MEMORANDUM

Kamman Hydrology & Engineering, Inc.

Date: April 30, 2007

To: Howard Bailey, Nautilus Environmental

From: Greg Kamman and Shawn Higgins

Subject: Santa Clara River Estuary Water Budget and Salinity Assessment

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Introduction

This memorandum presents results of a dry season (i.e., no river inflow) water budget and salinity assessment of the Santa Clara River Estuary. Salinity levels in the estuary were estimated by incorporating a mass balance equation into an existing water budget model. Three distinct fill and breach cycles were captured in hydrologic monitoring data from 2004 (Fig. 1). Data from the spring event (4/8/04 to 5/16/04) were chosen to calibrate the model. The model was then validated using data from the summer (6/8/04 to 7/15/04) and autumn (11/8/04 to 12/14/04) fill/breach events. The updated model simulated changes in water level and salinity in the estuary under a suite of Water Treatment plant release scenarios, including 7-MGD, 5-MGD, 3-MGD, and 0-MGD. Model simulations of the various Water Treatment plant release scenarios began in April and ran through mid-December. Results show that decreasing rates of Water Treatment plant releases slightly increase estuarine salinity levels and lengthen the duration of time during which the barrier beach is closed. Even under the most extreme scenario (0-MGD), however, the model suggests only a modest increase in salinity levels because inflow of relatively fresh groundwater maintains the system as a brackish water body.

Model Description

The water budget tracks hydrologic inputs and outputs at a daily time step using the water balance equation:

$$\Delta V = Q_{WT} + Q_{GW} - ET - Q_{BS} \qquad \text{(eqn-1)}$$

Where: ΔV is the change in the volume of water stored in the estuary (MGD)
Q_{WT} is the discharge from the Water Treatment plant (MGD)
Q_{GW} is the net discharge from/to the shallow groundwater (MGD)
ET accounts for the combined losses due to open-water evaporation and evapotranspiration (MGD)
and Q_{BS} is the discharge lost by seepage through the barrier beach (MGD).

Water level and surface area of the estuary are then calculated using stage-volume and stage-area relationships determined from a compilation of bathymetric survey information.

The model requires the user to input a water level in the estuary for the time at which the tidal inlet closes. For each day: (1) the initial water level is used to calculate an initial volume (V_i) and surface area for the estuary, (2) ΔV is calculated from eqn-1, (3) a final volume is calculated as $V_i + \Delta V$, and (4) a final water level is calculated from the stage-volume relation. The final water level and volume are then used to set the initial conditions for the next day and the model repeats.

The model tracks salinity in the estuary using the mass balance equation:

$$\Delta S = S_{WT} + S_{GW} - S_{BS} \qquad \text{(eqn-2)}$$

Where: ΔS is the change in the mass of salt dissolved in the estuary (kg)
S_{WT} is the mass of salt dissolved in the Water Treatment plant discharge (kg)
S_{GW} is the mass of salt dissolved in the discharge to/from the groundwater (kg)
and S_{BS} is the mass of salt dissolved in the water lost to beach seepage (kg)

The mass of salt dissolved in the individual components of the water budget for any given day is calculated as the product of the volume of water associated with that component (MG) and the salinity level (kg/MG) of that component.

An initial salinity level is specified for the water stored in the estuary upon closure of the tidal inlet. The product of this initial salinity and the initial volume of water in the estuary yields an initial mass of salt dissolved in the estuarine water (S_i). For each day: (1) ΔS is calculated using eqn-2, (2) a final mass of dissolved salt (S_f) is calculated as $S_i + \Delta S$, (3) S_f is divided by the volume of water stored in the estuary to calculate the daily salinity level. The final mass of dissolved salt is then used to set the initial condition for the next day and the model repeats.

Model Assumptions

The water budget is based on the following assumptions:

- Dry season conditions (i.e., no precipitation, no river inflow).
- A closed barrier beach preventing tidal exchange with the ocean.
- Evaporation/Evapotranspiration is a function of inundated surface area:

$$ET = c\,(ET_o / 12)\,A \qquad \text{(eqn -3)}$$

Where ET accounts for the combined losses due to open-water evaporation and evapotranspiration (in)
c = 1.1, a constant that converts ET_o to open-water evaporation and/or riparian vegetation evapotranspiration
ET_o is the daily reference evapotranspiration at Oxnard, CA (in)
and A is the inundated surface area (ft^2).

- Equation 3 assumes that dry season open-water evaporation and riparian vegetation evapotranspiration rates are equivalent.
- Beach seepage is a function of the daily estuary-ocean head differential, is modeled using the hydraulic conductivity of coarse sand (4.3 ft/day), and assumes that the barrier beach-estuary interface is 3000 feet wide and the beach width is 15 feet.
- The net discharge from/to the shallow groundwater system is a function of the daily estuary-groundwater head differential:

$$Q_{GW} = -2.33H + [21.485 - (dK)] \quad \text{(eqn-4)}$$

Where Q_{GW} is the net discharge from/to the shallow groundwater (MGD)
H is the daily water level in the estuary (feet NAVD88)
d is the daily recession of shallow groundwater levels = 0.015 (ft/day)
and K is an empirically derived transient term capturing the seasonal groundwater table recession.

This equation establishes a stage-groundwater relationship whereby Q_{GW} is a positive term in the water balance (net input) when the water levels in the estuary are lower than the adjacent shallow groundwater table and Q_{GW} is a negative term in the water balance (net output) when the water levels in the estuary are higher than the adjacent groundwater table. The y-intercept in the equation declines throughout the year to simulate declining elevations of the groundwater levels. In April, Q_{GW} is near zero when water level elevations are slightly above 9 feet (NAVD88). Later in the summer, Q_{GW} is near zero when water level elevations are about 8 feet (NAVD88).

The incorporation of a mass balance equation to estimate salinity is based on the following assumptions:

- The estuary is well-mixed.
- Salinity levels of Water Treatment plant releases are 1 ppt.
  - Determined from the average specific conductance of discharge at the outfall to the estuary for 2004.
  - Additional discrete water quality measurements from 11/6/03 indicate a slightly higher salinity range of 1.3-1.7 ppt.

- Salinity levels of groundwater inflows are 1.4 ppt.
    - Determined during model calibration.
    - This value is higher than published USGS water quality data from nearby wells, however, a higher value is expected because the USGS data is taken from deep wells and we assume that groundwater inputs to the estuary are from direct seepage and agricultural return flows of higher salinity shallow groundwater.
- Salinity levels of groundwater outflows are the same as the average estuary salinity on that given day.
- Salinity levels of the discharge lost by seepage through the barrier beach are the same as the average estuary salinity on that given day.

Model Calibration

Continuous water level and specific conductance data from the period 4/08/04 to 5/16/04 (Fig. 1) were used to calibrate the model. Salinity estimates were obtained from the specific conductance data using the equation:

$$S = 0.0006SC - 0.57 \qquad \text{(eqn-5)}$$

Where S is salinity (ppt)
and *SC* is specific conductance (μS/cm).

The salinity-specific conductance equation is derived from a linear regression of data taken as discrete water quality measurements on 11/6/03 and 2/18/04 ($n = 77$, $R^2 = 0.9995$).

Salinity data were not available for all days in the calibration period. The sensitivity of the instrument probe measuring specific conductance was limited to values less than 11,379.5 μS/cm (equivalent to a salinity of 6.26 ppt). As such, measurements of specific conductance during the initial days following the closure of the tidal inlet during early April 2004 exceeded the sensitivity of the probe (Fig. 1). As water levels rose, salinity decreased below the sensitivity of the probe on 4/19/04. Salinity decreased with increasing water level until 5/4/04 when salinity levels once again exceeded the sensitivity of the probe. This "spike" coincides with a brief period of wave overwash during a spring tide. Interestingly, salinity quickly returned to the lower concentrations observed just prior to the wave overwash and continued to decrease until the barrier beach was breached on 5/17/04. A time series of average daily salinity was constructed from the continuous data and used to calibrate and evaluate the model (Fig. 2).

The model parameters and ranges of values explored during the calibration process were: (1) initial salinity levels in the estuary following closure of the barrier beach (15 to 30 ppt), (2) salinity of groundwater inputs (1 to 3 ppt), and (3) salinity of Water Treatment plant releases (0.8 to 1.7 ppt). Values yielding a time series of salinity that most closely resembled the observed salinity in the estuary were:

- An initial average estuary salinity of 20 ppt.

- A groundwater inflow salinity of 1.4 ppt.
- A Water Treatment release salinity of 1 ppt.

Figure 2 illustrates the comparison of simulated and observed values of salinity and water level for the calibration period.

Model Validation

The model was run for two additional periods using salinity parameters from the calibration period. The only parameter adjusted for the validation runs was the initial water level in the estuary following closure of the barrier beach. Hydrologic monitoring data indicate that initial water level elevations were 5.0 feet (NAVD 88) following the closure of the barrier beach on 6/25/04 and 4.8 feet (NAVD 88) following the closure of the barrier beach on 11/4/04. Comparisons of simulated and observed values of salinity and water level for the two validation periods yielded acceptable results to validate the model (Fig. 3 and Fig. 4).

Simulation of Various Water Treatment Plant Discharge Rates

The water budget and salinity model was used to simulate conditions under the following Water Treatment plant release scenarios: 7-MGD, 5-MGD, 3-MGD, and 0-MGD. The simulation runs began on the same date of the calibration period (4/8/04) and were continued until either (1) water levels rose to an elevation where natural breaching of the barrier beach has been observed to occur repeatedly (10.12 feet), or (2) mid-December. The time series of simulated water levels and salinity in the estuary are plotted to illustrate the impact of reduced Water Treatment plant releases (Fig. 5).

Run 1: Water Treatment Plant releases 7-MGD

- Barrier beach is breached 29 days into simulation.
- Under the model calibration simulation, the barrier beach breaches after 46 days of filling at an average Water Treatment plant release rate of 5.9-MGD.
- Salinity on day 25 = 2.44 ppt.

Run 2: Water Treatment Plant releases 5-MGD

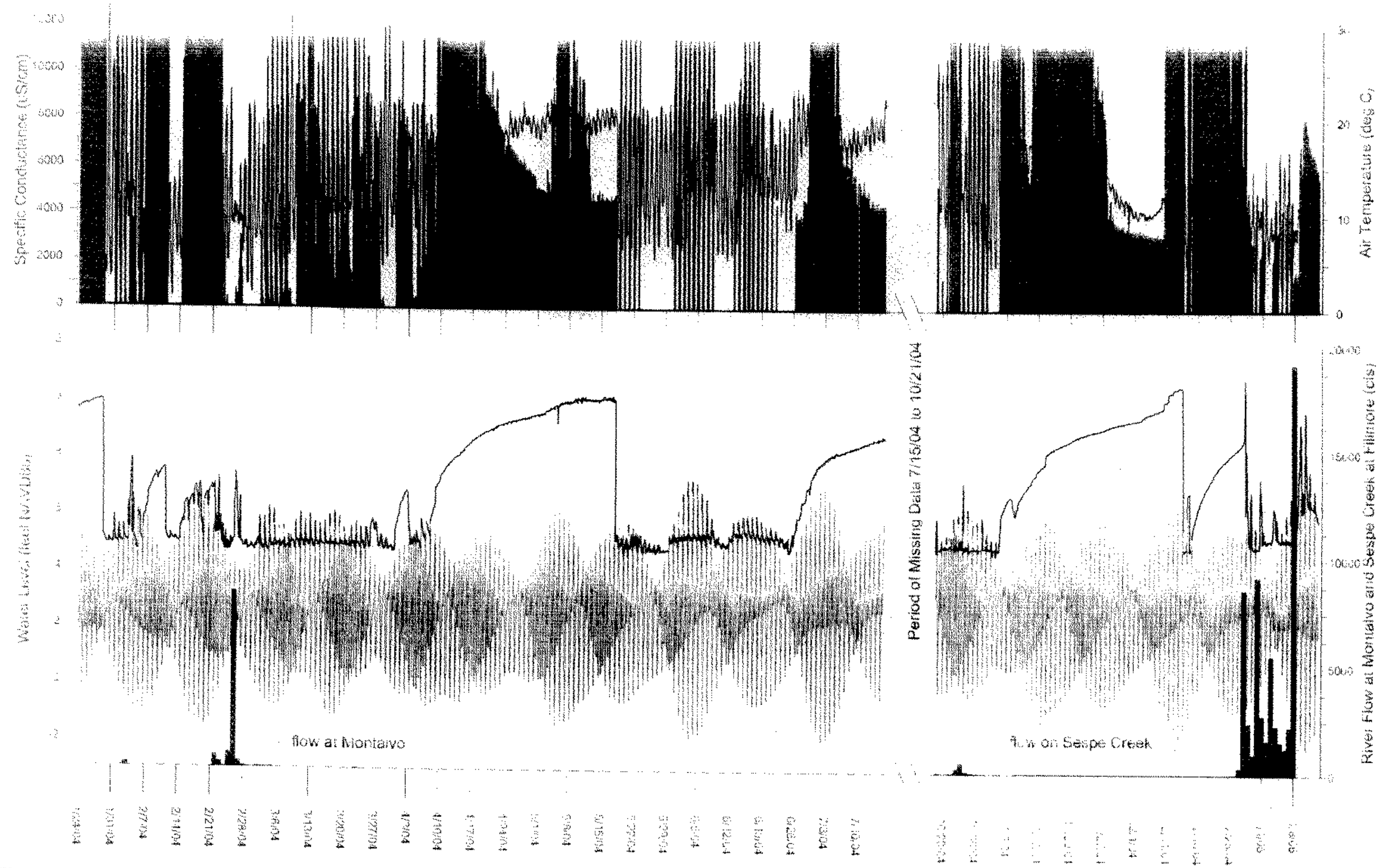
- Water level never exceeds the specified threshold (10.12 feet NAVD 88) to indicate a breaching of the barrier beach.
- Water levels do, however, come very close. Highest water level occurs 76 days into simulation at 9.93 feet.
- Salinity on day 25 = 2.81 ppt.
- Salinity on day 50 = 2.19 ppt.
- Salinity on day 75 = 1.81 ppt.
- Salinity on day 100 = 1.63 ppt.

Run 3: Water Treatment Plant releases 3-MGD

- Water level never exceeds the specified threshold to indicate a breaching of the barrier beach.
- Highest water level occurs 51 days into simulation at 9.22 feet
- Salinity on day 25 = 3.30 ppt.
- Salinity on day 50 = 2.84 ppt.
- Salinity on day 75 = 2.45 ppt.
- Salinity on day 100 = 2.21 ppt.

Run 4: Water Treatment Plant releases 0-MGD

- Water level never exceeds the specified threshold to indicate a breaching of the barrier beach.
- Highest water level occurs 31 days into simulation at 8.18 feet.
- Salinity on day 25 = 4.21 ppt.
- Salinity on day 50 = 3.98 ppt.
- Salinity on day 75 = 3.81 ppt.
- Salinity on day 100 = 3.72 ppt.



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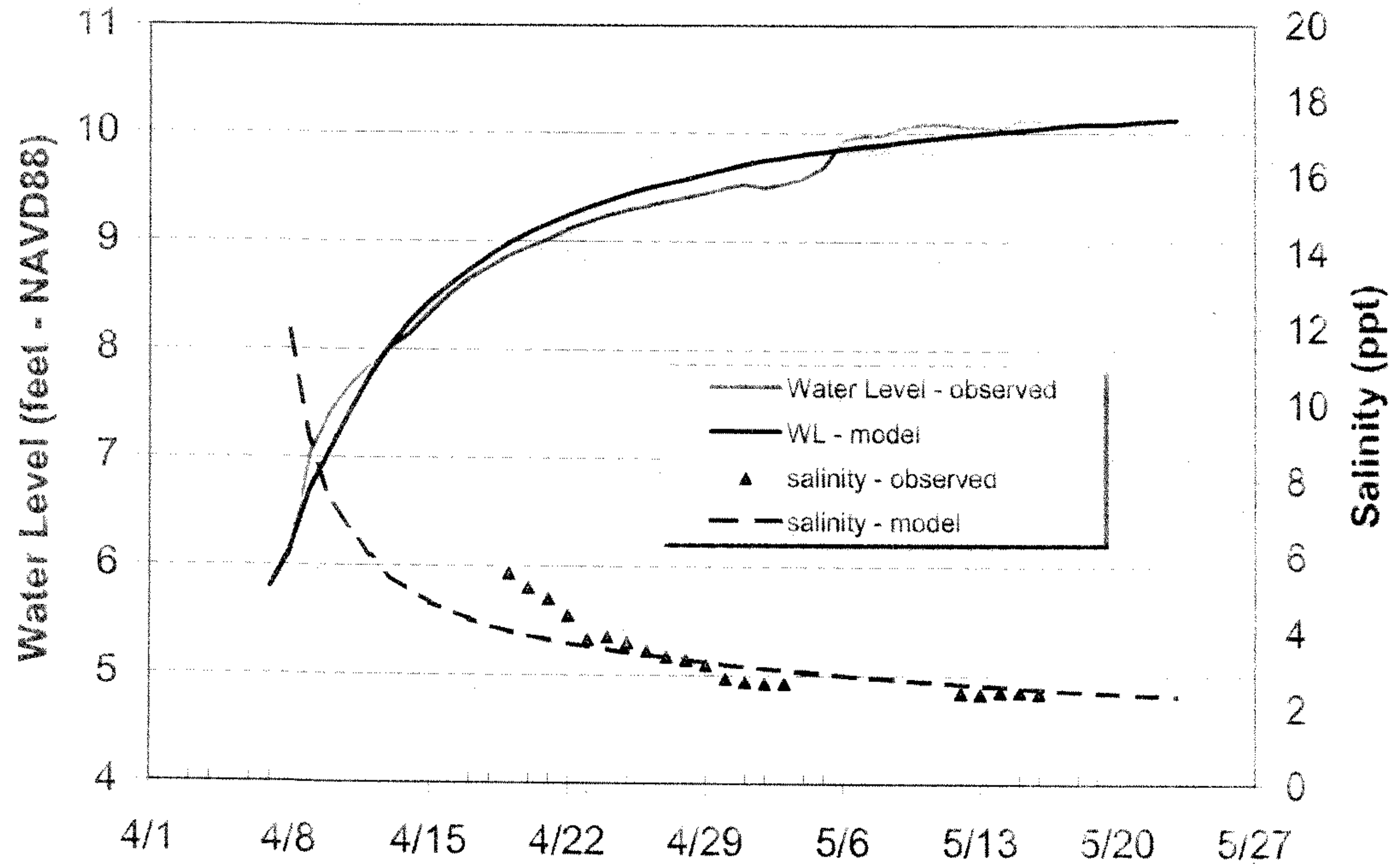
Hydrologic Monitoring Data: 1/23/04 to 1/14/05

ENVIRONMENTAL STUDY OF SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE
1



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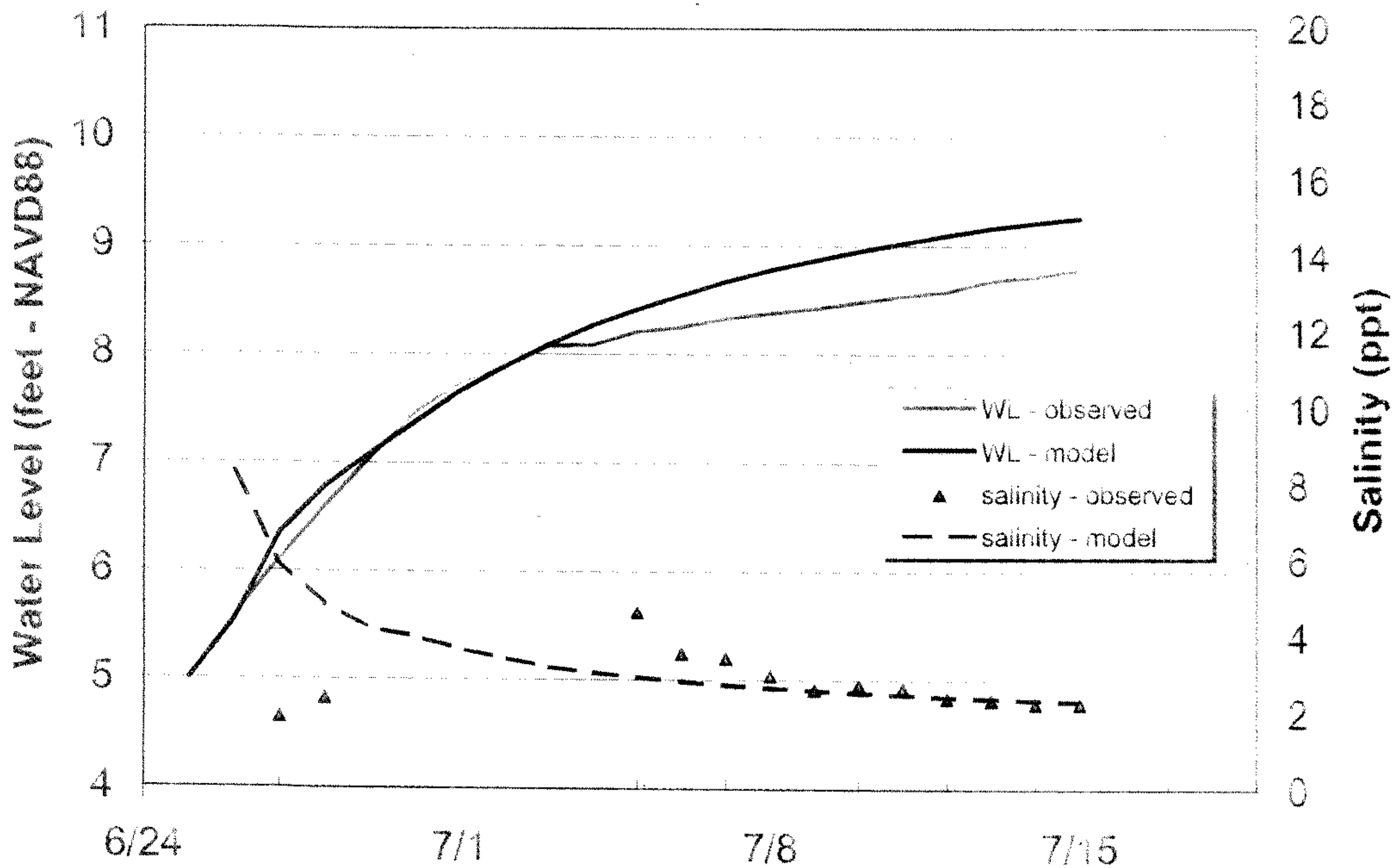
Santa Clara River Estuary Water Budget and Salinity Assessment

Calibration Period (4/8/04 - 5/16/04)

FIGURE 2



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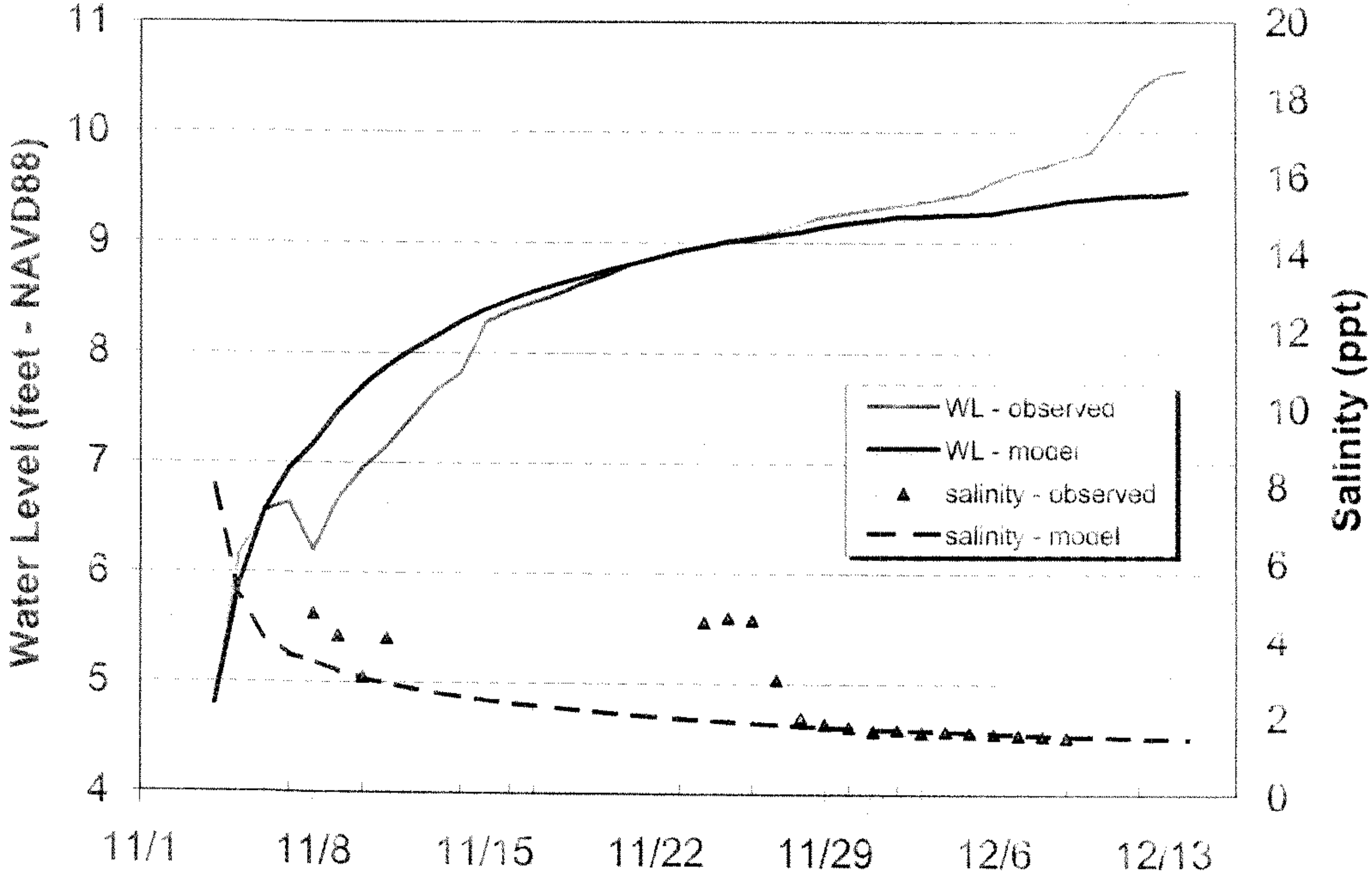
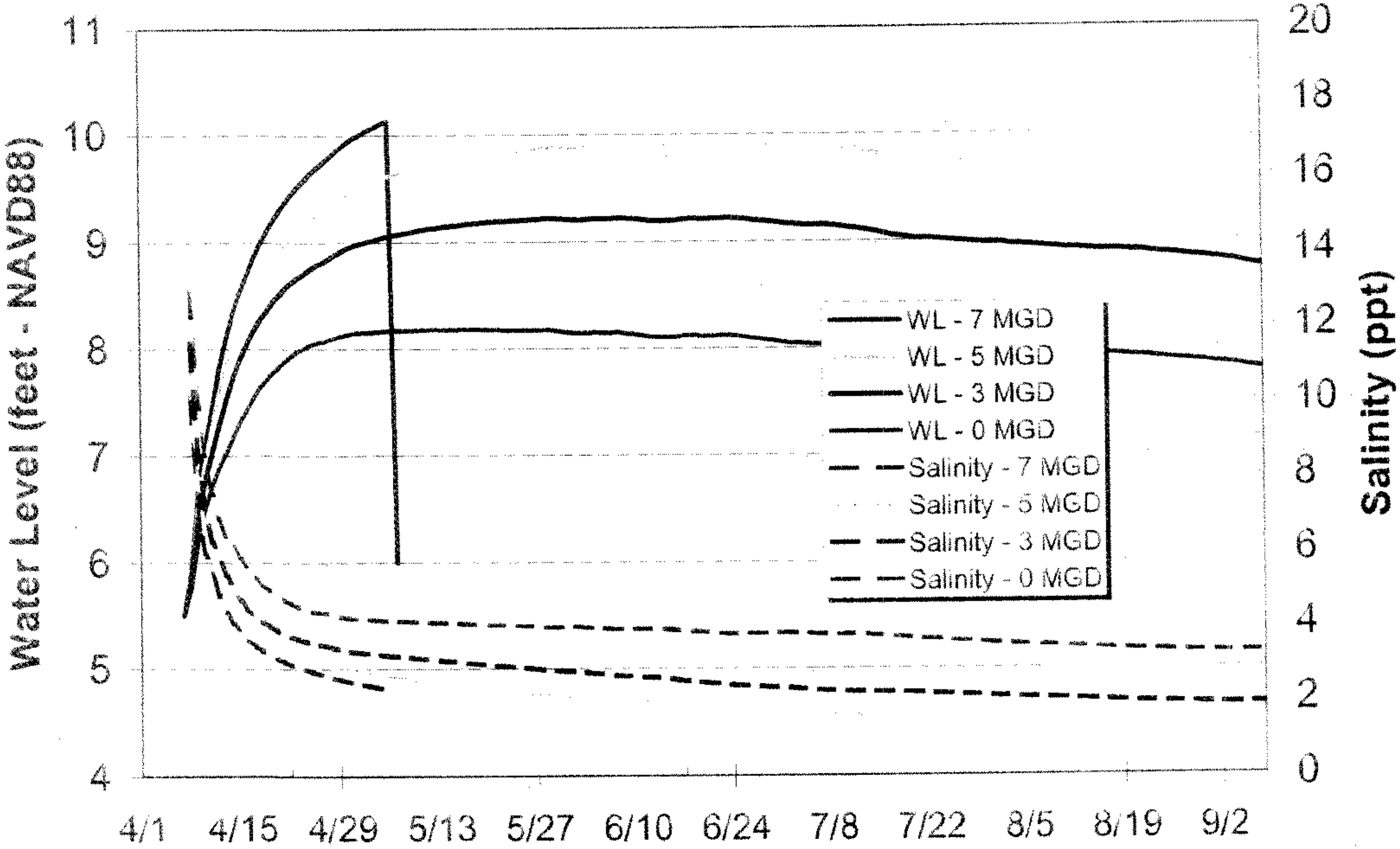
Santa Clara River Estuary Water Budget and Salinity Assessment

Validation Period (6/26/04 - 7/15/04)

FIGURE 3



Santa Clara River Estuary Water Budget and Salinity Assessment **Validation Period (11/4/04 - 12/14/04)**	FIGURE 4



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Santa Clara River Estuary Water Budget and Salinity Assessment

Simulation of Water Treatment Plant Release Scenarios

FIGURE 5

SalinityAssess_figs.xls fig5