POND 7 BITTERN SALINITY REDUCTION DURATION ESTIMATE REPORT

Napa Salt Marsh Restoration Project
Napa-Sonoma Marshes State Wildlife Area, California

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Prepared for:
US Army Corps of Engineers, San Francisco District
333 Market Street
San Francisco, California 94105

Prepared by:

GAIA Consulting, Inc.
2101 Webster Street, 12th Floor
Oakland, California 94612

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1.0 INTRODUCTION AND OVERVIEW

Pursuant to a task order with Eric Polson Consulting (Bittern and Salinity Reduction Time Periods for Pond 7, Napa River Salt Marsh Project), GAIA Consulting, Inc. (GAIA) was tasked with estimating the time required to remove bittern from Pond 7 at the Napa Salt Marsh Restoration Project. This memo describes how the calculations were performed, the assumptions made, the results of the work, and a discussion of the results.

The required information included both the time required to reach a bittern concentration of 5% and 1% of the initial concentration, and the time required to reach salinities of 175, 80 and 50 ppt in the pond, for three different dilution water scenarios. Concentrations of bittern and non-bittern salts are tracked separately because the two types of salinity have vastly different effects on habitat values. Bittern salinity must be below 5% of its initial concentration (15 ppt, given the initial concentration of 300 ppt assumed for these calculations) for habitat values to accrue; habitat values begin to accrue when non-bittern salinity drops below 175 ppt.

The three dilution water scenarios consisted of a base case scenario using no recycled water (Neighboring Waters Scenario, Scenario 1), the "project" case using 5,000 acre-feet/year of recycled water (Project Scenario, Scenario 2) and the "program" case using 15,000 afy of recycled water (Program Scenario, Scenario 3). These three scenarios are described in detail in the Feasibility Report for the project. GAIA developed a Microsoft Excel spreadsheet that calculates the annual salt concentrations (salinities), bittern salt masses, and non-bittern salt masses for Pond 7 for each of the three scenarios.

2.0 ASSUMPTIONS AND SOURCES OF INFORMATION

Two fundamental assumptions and numerous specific assumptions were made in order to conduct the estimate. The first fundamental assumption is that the Upper Ponds (Ponds 7, 7A, and 8) are operated as a unit, as described in the Feasibility Study. For all three scenarios water from Ponds 7A and 8 is mixed with water from Pond 7 in the mixing chamber, and then discharged to Napa Slough. For the Neighboring Waters Scenario, water from Pond 7A is also used as make-up water for Pond 7 (a direct connection from Pond 7 to Napa Slough is avoided to minimize the risk of an accidental bittern spill). In the scenarios including recycled water, the recycled water is first used as make-up water for Pond 7, and the remaining water is added as dilution water into the mixing chamber. The second fundamental assumption is that a constant mass of bittern salts (i.e., solid bittern) can be discharged each year.[1] Thus, as the concentration of the bittern decreases, the volume of liquid bittern discharged increases.

Specific assumptions include the following:

1. The initial bittern concentration is 300 parts per thousand (ppt) (based on Pond 7 April 2002 data documented in GAIA's 2002 Bittern Testing Results [GAIA, 2002]).
2. The depth of the liquid in the pond is 3 feet (the approximate depth noted in April 2002, i.e., the bittern volume that corresponds to the initial bittern concentration) (Wycoff, 2002). Given the size of the pond (306 acres), the total volume in the pond is 918 af. For the purposes of this estimate, this value is also considered the pond capacity, and it is assumed that sufficient make-up water is added each year to maintain the liquid level in the pond at 3 feet.

[1] While there is a bittern solids mass that can be calculated, the concept of bittern as a specific type of material with defined characteristics is not accurate from a strict scientific perspective. Bittern is composed of a variety of mineral salts derived from seawater. These salts have varying solubilities, which means that as bittern liquid becomes increasingly concentrated, the composition of the liquid bittern changes. The composition of the solid bittern salts also changes, as the composition of the precipitating minerals changes with increasing bittern liquid salinity. However, for the purposes of this calculation, working with a defined mass of bittern salts is correct, because all of the bittern is assumed to be in solution. Consequently, bittern can be discharged at a constant mass rate and the bittern mass can be used as a fixed quantity in the calculation.

3. There are no precipitated bittern salts. During physical sampling of the pond bottom sediments in April 2002 there was no discernable evidence of precipitated salts, indicating that at that pond depth and salinity, all bittern is in the dissolved state (GAIA, 2002). This state will be maintained during the salinity reduction process. Currently, the actual depth of the liquid varies with the season, as does the resulting concentration of the bittern liquid and the volume of precipitated bittern salts.
4. The allowable bittern liquid discharge rate at the starting bittern concentration is 1% of the total flow from the Upper Ponds (including recycled water for Scenarios 2 and 3). This concentration is based on a tentative agreement with regulatory agencies resulting from discussions of toxicity data collected in 1993 (SR Hansen & Associates, 1993). There is no formal (written) agreement with the regulatory agencies at this time.
5. The maximum feasible discharge from Pond 7 is equal to the modeled discharge from Pond 7A. This assumption sets the upper bound for the maximum flow from Pond 7 that is physically feasible. This assumption provides a ceiling on the volume of water that can be discharged from Pond 7, and is used as a check on the physical feasibility of the Pond 7 discharges assumed in the bittern reduction estimates. Preferably, flows from Pond 7 should be no more than 50% of the maximum feasible flow (this would result in the discharge from Ponds 7 and 7A coming equally from each pond). Modeled flow rates for the various ponds were taken from references PWA 2002b and PWA 2003b.
6. The average annual net evaporation rate for the project area is 23 inches per year (PWA 2002a), resulting in a total average annual evaporative water loss of 586 af.
7. The average salinity of the make-up water from Hudeman and Mud Sloughs is 15 ppt (in Napa River, the salinity ranges from 0 ppt during high flow events in the winter to 30 ppt in the dry months, [J&S 2003]). The specific gravity of seawater at 15 ppt is 1.012 g/cc or kg/l (CRC, 1978)
8. The maximum allowable change in salinity in the receiving water (Napa Slough) is 5 ppt from ambient. With a minimum estimated dilution factor of 3 (PWA 2003a), the combined discharge from the Upper Ponds should therefore be within 15 ppt of the ambient salinity.[2]
9. At present, the average salinity of Pond 7A is 60 ppt (J&S, 2003). Salinity reduction in Pond 7A will be completed before bittern removal is conducted (i.e., Pond 7A will be at ambient salinity once bittern removal is begun). As shown in the calculations in Appendix A, the estimated salinity reduction time for Pond 7A is approximately 6 months, and is accomplished by mixing water from Pond 7A with water from Pond 8 (which is currently at ambient salinity [Huffman 2004]). We have assumed that salinity reduction in Pond 7A will precede the bittern removal period. This assumption avoids the complexity of calculating a variable flow from the Upper Ponds during the first year of bittern removal. Some bittern could be discharged during this initial period; assuming no bittern is discharged is a conservative assumption increases the estimated bittern removal time.
10. Pond 8 is at ambient salinity (i.e., it is not contributing to the total salt load in the combined discharge [Huffman 2004]). Note that this assumption is different from the initial conditions in the Phase 2, Stage 1 salinity reduction modeling.
11. The average temperature of the ponds and receiving water is 60°F.
12. The ponds are well mixed.
13. The evaporation rate is unaffected by the salinity of the brine.[3]

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[2] The minimum dilution estimate is based on a slack low tide (i.e., when there is minimal water flow in the slough, and water levels in the slough are at low levels). The minimum dilution factor was calculated as a range of 3-6; using the lower end of the range provides for a conservative estimate of the available dilution. In addition, the dilution calculation assumed a heavy plume relative to the receiving water, which would reduce mixing (the dense solution would tend to settle to the bottom of the slough); as shown by the calculations performed for this estimate, if Pond 7A and 8 are at ambient salinities, the discharge will be close to ambient salinity as well.

[3] This assumption is somewhat conservative. Higher salinities actually reduce evaporation rates, so that at a slainity of 300 ppt, the evaporation rate would be approximately 80% of the freshwater evaporation rate. This would result in a net evaporation of approximately 15 inches rather than 23 inches per year, as used in this estimate. Using the actual evaporation that factors in the reduction in evaporation for higher salinities would slightly reduce the amount of salt added to Pond 7 for the Basecase Scenario.

3.0 CALCULATIONS

The estimates are based on relatively simple mass-balance calculations performed on an annual basis. Existing information on flows from the three ponds is limited to annual RMS flows. For simplicity, all estimates were developed using metric units (quantities available in non-metric units were initially converted to metric units, as shown on Table 3 (Initial Conditions Information); however, flowrates provided in Table 2 of this report are also shown in acre-feet per year, as the physical magnitude of that quantity is easier for most readers to grasp. The equations are provided below. Definitions for the various terms and variables are provided in Table 1. The following parameters were tracked separately: mass of water, bittern salts, and non-bittern salts; volume of bittern solution and make-up water; salinity (concentration) of bittern and non-bittern solutions; and total salinity.

Bittern salts and non-bittern salts were treated as conservative parameters (i.e., as separable elements that do not change with changing concentrations). Bittern salts are the salts currently contained in Pond 7; non-bittern salts are the natural seawater salts contained in Ponds 7A, and 8, and in the make-up water from the sloughs. For the purposes of assessing toxicity, treating bittern and non-bittern salts as conservative quantities is appropriate. Increasing the non-bittern salt concentrations relative to the bittern concentrations had little effect in toxicity studies (GAIA, 2002).

The calculations were carried out in 6 steps, as follows. Equations are numbered for ease of reference.

3.1 Step 1

The first step in the calculation was to determine the values of the fixed parameters. There are five fixed parameters:

- Total volume of bittern liquid in Pond 7 at the start of the salinity reduction period (Vbls, 1.135×10^9 liters [L]). Vbls is calculated by multiplying the acreage of Pond 7 by the depth (see assumption 2).

- Total mass of bittern liquid in Pond 7 at the start of the salinity reduction period (Mbls, 1.418×10^9 kilograms [kg]). The mass of bittern liquid was calculated by multiplying the volume of bittern by the specific gravity of the bittern.

- Total mass of bittern salts in Pond 7 at the start of the salinity reduction period (Mbss, 4.25×10^8 kg). The mass of bittern salts was calculated by multiplying the mass of bittern liquid by the bittern concentration (300 ppt, or 30% - see assumption 1).

- Specific gravity of the bittern (sgbs, 1.2494 g/cc). The specific gravity of bittern is calculated from the salinity using the equation by Millero and Poisson provided by Randal (Randal 1997, see Appendix B). This equation provided the closest fit compared to actual data provided in the CRC Handbook of Chemistry and Physics (CRC 1978). As shown in Appendix B, the CRC data is available only for salinities up to 149.5, and therefore cannot be used to estimate specific gravity for higher salinity solutions.

- Specific gravity of the make-up water (sgaw, 1.012 g/cc). The specific gravity for make-up water was also calculated using the formula by Millero and Poisson, to ensure consistency in the calculations.

- Annual mass of salt added to Pond 7 as a result of water lost to evaporation (Msae, 1.09×10^7 kg). The volume of make-up water (7.25×10^8 L) (assumption 6) was multiplied by its specific gravity to determine the total mass of the make-up water each year, including salt. The mass of salt added is simply the total mass of the make-up water multiplied by the concentration of non-bittern salts in the make-up water (15 ppt, or 1.5%, assumption 7).

The last parameter only applies to the Neighboring Waters Scenario. By definition (see assumption 2) Vbls also corresponds to the pond capacity.

3.2 Step 2

The key quantity in the estimate is the amount of bittern salts removed each year (Mbsq). With the constant-mass-discharge assumption used in conducting this estimate, the mass of bittern salts removed from Pond 7 each year is based on the amount that can be removed in Year 1 (refer to assumption 4). The amount that can be removed in Year 1 is the mass contained in the bittern volume corresponding to 1% of the total flow from the Upper Ponds (Vblq). Vblq ranges from 140 afy to 238 afy, in the first year, depending on the scenario (refer to Table 3, Initial Conditions). For the Neighboring Waters Scenario, for example, the mass of bittern salts discharged each year is the mass contained in 1.74×10^8 L (140 af) of bittern liquid with a bittern salt concentration of 300 ppt (concb).

The calculation is a two-part calculation; the mass of bittern liquid removed (Mblq) is calculated first by multiplying the volume of the bittern liquid by its specific gravity (sgbs), and then the mass of bittern salts contained in the bittern liquid is calculated.

(1) Mblq= Vblq*sgbs
(2) Mbsq = Mblq*concb

The mass of bittern that can be removed each year ranges from approximately 65,000,000 kg (approximately 72,000 tons) for the Neighboring Waters Scenario to approximately 110,000,000 kg (approximately 120,000 tons) for the Program Scenario. The mass of bittern salts removed each year for each scenario is shown Tables 4 and 5 for the Neighboring Water Scenario and Recycled Water Scenarios, respectively.

Steps 1 and 2, combined with the information on initial conditions (including modeled pond flows), provide all the information required to calculate the changes in the Pond 7 bittern concentration over time.

3.3 Step 3

In Step 3, the changing parameters are calculated and are used to determine the conditions at the end of the calculation (year), which become the starting conditions for the next calculation (year). As a simplifying assumption, the conditions existing at the start of each calculation cycle (year of discharge) are assumed to apply through the entire year. For example, the initial bittern salt concentration of 300 ppt and non-bittern salt concentration of 0 ppt in Pond 7 are assumed to occur throughout the first year. The implications of this simplifying assumption are discussed in Section 5.

Step 3a – Determine Mass of Bittern and Non-Bittern Salts Remaining at End of Year

To determine the concentration of the bittern in Pond 7 at the end of a given year, we must calculate the mass of bittern salts remaining at the end of the year (Mbsrem), by subtracting the mass of bittern salts removed (Mbsq, see calculation in Step 2) from the mass of bittern salts at the start of the year (Mbss).

(3) Mbsrem = Mbss – Mbsq

In addition, for the Neighboring Waters Scenario we have to calculate the amount of non-bittern salts in the pond (Msnew). The initial mass of non-bittern salts in Pond 7 is 0 kg. Non-bittern salts are added with the make-up water, and are discharged with the brine removed from Pond 7. Thus, Msnew is equal to the amount of non-bittern salts added as a result of make-up water (Msa) and make-up water lost to evaporation (Msae), less the amount of salt removed with the bittern (Msq). The mass of salt added with the make-up water is equal to the mass of make-up water added to bring the pond back to its initial capacity (Mwa) multiplied by the concentration of non-bittern salts in the make-up water (concsa). Mwa is calculated by multiplying the volume of make-up water added (Vwa) by the specific gravity of the make-up water (sgaw). The mass of salt added due to evaporative water losses (Msae) was calculated in Step 1 and is a fixed quantity each year.

(4) Mwa = Vwa*sgaw
(5) Msa = Mwa*concsa
(6) Msnew = Msa+Msae-Msq

Step 3b – Determine Volume of Water Added to Replace Bittern Liquid Removed, and Concentration and Density of Brine at End of Year

To calculate the concentration of the bittern liquid remaining in the pond (our measure of toxicity and desired output from the calculations), we must calculate the amount of water added (Vwa) to replace the volume of liquid removed. However, we cannot assume that Vwa is equal to the volume of liquid removed initially, because the high salinity in Pond 7 may lead to density effects as the solution is diluted. Thus Vwa must be determined by an iterative process.

Vwa was estimated as a percentage of Vblq; the initial estimate was set at Vwa = Vblq. The estimated volume of water added (Vwa) was then used to calculate the concentration (salinity) of the new solution. The concentration of the solution was used to calculate the density of the solution, and the known mass and density were used to calculate the new volume in Pond 7 (Vnew) based on the assumed input of water (Vwa). If Vnew was $1.135x10^9 \pm 0.001x10^9$ (i.e., approximately the pond capacity), the estimate of Vnew was considered acceptable, and the calculations conducted for the next year. If Vnew was greater than or less than the acceptable range, Vwa was adjusted accordingly, and the calculations performed again. The iteration for Vwa was performed by manually adjusting the value of Vwa as a percentage of the bittern liquid removed (Vblq). Vwa ranged from 98% to 102% of Vblq (i.e., there was only a small effect of specific gravity on volume). The calculation steps are described in detail below.

Concentration of the Brine at End of Year

The concentration in the solution at the end of the year consists of the mass of bittern liquid remaining in the pond (Mblrem), plus any non-bittern salts remaining (Msrem) and/or added to the pond (Msa+Msae), divided by the total mass (Mt) in the pond. Non-bittern salts are only present in Pond 7 with the Neighboring Waters Scenario. The total mass in the pond consists of the mass of bittern liquid remaining, the mass of any non-bittern salts added, and the mass of any water added. The concentrations of bittern, non-bittern salts, and total salinity were calculated using the following equations. For the recycled water case, the bittern salinity is equal to the total salinity.

For recycled water (zero salinity in the make-up water):

(7) Mblrem = Mbsrem + Mwrem
(8) Mt = Mblrem + Mwa
(9) concbnew = Mbsrem/Mt

For ambient water (15 ppt salinity in the make-up water)

(10) Mblrem = Mbsrem + Mwrem
(11) Msnew = Msrem+Msa+Msae
(12) Mt = Mblrem + Mwa + Msnew
(13) concbnew = Mbsrem/Mt
(14) concsnew = Msnew/Mt
(15) conctnew = (Msnew + Mbsrem)/Mt

All concentrations were converted to ppt for presentation in Tables 4 and 5.

Density of New Solution
Using the bittern salinity or total salinity calculated above as appropriate, the equation from Robert E. Randal's *Elements of Ocean Engineering* (Randal, 1997), shown below, was used to calculate the specific gravity of the new diluted bittern solution (sgnew).[4]

(16) ρ (equivalent to sgnew) = 999.842594+0.06793952*T-0.00909529T^2+0.0001001685*T^3-0.000001120083T^4+ 0.000000006536322*T^5+0.824493*S-0.0040899*T*S+0.000076438*T ^2*S-0.00000082467*T^3*S+0.0000000053875*T^4*S-0.00572466*S^1.5+0.00010227*T*S^1.5-0.0000016546*T^2*S^1.5+0.00048314*S^2)/1000

where:
T = temperature in degrees C
S = salinity in ppt (S = concbnew for Recycled Water Scenarios, S = conctnew for Neighboring Waters Scenario)

The specific gravity of the diluted bittern solution is then used to calculate the volume of the new solution, and determine whether the initial estimate of Vwa was correct.

(17) Vnew = (sgnew/Mt)

As stated above, Vnew was compared to the capacity of the pond (1.135×10^9 L). If Vnew is $1.135 \times 10^9 \pm 0.001 \times 10^9$, the estimate of Vnew is considered acceptable, and the calculation begins for the next year.

Completing Step 3 completes the calculations for the given year.

3.4 Step 4

The final step for each year's calculations is to determine whether the discharge flow from Pond 7 is physically feasible, and whether the combined flow from the Upper Ponds is within the acceptable range for total salinity.

Step 4a. Compare Vnew to the allowable flow from Pond 7. If Vnew is $\leq$ 50% of the estimated Pond 7A flow (refer to Table 3), Vnew is acceptable relative to the physically feasible discharge rate. (As shown in Tables 4 and 5, in all cases Vnew was well below 50% of the maximum possible flow from Pond 7.)

Step 4b. Estimate the salinity of the discharge, based on fractional salinities of the various streams entering the mixing chamber (as noted in the assumptions, Ponds 7A and 8 are assumed to be at ambient conditions, and their salinities were therefore set equal to the ambient water salinity).

Recycled Water Scenario
(18) concd = ((Vrw*concrw)+(Vp8+Vp7A)*concwa)+(Vblqnew*concbnew))/(Vrw+Vp7A+Vp8+Vblqnew)

Neighboring Waters Scenario
(19) concd = ((Vp8+Vp7A)*concwa)+(Vblq*concbnew))/(Vrw+Vp7A+Vp8+Vblq)

The values of Vrw and Vp8 are based on the initial conditions for the various scenarios, and are fixed values (i.e., it is assumed that neither the flow of recycled water nor the flow of water from Pond 8 is affected by how the total Pond 7 plus 7A discharge is split between Ponds 7 and 7A). The value of Vp7A is the difference between the combined Pond 7 plus 7A discharge (as defined by the initial conditions), and the flow

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[4] The output from the formula was checked against data provided in the CRC Handbook by Mr. Peter Mull of the San Francisco District (see Appendix B – Salinity and Specific Gravity Correlations), and was found to provide the best correlation.

from Pond 7 as calculated for the given year. The estimated salinity of the discharge was calculated for both summer (25 ppt ambient water salinity) and winter (5 ppt ambient water salinity) conditions.

3.5 Step 5

To begin the calculations for the following year, we must calculate the volume of bittern liquid that will have to be removed to ensure our mass removal criterion is met. To calculate the required volume, we divide the required mass removal by the specific gravity of the solution. For the Neighboring Waters Scenario, we also have to compensate for the effects of the non-bittern salt salinity on the specific gravity. The bittern salt concentration is divided by the total salt concentration to ensure that the correct mass of bittern is removed.

Recycled Water Scenario
(20) Vblqnew = (Mbsq/sgnew)

Neighboring Waters Scenario
(20) Vblqnew = (Mbsq/sgnew)*(concb/conct)

3.6 Step 6

Given that Vnew is acceptable based on salinity and flow criteria as verified in Step 5, calculate Mbsrem, estimate Vwa, calculate concbnew, concsnew, conctnew, sgnew, and Vnew for the new year as per Steps 3 to 5 above. Repeat Steps 3 through 5 until the mass of bittern salts remaining (Mbsrem) is less than the annual mass of bittern salts removed (Mbsq). For the last round of calculations (the last year of salinity reduction), set Mbsq equal to Mbsrem at the end of the previous year.

4.0 RESULTS AND DISCUSSION OF RESULTS

Based on the calculations conducted and summarized in Table 2 bittern and non-bittern salinity reduction would occur within 4 to 8 years, depending on the scenario selected. In all cases, bittern salinity targets of 5% of initial concentration and 1% of initial concentration are achieved in the same year. Table 2 shows the estimated duration for bittern salinity reduction and total salinity reduction for the three scenarios. For all of the scenarios, the total flow from Pond 7 would be less than 50% of the RMS flow calculated for Pond 7A in references PWA 2002b and 2003b. In addition, with exception of Year 4 summer salinity for the Program Scenario, the estimated salinity in the discharge is within 15 ppt of the ambient salinity; thus the discharge salinity is within the acceptable range, assuming a dilution factor of 3 in the near-field. Because the dilution factor in the near-field is typically greater than 3, the Year 4 discharge is also likely to be within permit tolerance. Thus, bittern and salinity reduction is feasible at the stated rates (i.e., required flows from Pond 7 are within physically reasonable and permissible ranges). If necessary, the volume of recycled water discharged in Year 4 could be reduced slightly to ensure that salinity thresholds are met; bittern removal would still be accomplished within the stated time period, as sufficient pre-dilution of the remaining bittern would still be provided.

If ambient water is used as make-up water (i.e., for the Neighboring Waters Scenario), some non-bittern salt buildup occurs in Pond 7. This build-up continues until the mass of salt discharged from Pond 7 exceeds the annual mass added due to net evaporation from the pond. Because the concentration of non-bittern salts in Pond 7 increases beyond the average ambient concentration, the concentration of non-bittern salt in Pond 7 will begin to decrease before the flow from Pond 7 equals the annual net evaporation. Based on the calculations performed for the Neighboring Waters Scenario, the non-bittern salinity in Pond 7 will still be slightly above ambient conditions (26.4 ppt versus 15 ppt) once the bittern has been removed from Pond 7 in Year 7. Pond 7 can be brought to ambient salinity very rapidly by flushing it once or twice towards the end of Year 7 or in Year 8.

5.0 ERRORS AND UNCERTAINTIES

Some error has doubtlessly been introduced into the estimate due to the need to make simplifying assumptions and use available information. The following factors were considered in evaluating the potential for significant errors that could result from simplifying assumptions.

5.1 Annual Bittern Discharge Estimate

Rate of Bittern Removal. Estimates of the mass of bittern discharged each year are based on the initial concentration of bittern in the pond. However, the bittern concentration in the pond decreases continuously, so the discharge volume calculated would not in fact result in the stated mass of bittern being removed (discharged). If the discharge flow from Pond 7 is not adjusted to compensate for the decreasing bittern concentration, the time required to complete the bittern removal effort would increase. During the initial years, annual flows do not change very much (e.g., increase from a Year 1 rate of 140 afy to 165 afy in Year 2 to 202 afy in Year 3 for the Neighboring Waters Scenario), but this effect becomes more pronounced as the bittern concentration becomes more dilute.

From a physical/operational perspective, this issue is easily addressed by simply periodically adjusting the gates on the discharge pipe to allow a slightly higher flow rate. During the later stages of the salinity reduction process, more frequent adjustments of the discharge rate may be required. Alternatively, the discharge gate could be automated, and the discharge rate adjusted based on an algorithm that considers pond level, incoming water volumes and salinities, and overall rate of salinity reduction.

Non-Bittern Salt Accumulation. The annual flow estimates also affect the projected rate of non-bittern salt accumulation for the Neighboring Waters Scenario. As described above, using the initial salinity at the start of each year results in a discharge estimate that is somewhat lower than the actual discharge estimate required to remove the target bittern mass. The rate of non-bittern salt accumulation, however, is in part a function of the fixed evaporation rate. The mass of non-bittern salt added therefore includes a fixed quantity each year in addition to any salt mass brought in with the water that replaces the discharged brine. Given a fixed annual input of non-bittern salts, higher flow rates would result in faster salt removal.

5.2 Seasonal Effects

Non-Bittern Salt Accumulation. The estimate assumes that the average salinity of slough water brought in as make-up water is 15 ppt. This may understate the actual mass of non-bittern salts entering the ponds, because more make-up water is required in the summer, when slough salinities and monthly evaporation rates are greatest. Also, during the dry season salinities in the sloughs may be slightly higher than river salinities.

Another seasonal effect results from the lower tides in the summer months. This may limit the amount of water that can be brought into the ponds in the summer months, and would therefore reduce the amount of non-bittern salts entering the pond (i.e., by ignoring this seasonal effect, the volume of water and the associated non-bittern salt mass brought into the ponds during the summer months may be overstated).

These two effects result in, respectively, a higher input of non-bittern salts, and a lower input of non-bittern salts than the input calculated as part of this estimate. It is unlikely that the total error would be sufficient to affect the habitat valuation with respect to the total non-bittern salt concentration. The total non-bittern salt concentration would have to increase to more than 50 ppt to result in a reduction in habitat value; this represents an increase of more than 40% over the maximum concentration calculated in this estimate. Furthermore, even if the total non-bittern salinity exceeds 50 ppt for a short period of time, the effect on habitat units, which are calculated over a 50-year period, would be negligible.

Permissible Discharge Concentration. The third seasonal effect pertains to the permissible discharge concentration. Receiving water salinity can drop very rapidly during the winter months (i.e., from near summer highs to near winter lows in several days during a large storm event). In that case the assumption made in this estimate that Pond 7A and 8 do not contribute any salt mass to the discharge relative to ambient conditions would not hold true (i.e., the ponds would still have near summer salinities, and the receiving water would be at winter salinity). In that case, the combined discharge could temporarily have a total salinity that is more that 15 ppt above ambient conditions. The higher rates of zero-salinity recycled water delivery in the Program Scenario would alleviate this concern; for the scenarios, salinity monitoring would have to be conducted to ensure that permit compliance is maintained during sudden changes in the salinity of the receiving water.

5.3 Variations in Annual Precipitation

This estimate does not take into consideration the natural annual variation in rainfall. If the project area should experience a period of drought, the time required to accomplish bittern and salinity reduction under the Neighboring Waters Scenario would increase, as the amount of make-up water required and the salinity of the make-up water would be both be adversely affected (the volume of make-up water required and its average salinity would both increase). In addition, the volume of make-up water available may be reduced, if the drought is severe and diversions from the local sloughs are restricted.

A period of drought may or may not affect the time required for bittern reduction under the recycled water scenarios. Currently, the proposal is for the water agencies to guarantee a minimum volume of recycled water to the project; this would mean that the bittern reduction period would be largely unaffected. The percentage of recycled water lost as evaporation make-up water to Pond 7 would increase slightly; however, the total average evaporative water loss is only 12% of the available recycled water volume under the Project Scenario, and 4% under the Program Scenario. Increasing the required volume of make-up water even 50% would only have a negligible effect on the bittern reduction period. A more substantial effect would result if some of the available recycled water is diverted to other more urgent needs (e.g., during a severe drought, the recycled water could be diverted to agriculture on an emergency basis).

A series of wet years (e.g., back-to-back el Niño events) could reduce the time required for non-bittern salinity reduction for the Neighboring Waters Scenario. The ambient water would have a lower salinity than during average water years, and less make-up water would be required to compensate for evaporation, leading to less non-bittern salt build-up in Pond 7. A series of wetter years would have little effect on the bittern reduction period for the Neighboring Waters Scenario unless the total flow through the Upper Ponds is increased. The net bittern mass discharge/flow from Pond 7 could not be increased unless the water flow from Ponds 7A and 8 is also increased. If Ponds 7A and 8 are kept at higher than normal water levels, and the total flow to the mixing chamber increases and the allowable bittern mass discharge rate from Pond 7 would increase. In this case, the time required for bittern reduction would decrease. However, this scenario is unlikely, as keeping ponds more full than typical during an el Niño year would increase the risk of flooding from the ponds.

A series of wet years may decrease the time required for bittern reduction for the Project and Program Scenarios. During the wetter years, the water agencies may increase the amount of recycled water made available to the project, if there is no other demand for the water. The total flow through the Upper Pond system would increase, and the allowable mass discharge of bittern would increase by a corresponding amount.

The probability of wet or dry years occurring during the bittern/salinity reduction period cannot be predicted, and using the average annual rainfall and evaporation rates as the basis for the estimate is the most appropriate approach.

6.0 REFERENCES

CRC. Date. (CRC 1978). Handbook of Physics and Chemistry, 59th Edition. Page D-296, Table 63, D-265, Definitions.

GAIA Consulting, Inc. 2002. (GAIA 2002). Bittern Toxicity Testing Results, Ion Composition of Bittern, and Sediment Salinity Data. September. - Page 1 and Table 1, *Anion/Cation and Salinity Concentrations in Water, Ponds 7 & 8, Napa Salt Marsh.*

Huffman, Tom. 2004. (Huffman 2004). Email. Subject: Salinities 1/16/04.

Jones & Stokes. 2003. (J&S 2003). Napa RiverSalt Marsh Restoration Project Draft Environmental Impact Report/Environmental Impact Statement. April. - Fig. 2-3, *Salinity Ranges and Pond Elevations*.

Robert E. Randal. 1997. (Randal 1997). Elements of Ocean Engineering. Page 19.

Phillip Williams and Associates. 2002. (PWA 2002a). Napa-Sonoma-Marsh restoration Feasibility Study – Hydrodynamic Modeling Analyses of Existing Conditions – Phase I Report. March. - Fig. 5-10, *Comparison of Evaporation from CIMIS and Cargill, Monthly Averages for 1993-2001*.

Phillip Williams and Associates. 2002. (PWA 2002b). Spreadsheet Showing Draft Estimate of Water Discharge Rates for 15,000 afy Recycled Water Case. May. Page 1.

Phillip Williams and Associates. 2003. (PWA 2003a). Napa Salt Ponds Phase 2 Stage 2 Salinity Reduction Modeling, CORMIX Modeling Technical Note. May. - Table 5.1, *Results of Initial Dilutions at Pond 4* and Table 5.2, *Results of Initial Dilutions at Upper Ponds*.

Phillip Williams and Associates. 2003. (PWA 2003b). Memorandum to Susanne von Rosenberg: Estimated Discharge Rates for Upper Ponds. October.

Wycoff, Larry. 2002. (Wycoff 2002). Telephone conversation between Mr. Larry Wycoff and Ms. Susanne von Rosenberg, Subject: Pond Conditions During Bittern Sediment Sampling. June.

TABLES

TABLE 1 – DEFINITION OF TERMS

Term	Definition
ρ	Density of the brine (grams/cubic centimeter or kilograms/liter)
bittern salts	Salts found in Pond 7 (salts remaining after sodium chloride has been harvested)
non-bittern	Salts found in Ponds 7A and 8, and surrounding sloughs – standard composition of sea salt.
concb	Pond 7 bittern salinity in ppt, (concb is 300 ppt in Year 1)
concd	Salinity of combined discharge from Upper Ponds
concs	Pond 7 non-bittern salinity in ppt, (concs is 0 ppt in Year 1)
concsa	Ambient (slough) water salinity in ppt (a constant value of 15 ppt)
conct	Pond 7 total salinity in ppt; (conct is 300 ppt in Year 1)
concbnew	Bittern salinity in ppt, new (at end of year)
concsnew	Non-bittern salinity in ppt, new (at end of year)
conctnew	Total salinity in ppt, new (at end of year)
Mblq	Mass of bittern liquid removed
Mblrem	Mass of bittern liquid remaining (Mblrem = Mbls – Mblq following Year 1; $Mblrem_{year(n+1)}$ = $Mblrem_{year(n)}$ – Mblq thereafter)
Mbls	Mass of bittern liquid, starting (initial mass in pond); Mbls = 1.418×10^9 kilograms
Mbsq	Mass of bittern salts removed (depends on the volume of dilution water initially available).
Mbsrem	Mass of bittern salts remaining (Mbsrem = Mbss – Mbsq following Year 1; $Mbsrem_{year(n+1)}$ = $Mbsrem_{year(n)}$ – Mbsq thereafter)
Mbss	Mass of bittern salts, starting (initial mass in pond); Mbss = 4.25×10^8 kg
Msa	Mass of non-bittern salts added (consists only of the mass added with make-up water used to bring the pond back up to the initial volume; this term does not include the salt added with water used to compensate for evaporation). This factor applies only to the Neighboring Waters Scenario.
Msae	Mass of non-bittern salts added with water used to compensate for evaporation; Msae = 1.09×10^7 kg. This factor applies only to the Neighboring Waters Scenario.
Msnew	Mass of non-bittern salts, new (at end of year). Msnew = Mss+Msae+Msa following Year 1; $Msnew_{year(n+1)}$ = $Msnew_{year(n)}$ +Msae+Msa-Msq thereafter. The initial non-bittern salt mass in Pond 7 is 0 kg.
Msq	Mass of non-bittern salts removed
Mss	Mass of non-bittern salts, starting
Mt	Total mass in pond (Mt = Mbsrem+Mwr+Mwa+Msa+Msae)
Mwa	Mass of water added (make-up water added to bring the pond back up to the initial volume; this term does not include the water added to compensate for evaporation)
Mwq	Mass of water removed
Mwrem	Mass of water remaining
Mws	Mass of water, starting (initial mass of water in the pond)
sg	Specific gravity
sgbs	Specific gravity of bittern liquid in Pond 7, starting (sgbs is 1.2494 g/cc at the start of Year 1)
sgnew	Specific gravity of liquid in Pond 7, new (at end of year, following removal of bittern and addition of make-up water)
sgaw	Specific gravity of ambient make-up water; sgaw = 1.012 grams/cubic centimeter
Vblq	Volume of bittern liquid removed in Year 1
Vblqnew	Volume of bittern liquid removed in subsequent years
Vblrem	Volume of bittern liquid remaining (Vblrem = Vbls – Vblq following Year 1, Vblrem = Vnew – Vblq thereafter)
Vbls	Volume of bittern liquid, starting (initial volume in pond; by definition also the pond capacity) Vbls = 1.135×10^9 liters (918 acre-feet)
Vnew	Volume of bittern liquid, new
Vrw	Volume of recycled water added
Vp7A	Discharge volume from Pond 7A
Vp8	Discharge volume from Pond 8
Vwa	Volume of water added (not including water used to compensate for evaporation)
Vwae	Volume of water added to compensate for evaporation

TABLE 2
ANNUAL FLOW FROM POND 7 AND BITTERN CONCENTRATIONAT YEAR END

SCENARIO	START	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8
Neighboring Waters									
Bittern Salinity (ppt)	300.0	260.1	218.4	175.4	130.0	82.0	30.3	0.0	
Non-Bittern Salinity (ppt)	0.0	9.7	18.8	26.9	33.2	36.6	34.1	26.3	15.0
Total Salinity (ppt)	300.0	269.8	236.9	201.6	162.4	117.7	63.7	26.3	
Flow (liters/year)	0.0	$1.735x10^8$	$2.048x10^8$	$2.499x10^8$	$3.196x10^8$	$4.439x10^8$	$7.277x10^8$	$1.112x10^9$	$1.135x10^9$
Flow (afy)	0.0	140.3	165.6	202.1	258.4	359.0	588.5	899	918.0
Project Scenario									
Salinity (ppt)	300.0	251.8	200.0	144.3	83.9	17.5	0.0	NA	NA
Flow (liters/year)	0.0	$2.163x10^8$	$2.668x10^8$	$3.493x10^8$	$5.046x10^8$	$9.083x10^8$	$1.135x10^9$	NA	NA
Flow (afy)	0.0	174.9	215.7	282.5	408.1	734.6	917.6	NA	NA
Program Scenario									
Salinity(ppt)	300.0	233.7	160.6	79.3	0.0	NA	NA	NA	NA
Flow (liters/year)	0.0	$2.936x10^8$	$3.955x10^8$	$6.081x10^8$	$1.134x10^9$	NA	NA	NA	NA
Flow (afy)	0.0	237.5	319.9	491.7	916.7	NA	NA	NA	NA

TABLE 3
INITIAL CONDITIONS INFORMATION
NAPA SALT MARSH RESTORATION PROJECT

ITEM	INITIAL CONDITION		
General Data and Information			
Pond 7 spring salinity:	300 ppt	28.9 baume	1.2494 spec. gravity
Pond 7 spring depth:	3 ft.	NA	NA
Pond 7 area:	306 acres	NA	NA
Pond 7 spring capacity:	918 af	3.00E+08 gal	1.14E+09 liters
Initial mass of total liquid (bittern) in Pond 7:	1.42E+09 kg	NA	NA
Initial mass of salts in Pond 7:	4.25E+08 kg	NA	NA
Salinity of tidal (slough) water (annual average)	15 ppt	1.61 baume	1.0112 spec. gravity
Salinity of recycled water (annual average)	0 ppt	0.00 baume	1.0000 spec. gravity
Net Evaporation (annual average)	23 in.	586.50 afy	7.25E+08 liters
Salt mass added due to evaporation (annual average)	1.09E+07 kg	NA	NA
Neighboring Waters Scenario			
Total flow for Pond 7A and 8 tidally-driven discharge	13,891 afy	NA	
Total flow for Ponds 7, 7A, and 8, tidally driven discharge	14,031 afy	NA	
Maximum Pond 7 Discharge Rate assuming 42" outlet (based on calculations for Pond 7A outlet): **(Note 1)**	8,729 afy	NA	
Allowable mass removal (1% of total flow at current concentration) assuming only Pond 7A and 8 as water sources	140 af Pond 7 brine	4.58E+07 gallons of bittern removal/year	1.74E+08 liters of bittern removal per year
"Project" Recycled Water Scenario			
Total flow for Pond 7A and 8 tidally-driven discharge	12,245 afy	NA	
Total flow for Ponds 7, 7A, and 8 plus 5,000 afy recycled water	17,493 afy	NA	
Maximum Pond 7 Discharge Rate assuming 42" outlet (based on calculations for Pond 7A outlet): **(see Note)**	7,556 afy	NA	
Allowable mass removal (1% of total flow at current concentration) assuming only Pond 7A and 8 as water sources	175 af Pond 7 brine	5.71E+07 gallons of bittern removal/year	2.16E+08 liters of bittern removal per year

TABLE 3 (cont.)
INITIAL CONDITIONS INFORMATION
NAPA SALT MARSH RESTORATION PROJECT

ITEM	INITIAL CONDITION		
"Program" Recycled Water Scenario			
Total flow for Pond 7A and 8 tidally-driven discharge	8,516 afy	NA	
Total flow for Ponds 7, 7A, and 8 plus 15,000 afy recycled water	23,746 afy	NA	
Maximum Pond 7 Discharge Rate assuming 42" outlet (based on calculations for Pond 7A outlet): **(Note 1)**	5,145 afy	NA	
Allowable mass removal (1% of total flow at current concentration) assuming only Pond 7A and 8 as water sources	237 af Pond 7 brine	7.76E+07 gallons of bittern removal/year	2.94E+08 liters of bittern removal per year

Note:
This estimate does not account for increases in discharge rate due to density; when higher discharges are allowable (i.e., when the bittern concentration in the pond has been reduced), density will have decreased somewhat as well.
af = acre feet
afy = acre feet per year
gal. = gallons
in. = inches
kg = kilogram
l = liter
NA = not applicable
ppt = parts per thousand
spec. gravity = specific gravity

References:

1. Flows/Discharge numbers from PWA memo, Oct 20, 2003
2. Initial salinity in parts per thousand (ppt) from GAIA Consulting letter report for the California Coastal State Conservancy: Bittern Toxicity Testing Results, Ion Composition of Bittern, and Sediment Salinity Data, September 12th, 2002
3. Millero & Poisson for salinity (ppt) to specific gravity conversion
4. Salinity to Baume Conversion based on Cargill Conversion Table (at 60 degrees F)

TABLE 4
ESTIMATE OF BITTERN DISCHARGE TIME AND POND 7 SALINITY
NAPA SALT MARSH RESTORATION PROJECT
NEIGHBORING WATERS SCENARIO

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Starting Salinity -- Bittern	300	260.1	218.4	175.4	130.0	82.0	30.3	Flush Pond 7 in Year 8 to achieve ambient salinity
Starting Salinity -- Salt	0	9.7	18.8	26.9	33.2	36.6	34.1	
Starting Specific Gravity	1.2494	1.2212	1.1913	1.1602	1.1266	1.0897	1.0469	
Total Liquid Volume Starting (l)	1.135E+09	1.135E+09	1.136E+09	1.135E+09	1.135E+09	1.135E+09	1.135E+09	
Total Liquid Volume Removed (l)	1.735E+08	2.048E+08	2.499E+08	3.196E+08	4.439E+08	7.277E+08	1.112E+09	
Total Liquid Volume Removed (afy)	140.3	165.6	202.1	258.4	359.0	588.5	899.0	
Total Liquid Volume Remaining (l)	9.617E+08	9.302E+08	8.866E+08	8.158E+08	6.913E+08	4.069E+08	2.374E+07	
Total Liquid Mass Starting (kg)	1.418E+09	1.386E+09	1.354E+09	1.317E+09	1.279E+09	1.236E+09	1.189E+09	
Total Liquid Mass Removed (kg)	2.168E+08	2.501E+08	2.977E+08	3.708E+08	5.001E+08	7.929E+08	1.164E+09	
Total Liquid Mass Remaining (kg)	1.201E+09	1.136E+09	1.056E+09	9.465E+08	7.788E+08	4.434E+08	2.485E+07	
Mass Water in Liquid Remaining	8.410E+08	8.295E+08	8.060E+08	7.557E+08	6.523E+08	3.912E+08	2.327E+07	
Bittern Salt Mass Removed (kg)	6.503E+07	6.503E+07	6.503E+07	6.503E+07	6.503E+07	6.503E+07	3.529E+07	
Bittern Salt Mass at Year End (kg)	3.604E+08	2.954E+08	2.304E+08	1.654E+08	1.003E+08	3.529E+07	0.000E+00	
Volume Make-up Water Added (l)	1.718E+08	2.048E+08	2.474E+08	3.180E+08	4.417E+08	7.262E+08	1.106E+09	
Mass Water added (kg)	1.711E+08	2.040E+08	2.464E+08	3.167E+08	4.400E+08	7.234E+08	1.102E+09	
Non-Bittern Salt Mass Removed (kg)	0.000E+00	1.992E+06	4.701E+06	8.584E+06	1.475E+07	2.666E+07	3.790E+07	
Non-Bittern Salt Mass Added (kg)	1.348E+07	1.398E+07	1.463E+07	1.570E+07	1.758E+07	2.189E+07	2.766E+07	
Non-Bittern Salt Mass at Year End (kg)	1.348E+07	2.548E+07	3.541E+07	4.252E+07	4.536E+07	4.059E+07	3.034E+07	
Volume at Year End (l)	1.135E+09	1.136E+09	1.135E+09	1.135E+09	1.135E+09	1.135E+09	1.134E+09	
Bittern Salinity at Year End	260.1	218.4	175.4	130.0	82.0	30.3	0.0	
Salt Salinity at Year End	9.7	18.8	26.9	33.2	36.6	34.1	26.3	
Total Salinity at Year End	269.8	236.9	201.6	162.4	117.7	63.7	26.3	
Specific Gravity at Year End (g/cc or kg/l)	1.2212	1.1913	1.1602	1.1266	1.0897	1.0469	1.0181	
Allowable Pond 7 Flow Rate (50% of Maximum Flowrate) (afy)	4,365	4,365	4,365	4,365	4,365	4,365	4,365	

TABLE 4 (cont.)
ESTIMATE OF BITTERN DISCHARGE TIME AND POND 7 SALINITY
NAPA SALT MARSH RESTORATION PROJECT
NEIGHBORING WATERS SCENARIO

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Estimated Salinity of Discharge -- summer conditions (ppt)	28	28	28	28	29	29	27	
Estimated Salinity of Receiving Water -- summer conditions (ppt)	25	25	25	25	25	25	25	
Estimated Salinity of Discharge -- winter conditions (ppt)	8	8	8	9	9	10	9	
Estimated Salinity of Receiving Water -- winter conditions (ppt)	5	5	5	5	5	5	5	

Notes:
Salt salinity can be reduced to ambient conditions either by increasing water flows during the latter portion of Year 7, or by flushing the pond several times in Year 8.
For formulas used above, see Table 6
Ambient water temperature = 68 degrees Fahrenheit
20.0 degrees Celsius

TABLE 5
ESTIMATE OF BITTERN DISCHARGE TIME AND POND 7 SALINITY
NAPA SALT MARSH RESTORATION PROJECT
PROJECT SCENARIO

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Starting Salinity -- Bittern	300	251.8	200.0	144.3	83.9	17.5
Starting Specific Gravity	1.2494	1.2071	1.1608	1.1133	1.0641	1.0124
Total Liquid Volume Starting (L)	1.135E+09	1.133E+09	1.134E+09	1.134E+09	1.133E+09	1.135E+09
Total Liquid Volume Removed (L)	2.163E+08	2.668E+08	3.493E+08	5.046E+08	9.083E+08	1.135E+09
Total Liquid Volume Removed (afy)	174.9	215.7	282.5	408.1	734.6	917.6
Total Liquid Volume Remaining (L)	9.189E+08	8.664E+08	7.851E+08	6.296E+08	2.251E+08	0.000E+00
Total Liquid Mass Starting (kg)	1.418E+09	1.368E+09	1.317E+09	1.263E+09	1.206E+09	1.149E+09
Total Liquid Mass Removed (kg)	2.703E+08	3.220E+08	4.054E+08	5.618E+08	9.665E+08	1.149E+09
Total Liquid Mass Remaining (kg)	1.148E+09	1.046E+09	9.114E+08	7.010E+08	2.395E+08	0.000E+00
Mass Water in Liquid Remaining	8.036E+08	7.825E+08	7.291E+08	5.998E+08	2.194E+08	0.000E+00
Bitten Salt Mass Removed (kg)	8.108E+07	8.108E+07	8.108E+07	8.108E+07	8.108E+07	2.009E+07
Bittern Salt Mass at Year End (kg)	3.444E+08	2.633E+08	1.822E+08	1.012E+08	2.009E+07	0.000E+00
Volume Make-up Water Added (L)	2.206E+08	2.721E+08	3.528E+08	5.071E+08	9.129E+08	1.140E+09
Mass Water added (kg)	2.198E+08	2.710E+08	3.514E+08	5.051E+08	9.093E+08	1.136E+09
Non-Bittern Salt Mass Removed (kg)	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Non-Bittern Salt Mass Added (kg)	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Non-Bittern Salt Mass at Year End (kg)	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Volume at Year End (L)	1.133E+09	1.134E+09	1.134E+09	1.133E+09	1.135E+09	1.136E+09
Bittern Salinity at Year End	251.8	200.0	144.3	83.9	17.5	0.0
Salt Salinity at Year End	0.0	0.0	0.0	0.0	0.0	0.0
Total Salinity at Year End	251.8	200.0	144.3	83.9	17.5	0.0
Specific Gravity at Year End (g/cc or kg/L)	1.2071	1.1608	1.1133	1.0641	1.0124	1.0000
Allowable Pond 7 Flow Rate (50% of Maximum Flowrate) (afy)	3,778	3,778	3,778	3,778	3,778	3,778
Estimated Salinity of Discharge -- summer conditions (ppt)	21	21	21	21	22	20
Estimated Salinity of Receiving Water -- summer conditions (ppt)	25	25	25	25	25	25
Estimated Salinity of Discharge -- winter conditions (ppt)	7	7	7	7	7	5
Estimated Salinity of Receiving Water -- winter conditions (ppt)	5	5	5	5	5	5

Notes: For formulas used above, see Table 6
Ambient water temperature = 68 degrees Fahrenheit (20.0 degrees Celsius)

TABLE 5 (cont.)
ESTIMATE OF BITTERN DISCHARGE TIME AND POND 7 SALINITY
NAPA SALT MARSH RESTORATION PROJECT
PROGRAM SCENARIO

	Year 1	Year 2	Year 3	Year 4
Starting Salinity -- Bittern	300	233.7	160.6	79.3
Starting Specific Gravity	1.2494	1.1907	1.1270	1.0604
Total Liquid Volume Starting (L)	1.135E+09	1.134E+09	1.135E+09	1.134E+09
Total Liquid Volume Removed (L)	2.936E+08	3.955E+08	6.081E+08	1.134E+09
Total Liquid Volume Removed (afy)	237.5	319.9	491.7	916.7
Total Liquid Volume Remaining (L)	8.415E+08	7.380E+08	5.265E+08	0.000E+00
Total Liquid Mass Starting (kg)	1.418E+09	1.350E+09	1.279E+09	1.202E+09
Total Liquid Mass Removed (kg)	3.669E+08	4.710E+08	6.853E+08	1.202E+09
Total Liquid Mass Remaining (kg)	1.051E+09	8.788E+08	5.934E+08	0.000E+00
Mass Water in Liquid Remaining	7.360E+08	6.734E+08	4.981E+08	0.000E+00
Bitten Salt Mass Removed (kg)	1.101E+08	1.101E+08	1.101E+08	9.530E+07
Bittern Salt Mass at Year End (kg)	3.154E+08	2.054E+08	9.530E+07	0.000E+00
Volume Make-up Water Added (L)	2.995E+08	4.015E+08	6.111E+08	1.139E+09
Mass Water added (kg)	2.983E+08	3.999E+08	6.087E+08	1.135E+09
Non-Bittern Salt Mass Removed (kg)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Non-Bittern Salt Mass Added (kg)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Non-Bittern Salt Mass at Year End (kg)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Volume at Year End (L)	1.134E+09	1.135E+09	1.134E+09	1.135E+09
Bittern Salinity at Year End	233.7	160.6	79.3	0.0
Salt Salinity at Year End	0.0	0.0	0.0	0.0
Total Salinity at Year End	233.7	160.6	79.3	0.0
Specific Gravity at Year End (g/cc or kg/L)	1.1907	1.1270	1.0604	1.0000
Allowable Pond 7 Flow Rate (50% of Maximum Flowrate) (afy)	2,573	2,573	2,573	2,573
Estimated Salinity of Discharge -- summer conditions (ppt)	11	11	10	8
Estimated Salinity of Receiving Water -- summer conditions (ppt)	25	25	25	25
Estimated Salinity of Discharge -- winter conditions (ppt)	5	5	5	5
Estimated Salinity of Receiving Water -- winter conditions (ppt)	5	5	5	5

Notes: For formulas used above, see Table 6

Ambient water temperature = 68 degrees Fahrenheit (20.0 degrees Celsius)

TABLE 6
CALCULATION FORMULAS
NAPA SALT MARSH RESTORATION PROJECT

Calculation Item	Formula
Ambient Water Temperature	60^{o} Fahrenheit; 15.6^{o} Celsius
Starting Salinity -- Bittern	=Given
Starting Specific Gravity	=Given
Total Liquid Volume Starting (L)	=(Pond 7 spring depth) x (Pond 7 area) x (43,560 x 7.5 x 3.785)
Total Liquid Volume Removed (L)	= 1% of total flow at current concentration in liters from Ponds 7A and 8
Total Liquid Volume Removed (afy)	=(total liquid volume)/3.785/ 7.5/43560
Total Liquid Volume Remaining (L)	=(total liquid volume starting) - (total liquid volume removed)
Total Liquid Mass Starting (kg)	=(Pond 7 spring capacity in liters) x (spec. gravity of Pond 7 salinity at beginning of year)
Total Liquid Mass Removed (kg)	=(total liquid volume removed) x (spec. gravity)
Total Liquid Mass Remaining (kg)	=(total liquid mass starting) - (total liquid mass removed)
Mass Water in Liquid Remaining	=(total liquid mass remaining) x (1000 - Starting Salinity of Bittern)/1000
Bitten Salt Mass Removed (kg)	=(total liquid mass removed) x (Starting Salinity of Bittern /1000)
Bittern Salt Mass at Year End (kg)	=[(total liquid mass starting) x (Starting Salinity of Bittern/1000)] - Bittern Salt Mass Removed
Volume Make-up Water Added (L)	=Total Liquid Volume Removed x (1.02) - *(please note that the factor varies between 0.98 to 1.02, depending on density effects)*
Mass Water added (kg)	=Volume Make-up Water Added x ((1000 - average salinity of tidal slough water in ppt)/1000)) x (spec. gravity of salinity of tidal slough water)
Non-Bittern Salt Mass Removed (kg)	=Given
Non-Bittern Salt Mass Added (kg)	=Given
Non-Bittern Salt Mass at Year End (kg)	=(non-bittern salt mass added) - (non-bittern salt mass removed)
Volume at Year End (L)	=[(total liquid mass remaining) + (mass of water added) + (non-bittern salt mass added)]/(spec. gravity at year end)
Bittern Salinity at Year End	=(bittern salt mass at year end) / [(bittern salt mass at year end) + (mass of water in liquid remaining) + (mass of water added) + (non-bittern salt mass added) + (nonbittern salt mass remaining)] x 1000
Salt Salinity at Year End	=(non-bittern salt mass at year end) / [(bittern salt mass at year end) + (mass of water in liquid remaining) + (mass of water added) + (non-bittern salt mass added) + (nonbittern salt mass remaining)] x 1000
Total Salinity at Year End	=(bittern salt mass at year end + non-bittern salt mass at year end) / [(bittern salt mass at year end) + (mass of water in liquid remaining) + (mass of water added) + (non-bittern salt mass added) + (nonbittern salt mass remaining)] x 1000
Specific Gravity at Year End (g/cc or kg/l)	=[999.842594+(0.06793952 x Ambient water temp. in ^{o}C) - (0.00909529 x Ambient water temp. in ^{o}C^2)+ (0.0001001685 x Ambient water temp. in ^{o}C^3) - 0.000001120083 x Ambient water temp. in ^{o}C^4 + (0.000000006536322 x Ambient water temp. in ^{o}C^5) + (0.824493 x total salinity at year end) - (0.0040899 x Ambient water temp. in ^{o}C x total salinity at year end) + (0.000076438 x Ambient water temp. in ^{o}C^2 x total salinity at year end) - (00000082467 x Ambient water temp. in ^{o}C^3 x total salinity at year end) + (0.0000000053875 x Ambient water temp. in ^{o}C^4 x total salinity at year end) - (0.00572466 x total salinity at year end^1.5) + (0.00010227 x Ambient water temp. in ^{o}C x total salinity at year end^1.5) - (0.0000016546 x Ambient water temp. in ^{o}C^2 x total salinity at year end^1.5) + (0.00048314 x total salinity at year end^2)]/1000
Allowable Pond 7 Flow Rate (50% of Maximum Flowrate) (afy)	=50% of maximum Pond 7 discharge rate

TABLE 6 (cont.)
CALCULATION FORMULAS
POND 7 BITTERN REMOVAL ESTIMATE
NAPA SALT MARSH RESTORATION PROJECT

Calculation Item	Formula
Estimated Salinity of Discharge -- summer conditions (ppt)	=[(volume of recycled water x salinity of recycled water) + (Total Liquid Volume Removed x Starting Salinity of Bittern) + (Total flow for Pond 7A and 8 tidally-driven discharge x Estimated Salinity of Receiving Water -- summer conditions)]/(volume of recycled water + Total Liquid Volume Removed + Total flow for Pond 7A and 8 tidally-driven discharge) *Note that the salinity of the recycled water is 0.*
Estimated Salinity of Receiving Water -- summer conditions (ppt)	=Given
Estimated Salinity of Discharge -- winter conditions (ppt)	=[(volume of recycled water x salinity of recycled water) + (Total Liquid Volume Removed x Starting Salinity of Bittern) + (Total flow for Pond 7A and 8 tidally-driven discharge x Estimated Salinity of Receiving Water -- winter conditions)]/(volume of recycled water + Total Liquid Volume Removed + Total flow for Pond 7A and 8 tidally-driven discharge) *Note that the salinity of the recycled water is 0.*
Estimated Salinity of Receiving Water -- winter conditions (ppt)	=Given

APPENDIX A

POND 7A SALINITY REDUCTION PERIOD

APPENDIX A
POND 7A SALINITY REDUCTION PERIOD

Table A-1 provides the assumptions and calculations made to estimate the required time to achieve ambient salinity in Pond 7A. The estimate assumes that the pond will be flushed as much as possible, and make-up water (at ambient salinity) added only as necessary to continue discharging to the mixing chamber. As make-up water is added to Pond 7A, the discharge rate will have to be increased to maintain an effective rate of non-bittern salt removal. The allowable discharge rate from Pond 7A is governed by the total salinity of the discharge. As long as the discharge salinity is no more than 15 ppt above the ambient concentration, the flow is within the acceptable range. Note that a variable discharge (achieved through electronic controls based on tide stage, current speed, and discharge and receiving water salinities) could significantly increase the overall discharge rate, and reduce the total time required to flush Pond 7A.

TABLE A-1
ESTIMATE OF POND 7A SALINITY REDUCTION PERIOD
NAPA SALT MARSH RESTORATION PROGRAM

Calculation Inputs and Required Outputs	Quantities and Units					
Pond 7A spring depth	3	ft.	NA		NA	
Pond 7A area	306	acres	NA		NA	
Pond 7A spring capacity	918	af	3.00E+08	gal	1.14E+09	liters
Initial Pond 7A Salinity	60	ppt				
Pond 8 Flow	5,162	afy	6.53E+09	liters/year	5.45E+08	liters/month
Pond 8 Salinity (same as ambient)	15	ppt				
Neighboring (Ambient) Water Salinity	15	ppt				
Permissible Salinity in Discharge	30	ppt				
Allowable Pond 7A Flow at Initial Salinity	2581	afy	3.27E+09	liters/year	2.72E+08	liters/month
Months Required to Flush Pond 7A	4.2	months				
Months Required to Flush Pond 7A with Safety Factor of 50%	**6.3**	**months**				

Notes:
Pond 7A area from Jones & Stokes, 2003 p. 2-3
Pond 7A salinity from Jones & Stokes, 2003 Figure 2-3 (average of range)
Pond 8 flow from PWA 2002b, p.2
Ambient water salinity from Jones & Stokes, 2003 Figure 2-3 (average of range for Napa River)
Permissible salinity in discharge based on maximum 5 ppt change in receiving water and minimum 3-fold dilution (PWA 2003, Tables 5-1 and 5-2)

APPENDIX B

SALINITY AND SPECIFIC GRAVITY CORRELATIONS

APPENDIX B
SALINITY AND SPECIFIC GRAVITY CORRELATIONS

Table B-1 provides the summary of salinity and specific gravity correlations performed by Mr. Peter Mull of the U.S. Army Corps of Engineers. Based on the evaluation performed, the Millero and Poisson equation (Randal, 1997) provided the closest correlation to the actual data provided in the CRC Handbook, and was used to estimate specific gravity from salinity values calculated for each year.

TABLE B-1
SPECIFIC GRAVITY VERSUS SALINITY CORRELATIONS

Salinity	Sp.Gr. from Handbook of Chem. & Physics	Salinity	Computed Sp. Gr. 5th order curve fit	Computed Sp.Gr. Linear curve fit	Temp, C	Density (kg/m^3) Computed from Millero & Poisson Formula	Sp.Gr. computed from Millero & Poisson
4.94	1.0037	4.94	1.0040	1.0037	20	1001.962068	1.0020
9.92	1.0075	9.92	1.0079	1.0076		1005.732175	1.0057
14.91	1.0112	14.91	1.0119	1.0116		1009.507741	1.0095
19.89	1.0150	19.89	1.0159	1.0156		1013.278642	1.0133
24.87	1.0188	24.87	1.0199	1.0196		1017.055331	1.0171
29.86	1.0225	29.86	1.0239	1.0236		1020.847359	1.0208
34.84	1.0263	34.84	1.0279	1.0276		1024.640957	1.0246
39.82	1.0301	39.82	1.0319	1.0316		1028.444823	1.0284
44.81	1.0339	44.81	1.0359	1.0355		1032.267516	1.0323
49.79	1.0376	49.79	1.0399	1.0395		1036.094453	1.0361
54.78	1.0414	54.78	1.0439	1.0435		1039.941626	1.0399
59.76	1.0452	59.76	1.0480	1.0475		1043.794151	1.0438
64.74	1.0490	64.74	1.0520	1.0515		1047.660191	1.0477
69.73	1.0528	69.73	1.0560	1.0555		1051.54796	1.0515
74.71	1.0566	74.71	1.0600	1.0595		1055.442245	1.0554
79.69	1.0604	79.69	1.0641	1.0635		1059.351149	1.0594
84.68	1.0642	84.68	1.0681	1.0674		1063.282864	1.0633
89.66	1.0680	89.66	1.0721	1.0714		1067.221902	1.0672
94.64	1.0719	94.64	1.0762	1.0754		1071.176376	1.0712
99.63	1.0757	99.63	1.0802	1.0794		1075.1545	1.0752
109.6	1.0833	109.6	1.0884	1.0874		1083.150703	1.0832
119.6	1.0910	119.6	1.0965	1.0954		1091.236383	1.0912
129.5	1.0987	129.5	1.1046	1.1033		1099.307046	1.0993
139.5	1.1065	139.5	1.1129	1.1113		1107.526901	1.1075
149.5	1.1142	149.5	1.1211	1.1193		1115.81581	1.1158
		150	1.1215	1.1197		1116.232085	1.1162
		160	1.1298	1.1277		1124.594509	1.1246
		170	1.1380	1.1357		1133.027815	1.1330
		180	1.1463	1.1437		1141.532772	1.1415
		190	1.1546	1.1517		1150.110085	1.1501
		200	1.1629	1.1597		1158.760402	1.1588
		210	1.1712	1.1677		1167.484321	1.1675
		220	1.1794	1.1757		1176.282398	1.1763
		230	1.1876	1.1837		1185.155149	1.1852
		240	1.1958	1.1917		1194.103057	1.1941
		250	1.2040	1.1997		1203.126575	1.2031
		260	1.2121	1.2077		1212.226127	1.2122
		262	1.2137	1.2093		1214.055197	1.2141
		270	1.2201	1.2157		1221.402113	1.2214
		280	1.2280	1.2237		1230.654911	1.2307
		290	1.2358	1.2317		1239.984879	1.2400
		300	1.2434	1.2397		1249.392354	1.2494
		310	1.2509	1.2477		1258.877658	1.2589
		320	1.2582	1.2557		1268.441098	1.2684
		330	1.2653	1.2637		1278.082963	1.2781
		340	1.2722	1.2717		1287.803533	1.2878
		350	1.2788	1.2797		1297.603073	1.2976
		35	1.0280	1.0277		1024.763005	1.0248

Source: Peter Mull, USACE 12/2/03