Circulation Narrative

The Salton Sea, as discussed previously, is large in surface area but quite shallow in depth. Inflow volume is 1.41 billion cubic meters per year, while the volume of the lake is 9.87 billion cubic meters, so each year one-seventh of the total volume of the Sea is replaced by inflows. Due perhaps to this massive refreshing of its liquid content, the lake is remarkably uniform in terms of salinity distribution, except where the New and Alamo Rivers enter the south basin of the Sea. This fresh water intrusion into the lake makes the south basin more resistant to mixing, and thus, has an impact on the circulation patterns of the Sea.

When freshwater enters a saline water body, the water typically displays a "wedge" of varying size and extent, based on the quantity of water coming into the saline body, the velocity of inflow, and the current circulation pattern of that saline water body. This contact between fresh and saline waters appears as a "wedge" of fresh water floating over the more saline water, due to the higher density of salt water versus fresh. In the Salton Sea, however, most freshwater inflows mix rapidly with ambient salt water, forming a relatively abrupt transition from freshwater to saltwater near the mouths of the inflowing rivers and drains (Salton Sea Restoration Draft EIS/EIR, 2000). The New and Alamo Rivers, however, extend a freshwater wedge into the south basin of the Sea whose horizontal extent is a function of current wind intensity. All other inflows to the Sea are rapidly diluted, stunting any impact on circulation they might impart.

Lake stratification is a separation of lake waters into horizontal layers generally caused by differences in temperature or salinity within the water column. Cooler and/or more saline water is denser, whereas warmer and/or fresher water is less dense. Denser water collects in the lower part of the column, while less dense water accumulates towards the surface. Lake warming occurs through solar insolation and conduction, and lake cooling through evaporation, conduction, and back radiation.

Wind can also have an interesting effect on circulation and temperature distribution within the Sea. During the summer, the surface temperature on the Salton Sea rises dramatically, especially in relation to bottom waters. When heated surface water is mixed downwards into the water column by wind, wind can actually decrease the surface water temperature, reducing the amount of heat lost to back radiation. A windy spring can thus actually induce more rapid heating of the waters of the Sea than a calm one.

The Salton Sea is often stratified for much of the year, generally from mid-winter to early fall, when the lake is warming. During the remainder of the year, or from early fall through mid-winter, the lake is cooling, and tends to be vertically isothermal with little variation in temperature, especially at night. The stratification within the Sea is directly responsive to ambient weather conditions. The Salton Sea is also considered to be polymictic, or subject to turnover and mixing of these thermohaline layers many times per year. The irregular mixing regime of the Salton Sea's water column greatly confuses the modeling of the hydrodynamics of this system (Watts, et al., 1999).

The Salton Sea actually has two separate basins, one in the north part of the Sea, and one in the south, with a berm or sill separating the two basins. This feature is only a few feet high, but is important due to its effect in creating profound differences in the circulation patterns between the two basins; these differences include how the gyres in these basins flow, which is in opposite directions. The currents within these gyres must scour and deposit sediments in a cycle that maintains the separation between the two basins despite ongoing sedimentation within the lake. How much of a role subsidence plays in sediment accumulation is not known. In addition, the southern basin shows evidence of periodic influxes of deep water from the northern basin, and yet the northern basin shows no evidence of such mixing, at least through preliminary observations (Cook, et al., 1998).

Although the two basins are of approximately the same length, the south basin is considerably wider than the north basin (25 km versus 16.5 km), but shallower (14 meters versus 12 meters). Since the south basin is shallower and wider than the north basin, it has more complete mixing during the warming period of the lake, as long as there is no salinity gradient present. This mixing yields profound differences between the two basins at times in terms of temperature, dissolved oxygen and sulfide characteristics and distribution, probably making the south basin a refuge for fish and benthic macroinvertebrates in the summer and fall (Watts, et al., 2000).

Due to its large size, 57 kilometer fetch, shallow depth, small hydrologic influx, and prolonged exposure to prevailing winds, the hydrodynamics of the Salton Sea are driven primarily by wind stress and shear, which generates turbulence (Cook, et al., 1998). Evaporation and conduction also produce a convection-type of vertical circulation, which together with the wind-driven currents constitute the primary forces driving the circulation patterns of the Sea (Watts, et al., 2000).

Convectional circulation mixes the entire water column on a near daily basis during the fall and winter, which is the cooling period of the lake. In addition, convection circulates at least the surface waters of the lake during the spring and summer, which is the warming period for the lake. Since the Sea is nearly isothermal during its cooling period, low wind speeds are often sufficient to induce vertical mixing. Convection in the surface waters during the warming period for the lake is likely due to the high evaporation rate and to the high differential between day and night surface water temperatures in those seasons (Watts, et al., 2000).

Coriolis effects are also a contributing factor as are pressure forces associated with waves and tides, although this effect is minimal. In addition, minor momentum is imparted by tributary inflows, particularly the New and Alamo Rivers. Inflowing streams impart a great deal of momentum and can be a primary, driving influence in the circulation patterns of many lakes, but the flows from the New, Alamo and Whitewater Rivers generate little momentum and exert a limited kinetic impact on the circulation of the Salton Sea (Cook, et al., 1998).

The predominant wind direction in the Salton Trough is from the northwest to the southeast. When ambient meteorological conditions were monitored to calibrate the circulation models, wind speed averaged 3.4 miles per hour at the north end of the Sea and 7.8 miles per hour at the south end. Water velocity, generated largely from wind shear, was approximately one-tenth that of wind speed (Salton Sea Restoration Draft

EIS/EIR, 2000). Although prevailing winds are from the north, there are also infrequent wind events originating in the opposite direction that are still oriented more or less along the long axis of the lake. Wind events can occur anytime of year, but the winds are generally strongest in the spring, and weakest in the summer (Watts, et al., 2000). Earlier studies noted a more pronounced eastward component to the prevailing wind apparent at the south end of the Sea (Salton Sea Restoration Draft EIS/EIR, 2000), but Watts (2000) reports that any winds from the west were weak and of short duration. He further states that their monitoring revealed that the same prevailing wind patterns dominated in the south basin area as in the north basin area.

The results of these models demonstrate that flow at the surface of the lake, as driven by the wind, is towards the southeast until contact with the shoreline is achieved. At this point, water "piles up" due to hydrostatic pressure, producing a slightly higher water level at the southeast end of the Sea, which in turn causes a downward flow, called downwelling, that pushes the water to the bottom of the lake for a return to the northwest end of the lake. The mid-depth and bottom level currents mimic the velocity at the surface, although they are somewhat reduced. The circulation models then demonstrate that the direction of flow should be opposite to the prevailing wind direction (to the northwest), ultimately resulting in upwelling at the northwest boundary of the Sea (Cook, et al., 1998). Circulation patterns observed at the Sea are much more complex than indicated by this model, but more complete monitoring information is being collected which will add to the sophistication of the circulation modeling in the future.

For the circulation modeling results shown here, lake bottom and shoreline friction, Coriolis forces, and wind stress effects are represented. On the other hand, varying meteorological conditions, turbulence, or water quality variations, as indicated by temperature and salinity gradients, are not. These results are also derived assuming the lake is vertically homogeneous (within the water column), which it is usually not. The impact that lake stratification has on circulation is not yet known. Regardless, the Salton Sea has one gyre in the northwest basin of the Sea with the currents circulating clockwise, and one gyre in the southeast basin in which the water rotates in a counterclockwise gyre. Both gyres likely involve both horizontal and vertical flow around the respective centers of each gyre.

Some of the graphic elements ideas are:

1. Some graphic to show what a cubic meter is, and what the unit volumes of the Salton Sea are. Also, determine what scale or units we'll use: metric or English.
2. A graph showing the variation in water velocity in a wind-driven circulation system. The top part of the graph shows the rapid movement of water to the southeast due to wind shear, and the lower part of the graph shows the return of water to the northwest, but with a drag effect from bottom friction.
3. We need to show a map of CIMIS station locations, either here or elsewhere in the Atlas to demonstrate the meteorological component of the circulation studies.
4. Plan views of the Sea with morning and afternoon wind data modeled into speed and direction vectors, to show how different AM and PM winds are (they are virtually opposite in direction). However, the diurnal variation in wind intensity and speed may be more appropriate to the climate section of the Atlas.
5. Plan view of the Sea with wind speed and direction for each of several meteorological stations averaged into a daily pattern. Rose diagrams plotted on top of the CIMIS station locations in the plan view may be especially informative. This graphic is important because there is a direct, visually compelling correlation to surface circulation. This correlation is striking enough that the AM and PM comparisons can be discarded.
6. I have left out any information to show changes in air temperature, solar radiation and relative humidity, which I think confuse the issue. Water quality conditions, including temperature, salinity and suspended sediments, will be covered in the chemical and physical limnology section, and sediment distribution in the sediment section, but we should add hooks. We could also add commentary on the need for more data on bottom roughness, horizontal and vertical turbulence, and wind stress to improve the model.
7. A longitudinal cross-section of the Sea emphasizing the presence of the north and south sub-basins, possibly with arrows to indicate the direction of flow within the gyre. We can also show drawdowns on this cross-section, with links to levels of the Sea and engineering alternative sections. I envision something similar to Orlob's graphics, but with color shading of depth ranges using our bathymetry.
8. Plan views of the Sea displaying velocity and direction vectors of lake circulation so that surface currents can be contrasted with mid-level and bottom circulation. This graphic can also include dominant wind speed and direction. This graphic could be improved using color shading of sediment grain size distribution on the Sea floor, and relative water velocity would be more meaningful if we had comparable rates from other hydrographic systems or lakes.
9. Much of the circulation story is the alteration to existing circulation patterns that would occur if and when engineering alternatives are implemented. Restricted circulation in many of the alternatives causes stagnation in parts of the Sea. We may also want to show only a link to the engineering alternatives section.
10. Lastly, we can show the modeled surface and bottom velocity maps, in which a strong counterclockwise gyre is visible in the south basin and a lesser clockwise gyre in the north basin. The expressions of these gyres are visible in both surface and bottom currents, but the velocity is considerably slower on the bottom, as expected.