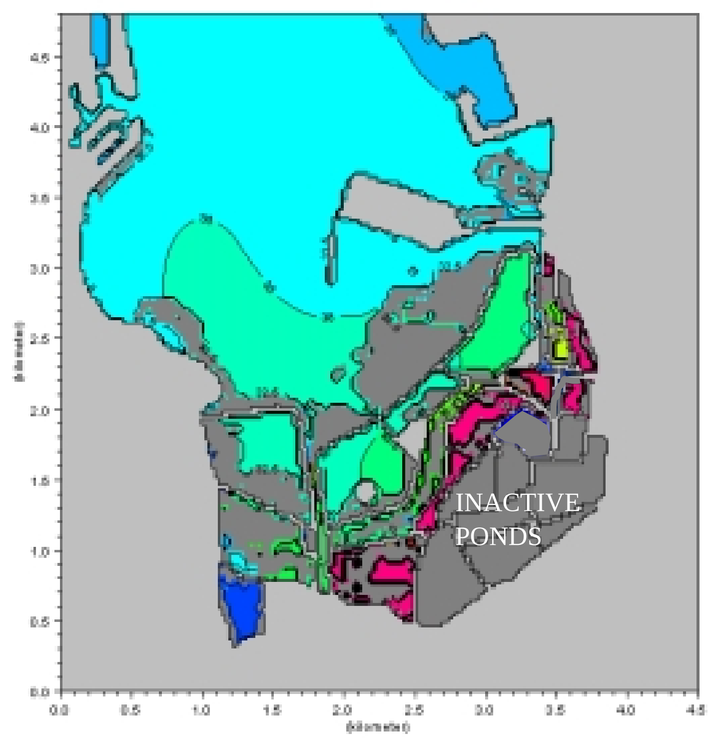
PWA Ref 1631

PWA



Salinity
Distribution in
South San Diego
Bay at *high tide*
7 days after breach.





Salinity
Distribution in
South San Diego
Bay at *low tide*
7 days after breach.

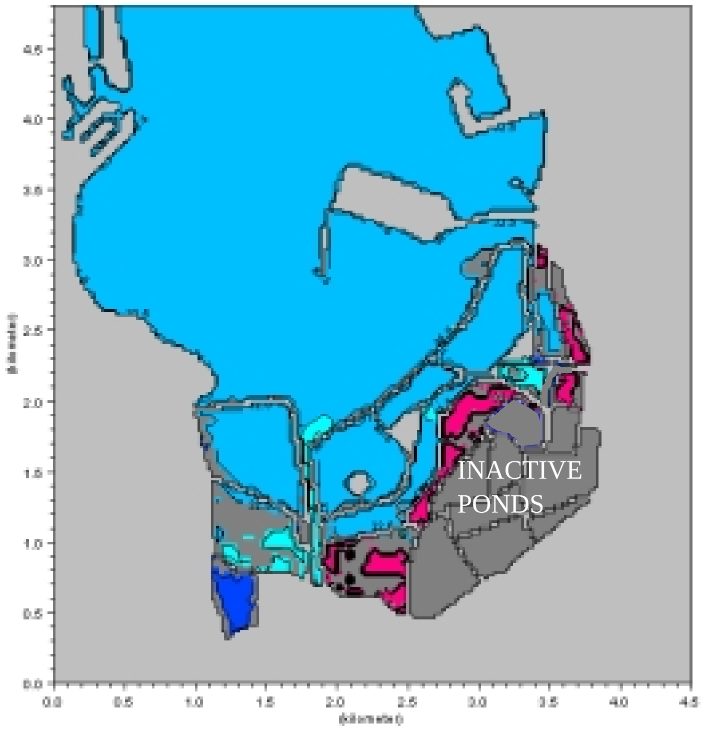
Notes: Simulated salinities at low and high tides, 7 days after breach of Alternative D.

figure 14

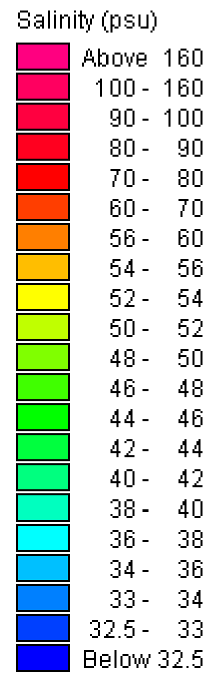
South San Diego Bay Salt Ponds
Salinity Distribution in the South Bay & Ponds,
Phase 3, 7 Days After Breach

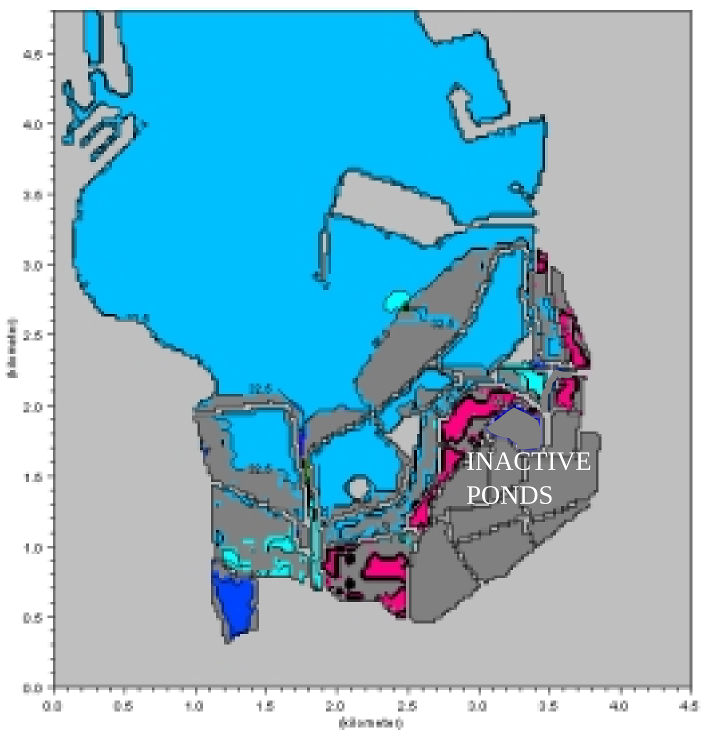
PWA Ref 1631

PWA



Salinity Distribution in South San Diego Bay at *high tide*
28 days after breach.





Salinity Distribution in South San Diego Bay at *low tide*
28 days after breach.

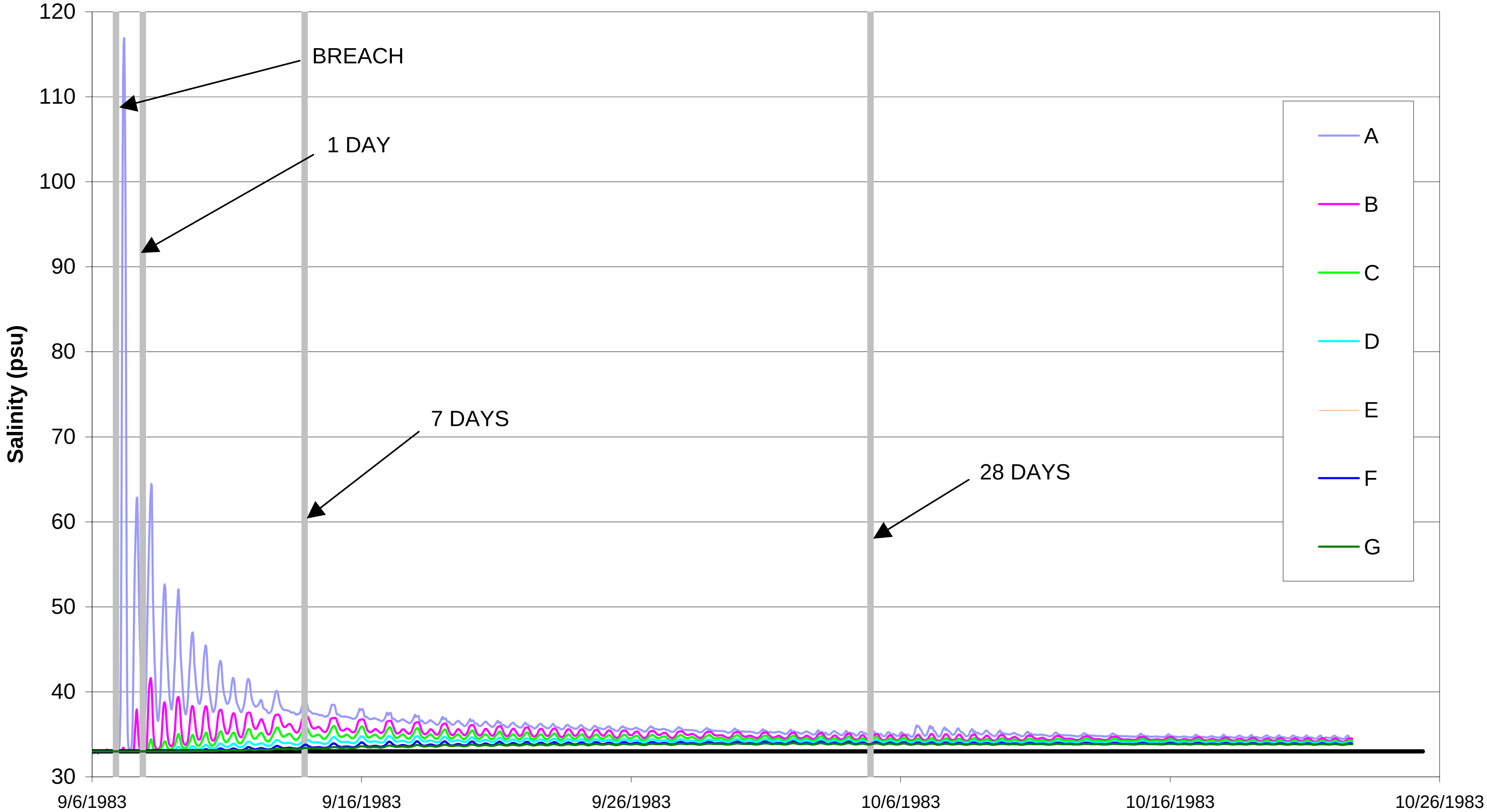
Notes: Simulated salinities at low and high tides, 28 days after breach of Alternative D.

f igure 15

South San Diego Bay Salt Ponds
Salinity Distribution in the South Bay & Ponds,
Phase 3, 28 Days After Breach

PWA Ref 1631

PWA



Notes: See Figure 4.6 for location points A through G.

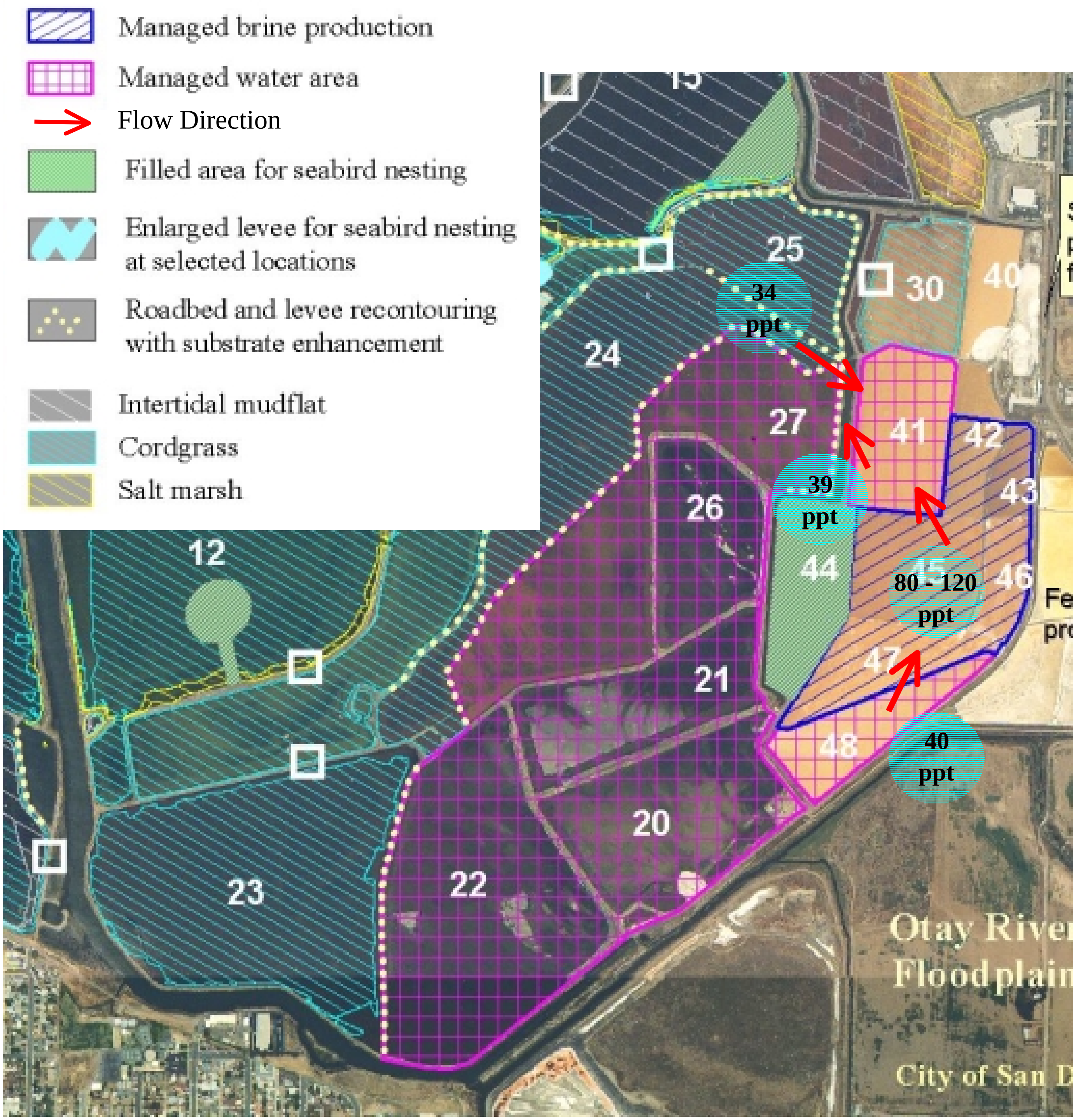
figure 16

South San Diego Bay Salt Ponds

San Diego Bay Salinity Time Series , Phase 3

PWA Ref 1631

Projects\1631-00_San_Diego_Salt_Ponds\Task6-Reporting\figures\ Chapter4_ALTD-rev.xls \ fig16



Source: Background image from USFWS (01 November 2002)

figure 17

South San Diego Bay Salt Ponds

Configuration of Brine Complex

PWA Ref 1631

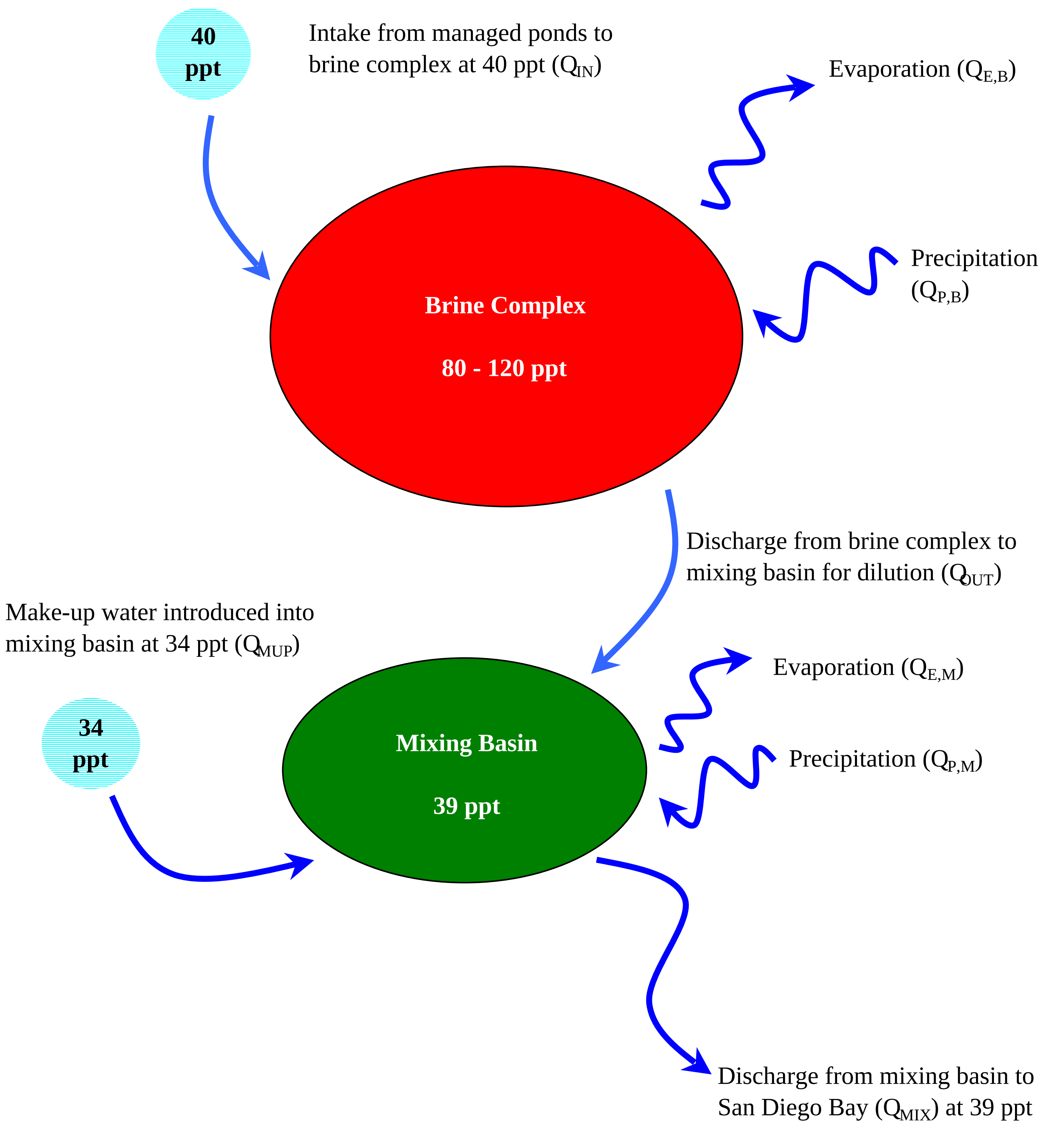
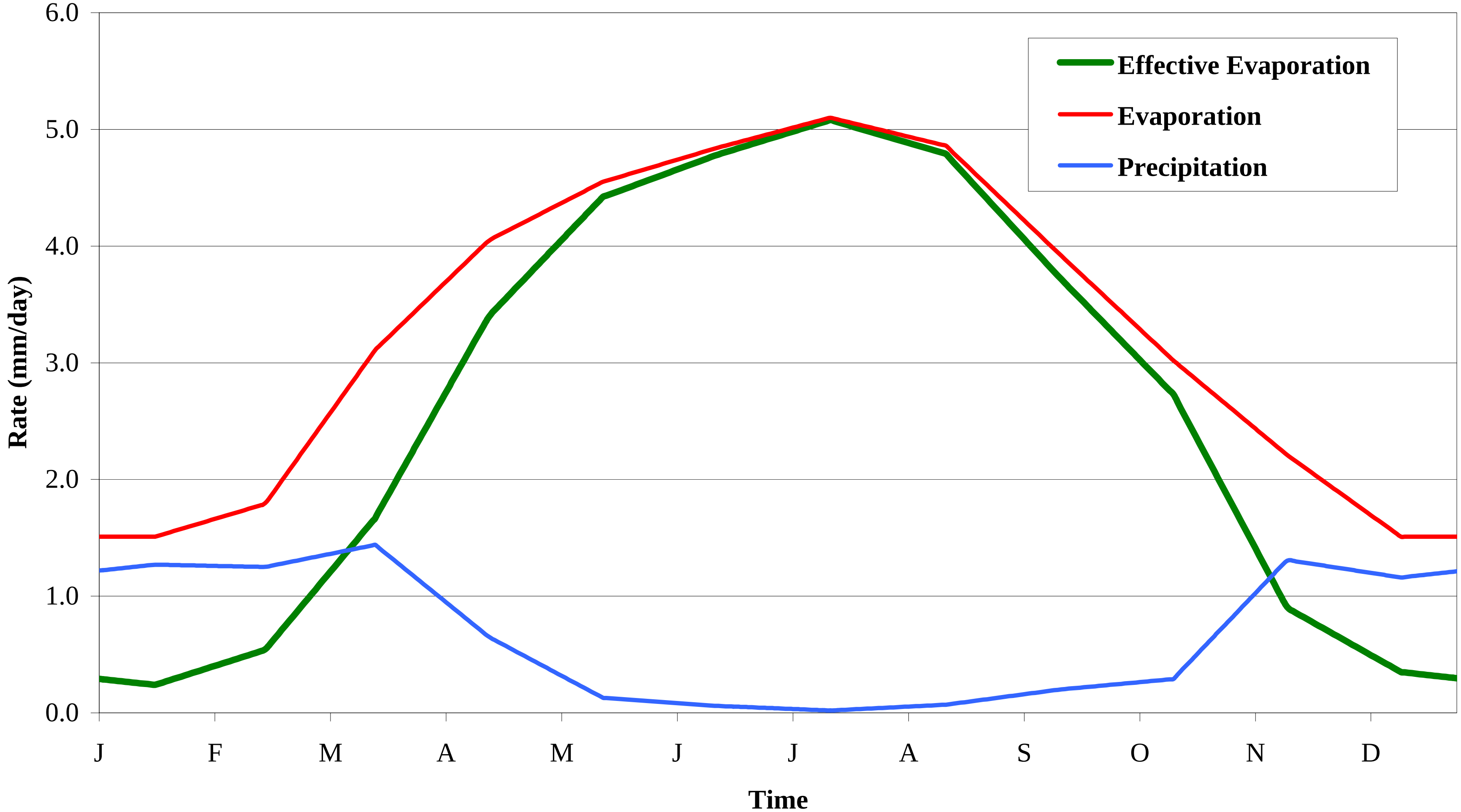


figure 18

South San Diego Bay Salt Ponds

Conceptual Layout of Box Model

PWA Ref 1631 PWA



Notes: Precipitation from 1961 to 1990; Freshwater evaporation from 1918 to 1979 (values independently adjusted with Fullerton Class A pan coefficient)

Source: National Weather Service (NWS)Cooperative Network - Chula Vista.

figure 19

South San Diego Bay Salt Ponds

Monthly Mean Evaporation and Precipitation Rates for Chula

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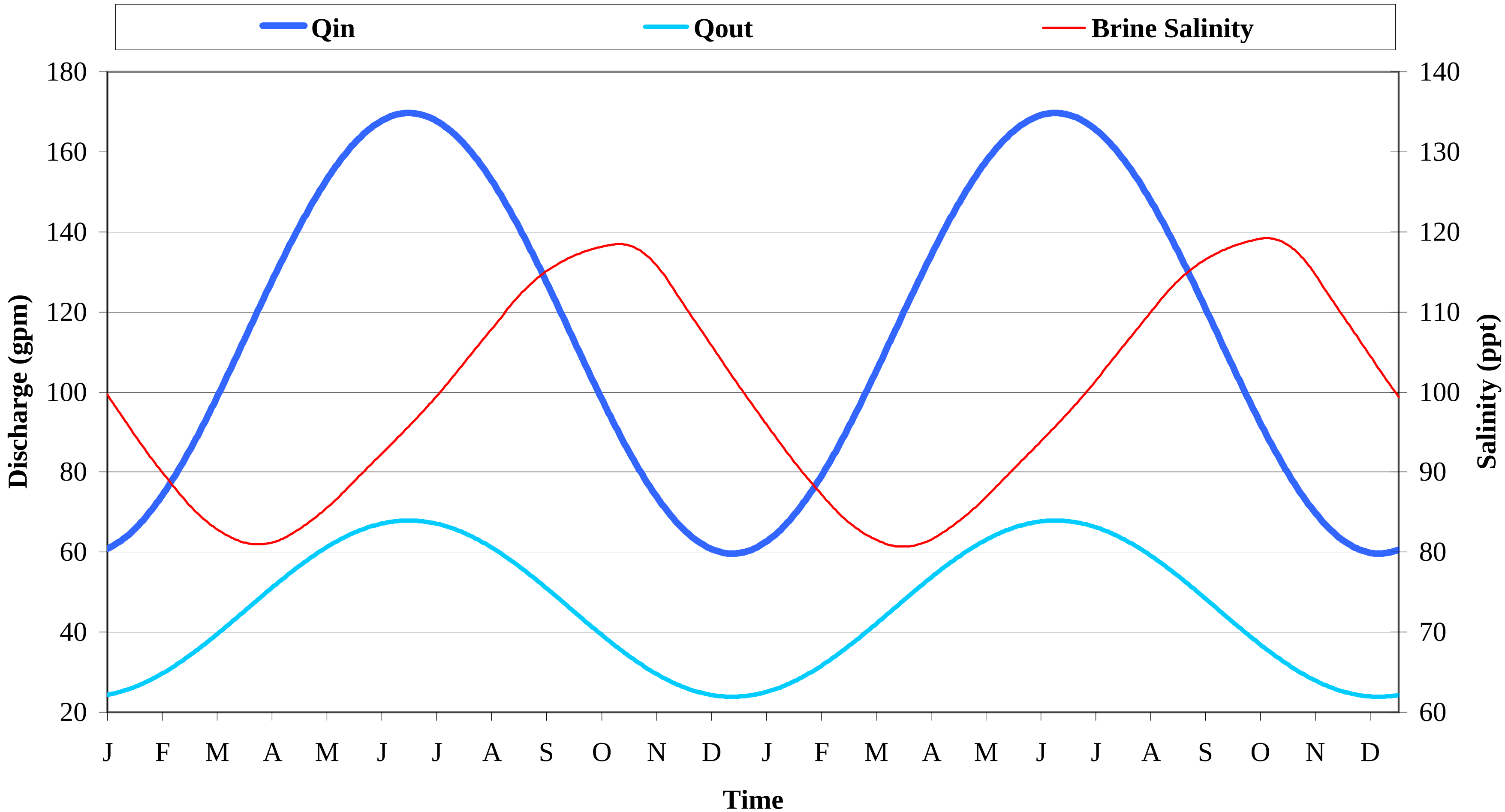
PWA



Notes: Fit flows to a sine-wave and solve for time-varying volume and salinity of brine complex; set volume and salinity of mixing basin as constants and solve for time-varying flow (Run 4).

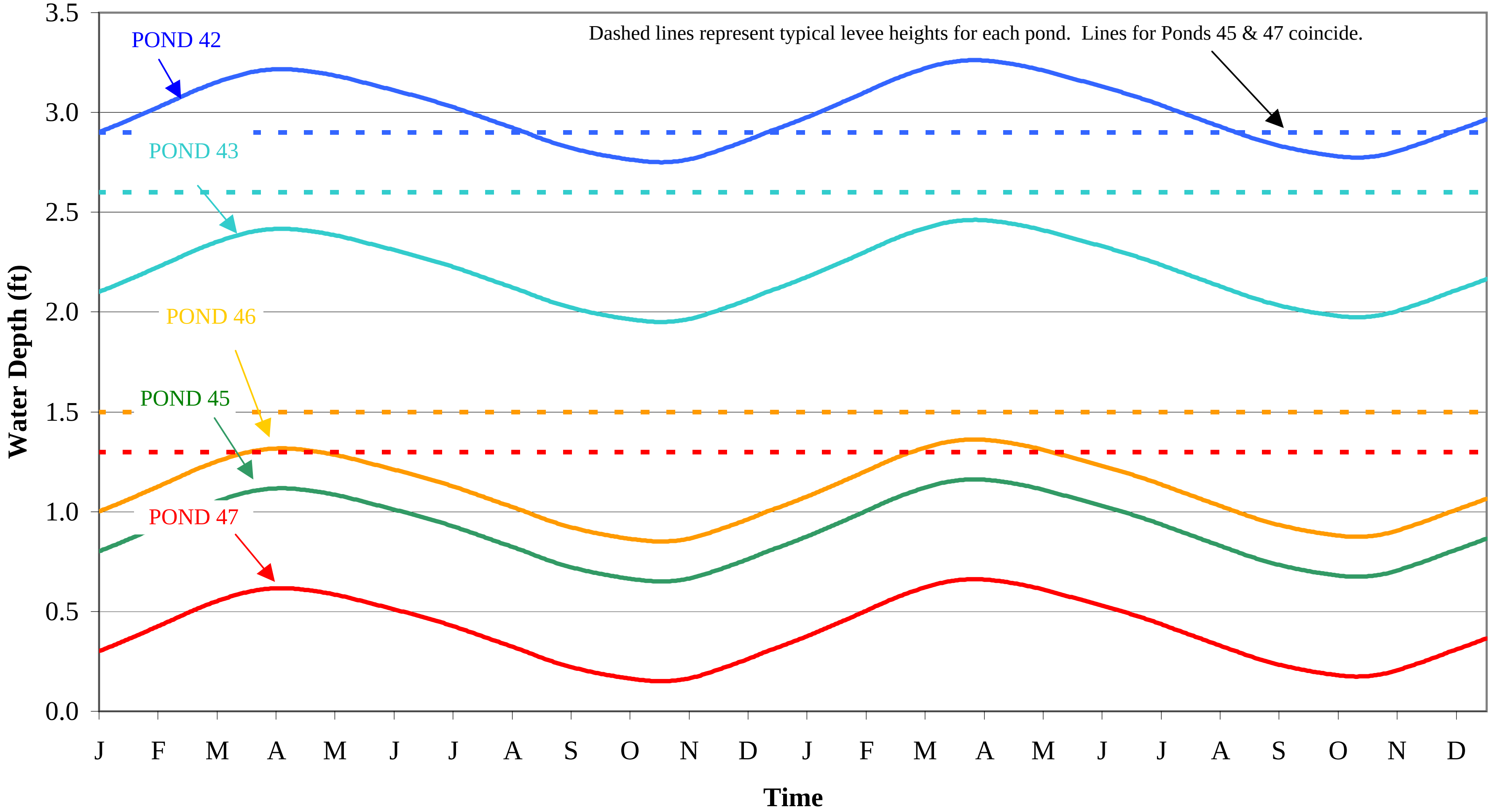
figure 20

South San Diego Bay Salt Ponds

Time Series of Discharges and Salinity in Brine Ponds

PWA Ref #1631

PWA



Notes: Fit flows to a sine-wave and solve for time-varying volume and salinity of brine complex; set volume and salinity of mixing basin as constants and solve for time-varying flow (Run 4)

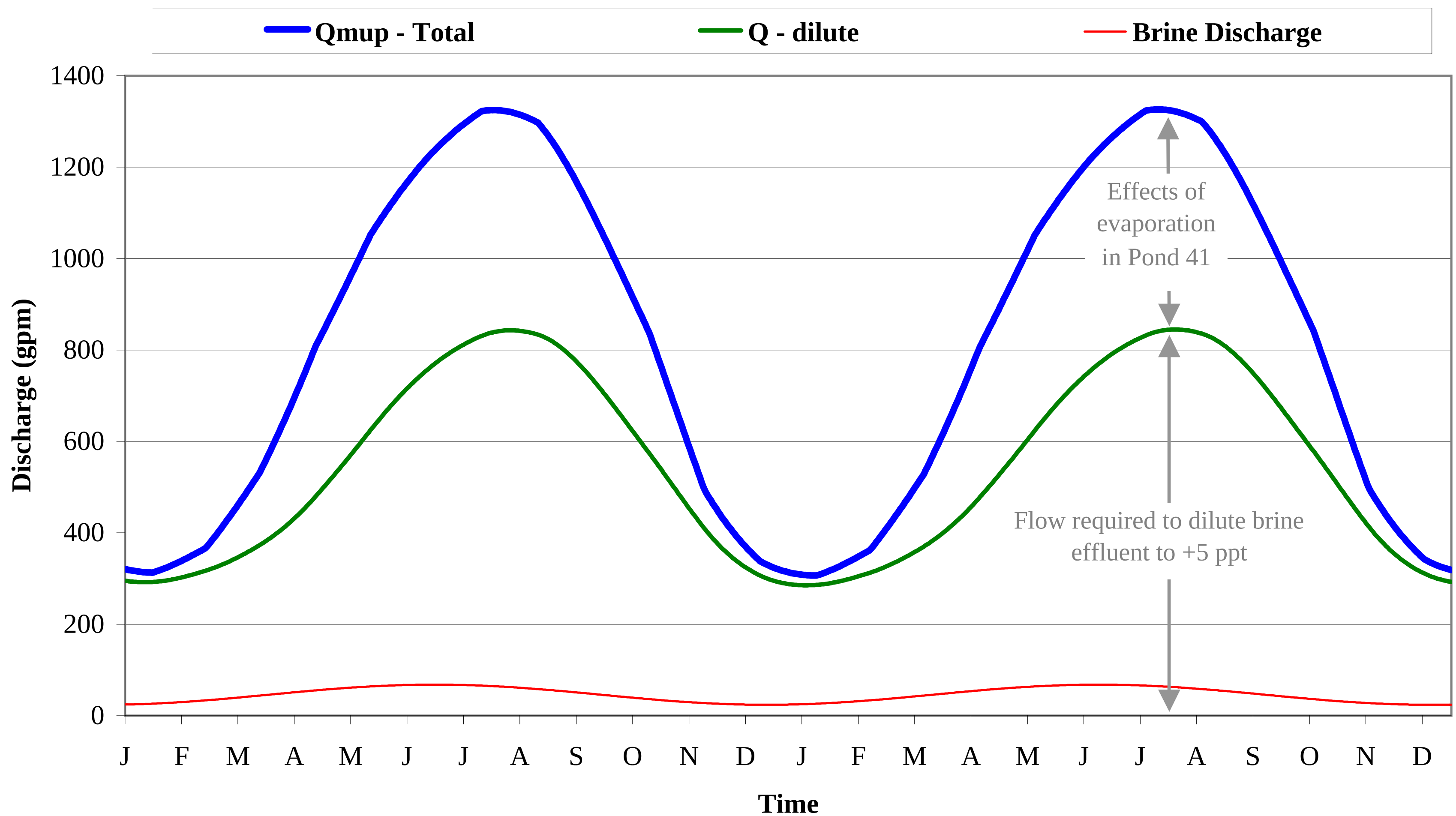
figure 21

South San Diego Bay Salt Ponds

Time Series of Brine Pond Water Depths

PWA Ref #1631

PWA



Notes: Fit flows to a sine-wave and solve for time-varying volume and salinity of brine complex; set volume and salinity of mixing basin as constants and solve for time-varying flow (Run 4). Discharge into the bay is = Qmup-total (blue line) + Qout (red line) - Pond 41 Evap.

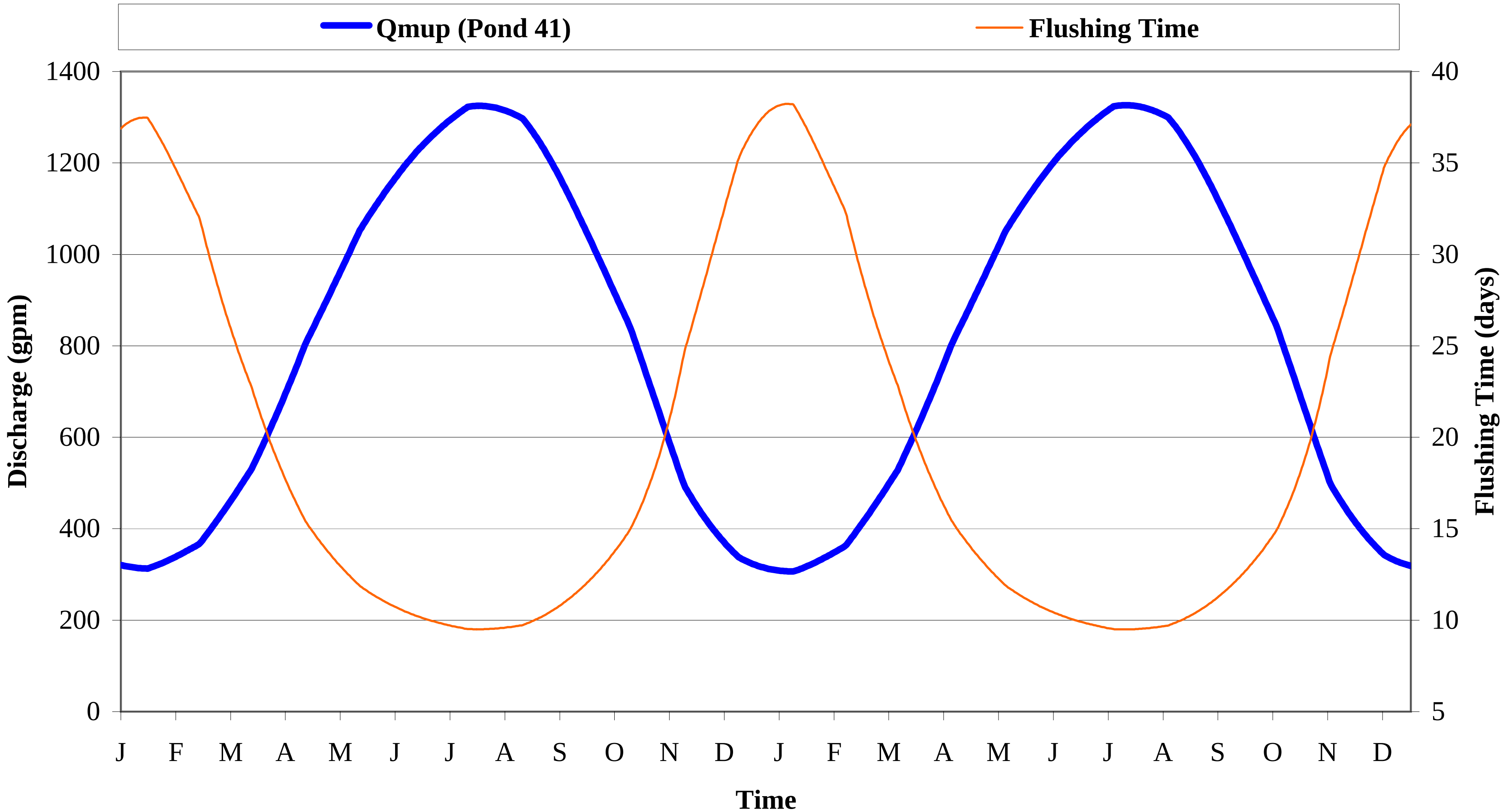
figure 22

South San Diego Bay Salt Ponds

Time Series of Mixing Basin Discharges

PWA Ref #1631

PWA



Notes: Fit flows to a sine-wave and solve for time-varying volume and salinity of brine complex; set volume and salinity of mixing basin as constants and solve for time-varying flow (Run 4)

figure 23

South San Diego Bay Salt Ponds

Flushing Time in Mixing Basin

PWA Ref #1631