

# **Box Model of a Series of Salt Ponds, as Applied to the Alviso Salt Pond Complex, South San Francisco Bay, California**

By Megan A. Lionberger, David H. Schoellhamer, Gregory G. Shellenbarger,  
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Prepared in cooperation with the U.S. Fish and Wildlife Service

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## Conversion Factors

Inch/Pound to SI

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<b>Area</b>		
acre	0.4047	hectare (ha)
<b>Volume</b>		
cubic foot (ft <sup>3</sup> )	0.02832	cubic meter (m <sup>3</sup> )
<b>Flow rate</b>		
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m <sup>3</sup> /d)
<b>Transmissivity</b>		
foot squared per second (ft <sup>2</sup> /s)	0.09290	meter squared per second (m <sup>2</sup> /s)

SI to Inch/Pound

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>		
millimeter (mm)	0.03937	inch (in.)
meter (m)	1.094	yard (yd)
<b>Area</b>		
square meter (m <sup>2</sup> )	6.290	square foot (ft <sup>2</sup> )
<b>Volume</b>		
cubic meter (m <sup>3</sup> )	6.290	barrel (petroleum, 1 barrel = 42 gal)
<b>Flow rate</b>		
meter per second (m/s)	3.281	foot per second (ft/s)
millimeter per day (mm/d)	0.03937	inch per day (in/d)
<b>Mass</b>		
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Some vertical coordinate information is referenced to the now superseded National standard geodetic reference for elevation, the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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## Abstract

This report documents the development and application of a box model to simulate water level, salinity, and temperature of the Alviso Salt Pond Complex in South San Francisco Bay. These ponds were purchased for restoration in 2003 and currently are managed by the U.S. Fish and Wildlife Service to maintain existing wildlife habitat and prevent a build up of salt during the development of a long-term restoration plan. The model was developed for the purpose of aiding pond managers during the current interim management period to achieve these goals.

A previously developed box model of a salt pond, SPOOM, which calculates daily pond volume and salinity, was reconfigured to simulate multiple connected ponds and a temperature subroutine was added. The updated model simulates rainfall, evaporation, water flowing between the ponds and the adjacent tidal slough network, and water flowing from one pond to the next by gravity and pumps. Theoretical and measured relations between discharge and corresponding differences in water level are used to simulate most flows between ponds and between ponds and sloughs. The principle of conservation of mass is used to calculate daily pond volume and salinity. The model configuration includes management actions specified in the Interim Stewardship Plan for the ponds. The temperature subroutine calculates hourly net heat transfer to or from a pond resulting in a rise or drop in pond temperature and daily average, minimum, and maximum pond temperatures are recorded. Simulated temperature was compared with hourly measured data from pond 3 of the Napa–Sonoma Salt Pond Complex and monthly measured data from pond A14 of the Alviso Salt-Pond Complex. Comparison showed good agreement of measured and simulated pond temperature on the daily and monthly time scales.

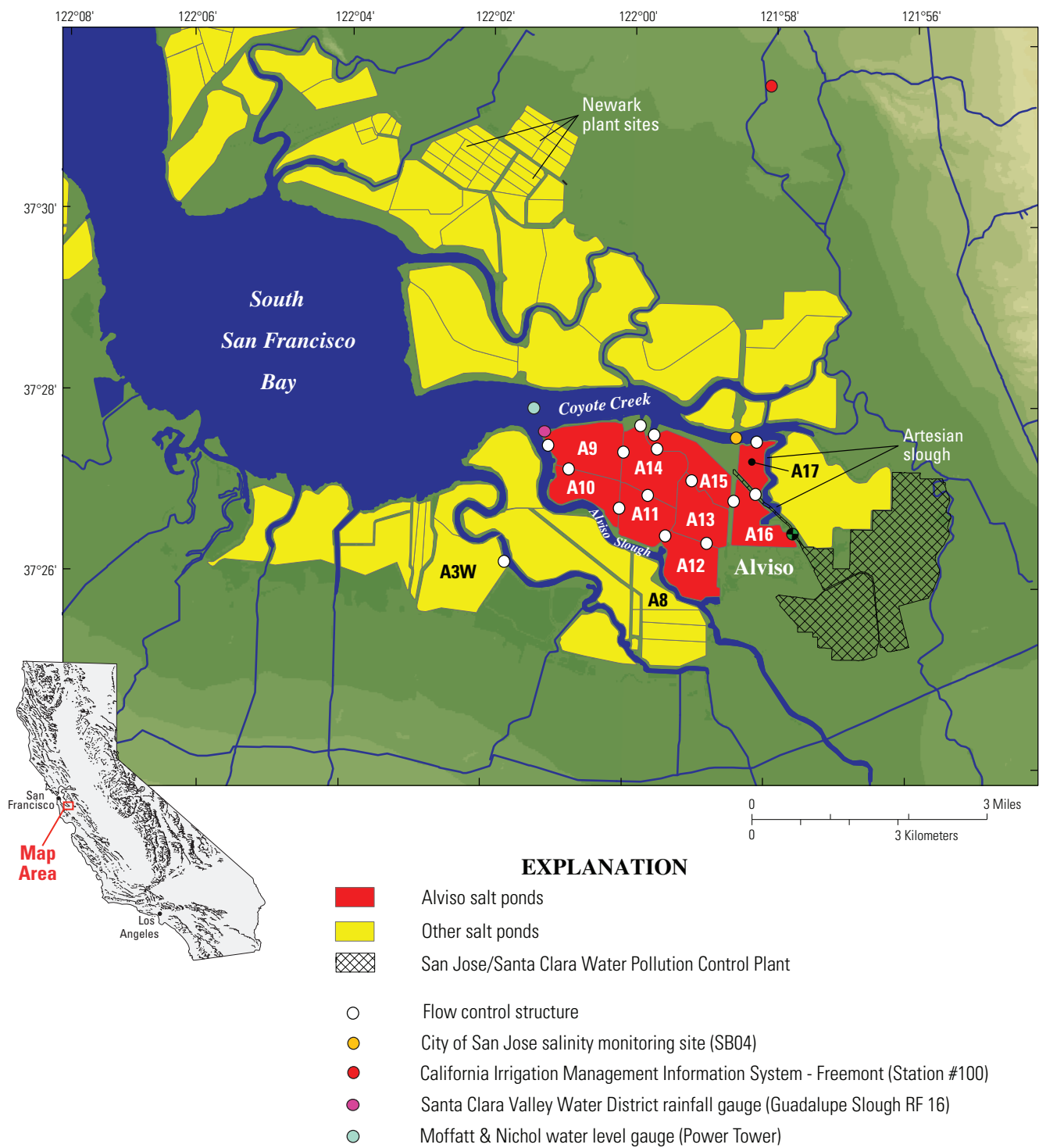
## Introduction

In March 2003, 16,500 acres of salt evaporation ponds owned by the Cargill Corporation in the San Francisco Bay estuary were purchased using State, Federal, and private funds. Currently, the California Coastal Conservancy is leading a collaborative planning effort with the U.S. Fish and Wildlife Service (USFWS) and the California Department of Fish and Game (DFG) to restore some of the ponds to tidal action while providing for flood management, public access, and recreation.

The draft restoration plan envisions restoration of 50 to 90 percent of the acquired ponds within 50 years (South Bay Salt Pond Restoration Project, 2007). The ponds will be operated and maintained according to the South Bay Salt Ponds Initial Stewardship Plan (ISP) until they are restored. The goals of the ISP are to maintain existing wildlife habitat and to prevent a build up of salt in the ponds in a cost-effective manner until the long-term restoration plan is in effect (Life Science! Inc., 2003).

A salt-pond box model (SPOOM) was developed by Lionberger and others (2004) to simulate water volume and salinity of a salt pond for use in estimating water and salinity budgets for ponds in the Napa–Sonoma Salt Pond Complex. The model uses the principle of conservation of mass to calculate daily pond volume and salinity and includes a salt crystallization and dissolution algorithm. Model inputs include precipitation, evaporation, infiltration, and water transfers. SPOOM was reconfigured to simulate volume and salinity for a portion of the purchased South Bay salt ponds, Alviso salt ponds A9–A17 ([fig. 1](#)), and a temperature subroutine was added. SPOOM will be used by the USFWS to assist with the management of the ponds as bird habitat.

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**Figure 1.** The Alviso Salt Pond Complex, South San Francisco Bay, California. The ponds are labeled A9–A17. Locations of flow control structures and data sources are shown.



## Purpose and Scope

This report documents the changes made to SPOOM to simulate salt-pond function for Alviso salt ponds A9–A17 in South San Francisco Bay. Changes to the model include input data and boundary conditions specific to the Alviso salt pond area, the ability to simulate conditions for the entire system of ponds in one simulation run rather than just for an individual pond, and a new temperature subroutine to simulate daily average, minimum, and maximum pond temperature. The temperature subroutine was validated by comparing simulated pond temperatures to hourly and monthly temperature data collected in pond 3 of the Napa–Sonoma Salt Pond Complex and Alviso salt pond A14. This report also describes how the model can be used by the USFWS to achieve pond salinity and depth goals of the ISP. The user is able to specify the connectivity between ponds, how screw gates and combination gates are controlled, and the vertical datum and unit systems used during the simulation.

This modification of the original SPOOM represents the specific conditions of the Alviso salt ponds only and cannot directly be used to simulate salt-pond function elsewhere. Nevertheless, this report illustrates how similar modifications can be made to the basic SPOOM model (Lionberger and others, 2004) to simulate pond geometries, hydraulic structures, tidal effects, and meteorological input data applicable to other salt ponds in other locales.

## Description of the Study Area

Commercial salt production in South San Francisco Bay began in the 1850s during the gold rush when dikes were built around salt marshes for the collection and evaporation of seawater. By the 1930s, almost half of the South Bay's historical tidal marshes had been converted into salt ponds (San Francisco Estuary Institute, 1999). In 1974, approximately 13,000 acres of South Bay salt ponds were sold to the Federal Government by the Leslie Salt Company to form the San Francisco Bay National Wildlife Refuge, now managed by the USFWS. The Alviso ponds were included in this transaction. The Leslie Salt Company retained the mineral rights to the ponds and continued to use the ponds for salt production until it sold all its existing land holdings and mineral rights to the Cargill Corporation in 1978. In March 2003, Cargill sold 16,500 acres of salt ponds and mineral rights to DFG and USFWS.

Historically, salt was produced during the spring through the fall dry season by evaporation of water from the ponds. Water entered the pond system from intakes in

the southwestern ponds and flowed by gravity sequentially through the pond system toward the Newark Plant site where the evaporation process was completed and the salt harvested.

The bathymetry of Alviso ponds A9–A17 was surveyed by the USGS in summer 2002, fall 2003, and spring 2004. Pond depths were measured using a single beam echo sounder or an acoustic Doppler current profiler (Takekawa and others, 2003), and pond bottom elevations were determined in reference to USGS benchmark elevations. Concurrent measurements of location in the ponds were made using the global positioning system, and contour maps were prepared to enable the calculation of pond volumes for any depth of water. [Table 1](#) summarizes the survey results for a pond water-surface elevation of 1.5 feet, NGVD 29.

**Table 1.** Surface area and volume of Alviso ponds A9–A17.

[Water-surface elevation is 1.5 feet, referenced to NGVD 29 vertical datum. ft<sup>2</sup>, square feet; ft<sup>3</sup>, cubic feet]

Pond	Surface area (million ft <sup>2</sup> )	Volume (million ft <sup>3</sup> )
A9	15.3	17.8
A10	10.3	28.9
A11	11.3	46.6
A12	13.2	68.3
A13	11.7	46.2
A14	14.6	36.3
A15	10.3	32.3
A16	10.2	32.2
A1	75.0	9.0

The seven-pond system has been modified from its original flow pattern as specified by the ISP. The system consists of a set of flow-through ponds A9 (intake), A10, A11, and A14 (outlet), batch ponds A12, A13, and A15 (intake), and two other flow-through ponds, A16 (intake) and A17 (outlet). Slough water flows through the ponds by gravity through culverts equipped with flap gates and screw gates to control water movement. Outlet ponds are also equipped with removable weirs to control minimum pond depths when needed. The batch ponds are operated as high-salinity ponds, through which water is moved, as needed, to maintain target salinities and water depths. Intake and outlet pond culverts are equipped with combination gates that function as either a screw gate or as a flap gate allowing for unidirectional, bidirectional, or no flow. A pump is located in pond A13 to pump either to pond A14 or A15 at a rate of 22,000 gallons per minute (gal/min). A pump also is located in pond A8 to transfer water into pond A11 at a rate of 4,000 gal/min.

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The Alviso salt ponds are located within the Pacific Flyway and serve as staging and wintering areas for migratory waterfowl and shorebirds (Harvey and others, 1992). Water level, salinity, and temperature are key habitat criteria for bird use and food supply (Takekawa and others, 2001; 2006). Accordingly, target water levels and salinities for each pond have been specified by the ISP (table 2).

Winter inflow controls also have been specified by the ISP to minimize entrainment of salmonids. Thus, ponds A9 and A15 are closed to tidal inflow and the intake-outlet circulation of pond A16 and A17 are reversed from December 1 to May 31. Pond A14 is closed to tidal flow from December 1 to April 30, although bidirectional tidal flow is allowed during May to maintain salinity levels below 40.

**Table 2.** Targeted summer and winter water-surface elevations and summer salinities during the South Bay Salt Ponds Initial Stewardship Plan period for Alviso ponds A9–A17.

[The Initial Stewardship Plan does not include target water-surface elevations for ponds A12–A15 because they are operated as batch ponds to maintain high salinity. Data from Life Science! (2003). ft, feet; na, not applicable]

Pond	Water-surface elevation (ft)		Dimensionless
	Summer	Winter	Salinity (in summer)
A9	2.0	1.5	0–40
A10	1.8	1.5	0–40
A11	1.3	1.4	0–40
A12	na	na	120–150
A13	na	na	120–150
A14	0.9	1.3	0–40
A15	na	na	120–150
A16	2.3	2.2	0–40
A17	2.3	2.2	0–40

## Model Description

The salt pond box model, SPOOM (Lionberger and others, 2004), which represents a salt pond as a well-mixed box of saltwater, originally was formulated to simulate salt pond function in the Napa–Sonoma Salt Pond Complex. SPOOM, written as a computer program in Visual Basic for Excel, simulates water volume and salt mass using the principle of conservation of mass. Water transfers, rainfall, and evaporation are accounted for by the mass balance calculations. An infiltration rate also can be included. As originally formulated, the model simulates water volume in cubic meters and salinity in dimensionless units (1978 Practical Salinity Unit Scale) on a daily time step. Lionberger and others (2004) provide a detailed description of SPOOM.

SPOOM was modified to simulate salt pond function in Alviso salt ponds A9–A17. Other modifications include the addition of a temperature subroutine to simulate daily average, minimum, and maximum pond temperatures and the ability to simulate conditions in all the ponds in a salt pond complex in a single model run. Although the simulation results are given as daily values, the calculation time step is hourly in order to incorporate the fluctuating tidal water-surface elevation into the water transfer subroutine and to be able to determine daily average, minimum, and maximum pond temperatures. Pond volume calculations either can be made in inch-pound or metric units, and water-surface elevations can be determined relative to either vertical datum NGVD 29 or NAVD 88. Some data used in the model were developed or measured in inch-pound units while others were developed or measured in metric units, depending on convention.

Four new worksheets were added to SPOOM to simulate pond-management operations. The Weirs worksheet allows the user to enable weirs in outflow ponds (ponds A14, A16, and A17) and to define box weir variables including weir length, weir crest elevation, weir height, and the number of weir boxes. User inputs should be consistent with the unit system and vertical datum selected on the Main worksheet. The Pumping worksheet allows the model user to specify pumping rates between ponds A13 and A14, A13 and A15, and A8 and A11. Pond A8 salinity must be specified because it is outside the simulation area. The ScrewGates worksheet allows the user to simulate the use of a screw gate to reduce flow through each culvert connecting two ponds. The percent of the culvert area open to flow on a daily basis is entered if it is less than 100 percent open. If the screw gate is operated fully open (at 100 percent), the worksheet cell is left blank. The ComboGates worksheet allows the user to simulate the use of a combination gate on a culvert connecting a pond to a slough. Combination gates (operated as either a hinged flap gate or a screw gate) at both ends of the culvert allow unidirectional, bidirectional, or no flow. This worksheet is used when a combo-gate flow control changes during a simulation (that is, unidirectional to bidirectional). Otherwise, the flow direction through the culverts can be defined on the Main worksheet. This will be described in more detail in the ‘Using the Model’ section of this report.

## Temperature

A new subroutine was added to SPOOM to calculate daily average, minimum, and maximum pond temperature from hourly calculations of net heat transfer. The terms of the heat transfer budget are described below, followed by the results of temperature validation simulations using measured data.

The net heat transfer across the air-water boundary is the summation of multiple heat flux terms and is given as:

$$H_N = H_S + H_A - H_B - H_E - H_C \quad (1)$$

where

- $H_N$  is the net heat flux passing into or out of the pond, in watts per square meter per second;
- $H_S$  is the net short-wave solar radiation flux, in watts per square meter per second;
- $H_A$  is the net long-wave atmospheric radiation flux, in watts per square meter per second;
- $H_B$  is the long-wave water surface heat flux, in watts per square meter per second;
- $H_E$  is the energy loss from evaporation, in watts per square meter per second; and
- $H_C$  is the sensible heat flux, in watts per square meter per second.

Heat transfer from rainfall to the ponds is small and is not included (Webb and Zhang, 1997). The heat transfer terms in equation 1 are calculated as hourly average heat fluxes. The only directly measured heat flux term in equation 1 is net short-wave solar radiation,  $H_S$ , which was measured by California Irrigation Management Information System (CIMIS) at the Fremont station (fig. 1). The available record of hourly values of  $H_S$  are included in the HourlyData worksheet. The other terms in equation 1 are calculated as defined below:

Long-wave atmospheric radiation,  $H_A$ , varies with the moisture content of the air and is determined in the model using the following equation (U.S. Geological Survey, 1954):

$$H_A = 9.36 \times 10^{-6} \sigma (T_a + 273.15)^6 (1 + 0.17 C_L^2) (1 - R_L) \quad (2)$$

where

- $\sigma$  is the Stefan Boltzman constant,  $5.67 \times 10^{-8}$  in watts per square meters per Kelvins to the fourth power;
- $T_a$  is the temperature of air, in degrees Celsius;
- $C_L$  is the fraction of cloud cover; and
- $R_L$  is the reflectivity of the water surface for atmospheric radiation, 0.03.

Air temperature data were measured at the CIMIS Fremont station and are listed in the HourlyData worksheet. Cloud cover data were unavailable for the study area and were estimated using a procedure described in the 'Input Data' section of this report. Estimated fraction of cloud cover data also are listed in the HourlyData worksheet.

The long-wave water surface heat flux,  $H_B$ , is the heat lost from the water surface, and it is calculated by the Stefan-Boltzman equation:

$$H_B = \epsilon \sigma (T_w + 273.15)^4 \quad (3)$$

where

- $\epsilon$  is the emissivity of water, 0.97, a unitless value (Jobson, 1981);
- $\sigma$  is the Stefan Boltzman constant defined above; and
- $T_w$  is the average pond temperature in degrees Celsius.

Emissivity corrects for the fact that the water body is not an ideal blackbody radiator. The average pond temperature is calculated by the model during the previous hourly time step.

The energy loss from evaporation,  $H_E$ , is calculated by the following equation (Jobson, 1981):

$$H_E = \rho_w L E \quad (4)$$

where  $L$  is the latent heat of vaporization, in units of joules per kilogram, calculated as:

$$L = 2501000 - 2361 T_w \quad (5)$$

and the hourly average evaporation rate,  $E$ , in meters per second, is calculated by the model (Lionberger and others, 2004).

The sensible heat flux,  $H_C$ , which is heat that is conducted and convected between the water surface and the air, is calculated from the following equation (Jobson, 1981):

$$H_C = \gamma \rho L \psi (T_w - T_a) \quad (6)$$

where

- $\gamma$  is the psychrometric constant at sea level, 0.067 kilopascals per degrees Celsius; and
- $\psi$  is an empirical wind function, in meters per second per kilopascal.

The wind function is determined from the following equation:

$$\psi = \alpha + Nu \quad (7)$$

where

- the coefficients  $\alpha$  and  $N$  are empirical constants defined by Penman (1948) to be equal to 2.6 meters per second per kilopascal and 14 kilopascal<sup>-1</sup>, respectively; and
- $u$  is wind speed, in meters per second.

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Wind speed data were measured at the CIMIS Fremont station and are listed in the HourlyData worksheet.

Once the net heat flux,  $H_N$ , is determined, the hourly pond temperature is calculated as:

$$T_{NEW} = T_w + \frac{H_N \Delta t A}{\rho_w c_p V} \quad (8)$$

where

$T_{NEW}$  is the updated hourly pond temperature,  
in degrees Celsius;

$\Delta t$  is the time step, in seconds;

$A$  is the pond area, in square meters;

$\rho_w$  is the water density, in kilograms per cubic meter;

$c_p$  is the heat capacity of saltwater, 3,950 joules  
per kilogram per degrees Celsius; and

$V$  is the pond volume, in cubic meters.

Calculated hourly pond temperatures are averaged over 24 hours to obtain a daily average pond temperature. Daily minimum and maximum average pond temperatures are the lowest and highest simulated hourly pond temperatures during the 24-hour period. Minimum and maximum daily temperatures are important ecological factors for many aquatic organisms; therefore, these data are critical criteria for meeting habitat goals.

The temperature subroutine does not consider the effects of temperature difference between incoming water transfers and pond water. These effects are likely to be small because the volume of water transfers typically is small, compared to the volume of the pond (less than 1 percent for daily pond-to-pond water transfers), and any incoming water transfer is assumed to be dispersed instantly within the pond. Although the volume of incoming water from the slough can be significant (up to 30 percent of daily pond A9 volume), no long-term slough water temperature data currently are available. Point measurements taken by the USGS almost simultaneously in Alviso Slough and pond A9 indicated little temperature difference. On that basis, the effects of temperature difference between incoming slough water and pond water also are considered to be small.

### Temperature Validation

The temperature subroutine was validated by comparing simulated temperatures to measured pond temperatures on hourly and monthly timescales. Two data sets were used

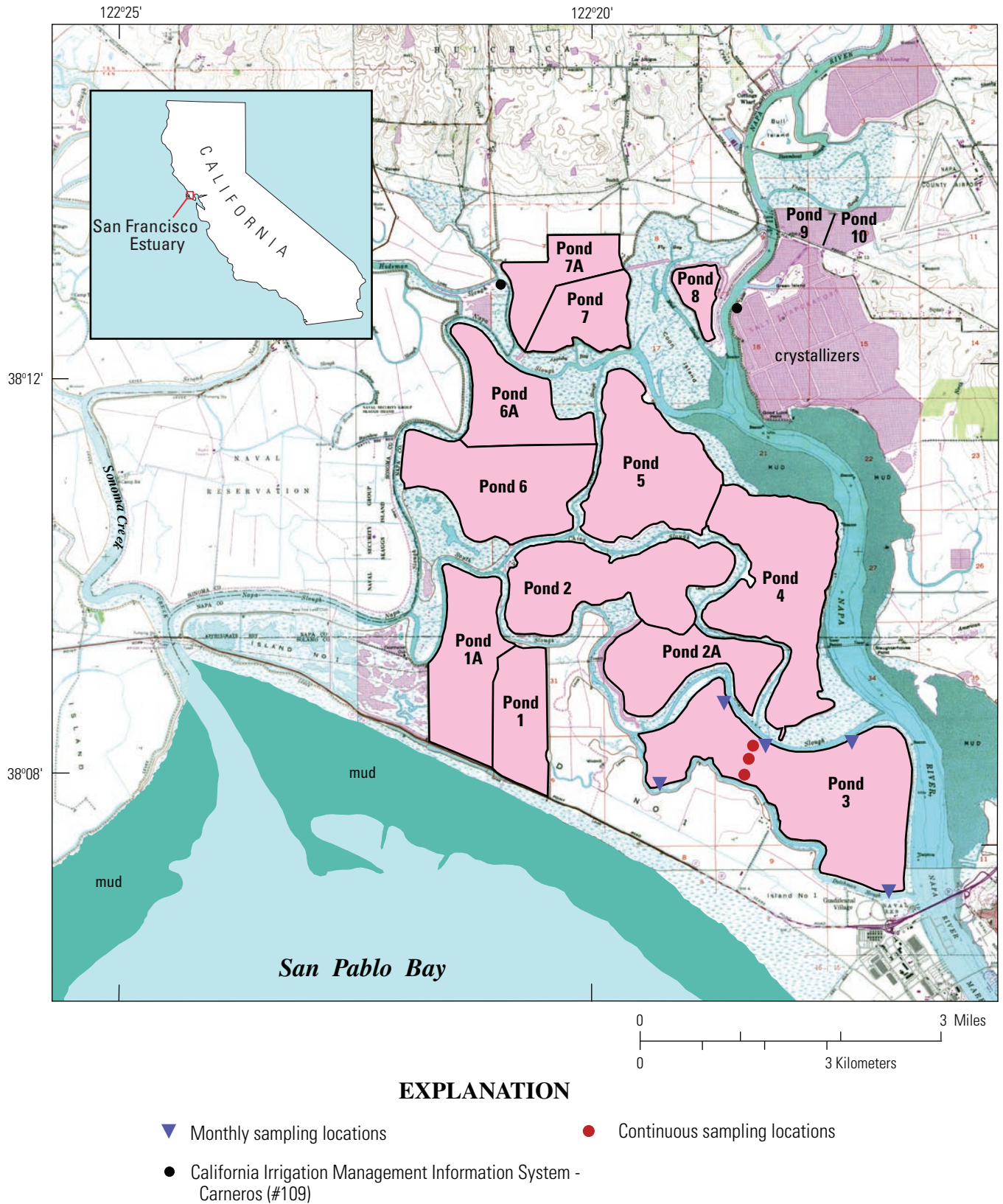
to validate the temperature subroutine; temperature data collected every 12 seconds over a 1-month period to validate hourly temperature simulations and data collected monthly over a 27-month period to validate monthly temperature simulations. Sub-hourly temperature data from pond 3 of the Napa salt ponds in North San Francisco Bay (fig. 2) were used because continuous data were unavailable for the Alviso salt ponds. Monthly data from the Alviso salt ponds were used, but the CIMIS Fremont weather station was not active during the data-collection period. Consequently, historical meteorological data from 1993 to 1995 were used to simulate pond temperatures measured during 2003–2005.

Validation of the temperature model on the hourly time scale was performed using the temperature data collected continuously in pond 3 of the Napa–Sonoma Salt Pond Complex in May 2001 (J. Bricker, written commun., formerly of Stanford University 2004). Data were collected in pond 3 along a transect at three different depths at each of three locations (fig. 2) and averaged spatially (nine-point mean) and then averaged temporally over 60 minutes to obtain a single average pond temperature for each hour.

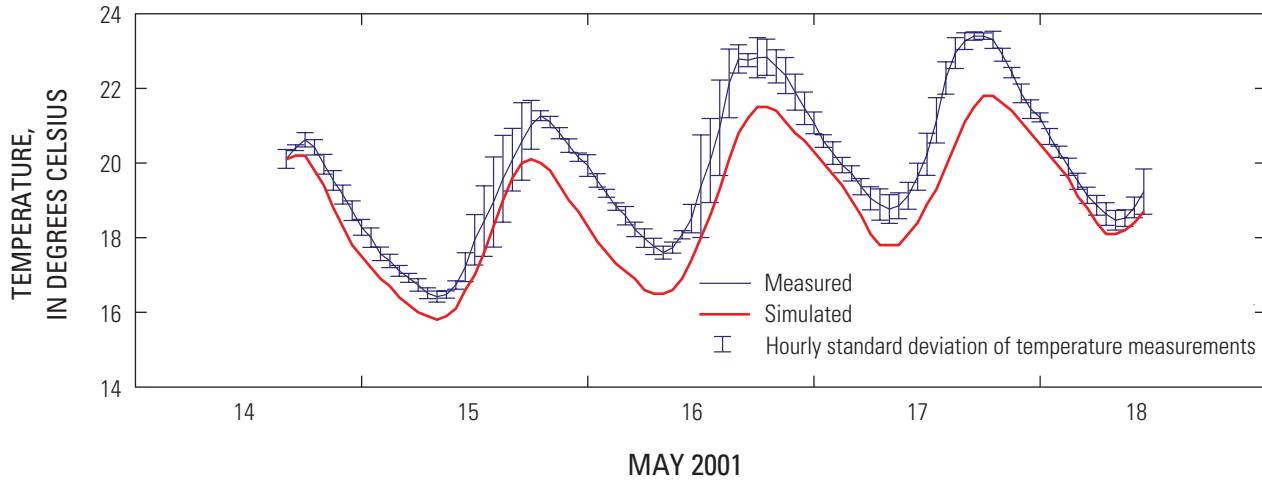
Hourly average pond temperatures were simulated by SPOOM using meteorological data from the CIMIS Carneros weather station (#109) and compared with the measured data (fig. 3). The simulated temperatures have similar diurnal temperature patterns as the measured data, although simulated values were less than measured values by an average of 1.0°C. Some of this apparent bias in simulation may result from the assumption that measured temperatures at different depths along a single transect represent an average pond temperature. The error bars shown in figure 3 are based on the standard deviation of the temperature measurements at the nine points along the transect and indicate an average variation of about 0.3°C. Additional once-monthly measurements of temperature at five discrete locations in Pond 3 from April 1999 to October 2001 showed an average standard deviation among the five in-pond locations of about 1.5°C. On this basis, the average difference between simulated and measured temperatures for the validation appears reasonable, and no model adjustments were made to try to achieve a better fit to measured data.

Validation of the SPOOM temperature model on the monthly time scale was performed using temperature data measured in pond A14 from May 2003 to August 2005 during the daytime at monthly intervals. Measurements were taken from a minimum of three discrete locations in the pond and averaged to obtain an average pond temperature (U.S. Fish and Wildlife Service, 2006).





**Figure 2.** The Napa–Sonoma Salt Pond Complex, San Francisco Bay, California. The locations of pond 3 and where temperature data were collected are shown.



**Figure 3.** Hourly temperature model validation of pond 3 of the Napa–Sonoma Salt Pond Complex. Bars on the measured temperature time series indicate the standard deviation of the nine simultaneous measurements taken at three depths and three locations in the pond.

SPOOM is not configured to simulate the pond temperatures from May 2003 to August 2005, because meteorological data for that period are unavailable from the CIMIS weather station at Fremont. Instead, the temperature model was validated using historical meteorological data for a period (May 1993 to August 1995) that was considered to be similar to the May 2003 to August 2005 temperature data-collection period. Simulated daily average and daily maximum temperatures are compared to the measured once-monthly average temperatures in [figure 4](#). Simulated daily maximum temperature is considered to provide a better comparison to the measured values because temperature was measured only during the day and in shallow water near the shore where temperatures probably are higher than the pond average. Although the simulated temperatures do not perfectly match the measured temperatures, simulated data show month-to-month variability in average pond temperature that is very similar to variability shown by measurements. On this basis, using historical meteorological data from previous years to simulate future, hypothetical pond temperatures is considered to provide reasonable results. Simulated results were not adjusted to fit the measured data.

## Discharge Simulations

The previous version of SPOOM simulated daily volume and salinity of a single pond. SPOOM has been modified to simulate conditions in ponds A9–A17, simultaneously. The Alviso pond system is surrounded by tidal sloughs, so tidal elevations in the sloughs are used as boundary conditions for ponds with slough connections. Pond-to-slough discharge through culverts is controlled, in part, by the slough water-surface elevation. Flow rates through the culverts are calculated hourly to account for changing tidal and pond

water-surface elevations and summed over 1 day. SPOOM calculates the hydraulic head and the resulting flow through the culverts using rating curves. Rating curves are included for culverts with weir boxes, culverts with flap gates, new culverts with screw gates, old culverts with screw gates (36 and 48 in.), and the siphon connecting ponds A15 and A16.

Discharge from ponds to the tidal sloughs is controlled by weir boxes and by culverts equipped with combination gates at each end. Combination gates can function as either a flap gate to allow unidirectional flow or as a screw gate to prevent flow or allow bidirectional flow. [Figure 5](#) illustrates an example of unidirectional culvert flow. Weir boxes, located inside the pond and surrounding the culvert entrance, are roughly 9 ft x 9 ft x 6 ft and made of cast concrete with six bays of removable wooden weir boards ([fig. 6](#)). If the weir boards are fully removed, the culverts control pond discharge to the slough; otherwise, the weir box is the dominant hydraulic control. One possible exception is during high tide when the weir is submerged. The effect of the culvert would again dominate. To account for this the model calculates flow as culvert discharge and also as weir discharge and assumes the smaller of the two as the discharge for that hourly period.

Weir discharge can be determined from a standard weir equation (Sturm, 2001) as

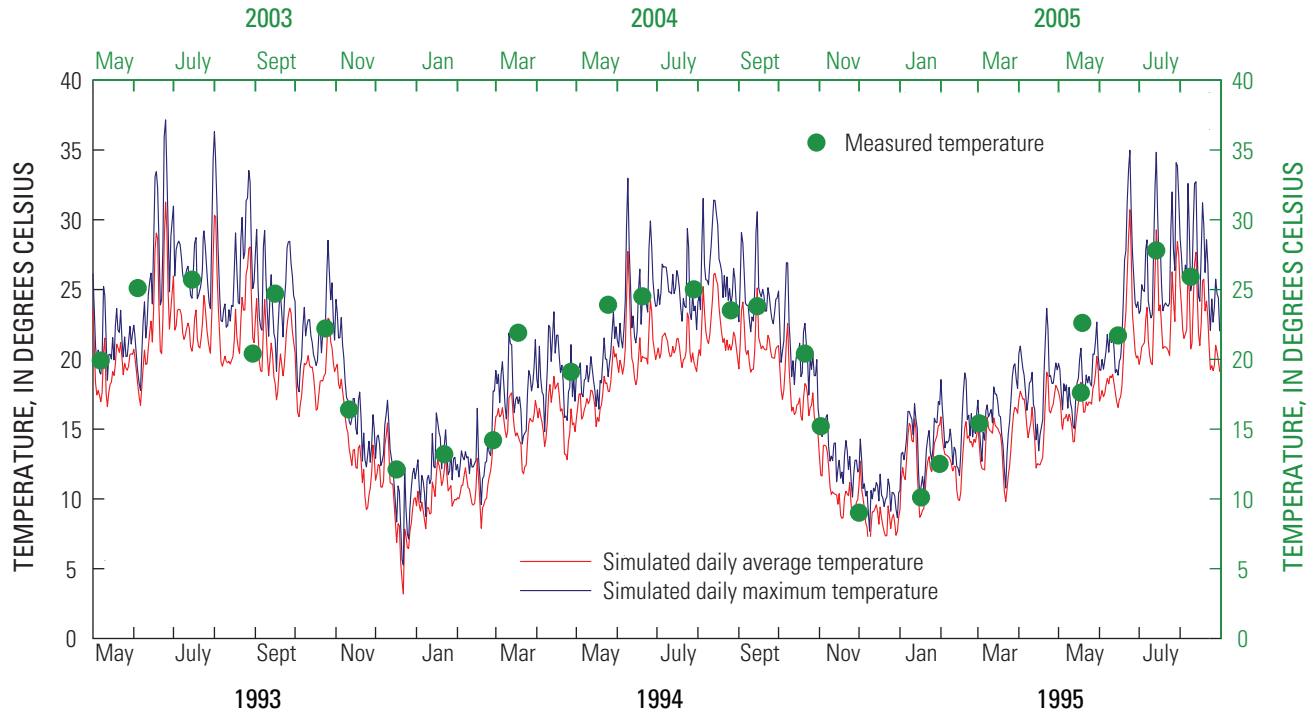
$$Q = \left(\frac{2}{3}\right) C_w b \sqrt{2g} H_w^{3/2} \quad (9)$$

where

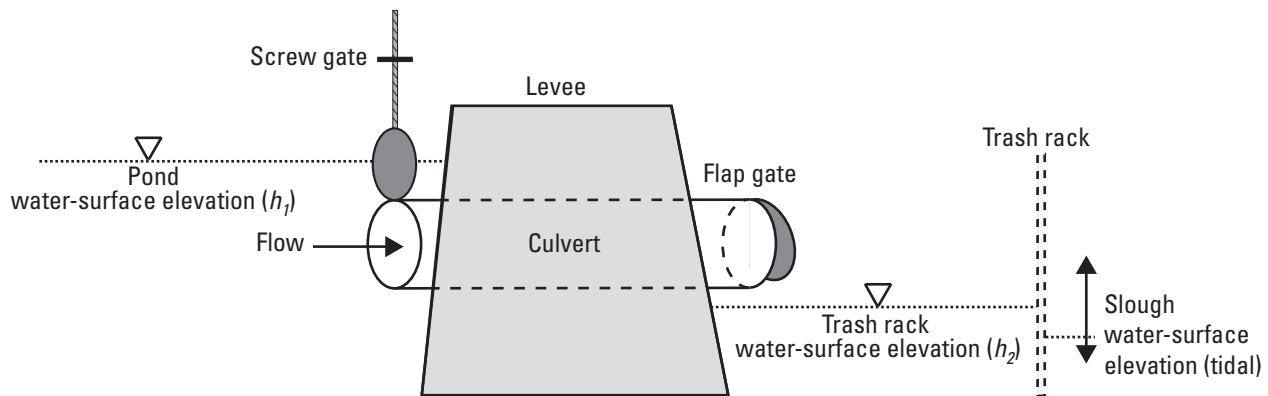
$Q$  is the discharge,

$b$  is the length of the weir perpendicular to the flow (figure 6, where  $b = b_1 + b_2 + b_3 + \dots b_6$ ),

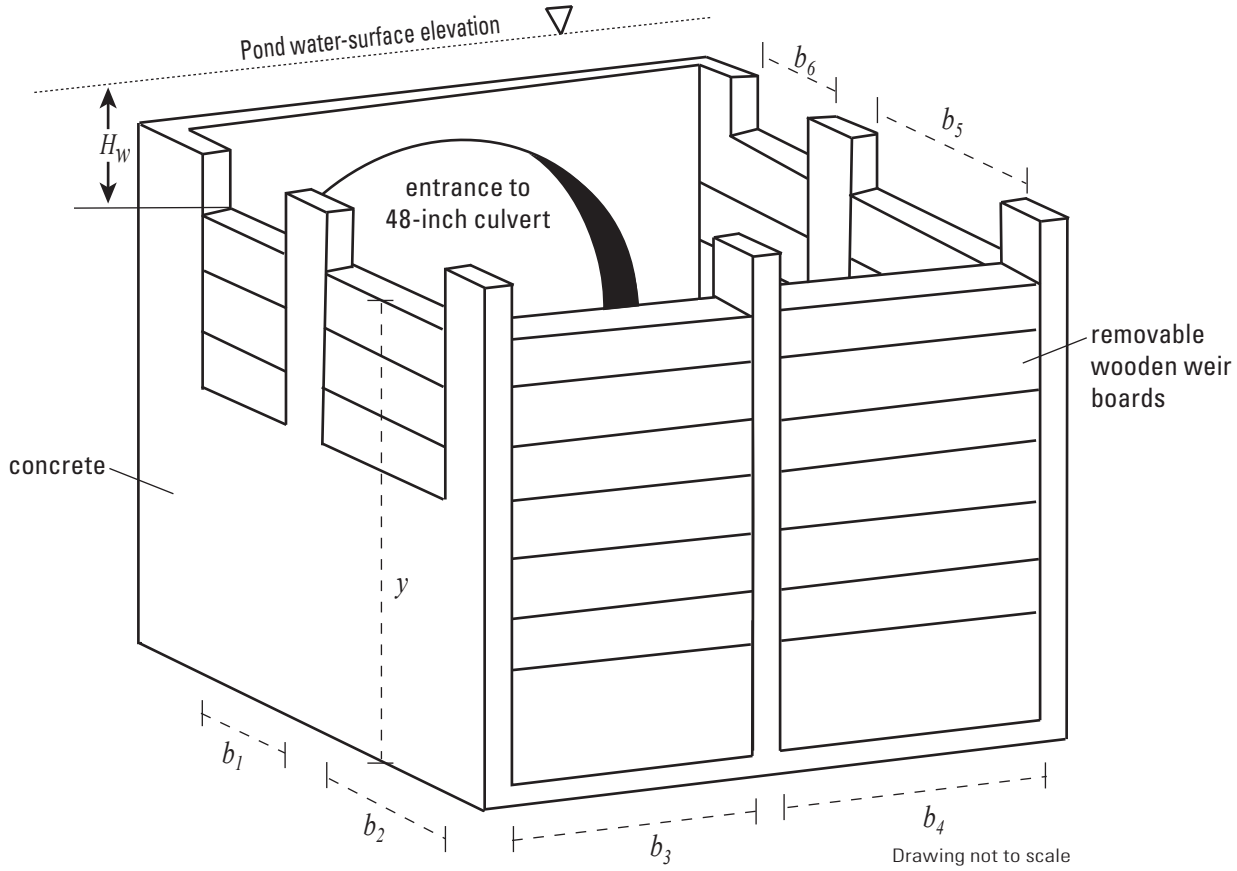
$H_w$  is the depth of water above the weir crest (head),



**Figure 4.** Monthly temperature model validation using monthly data collected in Alviso pond A14. The time scale along the bottom axis (in black) corresponds to the simulated temperatures. The time scale along the top axis (in green) corresponds to the measured temperatures.



**Figure 5.** Schematic diagram of culvert discharge structure used in the Alviso salt ponds, California. The water-surface elevation in the slough changes with the tide. The trash rack prevents debris in the sloughs from blocking the hinged flap gate.



**Figure 6.** Schematic diagram of weir box structure used in Alviso salt ponds, California.  $H_w$  represents the height of the pond water surface above the weir boards,  $b$  is the width of the weir boards, and  $y$  is the height of the weir boards above the pond bottom.

and

$$C_w = 0.602 + 0.075 \left( \frac{H_w}{y} \right) \quad (10)$$

where

$y$  is the height of the weir above the pond bottom (fig. 6), and

$C_w$  is the discharge coefficient that incorporates the effects on discharge of the approach velocity, head loss, and contraction.

Culvert discharge from pond to slough without the use of a weir box is affected by tidal conditions in the slough. A series of culvert discharge measurements in pond A3W (fig. 1) during a tidal cycle was used with a form of the Bernoulli equation to develop a relation between culvert discharge from a pond to a slough and the difference in water-surface elevations of the pond and slough. The discharge relation is assumed valid for the other discharge ponds in the Alviso Salt Pond Complex because their discharge structures are similar to that of pond A3W. Culvert discharge was measured using a downward-looking acoustic Doppler current profiler

(ADCP). The ADCP was mounted in a small aluminum sled and towed across the pond about 3–15 ft upstream from, and perpendicular to, the culvert inlet. Measured point velocities were integrated over depth and path length to compute total culvert discharge. Culvert discharge also can be calculated using the following form of the Bernoulli equation applied to the upstream and downstream ends of the culvert (Shellenbarger and others 2007):

$$Q = A \sqrt{\frac{2gH_p}{1+K_L}} \quad (11)$$

where

$A$  is the cross-sectional area of the culvert, in square feet;

$g$  is the acceleration of gravity, 32.2 ft per second squared;

$H_p$  is the hydraulic head, or difference between upstream and downstream water-surface elevations, in feet; and

$K_L$  is a loss coefficient variable.



This equation assumes the culvert is flowing full as a result of the backwater conditions produced by a hinged flap gate on the slough side of the culvert. The measured pond discharges and values of hydraulic head ( $H_p$ ) were used in equation 9 to solve for the loss coefficient,  $K_L$ , representing all energy losses, including entrance, friction, contraction, and exit as well as unquantifiable losses associated with the flap gates. The loss coefficient does not include losses associated with the screw gate. The model assumes that the screw gate is only used to completely close the culvert to prevent flow (only for culverts connecting ponds to sloughs), otherwise the screw gate is kept fully open, as shown in [figure 5](#). The loss coefficient was found to vary with hydraulic head in a manner best described by two best-fit equations, ([fig. 7](#)). At low heads ( $H_p < 0.626$  ft),  $K_L$  exponentially decreases with increasing head,

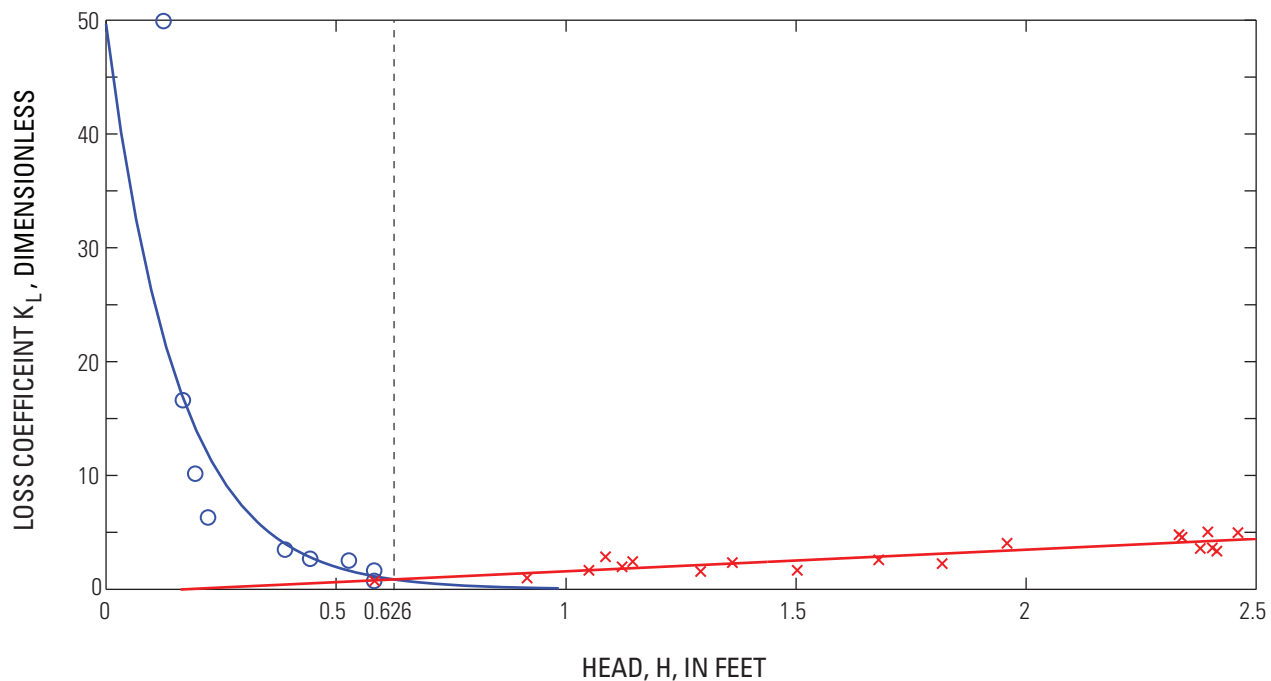
$$K_L = 49.7e^{-6.47H_p} \quad (12)$$

This probably is due to the flap gate opening further as head increases. At high heads ( $H_p > 0.626$  ft),  $K_L$  linearly increases with an increase in head.

$$K_L = 1.90H_p - 0.321 \quad (13)$$

The exponential function defined by equation 10 and the line defined by equation 11 intersect at  $H_p = 0.626$  ft.

When slough water-surface elevations fall below the elevation of the inside bottom of the culvert, or culvert invert, the flap gate is the dominant hydraulic control. Therefore, tidal slough water-surface elevations that fall below the elevation of the culvert invert are neglected and the hydraulic head is measured as the difference between the pond water-surface elevation and the culvert invert elevation. Culvert invert elevations are given in [table 3](#).



### EXPLANATION

#### Lines from equations

- for  $H_p < 0.626$ , from equation 10  
 $K_L = 49.7e^{-6.47H_p}$
- for  $H \geq 0.626$ , from equation 11  
 $K_L = 1.90 \times H_p - 0.321$

#### Data used to derive best-fit equations

- for  $H < 0.626$
- × for  $H \geq 0.626$

**Figure 7.** Loss coefficient,  $K_L$ , as a function the hydraulic head for culverts connecting ponds to sloughs (eqs. 10 and 11). (Modified from Shellenbarger and others, 2007).

**Table 3.** Elevations of the culvert inverts for Alviso ponds with slough connections.

[Elevation is referenced to NGVD 29 vertical datum. ft, feet]

Pond	Outlet culvert invert elevation (ft)
A14	-3.0
A15	-2.0
A16	-1.6
A17	-1.5

Pond-to-pond discharge is controlled by a series of culverts equipped with screw gates to regulate flow. Some of these culverts were in place before the ISP period, and some new culverts were installed for managing the ponds during the ISP period. Because older culverts can be filled partially with debris, they will not flow to their full capacity as would new culverts. Consequently, pond-to-pond culvert discharge is simulated in two ways: using theoretical flow-rating curves for new culverts and measured flow-rating curves for existing culverts.

Theoretical flow rating curves used for new culverts are based on the assumption that the culvert is submerged fully and flowing under outlet-control conditions (American Society of Civil Engineers, 1992). The rating curve is a function of the hydraulic head across the culvert and is of the form

$$Q = A \left[ \frac{2gH_p}{\left( K_s + 1 + \frac{29n^2L}{R^{1.33}} \right)} \right]^{1/2} \quad (14)$$

where

- $Q$  is the flow rate, in cubic feet per second;
- $A$  is the culvert area, in square feet;
- $g$  is gravitational acceleration, in feet per second squared;
- $H_p$  is the hydraulic head, or difference between water-surface elevations in the ponds, in feet;
- $K_s$  is the screw gate loss coefficient;
- $n$  is the Manning's roughness coefficient;
- $L$  is the culvert length, in feet; and
- $R$  is the hydraulic radius, in feet.

Manning's roughness coefficient values are available from a number of sources and often are presented as a range. The value used in this study (0.022) is at the mid-point of a range for corrugated metal pipe given by White (1999; table 10.1).

The screw gate loss coefficient,  $K_s$ , varies, depending on the size of the culvert-flow area. The ScrewGates worksheet allows the user to specify a percent of the culvert cross-sectional area,  $P$ , open to flow for a specific day for pond-to-pond connections. Based on gate valve loss coefficients listed by Jeppson (1976; table 3-1),  $K_s$  can be calculated from  $P$  using the following equation (fig. 8):

$$K_s = 163.4e^{-0.0677P} \quad (15)$$

At fully open,  $K_s$  is 0.19 and then increases exponentially with decreasing flow area.

Rating curves for old culverts with screw gates were developed from culvert discharge measurements using an ADCP and measured hydraulic heads ( $H_p$ , difference between upstream and downstream pond elevations). Measurement data were grouped by culvert dimensions, and discharge was related to hydraulic head using a best-fit exponential equation. The resultant rating curve for the 36-in. culverts was (fig. 9):

$$Q = 11.1 \cdot H_p^{0.880} \quad (16)$$

and the rating curve for the 48-inch culverts is (fig. 10):

$$Q = 36.8 \cdot H_p^{0.617} \quad (17)$$

An exponential rating curve also was determined (not shown) for the siphon-connecting ponds A15 and A16:

$$Q = 48.3 \cdot H_p^{7.363} \quad (18)$$

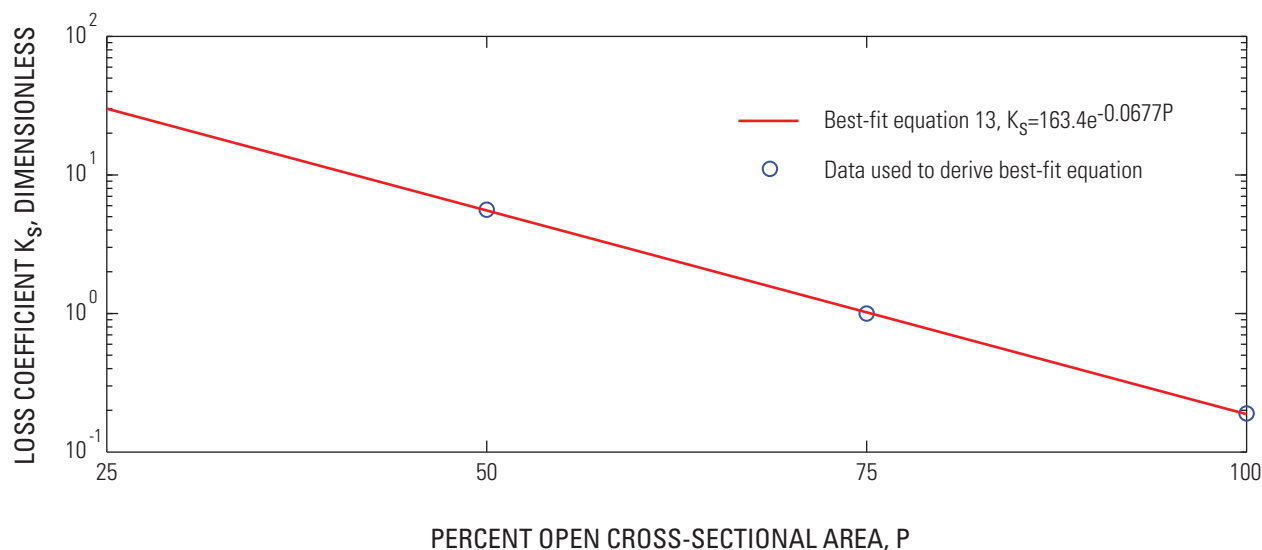
Only three measured flow rates were used to determine equation 16.

Culvert discharge was measured only when the screw gates were open fully. To calculate culvert discharge through a partially open screw gate on an old culvert, the ratio of discharge with a partially open gate to discharge with a fully open gate was assumed to be the same as that for a new culvert. On that basis, dividing equation 12 for a partially open screw gate condition by equation 12 for a fully open screw gate condition and rearranging terms provides the following equation for calculating culvert discharge with a partially open screw gate:

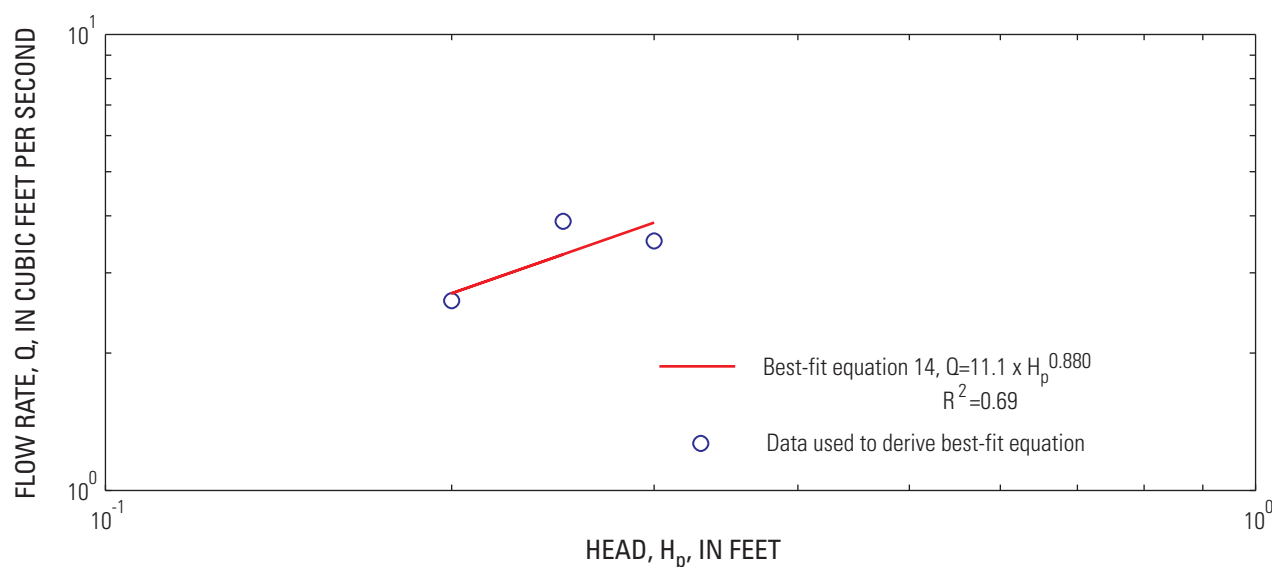
$$Q = \frac{\left( K_{s_{100}} + 1 + \frac{29n^2L}{R^{1.33}} \right)^{1/2}}{\left( K_s + 1 + \frac{29n^2L}{R^{1.33}} \right)^{1/2}} Q_{100} \frac{A}{A_{100}} \quad (19)$$

where

- $Q$  is the culvert flow with the screw gate closed partially;
- $Q_{100}$  is the culvert flow with the screw gate 100 percent open;
- $K_s$  is the entrance loss coefficient of the partially closed screw gate; and
- $K_{s_{100}}$  is the entrance loss coefficient when the screw gate is 100 percent open, (0.19);
- $A$  is the culvert cross sectional flow area with a partially closed screw gate; and
- $A_{100}$  is the culvert cross sectional flow area with the screw gate fully open.



**Figure 8.** Rating curve to estimate loss coefficient,  $K_s$ , using coefficient data from Jeppson (1976).



**Figure 9.** Flow rating curve for existing 36-inch culverts with fully open screw gates.

## Pond Area and Volume

The Geometry worksheet lists area and volume for ponds A9–A17 as functions of water-surface elevation, relative to vertical datum NAVD 88. The areas and volumes were calculated using ArcGIS geographic information system software (ESRI, Redlands California). Initially, boundaries for ponds A9–A17 were delineated by on-screen digitization using high-resolution digital orthophotos (0.3-meter pixel resolution) at a scale of 1:1,000 as a base layer. The orthophotos were obtained online from the USGS Seamless Data Distribution Delivery website (<http://gisdata.usgs.net/website/seamless/viewer.php>), and the pond boundary polygons were digitized

for the wetted perimeter, as observed in the orthoimagery, of each pond.

Bathymetric data for the Alviso ponds were obtained from the USGS Western Ecological Research Center as a series of spreadsheet files containing positional data as latitude, longitude, and elevation for points within each pond (Takekawa and others, 2005). These data were referenced to the horizontal and vertical datums, NAD 83 and NAVD 88, respectively. The spreadsheet data for each pond then were converted into point shapefiles using ArcGIS.

LiDaR (Light Detection and Ranging) elevation data, for an area including ponds A9–A17, were obtained from the Environmental Services Department of the City of San Jose (written commun., 2002). These data also were obtained in spreadsheet format and converted to point shapefiles. The horizontal and vertical datums were NAD 83 and NAVD 88, respectively. Data points located within the boundaries of the ponds then were eliminated from the dataset as they represented water-surface elevations rather than pond bottom elevations. The point shapefiles for the bathymetric and LiDaR data then were merged into a single point shapefile in ArcGIS. This file was converted to a Triangular Irregular Network (TIN) three-dimensional (3D) surface using the ArcGIS 3D Analyst extension and converted to a raster image. The raster image was clipped using each of the pond boundary polygons. The resulting raster images for each pond were analyzed using the 3D Analyst extension. Pond surface area and volume were determined by using a horizontal plane to represent the pond water surface. Calculations were performed by raising the water-surface elevation in 0.1-foot increments, based on the minimum and maximum elevation values for each pond TIN. The results of these calculations were exported automatically from the GIS software as text files which, subsequently, were converted into spreadsheet files.

SPOOM enables the user to perform simulations referenced to the NAVD 88 or NGVD 29 vertical datums by using a pull-down list located on the Main worksheet. A conversion factor (-2.69 ft or 0.82 m) for converting NGVD 29 elevations from NAVD 88 elevations was determined using VERTCON (<http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html>, accessed on August 30, 2007) and is applied in the model code. Thus, simulations can be made using either vertical datum without the need to change any geometry data.

## Meteorology Data

The worksheet HourlyData includes hourly average values of solar radiation, air temperature, fraction of cloud cover, wind speed, and evaporation for water years 1992–96, 1998 and 1999. Water year 1997 is excluded because of missing data. These data are necessary for the temperature subroutine. The meteorological data are historical data from the CIMIS weather station at Fremont (#100), except for the fraction of cloud-cover data and freshwater evaporation data.

Cloud-cover data were unavailable for the study area. A method was developed to estimate this parameter using solar radiation data measured by CIMIS. A 30-day centered mean and standard deviation of the mean of daily average solar radiation were calculated. The range of values used to calculate the mean and standard deviation of the first and last 14 days of the record were truncated so that an equal number of days were considered before and after the day being calculated. Fraction of cloud cover for each day was considered to be zero if solar radiation for the day was less than the average value minus one standard deviation, 1.0 if the solar radiation was greater than the average value plus one

standard deviation, and  $\sqrt{2}/2$  for all values of solar radiation in between.

The value of  $\sqrt{2}/2$  was chosen based on the assumption that the mid-range of fraction of cloud cover should correspond to the long-wave atmospheric radiation halfway between that for no cloud cover and that for complete cloud cover. The heat equation (eq. 2) indicates that long-wave atmospheric radiation is proportional to the square of the fraction of cloud cover. On that basis, the square of the fraction of cloud cover, midway between 0 (no cloud cover) and 1.0 (complete cloud cover), is 0.5, and the square root of 0.5 is  $\sqrt{2}/2$ . At most, the fraction cloud cover coefficient affects the long-wave atmospheric radiation term by 17 percent (eq. 2). Therefore, the model results are relatively insensitive to the coefficient estimates employed here.

Hourly freshwater evaporation rates were calculated using the Combined Aerodynamic and Energy Balance Method (Chow and others, 1998; Lionberger and others, 2004) and meteorological data from the CIMIS weather station at Fremont (#100). Salinity increases water density, thereby reducing the value of evaporation to less than the freshwater value. To account for the effect of salinity on evaporation, a correction factor is applied in the model to reduce evaporation.

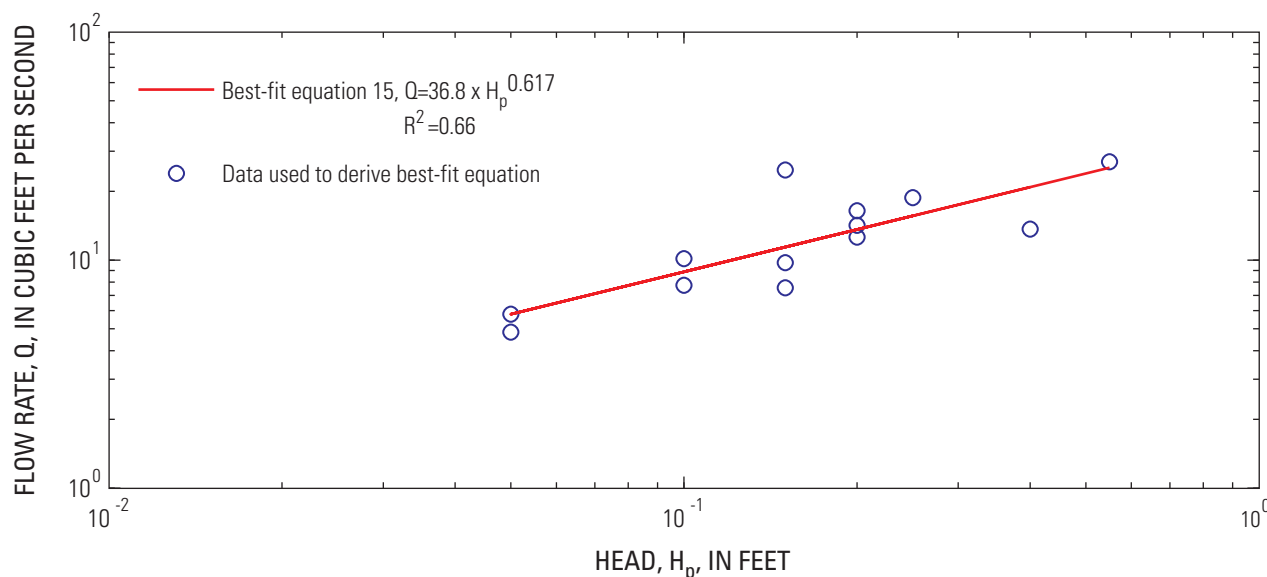
$$E_w = E_o \frac{\rho_o}{\rho_w} \quad (20)$$

where

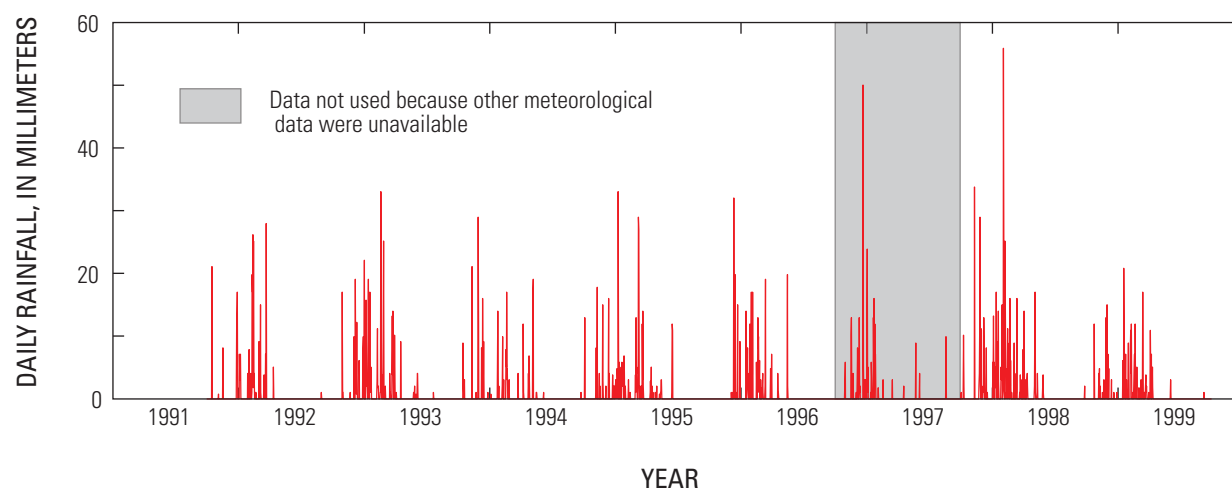
$E_w$  is the evaporation rate of saltwater at temperature T;  
 $E_o$  is the evaporation rate of freshwater at temperature T;  
 $\rho_o$  is the density of freshwater at temperature T; and  
 $\rho_w$  is the density of saltwater at temperature T.

The Rainfall worksheet contains daily rainfall rates from the closest rainfall gage to the ponds, Guadalupe Slough RF 16, operated and maintained by the Santa Clara Valley Water District (SCVWD) (figs. 1 and 11). The driest year of the record is water year 1994, with 71 percent of normal precipitation and the wettest year of record is water year 1998, with 163 percent of normal. Normal is defined in this report as the mean of the annual rainfall values for the 1992–1996 and 1998–1999 period of record included in the model. The model user also can enter custom rainfall data by choosing ‘Custom’ from the rainfall pull-down box on the Main worksheet and by entering a data series, in units of millimeters per day, in column C of the Rainfall worksheet. The range of dates specified by the user in the start date and end date pull-down boxes in the Main worksheet must be consistent with the dates of custom rainfall data.

Although the use of custom rainfall enables the user to simulate pond conditions for rainfall data outside the period of record in the model, other meteorological data used in the model are for the available period of record at the CIMIS station at Fremont only and, thus, may not be consistent with the custom rainfall.



**Figure 10.** Flow rating curve for existing 48-inch culverts with fully open screw gates.



**Figure 11.** Daily rainfall rates for water years 1992–99 on the Rainfall worksheet. The shaded area, covering water year 1997, is not included in the model because of missing meteorology data.

## Slough Water-Surface Elevation

Hourly slough water-surface elevation is the boundary condition for ponds with culverts connecting to the sloughs. Long-term water-surface elevation data were not available at any of the Alviso pond culverts connecting to the sloughs. Instead, tidal elevation data measured every 12 minutes from January 31 to April 29, 2004, by Moffatt and Nichol Engineers (2005) in Coyote Creek at Power Tower ([fig. 1](#)) were used to predict water-surface elevations for the dates when meteorological data were available (water years 1992–96, 1998, and 1999). Tidal harmonic analysis was applied to the data using T\_TIDE for MATLAB (Pawlowicz and others, 2002). Using the tidal harmonic constants extracted from this dataset, predictions of hourly tidal water-surface elevations

were made for the period of record included in the model using T\_PREDIC for MATLAB (Pawlowicz and others, 2002). Data from the Power Tower site ([fig. 1](#)) were used in this analysis because its location is the closest tidal elevation monitoring site to the ponds, located no more than 7 km from any of the slough-to-pond culverts. The model is based on the assumption that the tidal elevation at Power Tower represents tidal elevations in the sloughs at all culverts in the Alviso system. Tidal range decreases upstream of the Bay, however, and tidal data at Power Tower may not represent the tidal elevation at ponds A16 and A17 as well as at A9 and A14. Errors associated with the assumption that tidal elevations are the same throughout the sloughs are unknown. Hourly predicted tidal elevations are listed in the HourlyData worksheet.

## Slough Salinity

In summer and fall, slough salinities vary diurnally with the tides, with higher salinities at high tide and lower salinities at low tide owing to freshwater effluent from the San Jose/Santa Clara Water Pollution Control Plant. In winter and spring, slough salinities are more variable, depending on storm-water runoff. Since flows into the ponds are restricted during the winter and spring, SPOOM accounts only for slough salinities in the summer and fall. Continuous salinity data were measured half-hourly by the City of San Jose ESD at the Coyote Creek railroad trestle (SB04) from October 16, 1997, to October 30, 1997 (fig. 1, City of San Jose, written commun., 1997). This location was chosen because it is the closest downstream measurement site to the ponds and is centrally located between ponds with slough-connecting culverts. Salinities measured on the hour were plotted against hourly slough water-surface elevation estimated using T\_PREDIC for MATLAB (Pawlowicz and others, 2002) to formulate a rating curve to estimate slough salinities for use in the model (fig. 12). Because the salinity record is so short, the accuracy of the salinity prediction during other times of the

year is unknown. The data show hysteresis between flood and ebb tides. As a result, two rating curves were developed for application to flood tide

$$S = 3.3t^2 - 3.4t + 8.3 \quad (21)$$

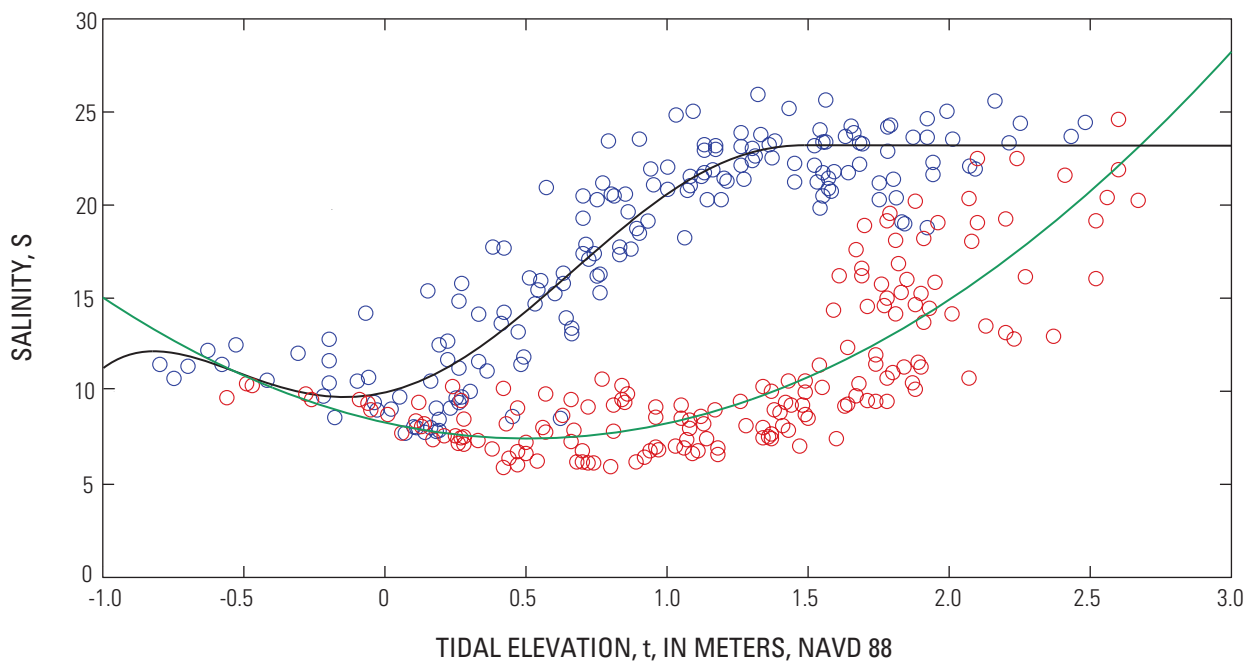
and to ebb tide

$$\begin{aligned} S &= 1.9t^5 - 6.2t^4 - 0.74t^3 + 12t^2 + 3.5t + 9.8 \text{ for } t < 1.45 \text{ m} \\ S &= 22.6 \text{ for } t > 1.45 \text{ m} \end{aligned} \quad (22)$$

where

$S$  is the slough salinity, and  
 $t$  is the tidal elevation, in meters,  
 NAVD 88 datum.

in column H of the HourlyData worksheet, estimates of hourly tidal direction of flood or ebb are listed, on the basis of whether the water level is increasing or decreasing. The model accesses the hourly tidal direction and tidal elevation given in column G, and applies the appropriate rating curve.



### EXPLANATION

#### Lines from equations

— For flood, from equation 21  
 $S = 3.3t^2 - 3.4t + 8.3$

— For ebb, from equation 22  
 $S = 1.9t^5 - 6.2t^4 - 0.74t^3 + 12t^2 + 3.5t + 9.8$   
 $S = 22.6$

#### Data used to derive best-fit equations

○ For flood  
 ○ For ebb

for  $t < 1.45$  meters  
 for  $t \geq 1.45$  meters

**Figure 12.** Rating curves of slough salinities for flood and ebb tides as a function of tidal elevation.



The only pond able to receive inflow from the sloughs in winter is pond A16. The culvert connecting pond A16 to the slough is located near the wastewater treatment plant outlet to the slough. Continuous salinity measurements taken in summer just upstream from the A16 culvert indicate that the salinity is zero most of the time. Slough salinity will be even fresher in winter owing to storm runoff. Therefore, the salinity of slough inflows into pond A16 during winter is assumed to be zero.

## Using The Model

SPOOM simulates pond volume, salinity, and temperature for Alviso ponds A9–A17 using historical data collected during 7 years with variable start and end dates. The model gives the user many options to make it a versatile management tool. There are six worksheets (Main, Weirs, Rainfall, Pumping, ScrewGates, ComboGates) in which the user can specify parameters to customize the pond simulation.

On the Main worksheet ([fig. 13](#)), the user can:

- Select a vertical datum system for pond elevations, NGVD 29 or NAVD 88.
- Select a unit system for initial pond elevations and output (metric or inch-pound).
- Select a water year for simulation on the Main worksheet from a pull-down menu that lists the annual percent of normal precipitation and temperature, relative to the annual averages from the 7 water years or select a custom rainfall water year.
- Select start and end dates of the simulation period.
- Select to simulate temperature or not (choosing not to simulate temperature will reduce the simulation run time).
- Specify the initial pond water-surface elevations (relative to the chosen datum and unit systems), and pond temperatures (in degrees Celsius).
- Define which ponds are connected hydraulically and how they are connected.

On the Weirs worksheet ([fig. 14](#)), the user can:

- Specify the use of weirs for discharge periods to sloughs from ponds A14, A16, A17.
- Specify total weir length, in feet or meters.
- Specify elevation of the weir crest, in feet or meters, NGVD29 or NAVD88.
- Specify weir height, in feet or meters.
- Specify the number of weir boxes.

On the Rainfall worksheet ([fig. 15](#)), the user can:

- Enter a user-defined rainfall series in column C, in millimeters.

On the Pumping worksheet ([fig. 16](#)), the user can:

- Specify the daily pumping rate from pond A13 to pond A14, in gallons per day.
- Specify the daily pumping rate from pond A13 to pond A15, in gallons per day.
- Specify the daily pumping rate from pond A8 to pond A11, in gallons per day and salinity in pond A8.

On the ScrewGates worksheet ([fig. 17](#)), the user can:

- Enter the percent of the culvert flow area, if it is less than 100 percent, for any culvert connecting two ponds in the pond system.

On the ComboGates worksheet ([fig. 18](#)), the user can:

- Specify daily directional culvert flow for ponds with slough connections: None, Inflow, Outflow, or Bidirectional, when ‘Custom’ is selected in pond-to-slough connection dropdown lists on the Main worksheet

The Main worksheet includes a table for the user to define which ponds flow to one another and under what conditions. The table is set up with ‘flow from’ on the vertical axis and ‘flow to’ on the horizontal axis. Entries on the axes include ponds A9–A17 and the surrounding sloughs. Water bodies that are not adjacent to one another and, therefore, that cannot have flow between them are shown blocked out in black.

Within the table, there are two types of connections: slough-to-pond and pond-to-pond. Each has a different set of inputs to define its connection. [Figure 19](#) shows an example, highlighted in yellow, of an input for a culvert connecting a slough and a pond: flow is from Alviso Slough to pond A9. The first line describes the flow direction of the culvert. A pull-down menu is exposed when a cell is selected to allow the user to choose the flow direction from a list. The list entries include ‘Inflow’, ‘Outflow’, ‘Bidirectional’, ‘Custom’, or ‘None’. If there is no connecting culvert or the culvert is closed in both flow directions, ‘None’ is selected; if the culvert flows from the slough to the pond, ‘Inflow’ is selected; and if the culvert flows from the pond to the slough, ‘Outflow’ is selected. For the case of muted tidal flow when the culvert is capable of inflow and outflow, ‘Bidirectional’ is selected. Some simulations will require a change in culvert flow regime within the simulation period. In this case, ‘Custom’ is selected and the flow directions are specified in the ComboGates worksheet as daily values. The second line describes (1) the number of culverts and (2) the diameter of the culvert(s), in inches. A pull-down menu is exposed when each of these cells are selected. Entries in the quantity cell pull-down menu are 1 and 2, and in the diameter cell pull-down menu are 36 and 48 inches. These cells also can be left blank when the flow direction is selected as ‘None’. The third and fourth lines intentionally are left blank.

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Click the Calculate Button to Activate the Pond System Simulation

Calculate

User Inputs:

Infiltration (m<sup>3</sup>/day) 0

Rainfall/Temperature Year 1992: 89% of Normal Precipitation/100% of Normal Temperature

Start Date 10/01/1991

End Date 05/30/1992

Simulate Temperature? Yes

Vertical Datum MAYD88

Unit Scale (for initial inputs and outputs) inch-pound

---Select a cell and use the pull down lists to choose flow direction, connection, quantity, and diameter---

From	To	A9	A10	A11	A12	A13	A14	A15	A16	A17
Flow Direction (Inflow, Outflow, Bidirectional, Custom, None)		Custom	None	None	None	None	Custom	None	Custom	Custom
quantity, diameter (in.)		2 48					2 48	1 48	1 48	1 48
Connection (New, Existing, None, Siphon, Pump)		None	New	None	None	None	None	None	None	None
quantity, diameter (in.)			1 48				1 36			
Min. Water Level, Max. Water Level			0 3				0 3			
Min. Salinity, Max. Salinity			0 40				0 40			
Connection (New, Existing, None, Siphon, Pump)		New	None	New	None	None	None	None	None	None
quantity, diameter (inches)		1 48		1 48			Existing			
Min. Water Level, Max. Water Level		0 3		0 3			0 3			
Min. Salinity, Max. Salinity		0 40		0 40			0 40			
Connection (New, Existing, None, Siphon, Pump)		None	New	None			None			
quantity, diameter (inches)			1 48				1 48			
Min. Water Level, Max. Water Level			0 3				0 3			
Min. Salinity, Max. Salinity			0 40				0 40			

Main Charts / Flows / Rainfall / HourlyData / Pumping / ScrewGates / FlapGates / Geometry / A9Results / A10Results / A11Results / A17Results

Ready

Figure 13. A screen print of the Main worksheet from the SPOOM workbook.

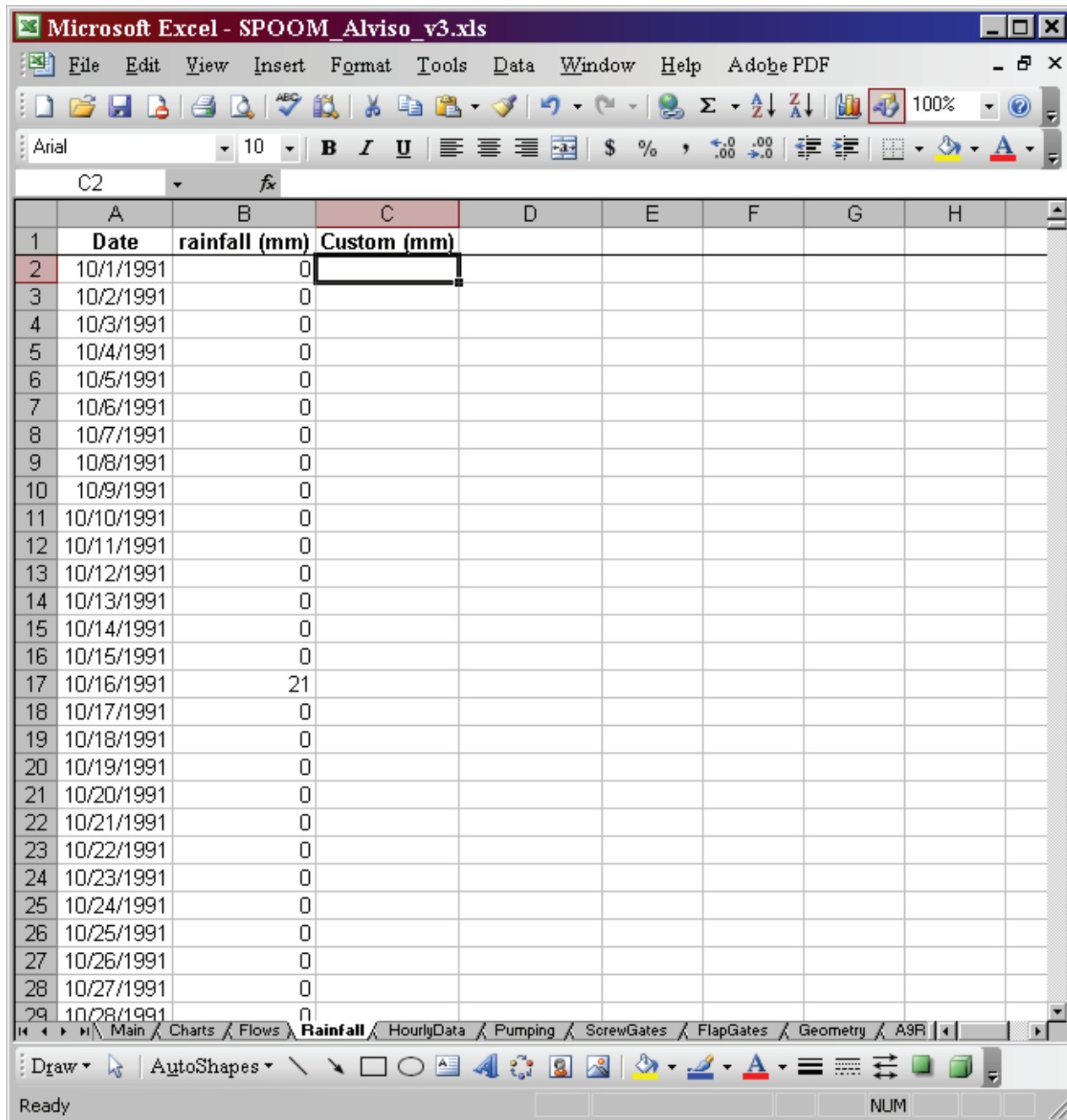


	A	B	C
1	<b>ENTER VALUES CONSISTENT WITH UNIT SCALE AND</b>		
2	<b>VERTICAL DATUM SELECTED ON THE MAIN WORKSHEET!</b>		
4	<b>Pond A14</b>		<b>Pond A16</b>
6	Are Weir(s) used during outflow periods (excludes bidirectional flow periods):	Yes	Are Weir(s) used during outflow periods (excludes bidirectional flow periods):
8	Total Weir Length (feet or meters):	24	Total Weir Length (feet or meters):
10	Elevation of Weir Crest (feet or meters, NGVD29 or NAVD88):	1.667	Elevation of Weir Crest (feet or meters, NGVD29 or NAVD88):
12	Height of Weir (feet or meters):	6	Height of Weir (feet or meters):
14	# of Weir Boxes:	1	# of Weir Boxes:
17	<b>Pond A17</b>		
19	Are Weir(s) used during outflow periods (excludes bidirectional flow periods):	Yes	
21	Total Weir Length (feet or meters):	24	
23	Elevation of Weir Crest (feet or meters, NGVD29 or NAVD88):	3.066	
25	Height of Weir (feet or meters):	6	
27	# of Weir Boxes:	1	

**Figure 14.** A screen print of the Weirs worksheet from the SP00M workbook.

Winter inflow restrictions are required by the ISP to minimize entrainment of salmonids from December 1 to May 31. It specifies that ponds A9 and A15 are closed to tidal inflow and the intake-outlet circulation of pond A16 and A17 are reversed. Pond A14 must be closed to tidal inflow from December 1 to April 30 and can be open to bidirectional tidal flow during the month of May to maintain salinity levels. To specify the ISP or other inflow restrictions, flow directions can be specified on the Main worksheet or on the ComboGates worksheet if 'Custom' is selected in the first line of the slough to pond entry on the Main worksheet (fig. 19). The ComboGates worksheet allows the user to define multiple tidal flow controls for each pond during a simulation period. On the ComboGates worksheet, flow direction (None, Inflow, Outflow, or Bidirectional) is selected for each day of the simulation period from a pull-down list given in each cell. ISP inflow restrictions are specified in the original SP00M ComboGates worksheet.

The second type of connection is pond-to-pond, as shown highlighted in yellow in figure 20: flow is from pond A9 to pond A10. The first line defines whether the pond is connected and the kind of connection. The five possible entries for this line are 'New', 'Existing', 'None', 'Siphon', or 'Pump' and are specified by the user from a pull-down list when a cell is selected. 'New' and 'Existing' refer to when the culverts were constructed: for the ISP or prior the ISP. 'None' is selected for ponds without a connecting culvert. 'Siphon' is selected for the siphon between ponds A15 and A16 and 'Pump' is selected for the pumping connections between ponds A13 and A14, ponds A13 and A15. In addition to specifying 'Pump' on the Main worksheet, pumping rates must be entered in the Pumping worksheet. The second line is similar to the slough-to-pond case with pull-down lists for quantity and diameter of the connecting culverts. The third and fourth lines refer to the management guidelines of the 'flow from'



**Figure 15.** A screen print of the Rainfall worksheet from the SPOOM workbook.

pond, as specified by the model user. The third line indicates the minimum and maximum water level, relative to the chosen datum and unit system, and the fourth line indicates the minimum and maximum salinity. If the calculated pond depth or salinity is outside the specified ranges on a given day, the Results page will alert the user by showing the depth or salinity cell filled in red.

The Weirs worksheet allows the user to specify weir box operation for discharge ponds A14, A16 and A17. The flow direction of these ponds can vary during the simulation period, as specified in the ComboGates worksheet, and

will not always be outflow. For example, A14 is allowed to have bidirectional flow during May, and A16 is an outflow pond only when A17 is an inflow pond, and vice versa. As a result, the ponds with weir use specified as 'yes' will not simulate weir flow if the ponds are inflow or bidirectional. The model assumes the weir boards are removed during these periods. The Weir worksheet also allows the user to specify weir lengths, heights, and crest elevations. Inputs must be consistent with the unit system and vertical datum specified by the user on the main worksheet.

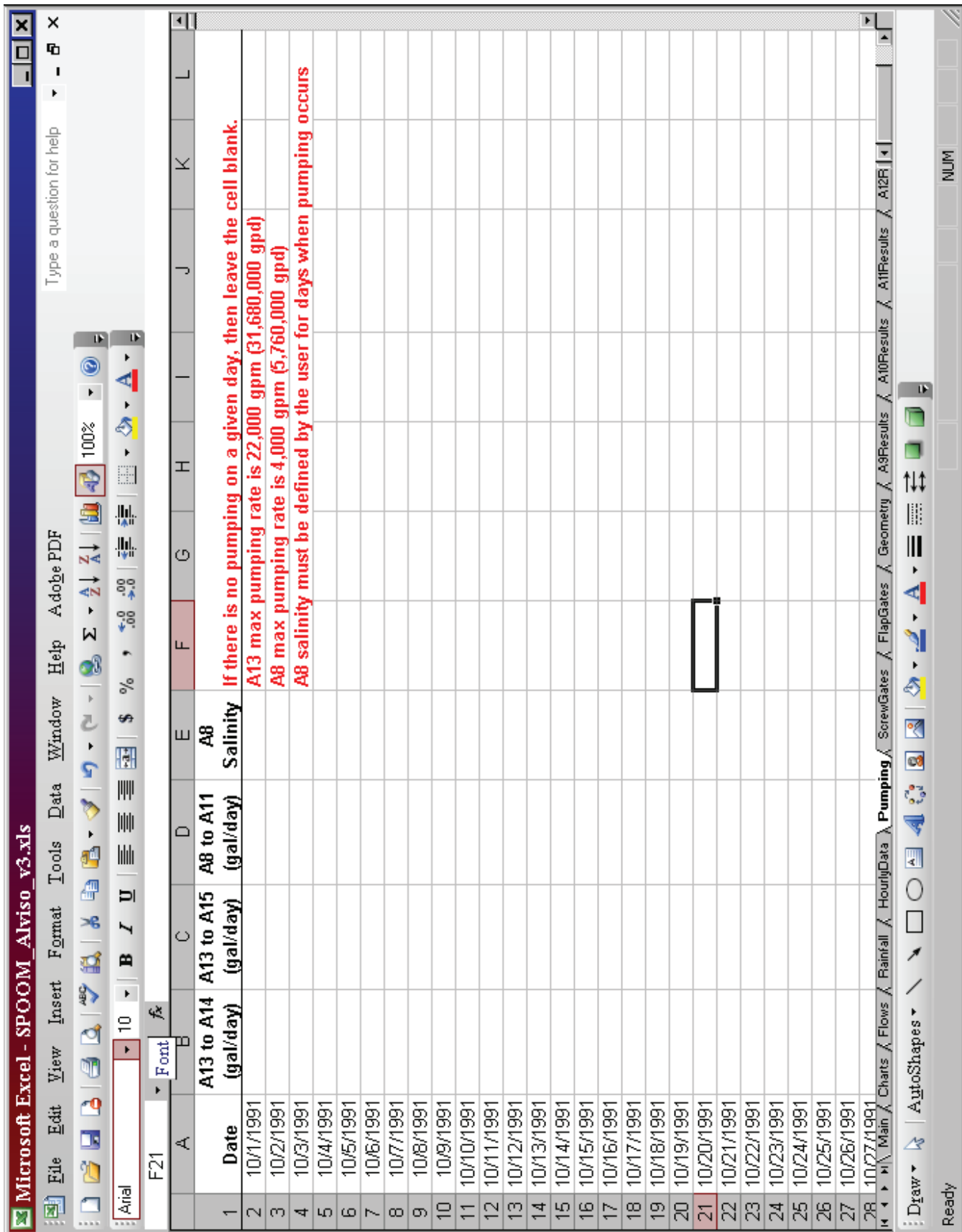


Figure 16. A screen print of the Pumping worksheet from the SPOOM workbook.

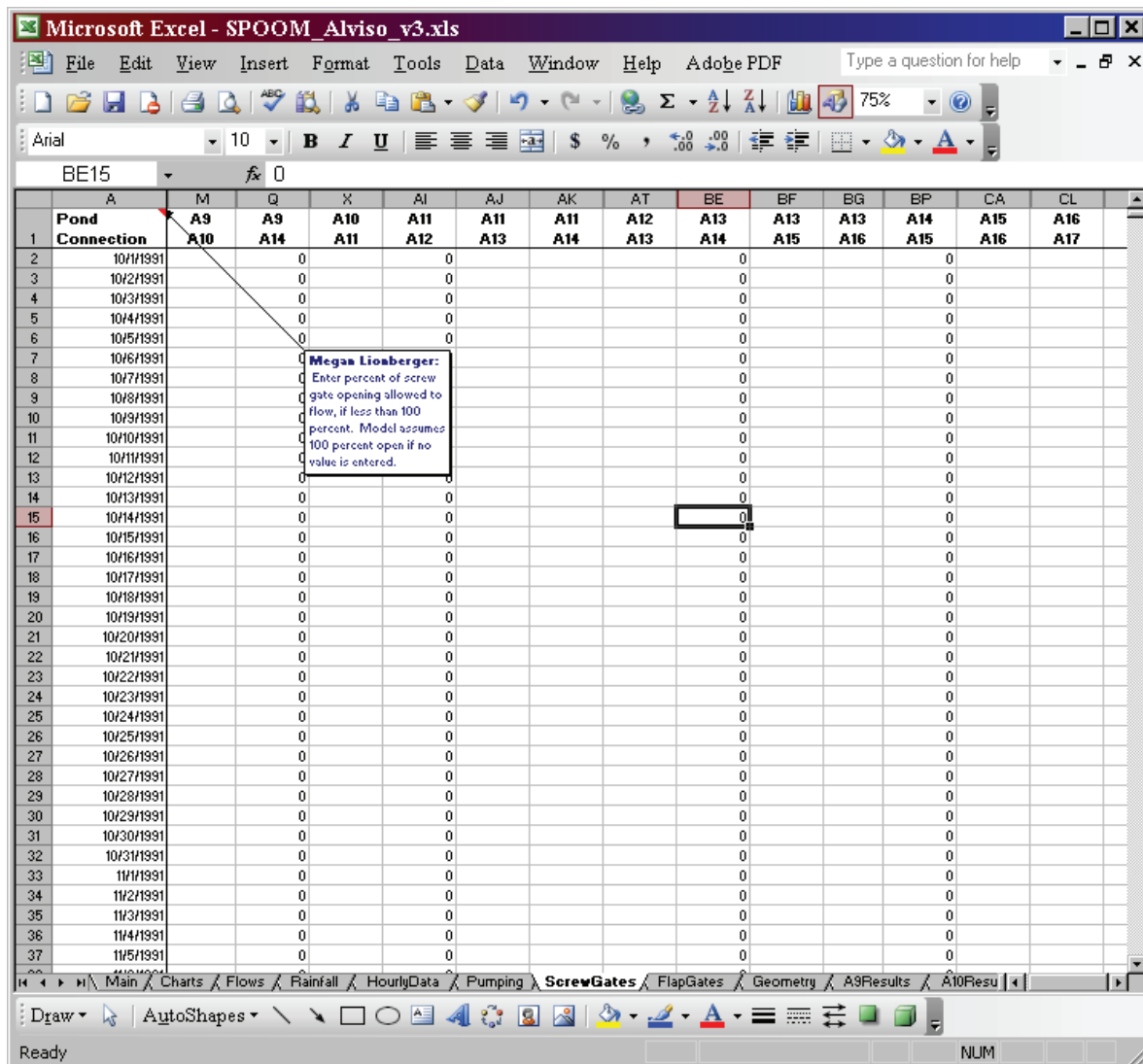


Figure 17. A screen print of the ScrewGates worksheet from the SPOOM workbook.

The ScrewGates worksheet allows the user to specify screw gate operations for each of the pond-to-pond connections. If a screw gate is less than fully open, the value of the percentage of area open to flow is entered for each day. If the screw gate is open fully, the cell remains empty.

To initiate a model run, the user chooses the base water year, the start and end dates of the simulation, and 'yes' or 'no' to model temperature, and then clicks the 'Calculate' button on the Main worksheet. Once the simulation is complete, the figures on the Charts worksheet are updated, as are the individual pond results worksheets that list daily outputs of depth, salinity, and temperature, and the Flows worksheet. Daily pond depths and salinities that are not within the ranges of the management guidelines specified by the model user in the Main worksheet are highlighted in red in the individual pond results worksheets.

## Example of Using the Model

Application of the model is demonstrated by the following example: The ISP indicates that A14 is a tidal outflow pond during the month of August, although there may be instances when it must be closed, such as for low dissolved-oxygen concentrations. A prediction of the water-surface elevation and salinity at the end of the month and the difference between the open and closed scenarios would be useful information for pond managers. In this example, two simulations will be made for pond A14: (1) normal tidal outflow conditions and (2) no tidal outflow. The results will be compared to determine how outflow affects water level, salinity, and temperature in pond A14.

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	A	B	G	H	I	J	CX	CY	CZ	DA	DB	DC	DD
1	Slough/Pond connection	Alviso SI A9	Cogote Cr A14	Cogote Cr A15	Artesian SI A16	Cogote Cr A17							
2	10/1/1991	Inflow	Outflow	None	Outflow	Inflow							
3	10/2/1991	Inflow	Outflow	None	Outflow	Inflow							
4	10/3/1991	Inflow	Outflow	None	Outflow	Inflow							
5	10/4/1991	Inflow	Outflow	None	Outflow	Inflow							
6	10/5/1991	Inflow	Outflow	None	Outflow	Inflow							
7	10/6/1991	Inflow	Outflow	None	Outflow	Inflow							
8	10/7/1991	Inflow	Outflow	None	Outflow	Inflow							
9	10/8/1991	Inflow	Outflow	None	Outflow	Inflow							
10	10/9/1991	Inflow	Outflow	None	Outflow	Inflow							
11	10/10/1991	Inflow	Outflow	None	Outflow	Inflow							
12	10/11/1991	Inflow	Outflow	None	Outflow	Inflow							
13	10/12/1991	Inflow	Outflow	None	Outflow	Inflow							
14	10/13/1991	Inflow	Outflow	None	Outflow	Inflow							
15	10/14/1991	Inflow	Outflow	None	Outflow	Inflow							
16	10/15/1991	Inflow	Outflow	None	Outflow	Inflow							
17	10/16/1991	Inflow	Outflow	None	Outflow	Inflow							
18	10/17/1991	Inflow	Outflow	None	Outflow	Inflow							
19	10/18/1991	Inflow	Outflow	None	Outflow	Inflow							
20	10/19/1991	Inflow	Outflow	None	Outflow	Inflow							
21	10/20/1991	Inflow	Outflow	None	Outflow	Inflow							
22	10/21/1991	Inflow	Outflow	None	Outflow	Inflow							
23	10/22/1991	Inflow	Outflow	None	Outflow	Inflow							
24	10/23/1991	Inflow	Outflow	None	Outflow	Inflow							
25	10/24/1991	Inflow	Outflow	None	Outflow	Inflow							
26	10/25/1991	Inflow	Outflow	None	Outflow	Inflow							
27	10/26/1991	Inflow	Outflow	None	Outflow	Inflow							
28	10/27/1991	Inflow	Outflow	None	Outflow	Inflow							

FlapGates / Geometry / A3Results / A10Resu

Ready

Figure 18. A screen print of the ComboGates worksheet from the SPOOM workbook.

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A16

1 User Inputs:

2 Infiltration (m<sup>3</sup>/day) 0

3 Rainfall/Temperature Year 1992: 89% of Normal Precipitation/103% of Normal Temperature

4 Click the Calculate Button to Activate the Pond System Simulation

5 Calculate

6 Start Date 10/01/1991

7 End Date 09/30/1992

8 Simulate Temperature? Yes

9 Vertical Datum NAVD88

10 Unit Scale (for initial inputs and outputs) inch-pound

11 \*\*Select a cell and use the pull down lists to choose flow direction, connection, quantity, a

12 To

13 From

14 A9 A10 A11 A12 A13 A14

15 Sloughs Flow Direction (Inflow, Outflow, Bidirectional, Custom, None) Custom

16 quantity, diameter (in.) 2 48

17 A9 Connection (New, Existing, None, Siphon, Pump) None New None None None None

18 quantity, diameter (in.) 1 48

19 Min. Water Level, Max. Water Level 0 3

20 Min. Salinity, Max. Salinity 0 40

21 A10 Connection (New, Existing, None, Siphon, Pump) New None New None None None

22 quantity, diameter (inches) 1 48

23 Min. Water Level, Max. Water Level 0 3

24 Min. Salinity, Max. Salinity 0 40

25 A11 Connection (New, Existing, None, Siphon, Pump) None New None Existing None New

26 quantity, diameter (inches) 1 48

27 Min. Water Level, Max. Water Level 0 3

28 Min. Salinity, Max. Salinity 0 40

29 A12 Connection (New, Existing, None, Siphon, Pump) None New None Existing None New

30 quantity, diameter (inches) 1 48

31 Min. Water Level, Max. Water Level 0 3

32 Min. Salinity, Max. Salinity 0 40

33 A13 Connection (New, Existing, None, Siphon, Pump) None New None Existing None New

34 quantity, diameter (inches) 1 48

35 Min. Water Level, Max. Water Level 0 3

36 Min. Salinity, Max. Salinity 0 40

37 A14 Connection (New, Existing, None, Siphon, Pump) None New None Existing None New

38 quantity, diameter (inches) 1 48

39 Min. Water Level, Max. Water Level 0 3

40 Min. Salinity, Max. Salinity 0 40

Main Charts Flows Rainfall HourlyData Pumping ScrewGates FlapGates Geometry A9Results A10Results

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Figure 19. An example of the slough-to-pond connection on the Main worksheet, highlighted in yellow.

Initial conditions for the two simulations were determined by starting the simulation at the beginning of the water year to allow the model to become insensitive to the specified initial conditions and to allow for the influence of winter flow controls on the ponds. The water year used for these simulations is 1993. This year was chosen because of its relatively normal precipitation and temperature (105 percent of normal precipitation and 102 percent of normal temperature).

The model was set up to operate the ponds under the ISP. In the Main worksheet, pond connections were defined and the slough flow directions were selected as 'Custom' to

have more control over the system during winter. Vertical datum 'NGVD 29' and unit measurement 'inch-pound' were selected. Weir use was set to 'no' for ponds A14, A16, and A17. Therefore, pond outflows were controlled by culverts only. The ScrewGates worksheet was modified to block flow between A9 and A14, A11 and A12, A13 and A14, and A14 and A15 (set to zero). In the ComboGates worksheet, ponds without connections to their adjacent sloughs were defined as 'None' (ponds A10–A12). Connections between Alviso Slough and A9, and Coyote Creek and A17 were selected as 'Inflow'. Connections between Coyote Creek and A14, and



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**User Inputs:**

Infiltration (m<sup>3</sup>/dag) 0

Rainfall/Temperature Year 1992: 89% of Normal Precipitation/103% of Normal Temperature

Click the Calculate Button to Activate the Pond System Simulation

Calculate

Start Date 10/01/1991

End Date 09/30/1992

Simulate Temperature? Yes

Vertical Datum NAVD88

Unit Scale (for initial inputs and outputs) inch-pound

**Initial Pond Temperatures (°C)**

A9	24.4
A10	23.3
A11	23
A12	22.5
A13	23
A14	28.4
A15	22.7
A16	23.1
A17	23.4

**From To**

	A9	A10	A11	A12	A13	A14
<b>Sloughs</b>	Custom	None	None	None	None	Custom
Flow Direction (Inflow, Outflow, Bidirectional, Custom, None)	2	48				2
quantity, diameter (in.)						
<b>A9</b>	None	New	None	None	None	None
Connection (New, Existing, None, Siphon, Pump)		1				1
quantity, diameter (in.)		0				0
Min. Water Level, Max. Water Level		0				0
Min. Salinity, Max. Salinity		0				0
<b>A10</b>	New	None	New	None	None	None
Connection (New, Existing, None, Siphon, Pump)	1		1			
quantity, diameter (inches)	0		0			
Min. Water Level, Max. Water Level	0		0			
Min. Salinity, Max. Salinity	0		0			
<b>A11</b>	None	New	None	Existing	None	New
Connection (New, Existing, None, Siphon, Pump)		1		1		1
quantity, diameter (inches)		0		0		0
Min. Water Level, Max. Water Level		0		0		0
Min. Salinity, Max. Salinity		0		0		0
<b>A12</b>						
Connection (New, Existing, None, Siphon, Pump)						

Main Charts Flows Rainfall HourlyData Pumping ScrewGates FlapGates Geometry A9Results A10Resi

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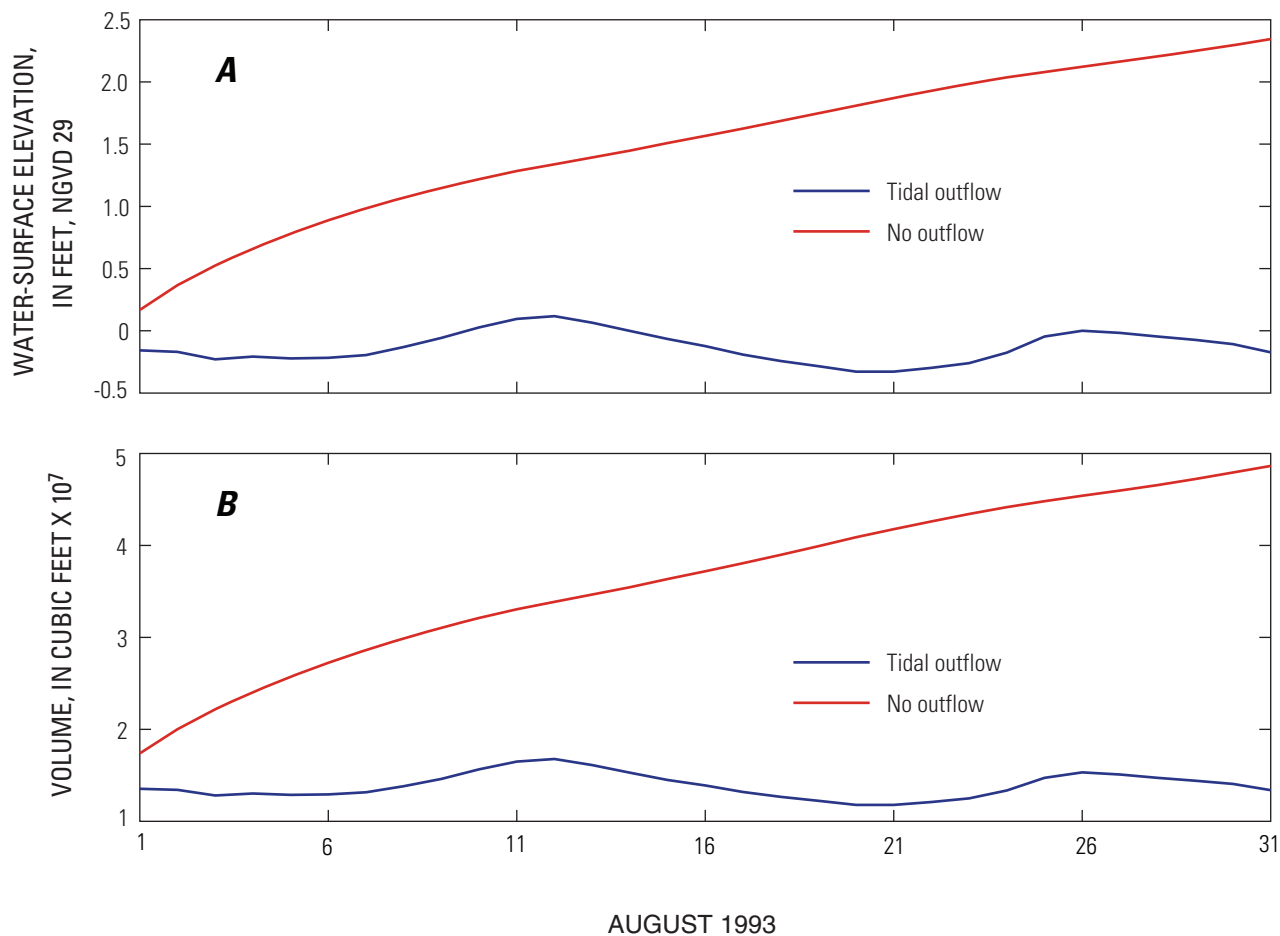
**Figure 20.** An example of the pond-to-pond connection on the Main worksheet, highlighted in yellow.

Artesian Slough and A16 were selected as 'Outflow'. The ComboGates worksheet was set up for the winter flow control periods. Circulation of ponds A16 and A17 was reversed and ponds A9 and A14 were selected as 'None' from December 1 to April 30. During the month of May, pond A14 was defined as 'Bidirectional' while the other winter-flow controls remained the same. The resulting temperatures, salinities, and water-surface elevations on July 31 were entered as the initial conditions on the Main worksheet for the two simulations.

Normal tidal outflow conditions in pond A14 were simulated from August 1 to September 1. No changes were made to the pond management setup previously described. Results of simulated water-surface elevation and volume show a spring-neap cycle with more water in the pond during the

neap period than during the spring period (fig. 21). The mean salinity and temperature for the month are given in table 4.

The simulation period was run again with the Coyote Creek and pond A14 daily connection selected as 'None' in the ComboGates worksheet. All other pond connections and initial conditions were left unchanged. With no water leaving pond A14 and water continuing to flow in from pond A11, the pond water volume and water-surface elevation increased (fig. 21). Salinities were, on average, 8.7-percent higher with no outflow, and temperatures varied only a small amount (table 4). The increased salinity did not exceed the maximum allowable discharge salinity (40) to the sloughs.



**Figure 21.** Alviso pond A14 simulated (A) water-surface elevation and (B) volume from July 31 to September 1, 1993, for two tidal outflow scenarios.

**Table 4.** Summary of simulated daily salinity and mean temperature in Alviso pond A14 during August for two tidal outflow scenarios.

[Temperature shown in degrees Celsius]

Salinity			Temperature		
Daily	Open to tidal outflow	Closed to tidal outflow	Daily	Open to tidal outflow	Closed to tidal outflow
Average	20.8	22.6	Average	22.6	22.9
Minimum	20.2	21.4	Minimum	18.9	19.2
Maximum	21.3	23.8	Maximum	31.5	31.4

**Summary**

In March 2003, 16,500 acres of salt evaporation ponds owned by the Cargill Corporation in San Francisco Bay were purchased using State, Federal, and private funds. Currently the California Coastal Conservancy is leading a collaborative planning effort with the U.S. Fish and Wildlife Service (USFWS) and the California Department of Fish and Game (DFG) to restore most of the ponds to tidal action

while providing for flood management and public access and recreation.

The draft restoration plan envisions restoration of 50 to 90 percent of the acquired ponds within 50 years (South Bay Salt Pond Restoration Project, 2007). The ponds will be operated and maintained according to the South Bay Salt Ponds Initial Stewardship Plan (ISP) until they are restored. The goals of the ISP are to maintain existing habitat and to prevent a build up of salt in the ponds in a cost-effective manner until the long-term restoration plan is in effect (Life Science! Inc., 2003).



A salt pond box model (SPOOM) was developed by Lionberger and others (2004), written as a program in Visual Basic for Excel, to simulate water volume and salinity of a salt pond for use in estimating water and salinity budgets for ponds in the Napa–Sonoma Salt Pond Complex. The model uses the principle of conservation of mass to calculate daily pond volume and salinity and includes a salt crystallization and dissolution algorithm. Model inputs include precipitation, evaporation, infiltration, and water transfers. The SPOOM model was reconfigured to simulate volume and salinity for a portion of the purchased South Bay salt ponds, Alviso salt ponds A9–A17 (fig. 1), and a temperature subroutine was added.

SPOOM simulates each pond as one well-mixed box of saline water. Water enters the ponds from the adjacent sloughs and from rainfall and flows by gravity through the pond system and eventually is returned to the sloughs. Evaporation removes water from the pond, effectively increasing the salinity with time. The model user specifies pond-management operations such as screw-gate and combo-gate control, pumping rates, and winter flow controls to simulate pond function.

A new subroutine was added to SPOOM to calculate daily average, minimum, and maximum pond temperature from hourly calculations of net heat transfer. The temperature subroutine was validated by comparing simulated temperatures to pond temperatures measured on hourly and monthly timescales. Two data sets were used to validate the temperature subroutine; temperature data collected every 12 seconds over a 1-month period to validate hourly temperature simulations and data collected monthly over a 27-month period to validate monthly temperature simulations. Both simulations compared well to measured data.

SPOOM will be used by the USFWS for predicting how the pond system will respond under different management scenarios to achieve pond salinity and depths goals of the ISP. The user is able to specify how the ponds are connected, how screw gates and combination gates are controlled, and the vertical datum and unit systems used during the simulation. Historical meteorology data from 7 water years are included for pond simulations with an option for the user to enter a custom rainfall time series. An application of the model is presented, which compared two simulations for pond A14: (1) normal tidal outflow conditions and (2) no tidal outflow. The results were compared to determine how outflow affects water level, salinity, and temperature in pond A14.

## Acknowledgments

This study was funded by the USFWS Coastal Program and the U.S. Geological Survey (USGS) San Francisco Bay Priority Ecosystems Science Program. Details regarding the function of the Alviso salt ponds were provided by Marge Kohler, Clyde Morris, and Eric Mruz from USFWS, and

Pat Mapelli from Cargill. Pond survey data and pond A14 temperature data were provided by Nicole Athearn of the USGS. Temperature data from pond 3 of the Napa–Sonoma Salt Pond Complex were provided by Jeremy Bricker, formerly of Stanford University. Slough salinity data were provided by the Environmental Services Department (ESD) South Bay Monitoring Program, of the City of San Jose.

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