Field Monitoring and Hydrodynamic Modeling of the Salton Sea, CA.

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ABSTRACT

The Salton Sea, the largest surface water body in California, faces a myriad of problems associated with rising salinity and water surface level, plus large pollutant loading from inflowing tributaries. These problems pose threats to the region's ecosystem as evidenced by large kills of both aquatic and avian species in the area. In an initial phase of a comprehensive study of the area, two- and three-dimensional hydrodynamic models have been applied to characterize circulation and hydrodynamic transport processes. Modeling of the Sea has been complemented by a field monitoring program that will provide additional characterization of actual circulation, including data required to calibrate and verify model results. Three acoustic Doppler current profilers and a large number of temperature loggers will be deployed in the Sea to continuously characterize water velocities and temperature fluctuations. Additional probes will be deployed to gather instantaneous vertical profiles of conductivity, temperature, dissolved oxygen, and pH. Because of the Sea's large size, relatively shallow water depth, exposure to perennial winds, and small hydrologic influxes, the hydrodynamics of the system are driven primarily by wind and Coriolis forces. Three meteorologic stations near the shore of the Sea record wind magnitudes and directions in addition to air temperatures, relative humidity, and short wave radiation. Wind-induced friction on the Sea's surface was applied in the models using statistical information on winds recorded at these stations. Initial simulation results suggested the presence of several large gyres within the water body, located primarily within the northern and southern basins. Preliminary simulations of cases where salinity control barriers are proposed to isolate portions of the Sea indicate dramatic alterations of present (model produced) circulation patterns. Concerns for future control of water surface and salinity levels focus on understanding critical balances between inflowing water quality and quantity and the extreme desert climatic conditions that exist in the area.

INTRODUCTION

The modern day Salton Sea, often referred to as the largest anthropogenic water body in California, was formed late in 1904 as the result of a temporary levee break along the Colorado River. For a period of approximately 16 months thereafter water flowed through this break into the below-sea level depression, then known as the Salton Sink, filling it to a depth of more than 24 meters above its lowest elevation, approximately 85 meters below mean ocean sea level (msl). Since that time the water level in the Salton Sea has been seeking a balance between the harsh desert forces that extract water by evaporation (the only mechanism for removal of water from this closed-basin depression) and inflows of water from surface and subsurface sources. For a time following closure of the levee break, water levels declined rapidly as evaporation greatly exceeded inflow. A minimum level was reached in the 1920's, after which the level of the Sea once again began to rise, due in major part to importation of water for agriculture. By the 1990's water elevations reached levels exceeding -69.6 meters msl. Rising water encroached onto private property, causing loss of usable land and damage to property by flooding.

During the course of historical changes in the Sea's water balance, its salinity has also changed. Initially, the salinity of the Sea was about that of the Colorado River at the time of the levee break, but because of evaporative concentration, salinity began to rise as water levels fell towards the minimum water surface elevations reached in the 1920's. Subsequent to importation of water for irrigation, salt loads from irrigation drainage and return flows increased the salinity of the Sea to about that of the ocean. As agriculture and water importation continued to expand, not only did the Sea's water level increase, but salinity eventually surpassed that of the ocean until today when it is at its highest historical level, approximately 44 parts per thousand, or about 30 percent higher than that of the ocean.

To address these concerns, the Salton Sea Authority is supporting investigation of alternative measures to control water levels and salinity concentration in the Sea that would preserve and eventually restore its intrinsic values. Among possible alternatives are those that would physically alter the configuration of open water portions of the Sea by constructing diked impoundments. These impoundments would alter both natural circulation patterns and water quality in the Sea. Before such physical alterations are made in the Sea's configuration and bathymetry, it is necessary to determine the effects these changes may have on circulation patterns and how these may in turn influence water quality and the indigenous ecosystem.

BATHYMETRIC, METEORLOGIC AND HYDROLOGIC DATA

A detailed data set containing over 133,000 measured bathymetry points was obtained from the U.S. Bureau of Reclamation (Ferrari and Weghorst, 1995). This bathymetry file provided the data needed for formation of a finite element network. Initially a two-dimensional horizontal grid was constructed conforming to isobaths within the basin. Later, this grid was extended for three-dimensional representation, considering accelerations along the vertical axis. The unusually high level of detail allowed by the USBR data set permitted construction of a network closely approximating the real basin, although to minimize computational effort detail was provided only in areas of special interest, such as near the mouths of the three tributaries.

California Irrigation Management Information Stations (CIMIS) located close to the shore of the Sea provide continuous point measurements of wind magnitude and direction, short wave radiation, air temperature, and relative humidity. Wind friction boundary conditions for preliminary simulations with uncalibrated models were developed by statistical analysis of CIMIS wind data for the months of March and April, 1995. The analysis demonstrated the presence of a strong prevailing wind during these two months, determined to be virtually steady at 10.5 kph blowing from a west-northwesterly direction (azimuth of 112.5 degrees).

Hydrologic fluxes, primarily from the runoff of the New, Alamo, and Whitewater Rivers, and Salt Creek, plus dispersed irrigation drainage returns, were evaluated with respect to their potential influence on the Sea. From published reports of the U.S. Geologic Survey, the average yearly inflow from the rivers and the creek was estimated to be about 1.41×10^9 m^3/yr. An empirical relationship between volume and surface elevation (Hely et al., 1966) indicated that the impounded volume under average conditions for September 1993 (surface level = -69.5 meters msl) was about 9.87×10^9 m^3/yr. Thus, only about 0.00039 of the volume of the Sea enters on a daily basis and annually these sources account for about one-seventh of the Sea's volume. Because the hydrologic fluxes from these sources are small with respect to the Sea, it was considered reasonable in initial simulations of large scale circulation to neglect momentum transfer at points where tributaries enter. In future extensions of the models, when water quality responses to pollutant loadings are an issue, these fluxes will be considered.

FIELD MONITORNG

Although gauged tributary inflows, surface water heights, and meteorological data in the Salton Sea region have been recorded by various agencies over a several decades, concurrent synoptic measurements of water velocities and temperatures have never been made. While this information is important for understanding the dynamics of the Sea, it is especially crucial for the construction, calibration and validation of the models, and for meaningful interpretation of model results.

To obtain these essential data it is planned to deploy two RD Instrument acoustic Doppler current profilers (ADCPs) in the southern end of the Sea (see Figure 1) for almost an entire year. A third SonTek acoustic Doppler profiler, already deployed in a preliminary survey, will be used intermittently in the northern end. The southern end is being emphasized because the Salton Sea Authority has deemed this area most plausible for placement of diked impoundments to control salinity. The ADCPs continuously record velocities in three coordinate directions at regular intervals. Velocities are averaged over vertical increments, or bins, that are on the order of 0.5 meters for this project. Velocities are also averaged over a selected time interval, on the order of 15 to 30 minutes.

Six Brancker Research LTD. (accuracy +/- 0.05° C) and fourteen Onset Optic StowAway temperature loggers (accuracy +/- 0.2° C) will be placed on thermistor strings as shown in Figure 1. The Brancker loggers will be placed near the top and bottom of each string at the locations marked "2". Onset loggers will also be placed at depths equal to one-half and one-quarter the water column depth at these string locations. Strings at locations marked "1" will have loggers at the same depths as locations marked "2", but will only be equipped with Onset loggers. A single Onset logger will be placed in tributaries at the locations marked "3".

Numerous instantaneous profiles of conductivity, temperature, dissolved oxygen, and pH versus depth will be obtained at intervals throughout the year of field monitoring using Ocean Sensors 200 and Hydrolab H20 probes. Conductivity data already gathered in a preliminary field survey suggests that salinity and pH levels in the Sea are virtually spatially homogenous, except within regions close to where tributaries enter. Thus, field monitoring is expected to reveal information on seasonal variations in these parameters.

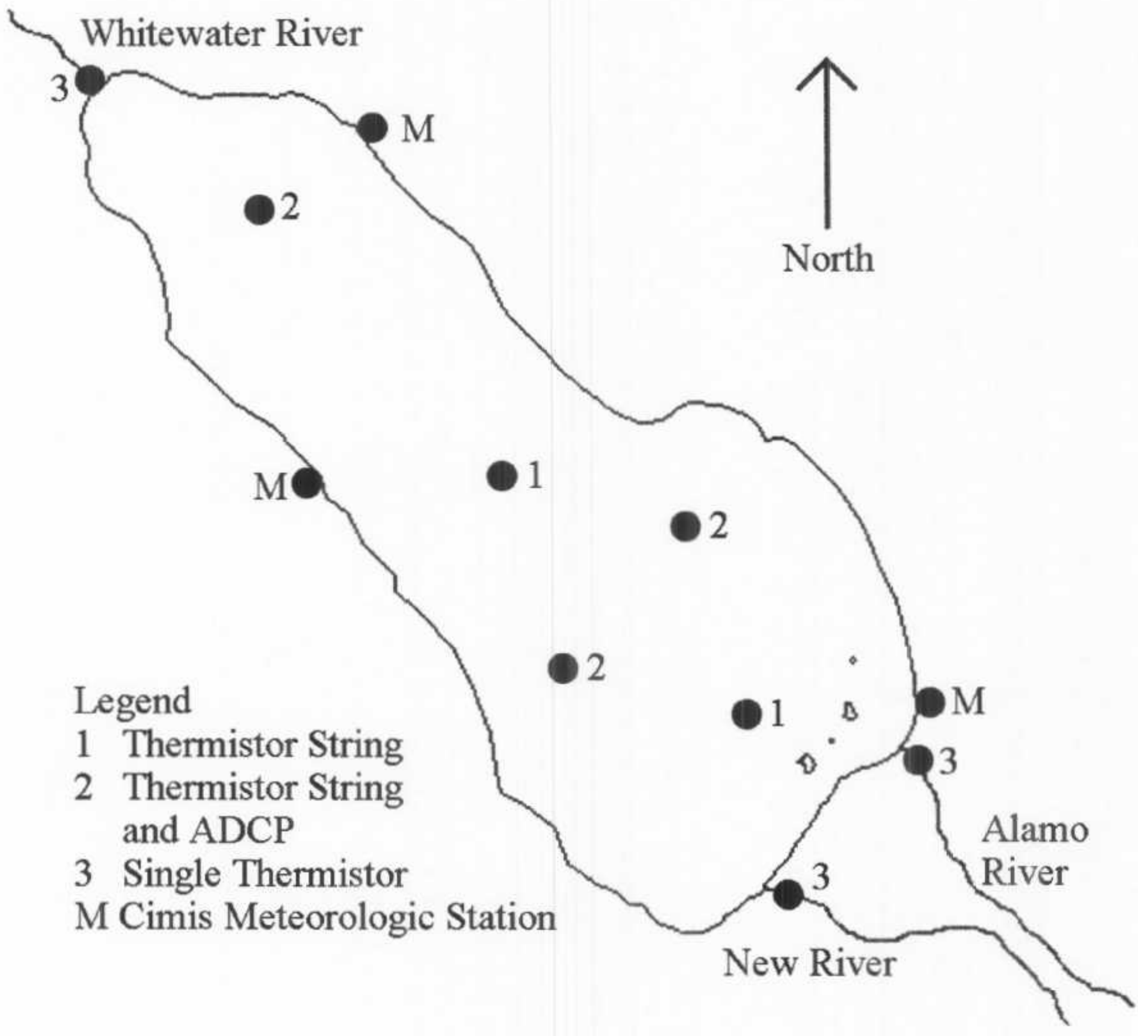

Figure 1 Locations of Field Monitoring Activity in the Salton Sea

PRELIMINARY MODEL APPLICATIONS

Two hydrodynamic models, RMA-2 and RMA-10, both formulated for the finite element solution method, were applied to simulate circulation in the Salton Sea. RMA-2 is designed to simulate two-dimensional, depth-averaged hydrodynamics for surface water systems in which external forcing induces complete vertical mixing. Turbulent energy losses, traction forces due to bottom friction, Coriolis forces, and surface wind stresses are represented in the model. It is capable of simulating both steady and unsteady state conditions. The model is well documented (King, 1994) and has been widely applied to estuarine systems.

RMA-10 is a model designed for simulation of hydrodynamic circulation where vertical velocities are important and densimetric stratification may be an significant factor. The model describes the state variables of pressure and velocity in three dimensions by solving a set of equations derived by combining the Navier-Stokes equations, volume continuity, advection-diffusion, and an equation of state relating water density to salinity, temperature, and suspended sediment. As with RMA-2, friction losses, Coriolis effects, and surface wind stresses are also represented. The model may be used to simulate time-dependent or steady-state simulations. RMA-10 has been utilized in similar hydrodynamic systems and is well documented (King, 1994b). Although the model is capable of simulating stratification due to water quality gradients along the vertical axis, preliminary results presented in this paper assume the fluid to be homogenous.

Three-dimensional results from RMA-10 at the mid-depth elevation are shown in Figure 2. Surface layer velocity vectors are higher than the mid-depth results and are generally orientated in the direction of the wind. Flow near the surface of the Sea travels southeast until it approaches the shoreline. At the southeastern end of the Sea the water surface level rises slightly due to flow along the surface. This increase of water surface elevation generates increased hydrostatic pressure and a resulting downward flow. Near the bottom of the Sea model-generated velocity vectors are approximately equal in magnitude to the mid-depth results and the flow is generally in a direction opposite to the wind, returning water back toward the northwest portion. As the flow approaches the northwest boundary, the fluid rises upward to the surface, creating an upwelling. At mid-depth, the flow is generally in a direction opposite to the wind. It is in this mid-depth region that gyres are most visible. Gyres can be seen at several locations, the strongest of which are found in the southeastern portion (see inset in Figure 2). Flow in these gyres not only circulates horizontally around the center of the gyre, but also vertically.

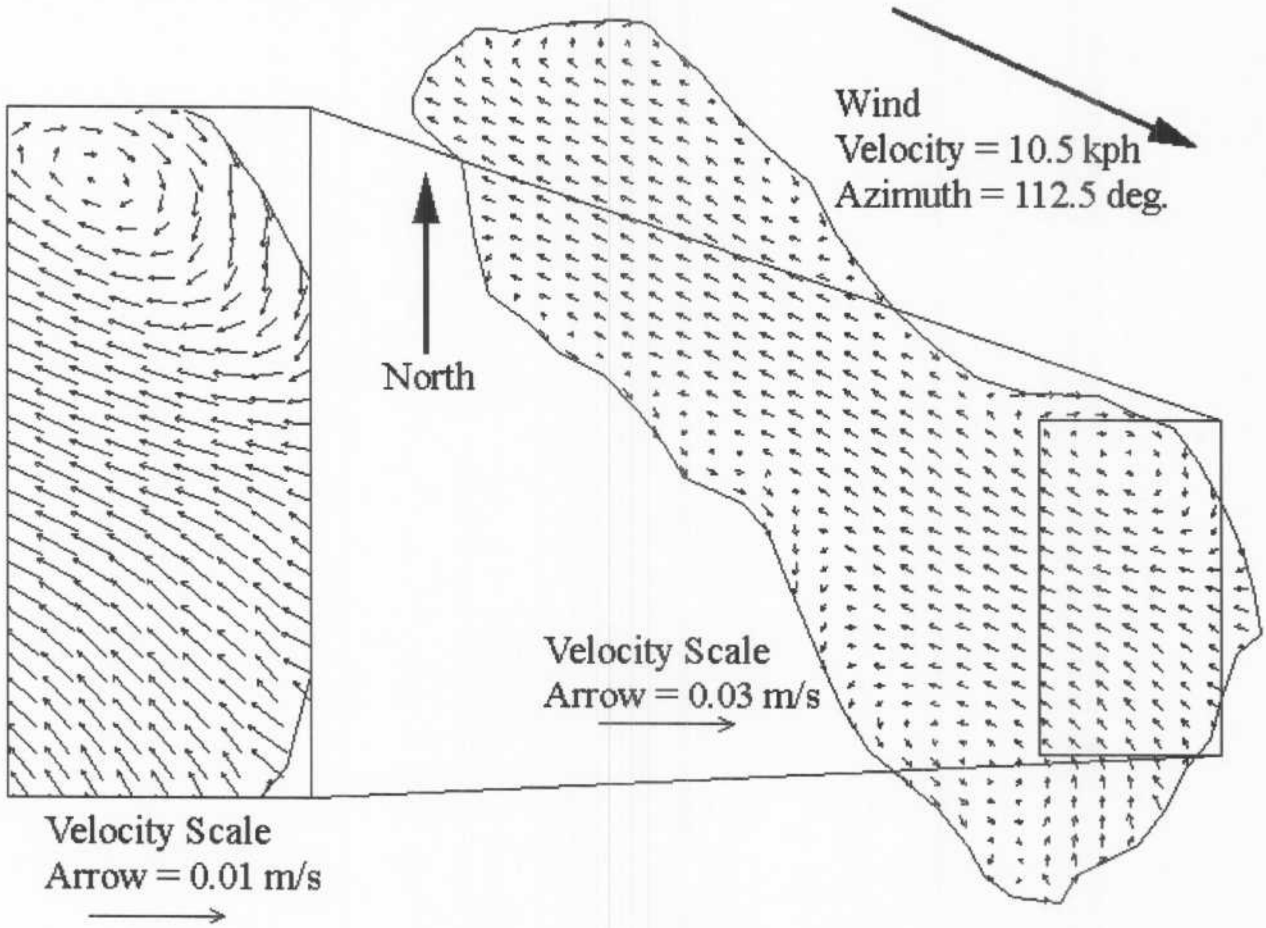

Figure 2 Three-dimensional Circulation Results: Mid-Depth Velocity Vectors

Results presented in these figures are for uncalibrated models. Calibration to different meteorological conditions, water quality parameters (such as gradients of temperature and salinity) and turbulence exchange coefficients could change the results. As data obtained from the field monitoring program becomes available, the Salton Sea models will be further developed, calibrated and verified.

CONCLUSIONS

Problems of increasing water levels and salinity are threatening the viability of the Salton Sea as a recreational and ecological resource. Solutions are being proposed that may alter the configuration of the Sea by isolating certain portions with physical barriers. Possible consequences of such alterations include changes in circulation and related redistribution of nutrients, sediments, and water quality constituents that affect ecological and recreational values. There is a perceived need for direct observation of hydrodynamic and water quality in the Sea that is now being addressed.

To quantify the effects that diked impoundments would have on the Sea's circulation, two finite element models were adapted to the bathymetry of the Sea and used to simulate circulation patterns induced by wind friction on the surface. Both models indicated the likely presence of large scale gyres which could result under conditions of a steady west-northwesterly wind.

To calibrate these models and to better understand circulation in the Sea, a field monitoring program is currently underway. The field program will gather water velocity, temperature, and conductivity data to complement meteorologic data and tributary flows already monitored in the system.

Additional improvements in the models are needed to account for the effects of stratification related to vertical differences in temperature and salinity, to accommodate the influences of inflow on water quality, and to consider variations in wind strength and direction at the Sea's surface. Direct field measurements of water currents, wind and other atmospheric characteristics, and water quality parameters will support development of the model and its ability to predict the effects of proposed diked impoundments.

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APPENDIX I. REFERENCES

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