Visualization of the Salinity Plume from a Coastal Ocean Water Desalination Plant

Author(s): John J. Helly and Kevin T. Herbinson


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Visualization of the salinity plume from a coastal ocean water desalination plant

John J. Helly, Kevin T. Herbinson

ABSTRACT: A salinity plume, with a maximum of 35.3 parts per thousand (ppt), was detected adjacent to the effluent source of a desalination plant on Santa Catalina Island, Los Angeles County, Calif., a 3% increase relative to the maximum of the control area. Four methods of visualizing these data were used to identify and describe the plume and one, volumetric visualization, was superior. This method revealed a surface and subsurface distribution of the effluent that is affected by tide and wave action. The plume is transported offshore and alongshore with a tidally-related separation of the diluted effluent into upcoast and downcoast parts with probable wave-related transport offshore. Water Environ. Res., 66, 753 (1994).

KEYWORDS: brine, desalination, effluent, ocean, salinity.

Desalination is an increasingly important source of fresh water for coastal communities in Southern California and in locations around the world where climate or geography limit access to fresh water. Globally, at present, fresh water production from ocean water is greatest on the Arabian Peninsula where production is about $7.6 \times 10^{8}$ m$^3$ (2 billion/d gal/day) using multistage flash distillation (MSF) (Abelson, 1991). In Southern California, where water consumption averages $15.2 \times 10^{8}$ m$^3$/d (4 billion gal/day), the Metropolitan Water District of Southern California expects to complete a $19 \times 10^{8}$ m$^3$/d (5-million-gal/day) pilot which will use distillation somewhere along the Southern California Coast by 1996 (Metropolitan Water District, 1992).

The effects of wastewater disposal in the ocean have been a matter of great concern and controversy for many years, but the specific effects of reject brine water appear to have received relatively little attention. Of the published and unpublished studies found, it appears that work involving the effluent from desalination plants has largely focused on bioassay evaluation of the toxicity of metal contaminants of the effluent, especially copper (Mandelli et al., 1971) and computer simulation of the outfall plume (NOAA, 1978).

This study was conducted to investigate the expected presence and distribution of a salinity plume generated by reject brine water effluent from a reverse-osmosis, desalination plant located at the Southern California Edison (SCE) power generating station at Pebble Beach, Santa Catalina Island, Los Angeles County, California. The desalination plant processes approximately 360,000 gallons per day of total wastewater and extracts $30 \times 10^{8}$ to $41 \times 10^{8}$ m$^3$/d (90,000 to 108,000 gpd) of fresh water, corresponding to a recovery rate of 25 to 30%.

The Pebble Beach desalination system consists of two sea water wells and piping systems, four reverse osmosis units, filters, a chlorination system, associated electrical systems, and a booster pump station. The reverse osmosis (RO) units are modular in design and operate as individual units. The system was designed to take advantage of waste heat from the electricity generators.

Sea water is pumped through a heat exchanger where it is heated to approximately 8.3°C (15°F) before being sent to the desalination units. The increased temperature of the sea water increases production efficiency of fresh water. The water is pre-filtered through three gravel bed filters then delivered to the RO units at a pressure of approximately $5.5 \times 10^{6}$ Pa (800 psi). Recovered water is treated with lime and CO$_2$ to control alkalinity and hardness and chlorine to ensure freshness.

Surplus sea water and brine effluent are mixed and pumped through a ten-inch PVC pipe to a concrete trough 4.5-m (15-ft) long and 2.1-m (7-ft) wide (Figures 1 and 2). The mixed brine spills from the trough and cascades down through the rip-rap seawall until it meets and mixes with sea water at the shoreline. Total vertical fall of the brine mixture is approximately 4.5 m (15 ft).

The water was sampled within a rectangular, 64-station grid using a probe which measured salinity, pH, dissolved oxygen, and temperature. The grid design is important to the visualization of the data and was selected to be regularly spaced along each grid axis. The study was controlled using an 8-station reference transect located 1000 m downcoast that was sampled on the second day.

Recently, the description of outfall plumes has advanced using a combination of techniques measuring components of the discharged waste but remain limited to two-dimensional, graphical characterizations using contour plots and XY scatter plots (NOAA, 1978). While important, these representations are often difficult to interpret and use for analytical purposes and are frequently found to have little value as a means of communicating important features of waste disposal systems to lay audiences.

The purpose of this paper is to present a new way to visualize oceanographic data specifically for the identification and description of effluent plumes. Salinity is used here without other parameters to demonstrate the ability to visualize and quantify a plume using a single, empirically measured parameter. The methods presented in this paper are organized to compare volumetric visualization with conventional methods. The older methods are represented by two- and three-dimensional, quantitative graphics generated using the same set of data.

Materials and Methods

A rectangular, 8 × 8 sampling grid was used to provide regularly spaced measurements in both offshore and alongshore directions as shown in Figure 3. Measurements were taken along eight transects conducted from the shoreline. The transects were spaced 10 m apart along the beach (that is, in the alongshore direction). Each transect was composed of eight stations spaced at 20-m intervals in the offshore direction. A continuous vertical profile (a cast) was taken at each of eight stations on each of the
eight alongshore transects resulting in 64 casts each day and 128 casts total for the two days of the study. The study area bottom contour is a rocky, uniform slope from inshore to offshore. The greatest depth sampled was at 22 m at a distance of 160 m offshore. A control transect was sampled at a distance of 1000 m south on the second day of the study.

The data were collected at flood tide on 18 September and ebb tide on 19 September, 1991. The weather was clear and calm with little wave action. The water was sampled within a rectangular, 64-station grid using a probe which measured salinity, pH, dissolved oxygen, and salinity. The sensor was operated from a 4.5-m (15-ft), inflatable boat except for those samples collected at grid points immediately adjacent to the shore, which were sampled by wading along the rip-rap. Positional accuracy of each grid station was determined visually through the use of two onshore markers located 10 m apart in the alongshore direction and tape markers at 20-m intervals on a nylon line used to measure position in the offshore direction. During this study, the salinity of the effluent ranged from 43.8 to 44.2 ppt.

Field operations were conducted from a 13.5-m (45-ft) vessel that was anchored offshore for use as a base for boat operations and examination of the data for quality control and quality assurance. During each transect, water quality data were stored in the on-board memory of the CTD, and the data were then electronically transferred to a ship-board computer at the end of each transect to permit quality control and quality assurance of the data acquisition process. A sample of the effluent was collected in a bucket and measured with the CTD to obtain discharge salinity values. Plant operations were reported to be constant over the two days of the study.

Four graphical methods were used to examine the data: two-dimensional scatter plots, three-dimensional scatter plots, two-dimensional contour plots, and three-dimensional, volumetrically rendered, iso-haline surfaces. To determine whether there was any noticeable elevation of salinity in the sampled area, it was hypothesized that by selecting the maximum salinity value of each cast, we would be able to define a salinity envelope corresponding to a plume if one existed. Since maxima reflect the greatest salinity values throughout the water column, the existence of adjacent, horizontal grid points with similar maxima would suggest a common source and transport process. Volumetric visualization methods enabled us to further examine this hypothesis by expanding the horizontal grid in the depth dimension.
Table 1—Salinity (parts per thousand) maxima at flood tide.

<table>
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<tr>
<th>Shoreline</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td></td>
<td>Downcoast</td>
<td>Effluent source</td>
<td>Upcoast</td>
<td></td>
<td></td>
<td></td>
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<tr>
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Table 2—Salinity (parts per thousand) maxima at ebb tide.

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</table>

Results

The results are summarized as maxima over the entire profile at a grid point by flood and ebb tide in Tables 1 and 2. Conventional representations of the data are presented before introducing the volumetric representations so that the reader is familiar with the data.

Conventional Representations

The data from the control transect are plotted in Figure 4 and those from the study area, for the first day at flood tide and the second day at ebb tide, are plotted in Figures 5 and 6, respectively. These graphs are two-dimensional scatter plots which display the data from every cast in the salinity versus depth coordinate system. This representation provides a concise summary of all salinity values measured and establishes the nature of the salinity sample space in terms of the range of values and their homogeneity. Vertical reference lines have been drawn at the maximum of the control transect values. These plots confirm the existence of elevated salinities in the study area in contrast to the control area. To localize and further describe the hyper-

Figure 4—Salinity values for control transect. Data were collected on day 2 of the study.

Figure 5—Flood tide salinity values by depth for all 64 sampling locations.
Salinity values in the alongshore and offshore directions, the data were plotted as three-dimensional scatter plots in Figures 7 and 8. These indicate that regardless of the tide, the highest salinity values are found directly adjacent to the effluent source located at alongshore transect number 4. These two figures also illustrate differences between the two tide periods suggesting an asymmetric transport of dilute effluent in the southerly, downcoast direction at ebb tide.

In comparing Figures 7 and 8, it can be seen that there is a salinity peak at ebb tide which is less pronounced at flood tide and distinctly concentrated to the south. Figures 5 and 6 show that these peaks are subsurface. The alongshore and offshore features are depicted more clearly in Figures 9 and 10 which present the iso-lines resulting from a spline fit of the maxima using a 25 × 25-node mesh. These figures additionally reflect a
nonuniform distribution of hypersaline water in the offshore direction in the form of water globules such as seen in Figure 10 centered at grid coordinates (3,2). Similar features can be seen in Figure 9.

**Volumetric Representations**

The volumetric images in Figures 11 and 12 depict the three-dimensional structure of the salinity plume especially in terms of the distinct surface and subsurface structure as well as alongshore and offshore distribution. The images were created using a computer visualization software system. These figures reveal features in the data that were not apparent in any combination of the other depictions.

These images are exaggerated in the depth dimension to emphasize the vertical structure of the data and illustrate areas of elevated salinity. They depict the sample space as a continuous three-dimensional volume of water with only areas of elevated salinity visible bounded by a wire-frame box with a grid structure which indicates the sample points within the sample space. Each image is showing the internal distribution of the hypersaline water in the range of approximately 33.2 to 35.0 ppt as indicated in Figure 12. The color coding is discussed in the figure captions. From these images, it can be seen that the plume is discontinuous with tide-specific features.

In Figure 12 the mass of water can be seen to follow the contours of the seafloor near the bottom as well as being distributed...
offshore at surface and subsurface depths. Figures 13 and 14 reveal the unique tidal features and confirm the discontinuous nature of the plume which is most clearly demonstrated by the dark patches in the offshore sample points. It is especially interesting to see the descending finger of intermediate salinity value (33.44 ppt) at ebb tide which is not present at flood tide. The distribution of water with elevated salinities extends at least 140 m offshore and 40 m in both upcoast and downcoast directions and appears to extend beyond the sampled area.

Discussion

This paper presents a new means of describing and depicting effluent plumes using visualization methods. The use of the single, salinity variable demonstrates the sensitivity of the method to small differences. The data show the presence of a salinity plume generated by the effluent from the desalination plant. While the reject brine water is substantially diluted, the volumetric method of visualizing the data provides a sensitive means for identifying the presence and nature of the transport and dilution process. Visualization of the data collected in this study show a distribution of the effluent which is probably transported alongshore by tide and offshore by waves. The maximum of 35 ppt represents approximately a 3% increase relative to the maximum of the control area.

The hypersaline water mass is separated into upcoast and downcoast components on an apparently tidal cycle; however, 8 hours were required to sample all 64 grid locations each day. Because this is longer than the tidal period, it is not possible to conclude that this is a tidal effect due to possible aliasing of other wave and tide phenomena into the two samples. As the water is transported offshore, it appears to be formed into distinctive globules of higher salinity perhaps caused by eddies produced by the ebb and flow of waves. The offshore effects are suggestive of water masses being "spawned" from the plume by the periodic energy of waves. Wave parameters such as period and energy were not measured but the sea conditions were mild and consistent on both days. Given that the plant output was continuous, these "hot spots" were not expected unless the "spawning" effect were real.

In summary, these conventional and volumetric figures depict elevated salinities adjacent to the effluent source and trending to the southeast and offshore at the surface and to the north below a few meters. The design of the discharge under study in this paper uses a broad cascading flow into a turbulent area along the shoreline for extensive mixing of the brine with the ocean receiving waters. Despite the resulting substantial dilution, the methods used for visualizing the data provide a sensitive means for identifying the presence and character of the transport and dilution process. The volumetric images confirm the gross features shown in the conventional graphics and elaborate the structure and distribution of the reject brine water in a clear and comprehensible manner not available in the other images.

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Authors. Dr. John J. Helly is Principal Scientist at the San Diego Supercomputer Center. Kevin T. Herbinson is Senior Research Scientist at Southern California Edison. Correspondence should be addressed to Dr. John Helly, San Diego Supercomputer Center, P.O. Box 85608, San Diego, CA, 92186-9784.

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