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MEMORANDUM

DATE: December 2, 2002

TO: Amy Hutzel, California State Coastal Conservancy

Cc: Susanne von Rosenberg, GAIA
George Harris, HSE
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FROM: Don Danmeier
Chris Campbell

RE: **Napa River Salt Marsh Restoration Phase 2 Stage 2 – Salinity Reduction Modeling**
PWA # 1591

INTRODUCTION

The California State Coastal Conservancy (Conservancy), California Department of Fish and Game (CDFG), and the U.S. Army Corps of Engineers (USACE) are in the process of planning ecological restoration of former salt ponds in the Napa-Sonoma Marsh Wildlife Area. Under contract with the Conservancy, Philip Williams & Associates (PWA) has assisted in the planning process by providing technical services associated with salinity reduction and restoration design development. The purpose of this memorandum is to provide an overview of salinity reduction options screened in earlier stages of the planning process (Stage 1), and present results from recent modeling efforts (Stage 2). Work in support of the restoration design has been presented separately (PWA 2002a, 2002b).

Maintaining suitable bird habitat in the ponds prior to restoration has been difficult because of aging infrastructure, prohibitive pumping costs, and intense evaporation during summer and fall. Consequently, salinity levels have continued to increase and complete drying of some pond areas has been observed after long periods of dry weather. The screening of salinity reduction options carried out in Stage 1 assumed continued buildup of salt based on each of the ponds. However, the no-project conditions assumed during the Stage 2 modeling effort were different due to recent changes to Pond 3. On August 12, 2002 CDFG personnel discovered a small hand-dug ditch along the Pond 3 levee to South Slough and subsequently constructed a second small ditch on September 9, 2002 to reduce pressure on the first ditch. Over the past three months, these two small ditches have had the effect of raising water levels, but tidal action remains extremely muted (approximately 0.1 ft in range in Pond 3).

KEY FINDINGS AND CONCLUSIONS

Results from the Stage 2 salinity reduction modeling lead to the following key conclusions:

- Breaching the exterior levee of Pond 4 during higher river flows would produce relatively short desalination times in Pond 6A, 6, 5 and 4. Increases in Napa River salinity are expected to be substantial but also of limited temporal extent. With tidal exchange through a 50-ft breach, simulated depth-average salinity in Napa River shows an increase of about 20 parts per thousand (ppt) in the vicinity of the breach and an increase of 10 – 12 ppt over a 2 km reach one day after the breach. After about a week, impacts are expected to decrease to approximately 5 – 10 ppt but cover a 6 km reach. River salinity is expected to return to no-project conditions after approximately one month, based on model results. These results assume initial salinities in Ponds 4 and 5 can be diluted to about 100 ppt before breaching the levee, and salinities in Ponds 6 and 6A can be reduced to about 30 ppt.

- Based on a qualitative assessment, a saline dense bottom plume is expected to develop and sink to the lowest sections of the river due to the density differences between pond and river waters. This saline bottom layer is likely to persist at concentrations similar to the pond levels, since turbulent mixing in the river would not likely overcome the stabilizing effect of the heavy saline plume and lighter river water. The dense saline water is expected to sit on the river bed in a fairly stationary manner, moving primarily due to gravitational forces (density differences), and have limited exchange along its interface with overlaying water.

- Elevated salinity levels in lower Napa River are not expected to restrict safe passage of fish following breaching. Simulated depth-averaged salinity levels are well below acceptable levels for steelhead trout and striped bass (as reported in JSA 2002) for most, if not all, of the lower Napa River over the entire desalination period. Although density differences between the effluent and receiving waters will increase the near-bottom salinities, concentrations near the surface will be below simulated values and provide connectivity between low salinity waters. Impacts to benthos are expected to be greater, since there is the potential for a plume of saline water to develop along the river bed (see above). However, this saline layer of water would be confined to the deepest sections of the river and follow a rapid substantial – and natural – decrease in salinity due to high river flows.

- Releasing water from Pond 7 at a 1:100 dilution ratio results in very slow flushing times for bittern. Discharges at a 1:20 dilution produce much more rapid flushing of bittern from Pond 7, but slough concentrations of bittern under these conditions are close to the 1% bittern toxicity threshold. Neither discharge rate produces a long-term build-up of bittern in the barotropic mixing zone, and time scales of the slough concentrations are similar to the time scales of the concentrations in Pond 7.

DESCRIPTION OF THE NUMERICAL MODELS

ONE-DIMENSIONAL NAPA RIVER MODEL

PWA applied a numerical model of the pond and slough systems in Stage 1 to screen various salinity reduction options. This model coupled a two-dimensional (2D) representation of the ponds and a one-dimensional (1D) schematization of the slough and river network. The model domain extended from the upstream reaches of Sonoma Creek and Napa River to their mouths, and included the looped slough network that connect the two. Detailed descriptions of the model, and its numerical schemes, calibration, and applications may be found in previous reports (PWA 2002a, 2002c, 2002d).

The efficiency of the 1D slough and river schematization allowed several proposed salinity reduction options to be examined at a cursory level during the early planning stages. Although this was appropriate for screening purposes, mixing processes in Napa River were greatly simplified by its 1D representation. In particular, only the longitudinal variation in salinity could be simulated since concentrations were assumed uniform across the width and depth of the river. This is analogous to instantaneous and complete mixing across the river, and is not appropriate if detailed descriptions of the vertical and transverse gradients in salinity are required. However, the sectionally-averaged salinity computed during the Stage 1 screening process can be interpreted as representative of ambient conditions beyond the initial mixing zone.

TWO-DIMENSIONAL BAY AND NAPA RIVER MODEL

A refined numerical model of the pond and slough systems was applied in Stage 2 to examine the preferred salinity reduction option as well as various restoration options. Due to the large tidal prism associated with restoration of the ponds and the proximity of the former model boundary at lower Mare Island Strait, the model domain was extended to include the entire San Francisco Bay. Additionally, the 1D schematization of lower Napa River was replaced by a 2D depth-averaged representation. The 1D schematizations of the sloughs, Sonoma Creek and upper Napa River were retained.

Although the 2D schematization of lower Napa River simulates transverse mixing processes, flow parameters are depth-averaged and cannot resolve vertical variations in density or concentration. Therefore, we applied approximate analytic tools when interpreting the model results in order to qualitatively assess the potential for a dense bottom plume to develop after release of hypersaline water from the ponds.

SCREENING OF SALINITY REDUCTION OPTIONS (STAGE 1)

PWA screened various salinity reduction scenarios as part of the Stage 1 modeling effort in order to identify feasible salinity reduction options. These model results were subsequently used to develop the salinity reduction options described in the Environmental Impact Report/Statement (EIR/S) (JSA 2002). Options 1A and 2 were variations on a common theme, in which make-up water from Napa River and the surrounding sloughs is used to raise the water levels in the northern ponds and drive flow in a southward direction before discharge into lower Napa River (Option 1A) or San Pablo Bay (Option 2). In these options, water is conveyed through a series of culverts, siphons and diffusers. The exception to this approach are Options 1B and 1C, which include a planned levee breach during a high river flow event.

The proposed options are briefly described below along with general findings. Complete descriptions of the Stage 1 model runs and conclusions of the screening analysis are included in PWA 2002a and PWA 2002d. Detailed descriptions of the proposed salinity reduction options can be found in JSA 2002. Note that in some instances details of the salinity reduction options vary slightly from the preliminary model runs.

Note that all screening simulations carried out in Stage 1 used the 1D Napa River schematization described above, and increases to the sectionally-averaged salinity were kept to +5 ppt (parts per thousand) or below. Thus, the times required for salinity reduction may increase if more stringent discharge criteria are applied. Additionally, the model runs do not consider dissolution of precipitated salts, which could increase desalination times. Unusually dry weather and/or poor circulation within the pond system may also extend the time required to effectively desalinate the system.

SALINITY REDUCTION OPTION 1A

The configuration of Salinity Reduction Option 1A is shown in **Figure 1** for the Lower Ponds (Ponds 3 through 6A). In general, make-up water is introduced at the northern end of the ponds and discharged into Napa River in the southern reaches of the pond complex. This option uses constructed intakes and outfalls for all ponds, including Ponds 3 and 4/5. These hydraulic structures include:

- an intake from Napa Slough to the north-central section of Pond 6A,
- an intake from Napa Slough to the north-central section of Pond 5,
- a siphon under Devil's Slough to route water from Pond 6 to Pond 5,
- an outfall to Napa River from the south-central portion of Pond 4,
- an intake from Napa River to the northeast corner of Pond 3,
- an intake from Dutchman Slough to southwestern side of Pond 3, and

- an outfall to Napa River from the southeast side of Pond 3.

For the purposes of the Stage 1 modeling, each intake and outfall was modeled as four 48-inch circular culverts fitted with flap gates. Additionally, four 100-ft breaches were assumed to be constructed in each of the two interior levees in Ponds 4/5 and 6/6A in order to enhance mixing. Note that under Option 1A, Pond 3 is hydraulically disconnected from Ponds 6A through 4.

Numerical simulations of this configuration showed sectionally-averaged increases in Napa River salinities were at the target maximum level of 5 ppt despite only moderate initial pond salinities (about 60 – 70 ppt in Ponds 4 and 5) due to the fact that hypersaline waters were not mixed in the low-salinity Pond 3 prior to discharge. These impacts could be lessened by reducing the number or sizes of the outfall culverts.

SALINITY REDUCTION OPTION 1B – LOWER PONDS

Figure 2 shows the configuration of Salinity Reduction Option 1B for the Lower Ponds. This option uses a controlled levee breach to desalinate Pond 3 during a high flow event. The remaining intakes and outfall locations are the same as for Option 1A. Note that although the 50-ft breach to Napa River was later relocated to the southeastern corner of Pond 3, the modeled configuration shown in **Figure 2** is not expected to produce findings that would be materially different.

Results from the screening-level analysis indicate that Pond 3 could be flushed to ambient levels in a several weeks, and that sectionally-averaged salinities in Napa River would increase by about 8 ppt before returning to no-project levels in approximately two months. However, since breaching would coincide with a high flow event when salinities are at a minimum, the sectionally-averaged concentration in the Napa River computed by the model was below conditions during normal dry periods.

SALINITY REDUCTION OPTION 1C – LOWER PONDS

Salinity Reduction Option 1C is shown in **Figure 3**, and consists of planned breaches along the Pond 4 and Pond 3 levees to Napa River during a high flow event. This configuration is similar to Option 1B, but with an additional 50-ft breach into Napa River from Pond 4.

Results from the screening-level analysis indicate that the Lower Ponds could be flushed to ambient levels after several months. Sectionally-averaged salinities in Napa River are expected to increase by about 20 ppt before returning to no-project levels in approximately two months. However, since breaching would coincide with a high flow event when salinities are at a minimum, the sectionally-averaged concentration in the Napa River computed by the model was similar to conditions during normal dry periods.

Initial screening by PWA indicated that this option might be feasible and offer other benefits (see below) if discharge criteria could be modified during a high Napa River flows. Therefore, the Project Team decided to analyze a breach desalination option more closely in Stage 2. Results from the Stage 2 effort are summarized later in this memorandum.

SALINITY REDUCTION OPTION 1 – UPPER PONDS

Screening of salinity reduction in the Upper Ponds (Ponds 8, 7A and 7) was carried out independently since this complex is hydraulically separated from the Lower Ponds for all salinity reduction options except for Option 2. Flows from Ponds 7, 7A and 8 are combined with recycled water at a mixing chamber before discharging into the Napa Slough, as shown in **Figure 4**. Constant flow rates of 5,000 and 15,000 ac-ft/yr of freshwater were assumed to determine if desalination could be accelerated using recycled water. A complete description and results of the proposed desalination option in the Upper Ponds are presented in a memorandum to the Sonoma County Water Agency (PWA 2002d).

The following hydraulic structures were included in the modeling of salinity reduction in the Upper Ponds under Option 1:

- intake from Mud Slough to Pond 8 via two 30-inch diameter circular culverts with flap gates,
- discharge from Pond 8 into the canal passing to the north of Pond 8 towards the mixing chamber via a 48-inch culvert with a flap gate,
- intake from Napa Slough to Pond 7 via a 48-inch diameter circular culvert with a flap gate,
- discharge from Pond 7A into the mixing chamber via a 48-inch culvert with flap gate,
- discharge from Pond 7 into the mixing chamber via a gate such that flow is adjusted to meet a pre-determined dilution ratio of bittern, and
- a recycled-water pipeline to Pond 7 and the mixing chamber.

Since bittern is toxic to aquatic organisms when released in concentrated form, discharges from Pond 7 were restricted. Therefore, the model was configured such that bittern discharges from Pond 7 to the mixing chamber achieved a specified dilution (1:100) prior to release to Napa Slough. This greatly reduced the flow through Pond 7 and led to significantly longer predictions of desalination times for this pond.

Although Ponds 7A and 8 desalinate more quickly than Pond 7, strong seasonal fluctuations are expected due to limited tidal exchange and intense summer evaporation. These variations will be stronger during unusually dry years and increase the flushing time for these ponds.

SALINITY REDUCTION OPTION 2 – PONDS 3 THROUGH 5

Like Option 1A, Salinity Reduction Option 2 relies on the extensive use of hydraulic structures to route water through the pond system. Desalination in Ponds 3 through 5 is shown in **Figure 5**, and uses the following hydraulic structures:

- an intake from Napa River to the northeast corner of Pond 3,
- an intake from Napa Slough to the north-central section of Pond 5,
- a siphon under South Slough to route water from Pond 4 to Pond 3, and
- an outfall to Napa River from the southeast side of Pond 3.

As before, the interior levee for Pond 4/5 would have four 100-ft breaches to enhance mixing.

In this approach, Pond 3 is used as a mixing chamber before discharging hypersaline water into Napa River. Salinity reduction is carried out in a phased approach, starting in Pond 3 and continuing to Ponds 4 and 5 after the salinity in Pond 3 reaches ambient levels. Screening-level analyses indicate that salinity reduction in the Lower Ponds may be accomplished within approximately two years under the phased approach given initial salinities of about 160 – 170 ppt in Ponds 4 and 5, and moderate salinity levels (under 40 ppt) in Pond 3.

Use of Pond 3 as a mixing pond prior to discharge into Napa River has the benefit of minimizing impacts to the receiving waters. Stage 1 results show that sectionally-averaged salinity in Napa River outside the initial mixing zone increases by approximately 2 ppt, well below the maximum criterion of 5 ppt

SALINITY REDUCTION OPTION 2 – PONDS 1 THROUGH 8

Option 2 combines salinity reduction in the Upper and Lower Ponds, as shown in **Figure 6**. It was initially expected that this configuration may lead to more rapid desalination time for Pond 7. The intakes at Ponds 7, 7A, and 8 would be similar to those under Salinity Reduction Option 1, although the outfall into Napa Slough would not be constructed, and no intakes would be required for Ponds 6/6A. Additional infrastructure for this option includes:

- installation of two 54-inch siphons from Pond 6 to Pond 2,
- replacement of an existing 72-inch siphon that connects Pond 2 to Ponds 1 and 1A with two 54-inch siphons, and
- construction of one new 72-inch outfall underneath Highway 37, allowing water to flow between San Pablo Bay and Pond 1.

As with Salinity Reduction Option 1, the interior levee for Pond 6/6A would have four 100-ft breaches to enhance mixing.

Numerical results show that combining the Upper and Lower Ponds during salinity reduction accelerates the flushing of Pond 7 by a factor of 2 to 3, but at the expense of introducing bittern to other ponds and negatively impacting aquatic habitat. Additionally, Option 2 would require more infrastructure than the other proposed salinity reduction options.

STAGE 2 SALINITY REDUCTION MODELING

Information learned during the screening process led to refinement of the salinity reduction options, and the Project Team chose to examine a levee breach option more closely due to the limited infrastructure involved, quicker desalination times, and the expectation that elevated salinity levels in Napa River would rapidly return to no-project conditions after a large initial release of salt from the ponds. Therefore, PWA applied the 2D bay and river model described above to assess the short-term salinity impacts to Napa River of a breach along the Pond 4 levee.

SALINTIY REDUCTION OPTION 1C – LOWER PONDS, PHASE 2

Salinity reduction modeled in Stage 2 is shown in **Figure 7** and includes desalination of Ponds 6A through 4. Make-up water is conveyed into Pond 6A via four 48-inch intake culverts fitted with flap gates, and limited tidal exchanged occurs through the 50-ft breach in the Pond 4 levee. Breaching of the levee was assumed to coincide with a 2-yr flood event in order to examine salinity reduction under the peak discharge of a typical winter season. The small ditches along Pond 3 constructed in the summer of 2002 (see Introduction) are expected to widen by natural means or intervention, and the increased tidal exchange will gradually reduce salinity in Pond 3 to ambient levels. Therefore, salinity levels in Pond 3 were assumed to be at ambient river levels, and this configuration shown in **Figure 7** is essentially Phase 2 of Salinity Reduction Option 1C.

Figure 8 shows the mean hourly streamflow along Napa River near Napa for February 2000 that was used as upstream boundary data. Daily mean salinity simulated by a separate predictive model (Knowles 2000) is plotted in the same figure to illustrate the rapid decrease in river salinity in response to freshwater runoff. Breaching of the Pond 4 levee was chosen to occur at 08:00 February 14, 2000 so that mixing is enhanced by flood discharges and river salinity is at a minimum. Measured water levels and salinity in the ponds from February 2002 (Table 1) were used since these represent the most likely conditions during a wet winter month given the existing conditions of the ponds.

Table 1. Assumed Initial Conditions

Pond	Salinity (ppt)	Water Level (m, NAVD88)
Pond 4	111	1.5
Pond 5	110	1.5
Pond 6	38	1.7
Pond 6A	35	1.7

Source: CDFG, Feb 2002 measurements

RESULTS

We extracted data at various points and times to characterize the temporal and spatial scales of salinity reduction and the associated impacts to Napa River. The paragraphs below present time series from the data points shown in **Figure 9** and 'snapshots' of salinity in lower Napa River after breaching. Salinity tolerances for indicator species are used to assess the impacts to the existing aquatic resources.

Salinity Reduction in the Ponds

Time series of water levels are plotted in **Figure 10** and show significant muting of the tidal fluctuations in the ponds due the undersized breach. These results show that a diurnal tide range of about 1.7 m in Napa River is reduced to approximately 0.2 m in Pond 4. Variance at the spring/neap frequency is of similar magnitude and produces a slowly varying water level with a period of about two weeks.

After its initial release to Napa River immediately after breaching, Pond 4 acts as a quasi-mixing chamber. Water from Ponds 6A through 5 slowly mixes within Pond 4 before limited tidal exchange discharges saline pond water into Napa River. This is demonstrated by the time series of pond salinities plotted in **Figure 11**. Note that salinities in the ponds drop before the levee breach due to the introduction of make-up water from Napa Slough and precipitation preceding the February 14 peak streamflow. Salinities in Ponds 4 and 5 drop from their initial values of 110 to below 20 ppt approximately one month after breaching. Salinities in Ponds 6 and 6A are less due to their lower initial values and dilution from make-up water from Napa Slough.

Note that these results do not include the effects of dissolution, which may attenuate the desalination process as pond salinities drop and precipitated salts are brought into solution. Although this would not significantly change the amount of salt discharged immediately after breaching, and hence the short-term impacts, leaching may extend the total desalination time of the ponds.

Salinity in Lower Napa River

Time series of depth-averaged salinity near the center of Napa River at the point of discharge are shown in **Figure 12** for with- and without-project conditions. These results show a 12 ppt increase immediately following breaching. Impacts at this location drop to approximately a 6 – 8 ppt increase after two weeks and less than a 2 ppt difference after a month. As evident in this plot, river salinity under no-project conditions is close to zero for much of the simulation time. Therefore, the absolute salinity simulated under with-project conditions closely approximates increases due to discharge from Pond 4.

Increases in Napa River salinity are greatest during ebb tides, as the water level in the river drops and saline water discharges from Pond 4. **Figure 13** shows contour plots of salinity along an 8-mile reach of Napa River near the point of discharge at various stages of the salinity reduction process during these ebb tides. The magnitude of salinity increases in Napa River is greatest immediately after breaching but limited in spatial and temporal extents. One day after breaching, increases in river salinities greater than 20 ppt are restricted to a local zone within about 200 m of the breach. More moderate increase of about 10 – 12 ppt cover a 2 km reach. After approximately one week, increases in salinity have dropped to between 5 – 10 ppt but cover a 6 km reach due to longitudinal dispersion. River salinities throughout the reach are elevated about 2 – 3 ppt three weeks after breaching.

Discharges from Pond 4 may be higher if circulation due to strong prevailing westerly winds changes the horizontal distribution of salinity in the pond. However, the relative importance of this effect is expected to be weaker in the breach option than in non-breach options since tidal mixing dominates in the immediate vicinity of the breach.

Effects on Aquatic Resources

Physical and chemical parameters play an important role in determining ecological productivity, and in estuarine settings such as Napa River, aquatic species must be able to tolerate naturally occurring changes in salinity or move to more favorable conditions. These naturally varying changes in salinity will be modified by discharges from the salt ponds, and impacts to the existing fish and benthic communities must be addressed.

PWA compared results from the numerical model to salinity tolerances of steelhead trout and striped bass to assess impacts of discharges from Pond 4 to the aquatic resources in Napa River. The salinity tolerances and likely presence at site by time of year of these indicator species are listed in Table 2. **Figure 14** and **Figure 15** plot the depth-averaged salinity in lower Napa River following the breach in terms of tolerable levels for steelhead and striped bass, respectively. Also shown are contour lines of the mid-salinity ranges that are well below the maximum tolerable levels. These figures indicate that only a very limited area immediately adjacent to the breach is above acceptable salinity levels for steelhead, and only for a matter of days. In less than one week, conditions in the river are well below the tolerable salinity concentrations for both fish, and large portions of Pond 4 also have acceptable salinities.

Table 2. Salinity Tolerance for Indicator Species

Species	Salinity Tolerance (ppt)	Likely Presence at Site
Steelhead trout (juvenile)	0 – 25	January – May
Striped bass (juvenile, adult)	0 – 35	Year round

Source: JSA 2002

Discussion of Results

Although the 2D schematization of lower Napa River provided better representation of mixing processes in the receiving waters than the previous 1D description, limitations of the depth-averaged model require careful interpretation of the results. Therefore, we applied approximate analytic methods to assess the potential for a dense bottom plume to develop in Napa River following the Pond 4 levee breach. These order-of-magnitude estimates may be refined in the future as monitoring data is collected from the Pond 3 ditches described above. Additionally, near-field modeling that is currently underway for pond discharges through diffusers may also increase our understanding of the mixing processes in Napa River and lead to revised interpretations of the dense bottom plume.

Although the results presented in **Figure 13** assume a uniform salinity over depth, the initial mixing may be strongly affected by differences between heavy hypersaline pond water and lighter river water. Additionally, these density differences may continue to affect mixing further downstream where the mixing is driven by the turbulence of the river. The non-dimensional parameters B/du^{*3} and B/Wu^{*3} can be used to qualitatively estimate the importance of density effects (Fischer *et al* 1979). Here, B is the flux of buoyancy in the effluent[1], u^* is the shear velocity in the river[2], and d and W are the depth and width of the river, respectively. B/du^{*3} and B/Wu^{*3} express the stabilizing power of the density difference per unit width and depth, respectively, relative to the mixing power in the stream.

In the case of hypersaline discharges through the Pond 4 breach, $B/du^{*3} >> 1$, indicating that water discharged from Pond 4 will spread rapidly across the river in the form of a density driven circulation and form a layer at the bottom. The vertical mixing between this dense bottom layer and the overlying river water is expected to be weak since B/Wu^{*3} is also large, and the heavy saline plume will likely persist at least until water in Pond 4 reaches near-ambient conditions.

1 $B=()\Delta/\Delta)gQ_E$, where $)\Delta$ is the density difference between the pond and river water, Δ is the ambient density in the river, g is the gravitational acceleration, and Q_E is the discharge rate of effluent.

2 $u^* = \sqrt{\tau_b/\rho}$, where τ_b is the resistance of the river bed to the flow.

Figure 16 and **Figure 17** show, at a conceptual level, how salinity may be distributed along a cross-section of Napa River downstream of the breach (see **Figure 18** for location map) under modeled and actual conditions, respectively. As illustrated in these two figures, a strong bottom plume of saline water may significantly change the distribution of salt in the river from the depth-averaged values simulated by the numerical model. Vertical variations in salinity caused by the more dense pond water would increase near-bottom salinity. Conservation of salt would require that this increase in near-bottom concentration be accompanied by a reduction in salinity closer to the surface.

Although a comprehensive biologically-based assessment is beyond the scope of the present modeling exercise, a few points seem relevant when determining the significance of a potential bottom layer of hypersaline water. Firstly, model results suggest connectivity of waters within acceptable salinity levels is maintained within the river when considering depth-averaged salinity. The development of a dense bottom plume is not likely to reduce this connectivity significantly since near-surface water would be at a salinity level below the depth-averaged values. Also, increases in river salinity due to pond discharges follow a rapid decrease preceding the breach. This variability occurs due to natural processes in the river and would already have an effect on the habitat. Finally, effects from a saline bottom plume should be assessed while keeping in mind that the existing benthos may already be impacted by previous dredge activity along Napa River.

TRANSPORT OF BITTERN IN THE SLOUGHS

Simulated salinity reduction in Pond 7 is complicated by the presence of concentrated liquid end products associated with commercial salt production (bittern) that are toxic to aquatic organisms if discharged in concentrated form. Therefore, discharges from this pond require significant dilution prior to discharge in order to prevent adverse impacts on existing ecological resources. The reduced flow rates through Pond 7 result in salinity reduction times that may span decades.

Given these lengthy desalination times, PWA simulated bittern discharges from Pond 7 to assess the potential for chronic water quality problems that may develop. Of particular interests are the point of discharge into Napa Slough and the barotropic convergence zone in the middle of the slough network, where tidal exchange is limited and effluent may accumulate (Warner 2000).

DESCRIPTION

PWA simulated flow through the Upper Ponds desalination option shown in **Figure 4** but used a conservative tracer to track bittern instead of sodium chloride salt. Flows through Ponds 7A and 8 were tidally driven, but discharges from Pond 7 were metered to achieve a high (1:100) or low (1:20) dilution at the mixing chamber.

In order to easily measure the dilution of bittern throughout the system, initial concentrations were assumed to be 100 ppt in Pond 7 and zero throughout the sloughs, in other ponds, and at the model boundaries. Two-year long simulations were carried out for each dilution criteria in order to capture the effects of residual transport processes in the sloughs and the reduction of bittern in Pond 7.

RESULTS

Data were extracted at the point of discharge into Napa Slough, inside Pond 7, and in the barotropic convergence zone (**Figure 9**) in order to plot the time series of bittern concentration. Sectionally-averaged concentrations from the 1:100 simulation are shown in **Figure 19**. A seasonal trend is clearly evident in the pond, as concentrations drop during the wet months and increase during the dry. Overall, the bittern concentration in Pond 7 drops to about 60% of its initial value after two years. Although Pond 7 discharges occur at 1:100 into the mixing chamber, sectionally-averaged concentrations in Napa Slough are an order of magnitude less than 1 ppt due to additional dilution in the slough.

Bittern concentrations in Napa Slough are significantly higher with Pond 7 discharges at a 1:20 dilution rate into the mixing chamber, as shown in **Figure 20**. Under these conditions, peak sectionally-averaged concentrations at the point of discharge is approximately 0.7 ppt, indicating an overall dilution of about 1:142. Seasonal trends are less apparent than in the 1:100 scenario since bittern discharged from Pond 7 quickly outpaces evaporation and masks the influence of rainfall. After two years of 1:20 discharge, bittern concentration in the pond is about 10% of its initial level.

Results from these simulations indicate that transport across the barotropic mixing zone is sufficient to preclude effluent build-up, and concentrations in the interior sections of the slough system follow trends in the pond levels.

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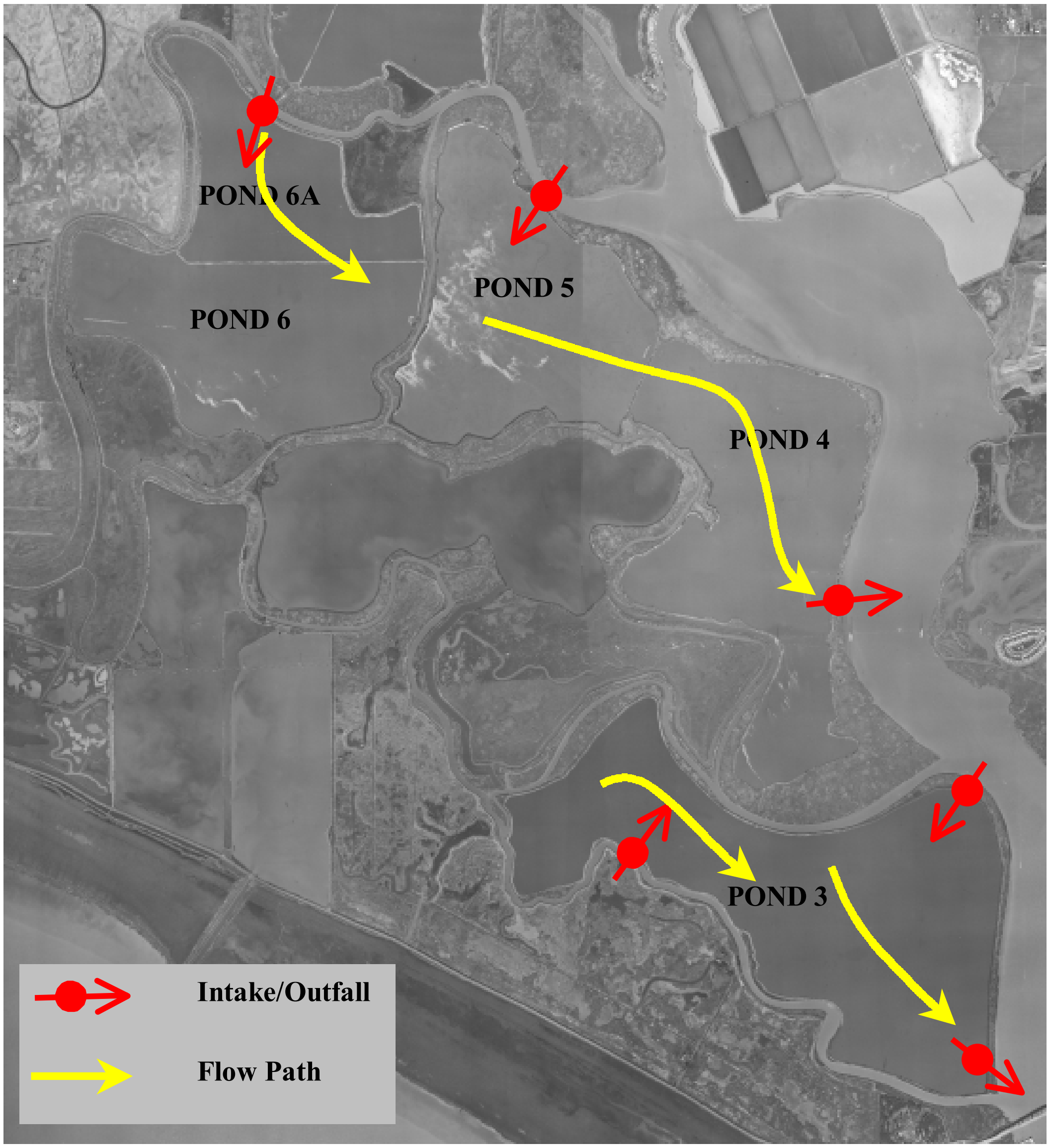

Figure 1 Salinity Reduction Option 1A – Lower Ponds

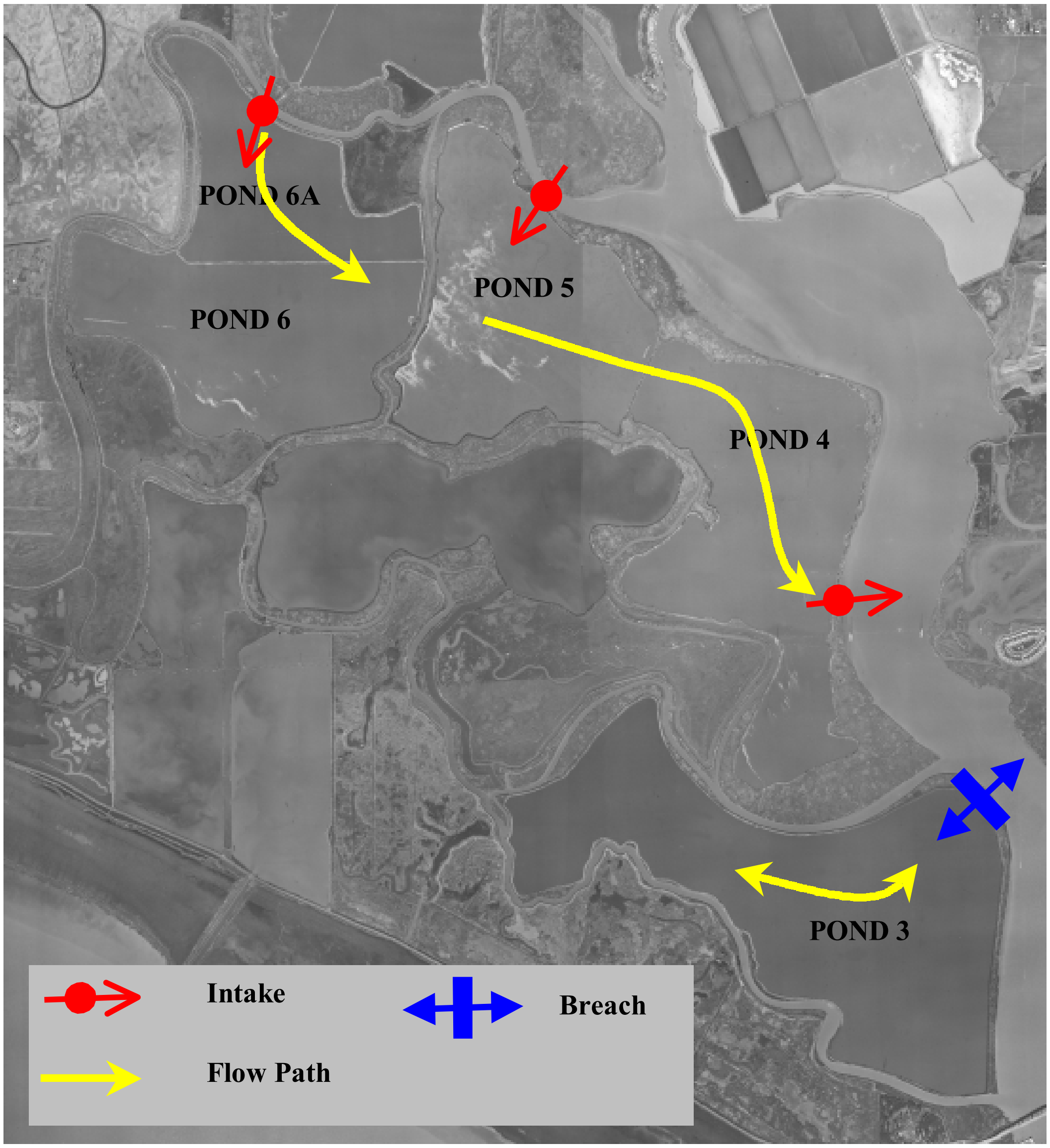

Figure 2 Salinity Reduction Option 1B – Lower Ponds

* Pond 3 breach to Napa River was modeled at northeast corner. Location later changed to southeast corner

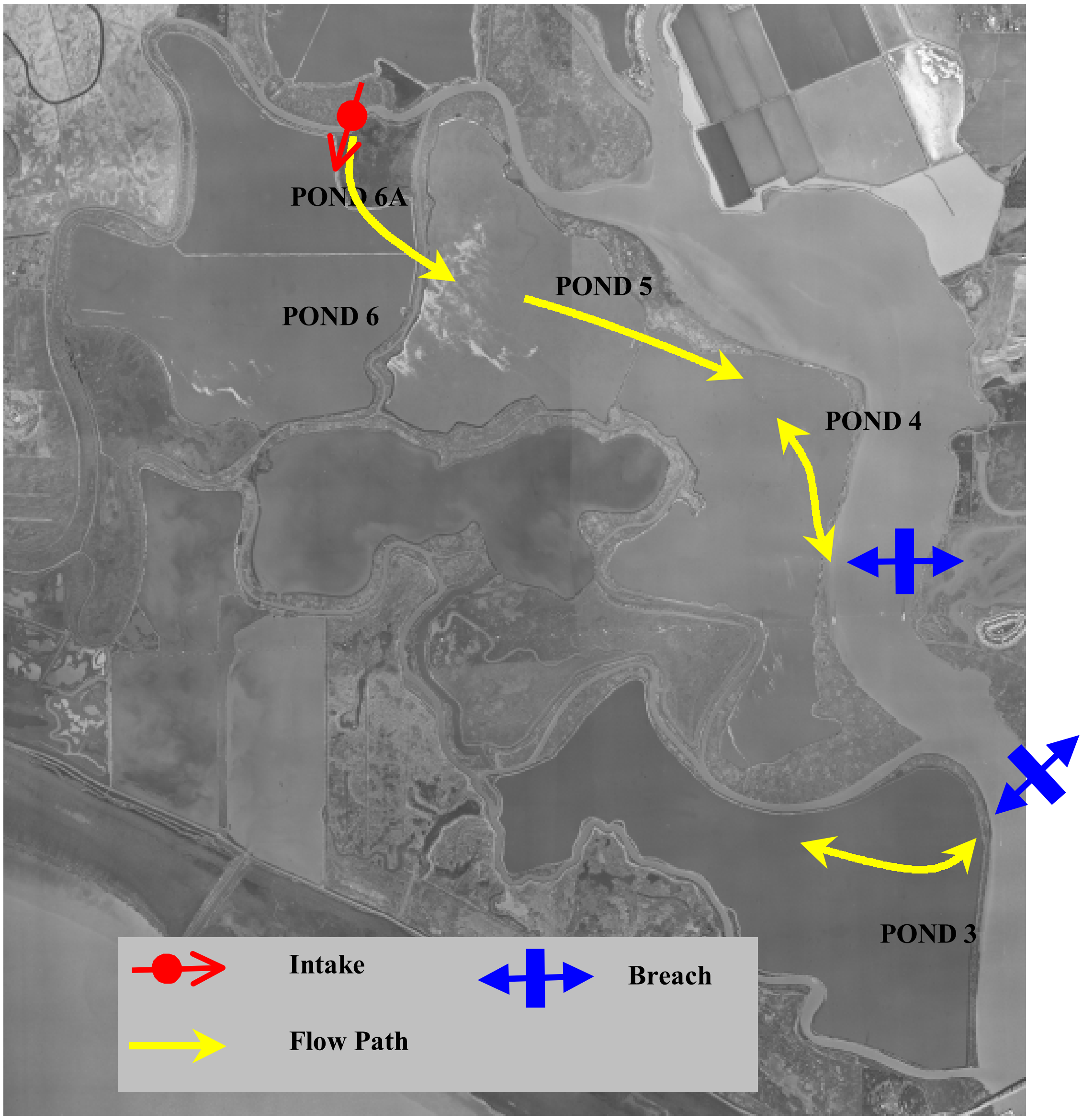

Figure 3 Salinity Reduction Option 1C - Lower Ponds

* Pond 3 breach to Napa River was modeled at northeast corner. Location later changed to southeast corner

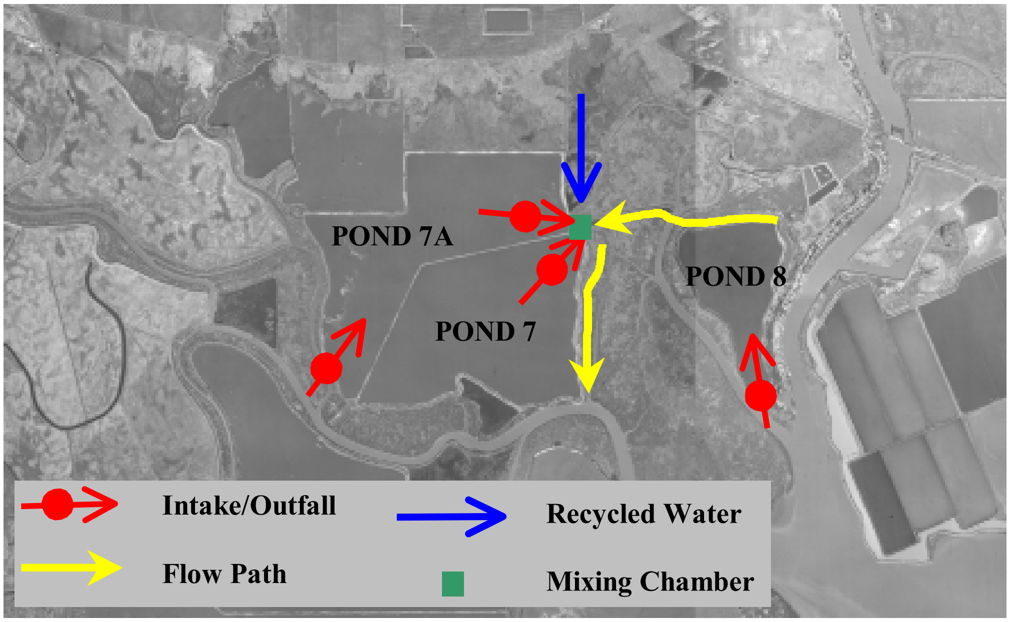

Figure 4 Salinity Reduction Option 1 – Upper Ponds

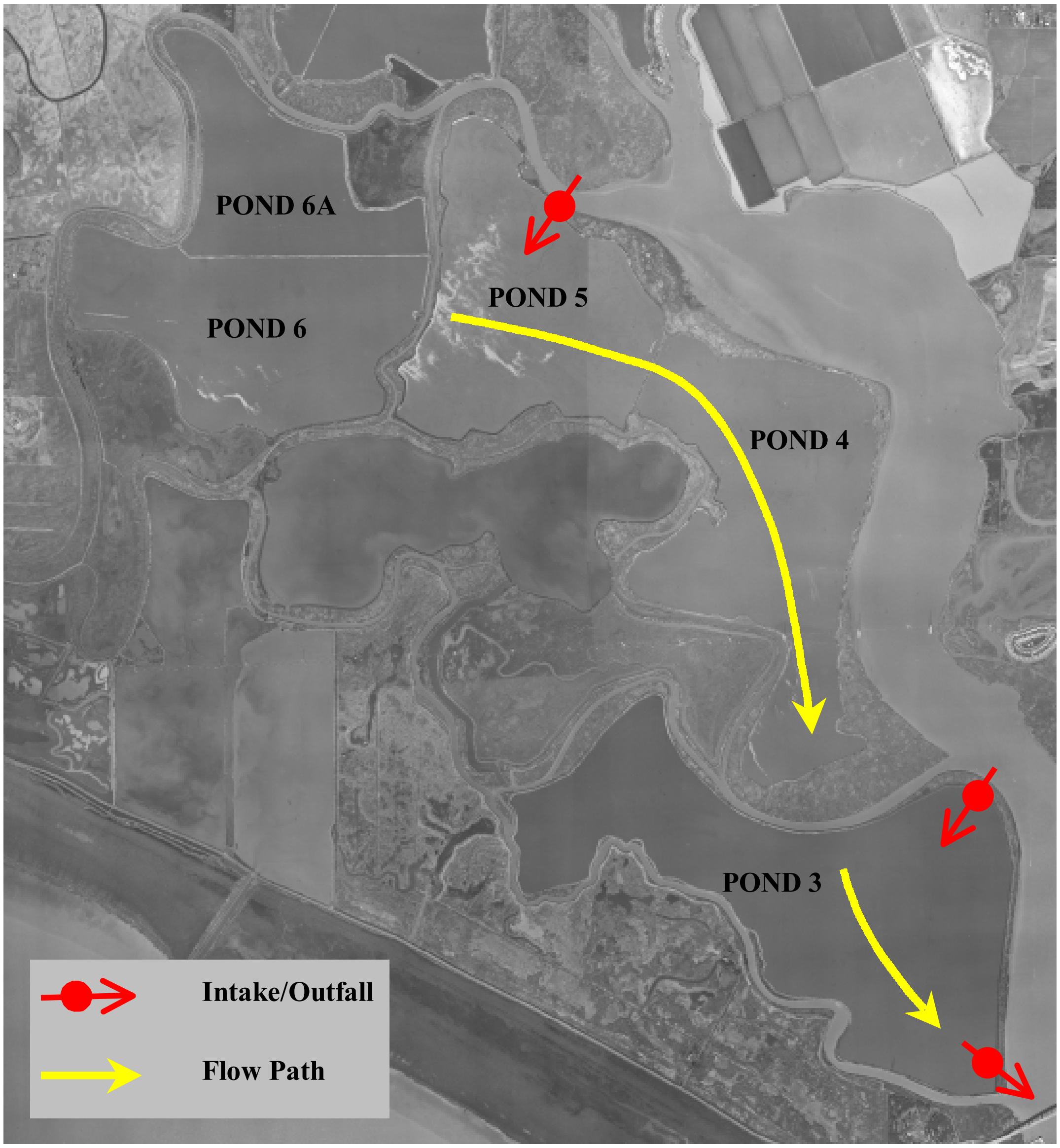

Figure 5 Salinity Reduction Option 2 – Ponds 3 through 5

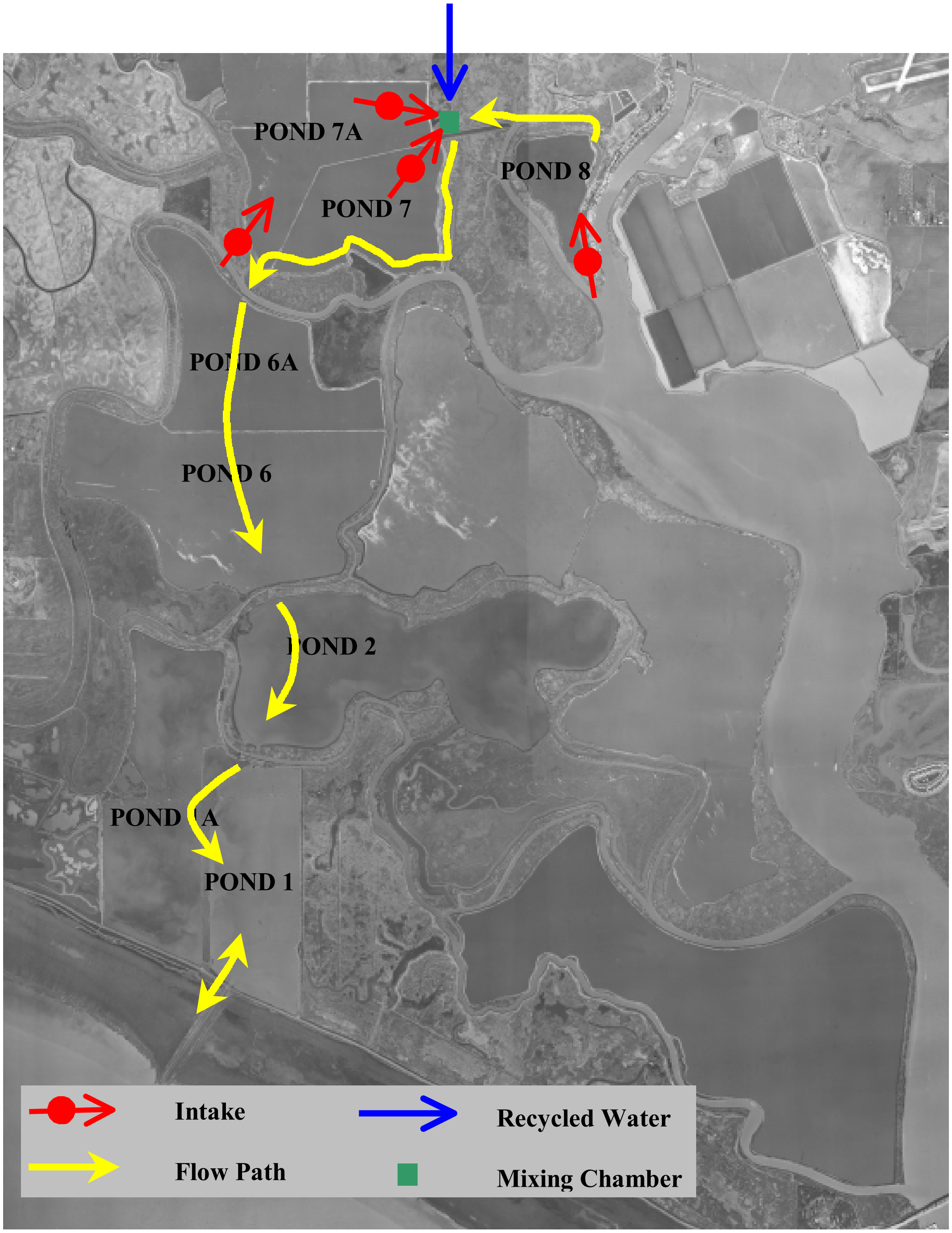

Figure 6 Salinity Reduction Option 2 – Ponds 1, 1A, 2, 6, 6A, 7, 7A, and 8

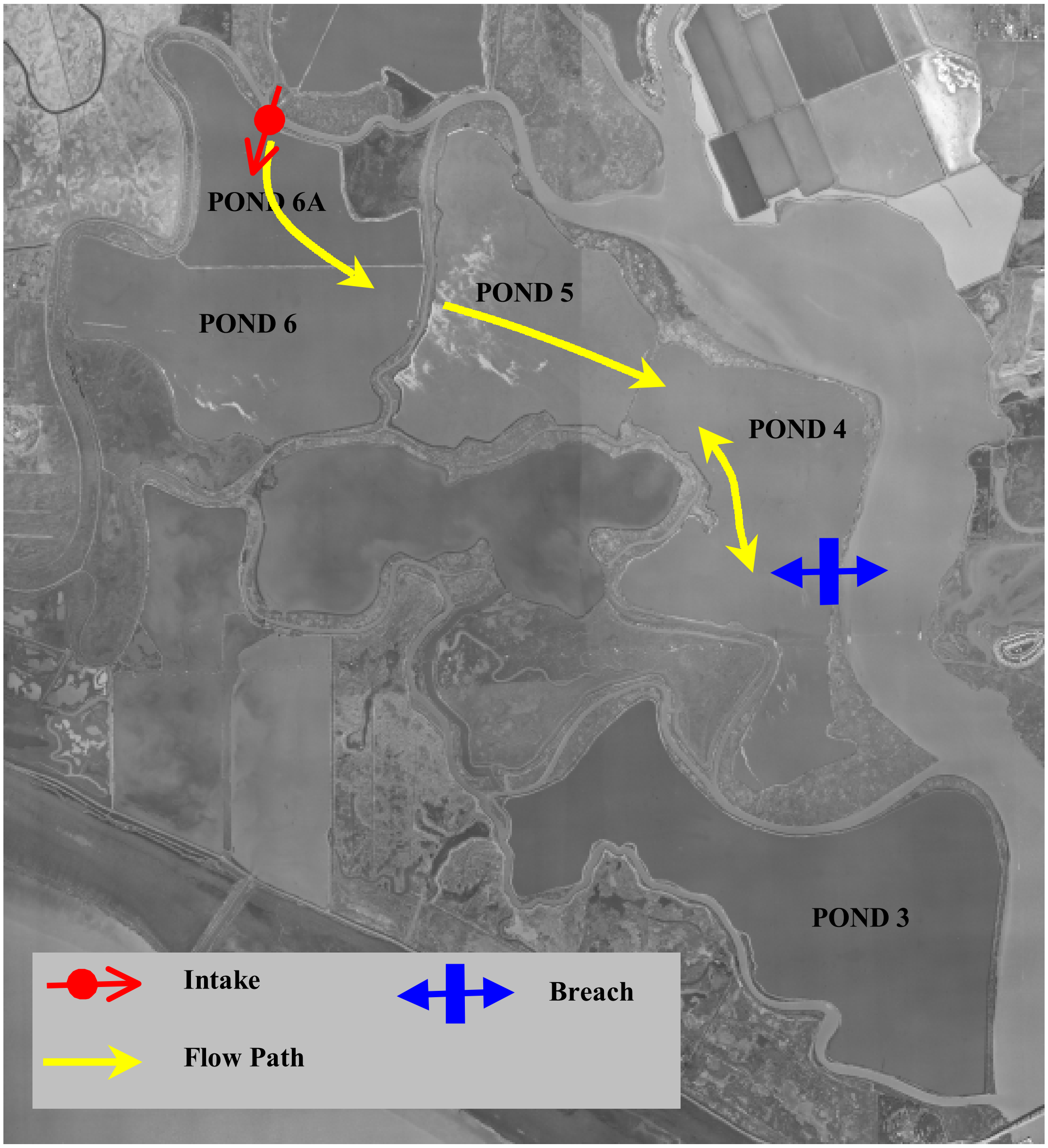

Figure 7 Salinity Reduction Option 1C – Lower Ponds, Phase 2

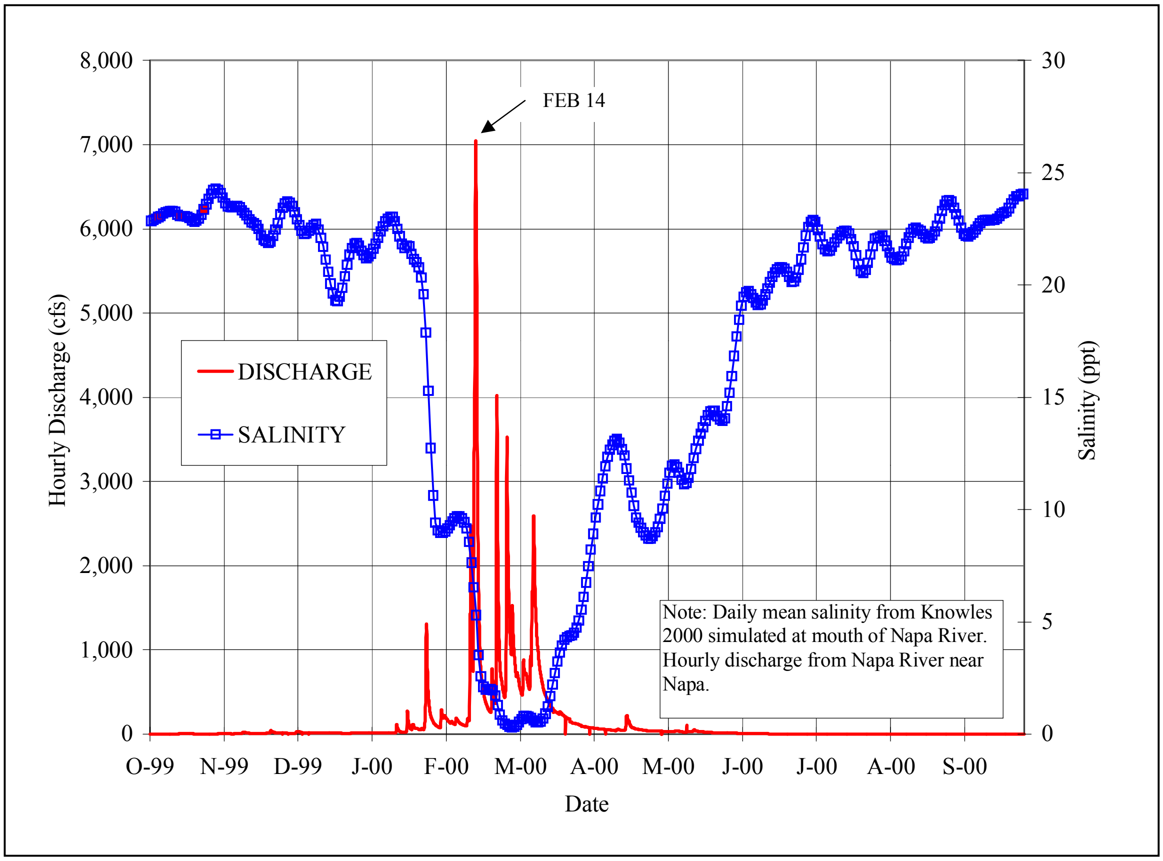

Figure 8 Napa River Streamflow

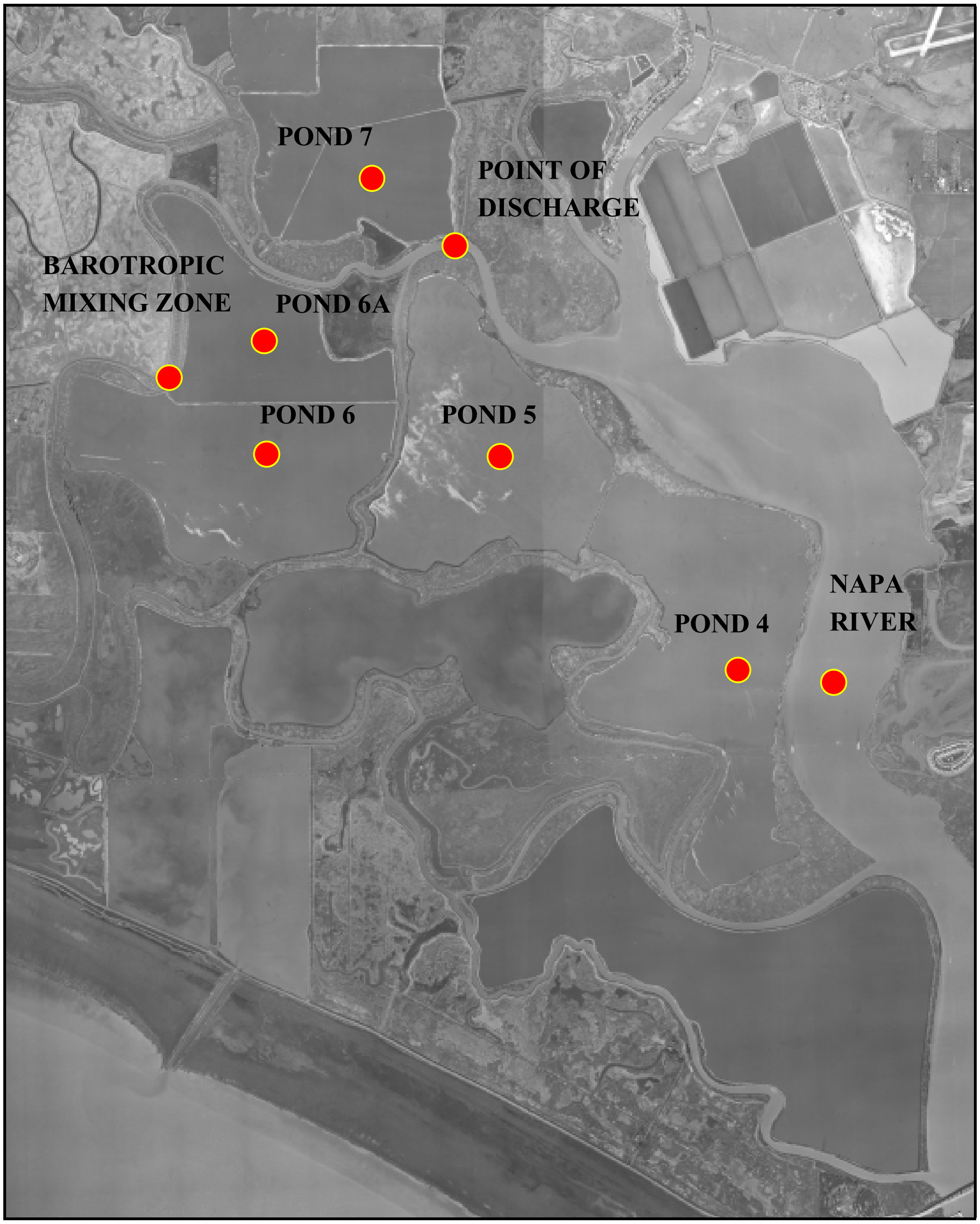

Figure 9 Location Map of Extraction Points

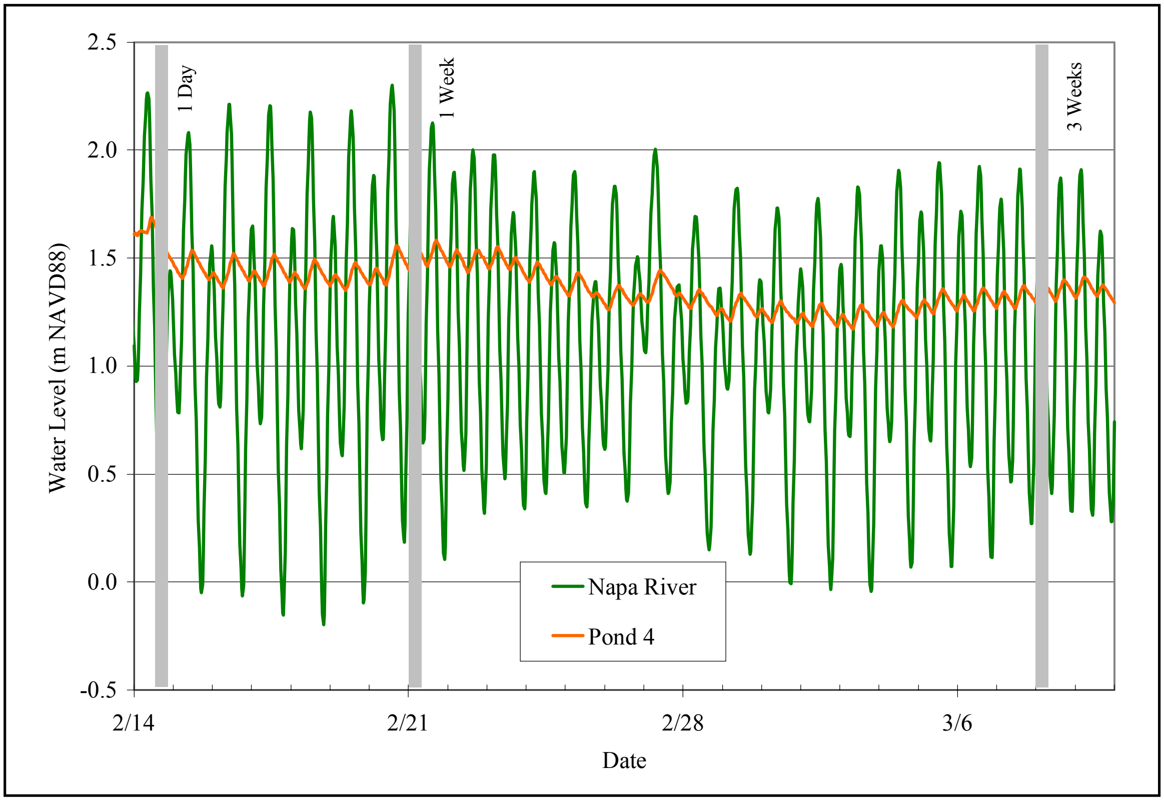

Figure 10 Water Levels in Ponds and River

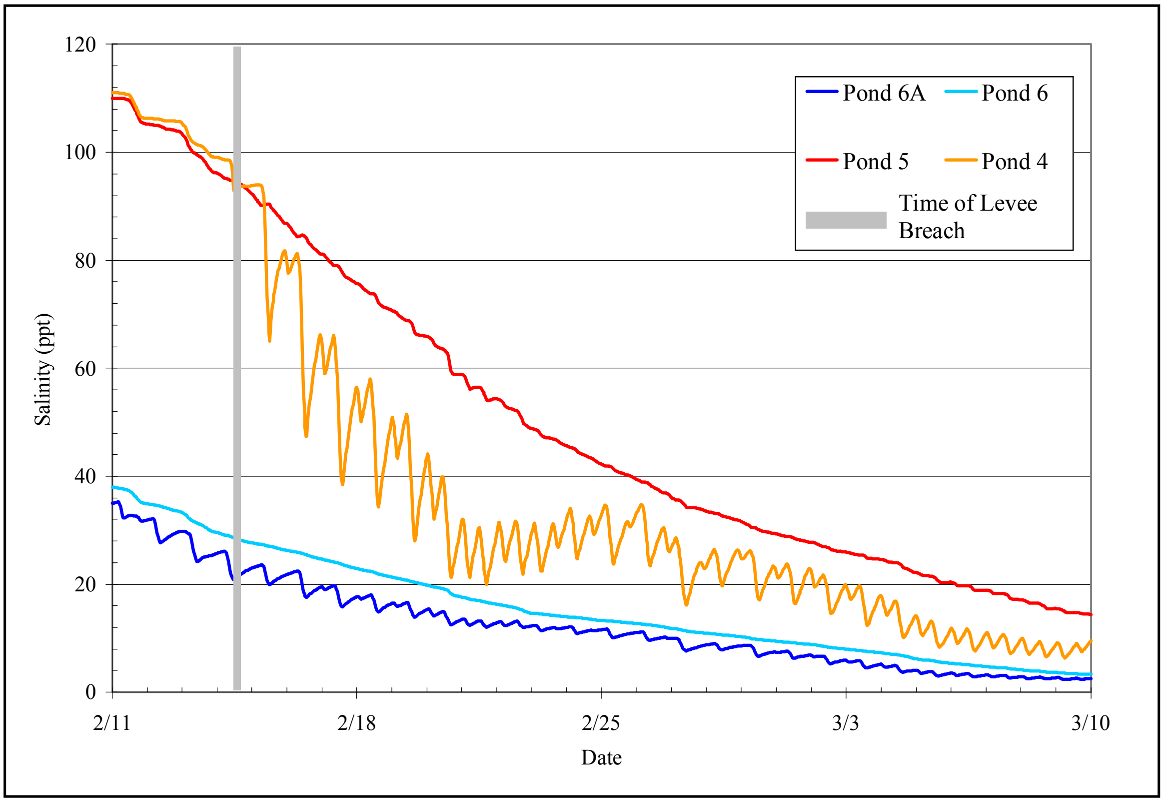

Figure 11 Salinity Reduction in Ponds

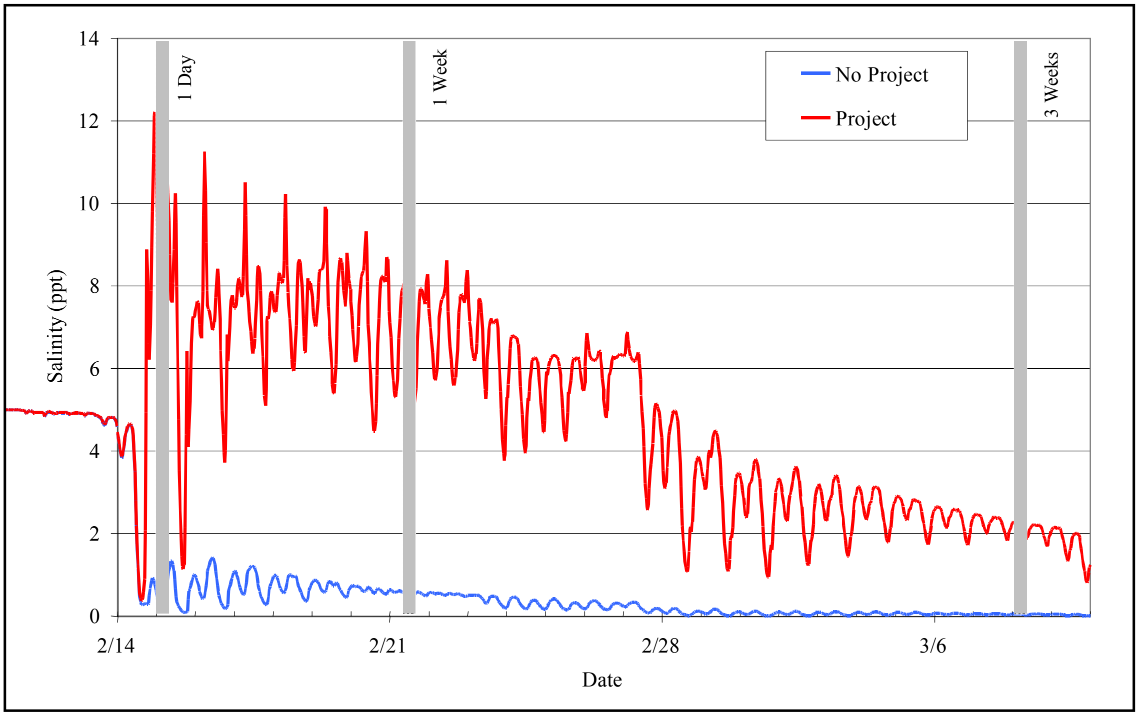

Figure 12 Napa River Salinity at Thalweg near Breach

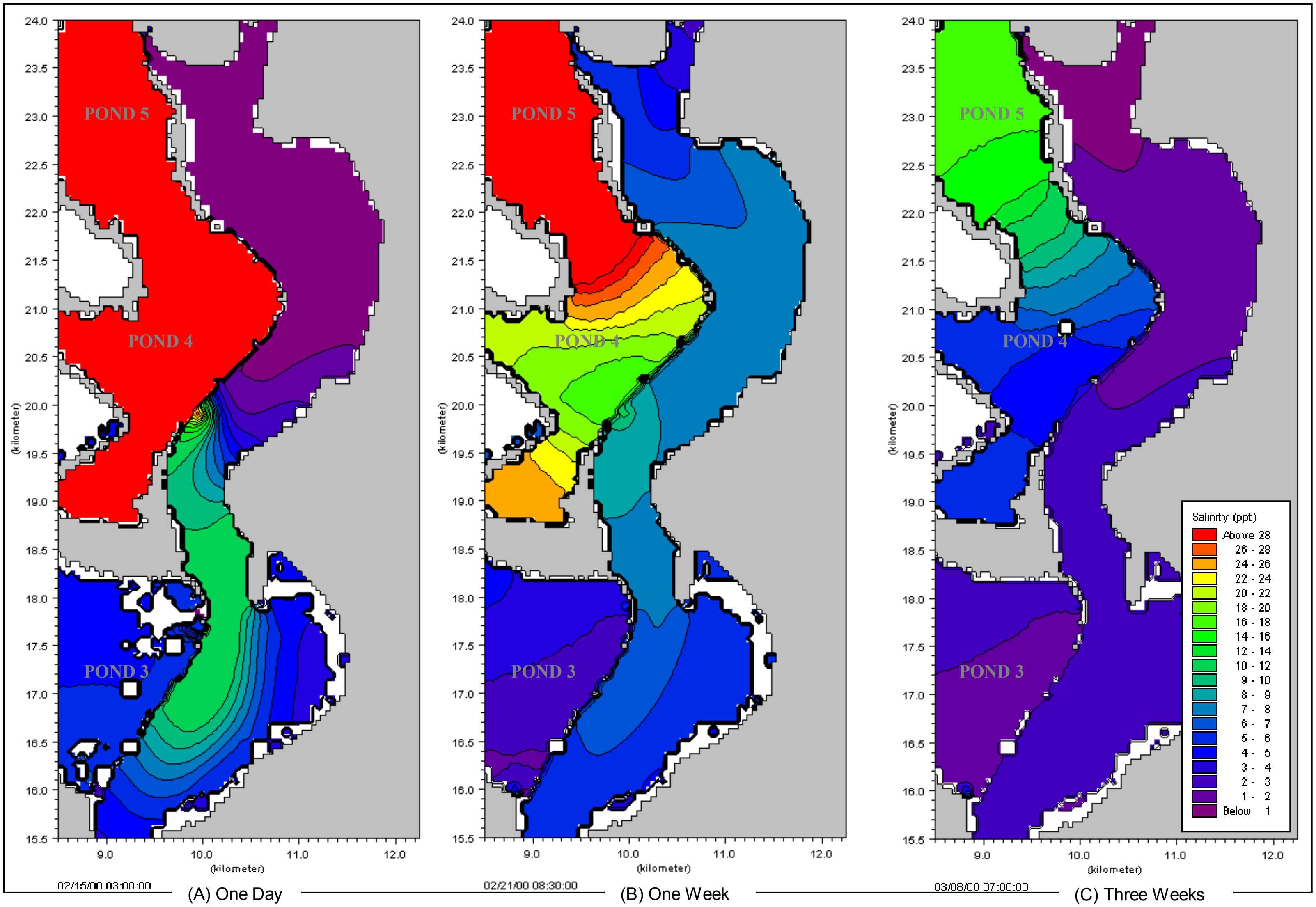

Figure 13 Salinity In Lower Napa River after Breach

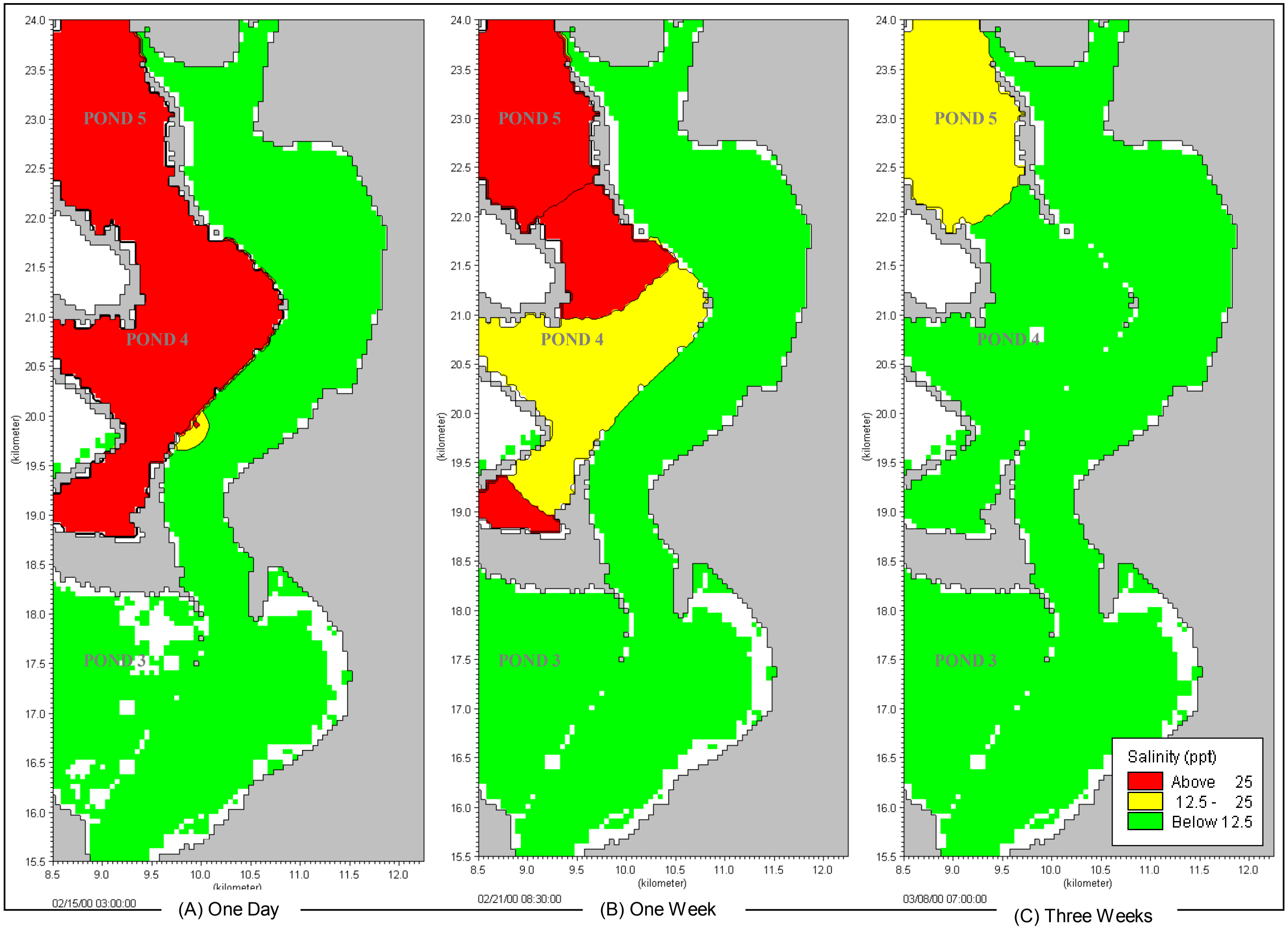

Figure 14 Salinity Tolerance for Steelhead Trout

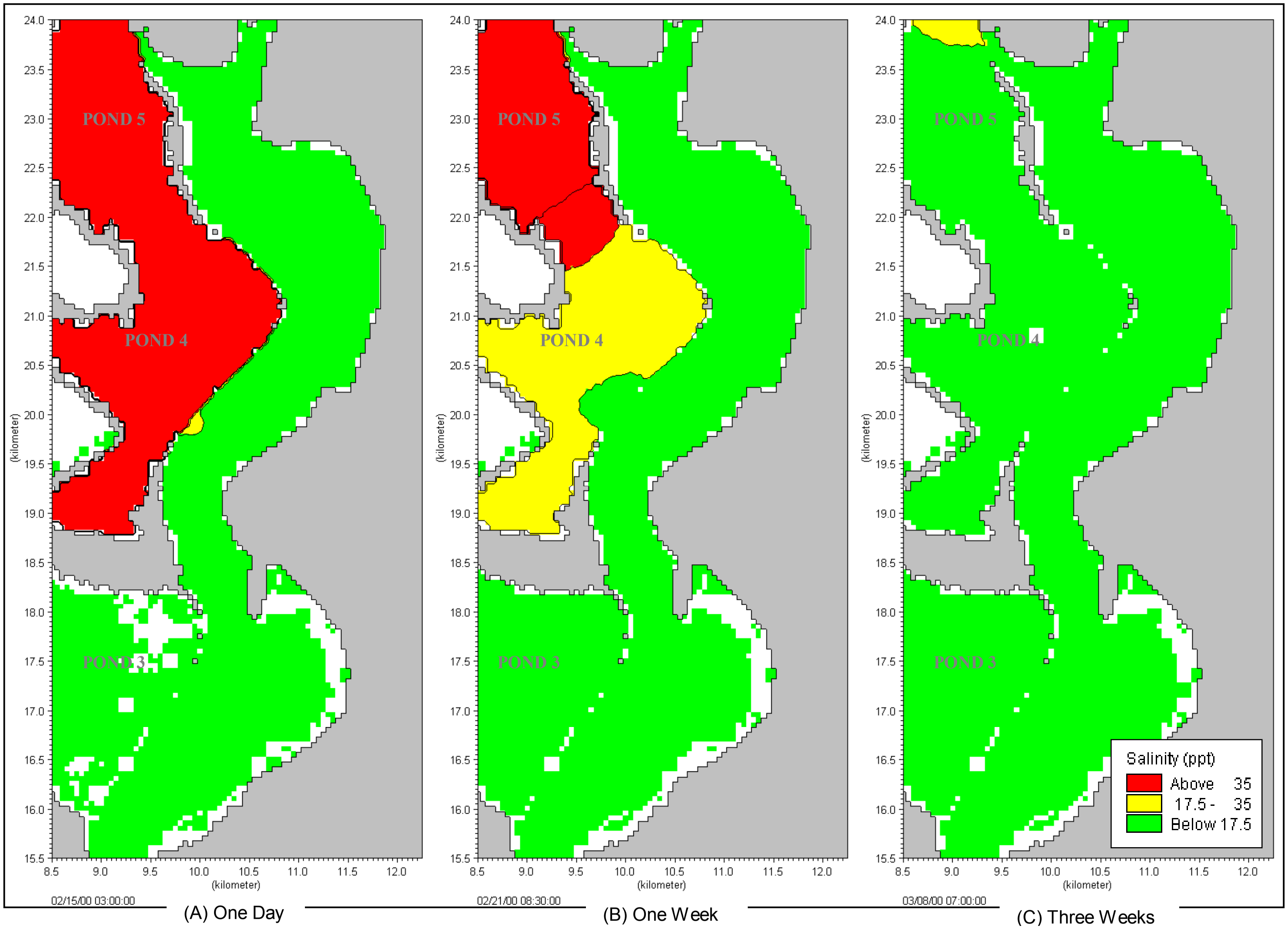

Figure 15 Salinity Tolerance for Striped Bass

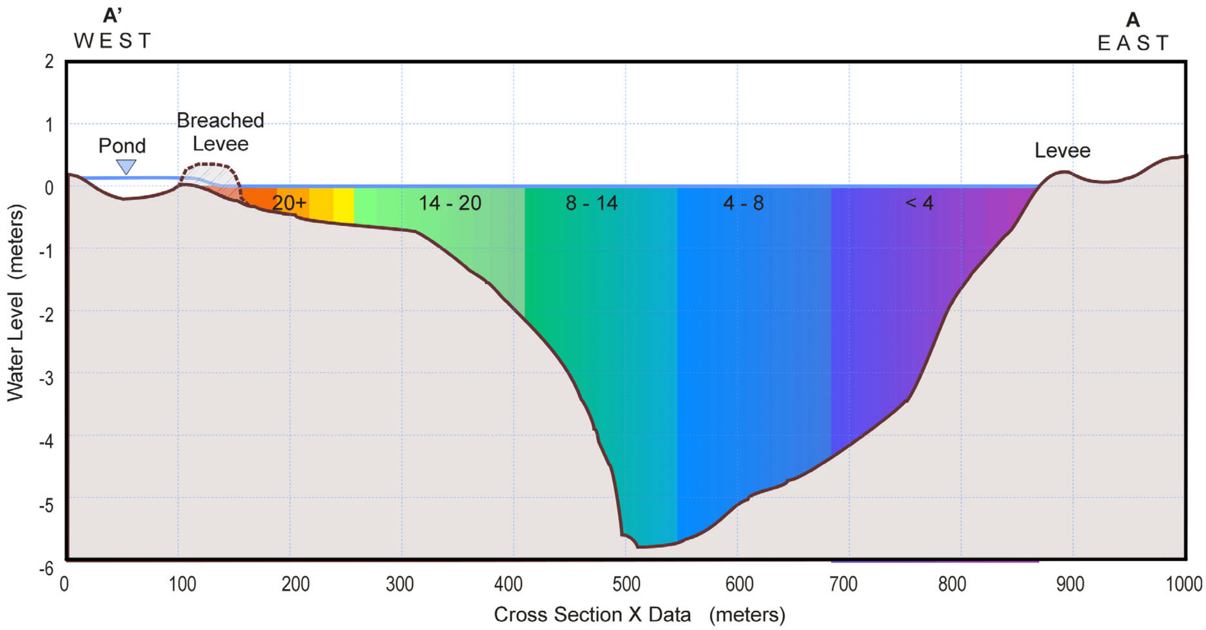

Figure 16 Description of Modeled (Depth-Averaged) Salinity Distribution

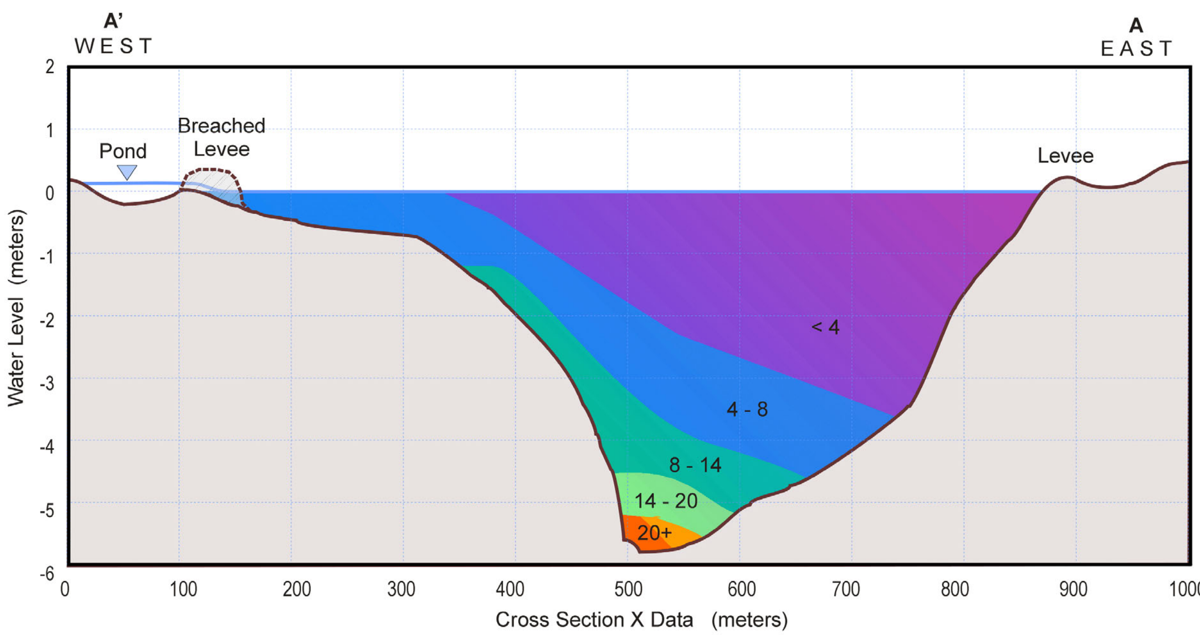

Figure 17 Conceptual Description of Salinity Distribution with Dense Bottom Plume

Figure 18 Location of Downstream Cross-Section

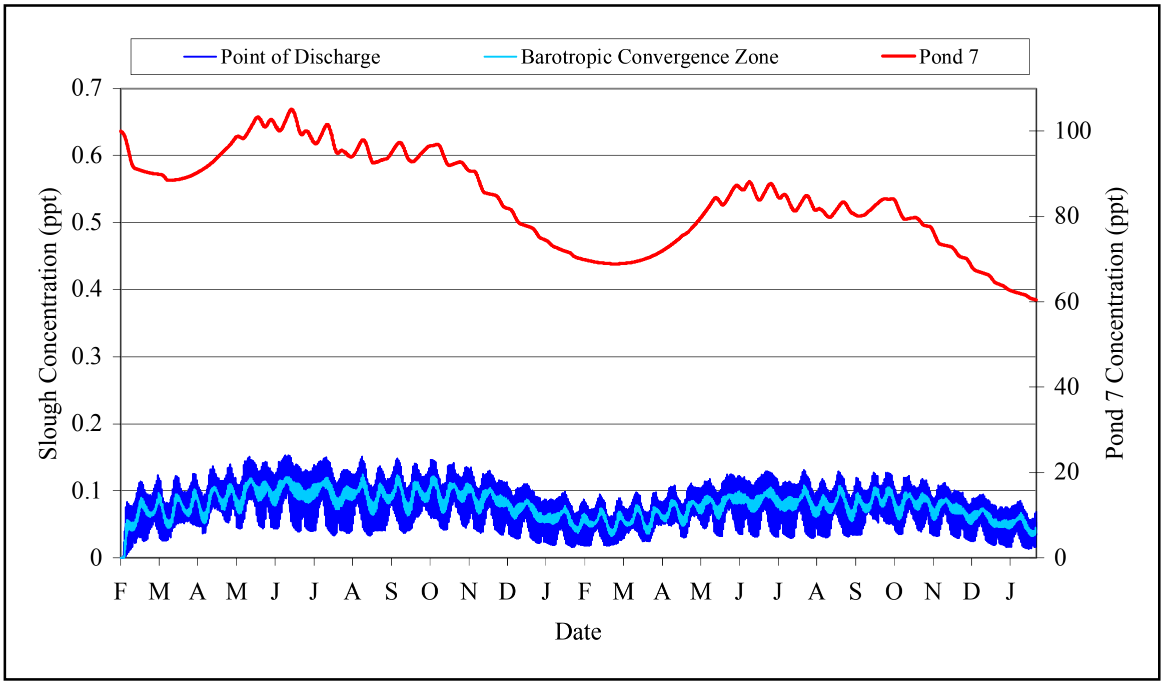

Figure 19 Results from 1:100 Bittern Discharges

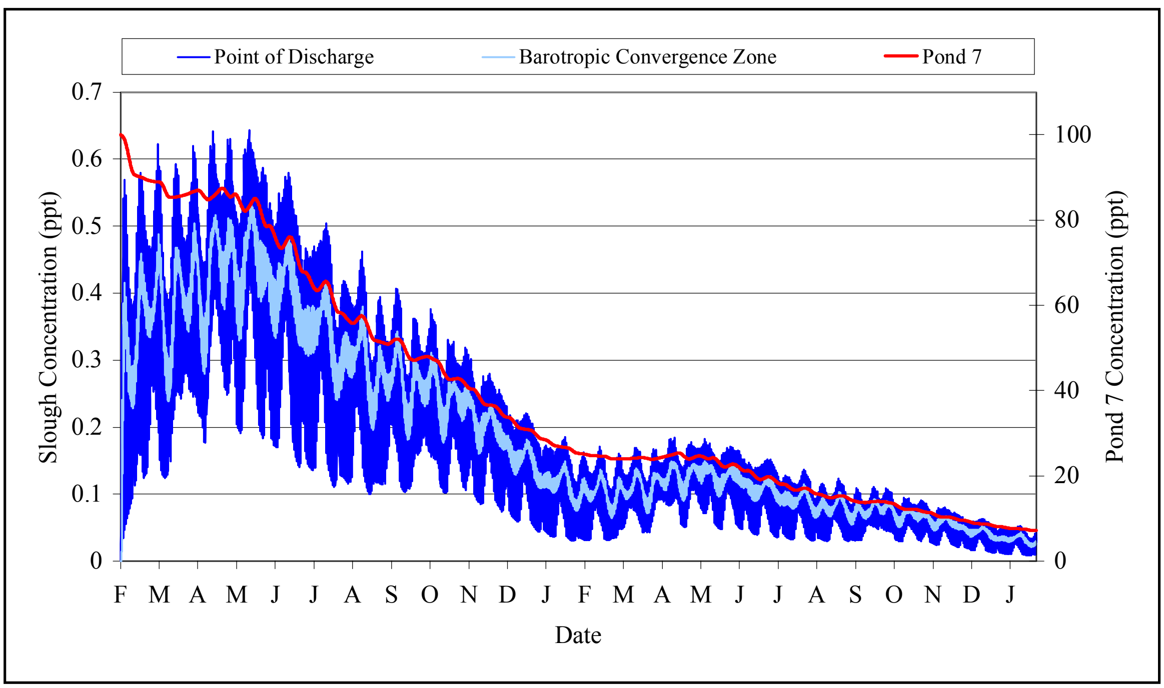

Figure 20 Results from 1:20 Bittern Discharges