Analysis of Intake and Discharge Salinity Regimes for a Desalination Plant

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Abstract-A desalination facility in Swansea, Massachusetts is under design to withdraw water from the Palmer River during the six-hour period around low tide while the brine discharge is scheduled during the 6-hr period around high tide. These time periods minimize the discharge salinity relative to ambient conditions. An analysis to determine the likely variation of ambient salinities at both the intake and discharge during plant operation was needed both as part of the information needs for plant design as well as an assessment of environmental impacts. The analysis required characterization of the present salinity structure so a field program was undertaken. Both a continuous time series of salinity and a series of vertical salinity profiles at the intake and discharge locations were part of this field program. The long term data was processed to determine the 6-hr block average salinities centered at low tide and high tide, corresponding to times of water withdrawal and discharge. Using exponential regressions the low tide and high tide salinities were related to river flow. The vertical profile data were then used to estimate the salinity at the intake and discharge. Using linear regressions, the intake and discharge salinities were calculated from the low tide and high tide salinities predicted from the exponential regressions. Typical seasonal salinities based on seasonal river flows were calculated.

I. INTRODUCTION

A desalination facility has been proposed by the Town of Swansea to supply additional fresh water for its citizens. The facility has been designed to withdraw water from the Palmer River during the six-hour period around low tide from a site just north of the Old Providence River Bridge in a scour hole approximately 9 m deep relative to Mean Tide Level (MTL). The intake will be located at approximately 4 m deep relative to MTL. The brine discharge is scheduled during the 6-hr period around high tide in a shallow depression (approximately 2 m deep relative to MTL). The discharge ports will be located near the bottom (approximately 0.2 to 0.5 m above the bottom. These time periods minimize the discharge salinity relative to ambient conditions

To get a sense of the likely variation of ambient salinities at both the intake and discharge an analysis of the data collected during the project field program was undertaken. The data was then analyzed via regression analysis to relate both the continuous time series of salinity to river flow and to salinity at the intake and discharge locations. Using this information a subsequent discharge modeling analysis was performed to determine the conceptual design of the discharge structure that minimizes the mixing zone and maximizes the dilution of the brine. The following sections describe the field program and the regression analyses. The modeling is not presented in this paper but additional details on all components of the study can be found in [1]. Additional information on the project can be found in the series of submittals under Massachusetts state regulations [2, 3]

II. FIELD PROGRAM

A field program was undertaken to characterize the bathymetry and hydrography of the Palmer River. The field program consisted of four components: 1) a bathymetric survey of the Palmer River; 2) stream gaging surveys to measure freshwater flow into the Palmer River; 1) long term monitoring of temperature and salinity at a site in the vicinity of the proposed water intake location; and 4) intensive field surveys of the longitudinal structure of salinity and water temperature consisting of 32 sites along the river including the specific intake and discharge locations. These surveys were designed to capture both spatial and temporal (i.e., seasonal) variations in the hydrography, and particularly both high and low freshwater flow conditions. Data from the field program was used to inform the subsequent discharge modeling effort. Figure 1 shows the general locations of the instruments used in the salinity analysis. The point denoted T with the yellow square icon is the location of the long term salinity measurement at the Old Providence Road Bridge. The numbered red dots indicate some of the intensive survey locations with 11 the intake location and 08 the discharge location.

A major component of the field study was the long term deployment of a YSI 600 instrument measuring salinity and tide level, among other parameters. It was located on the Old Providence River Bridge structure with the sensors located 1 m below MTL. Deployment lasted from 30 March 2004 through 10 November 2004 and captured the range of conditions expected at the site. River flow data from the United States Geological Survey Wading River gauge was acquired for the period and shown to be a good proxy for the flow in the Palmer River after adjustment for watershed area. Details of the deployment and data can be found in the project report [1]. Figure 2 shows the time series of salinity and river flow for the period. Salinity ranged from 0 psu to 32 psu, depending primarily on river flow, which varied from 0.19 to 17 m^3/s. The high flows in the early part of the record are clearly reflected in the measured salinity as are the smaller storm-induced flow peaks and subsequent depression of the river salinity.

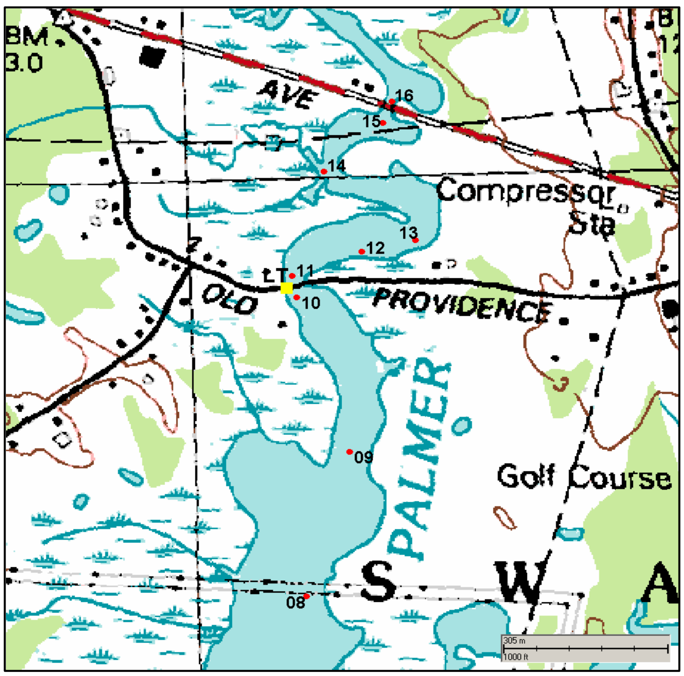

Figure 1. Location of stations for filed program. The point denoted T with the yellow square icon is the location of the long term salinity measurement. The numbered red dots indicate some of the intensive survey locations with 11 the intake location and 08 the discharge location.

In addition a series of vertical profiles of salinity with respect to depth were also acquired along the length of the river. The measurements at the intake site (station 10 in Figure 1) extended from August 2004 through June 2005 and at the discharge site (station 08) from March 2004 through June 2005. Focus for the regression analysis was restricted to the profiles taken at locations of the proposed intake and discharge during the period of the long term deployment. The sample depths were adjusted to be relative to MTL. Figure 3 shows the surveys at the intake location corrected to MTL. These data were not acquired during the high flow condition in the spring of 2004 and so show higher surface salinities (7 to 25 psu) and salinities at the intake depth (10 to 26 psu). Some profiles show increasing salinity with depth while others show a vertically uniform distribution.

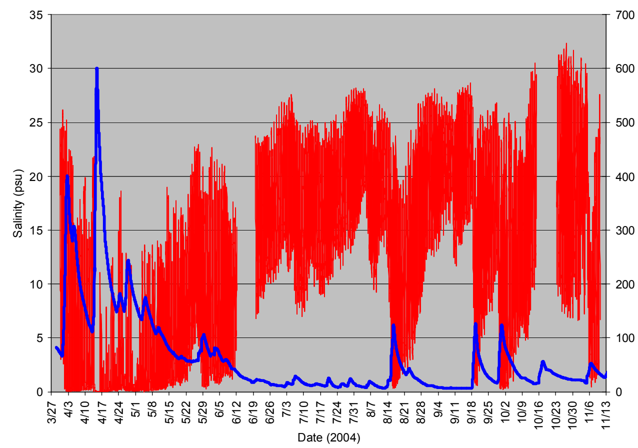

Figure 2. Long term variation of salinity and flow rate.

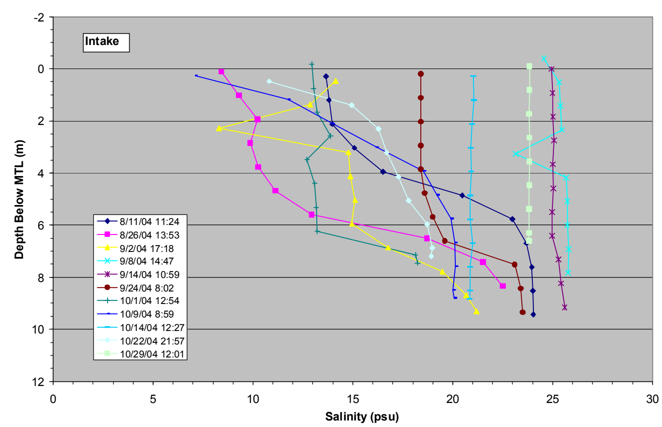

Figure 3. Vertical salinity variation from the surveys taken in summer and fall of 2004 at intake site.

Figures 4 and 5 show the salinity profiles at the discharge site. Some profiles show relatively uniform structure while others show increasing salinity near the bottom (approximately 2m). These profiles were divided into two sets with the second corresponding to the same times as the intake site measurements (shown in Figure 3).

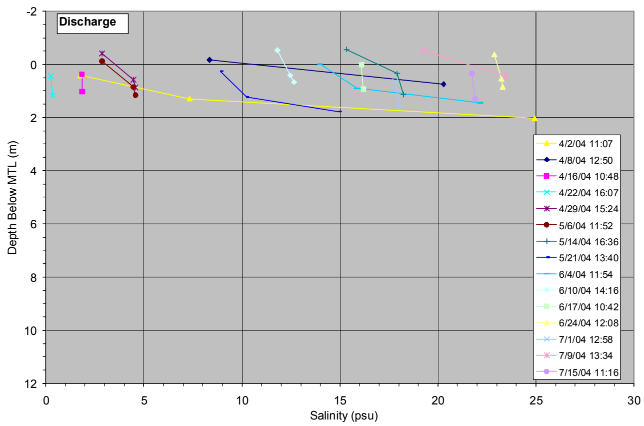

Figure 4. Vertical salinity variation from the surveys taken between April and mid July of 2004 at discharge site.

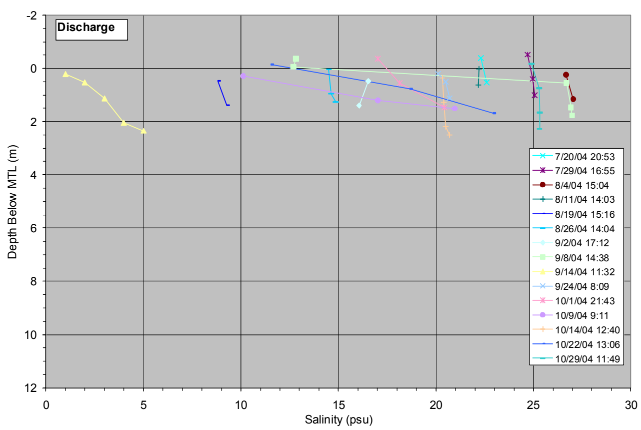

Figure 5. Vertical salinity variation from the surveys taken between mid July and October of 2004 at discharge site.

III. REGRESSION ANALYSIS

Salinity Analysis Based on River Flow Rate

The long term data was processed to determine the 6-hr block average salinities centered at low tide and high tide, corresponding to times of water withdrawal and discharge. Figure 6 shows these block averages plotted with the actual salinity time series. A total of 404 tidal cycles (or low and high tide pairs) were included in the analysis. The averaging reduces the range between high and low salinities but is more representative of the ambient salinities during facility operation. In general the high tide (peak) salinities drop approximately 2 to 3 psu during low river flow and 5 to 10 psu during high flow. The low tide salinities increase approximately 2 to 4 psu during low river flow and 0 to 5 psu during high flow.

These block average salinities were then regressed against river flow since river flow is the controlling factor. Figure 7 shows the low tide salinity variation with respect to flow which is clearly an exponential decay over time. Salinities up to 20 psu occur at low flows [less than 1 m^3/s] and drop quickly to 0 psu by 4 m^3/s. Also shown is a simple first order exponential regression curve. The correlation coefficient, r^2, for this relationship is high, 0.91, which shows that the regression represents the data well.

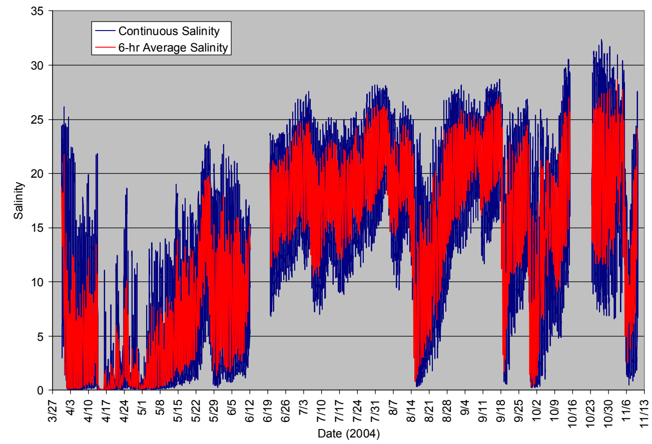

Figure 6. Long term continuous salinity with 6-hr block averages around high and low tide overlain.

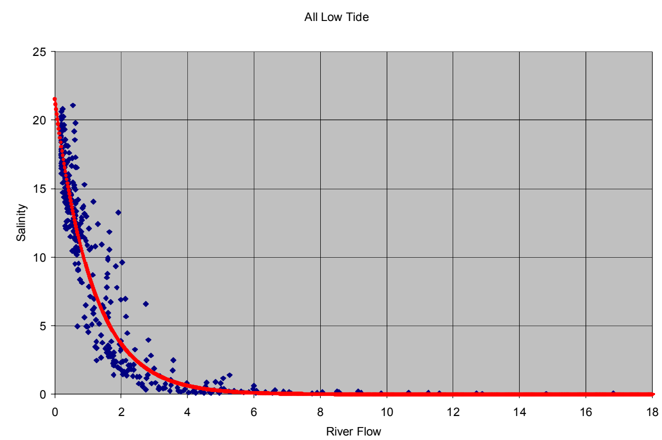

Figure 7. Variation of low tide averaged salinities as a function of river flow.

The same process was repeated for high tide conditions shown in Figure 7. Again the salinity exhibits an exponential drop as river flow increases although the drop is less dramatic and the spread of the data is larger than at low tide. Peak salinities above 25 psu are seen for low flows (less than 1 m^3/s). By 4 m^3/s the salinities have decreased, ranging from 0 to 15 psu. The least squares exponential regression line falls between this range. The correlation coefficient, r^2, for this relationship is somewhat lower, 0.82, but can still be considered a good correlation.

The exponential regression equations were then used to estimate low and high tide salinities. The results are shown in Figure 8 plotted against the averaged long term data. The low tide salinities (red dots) closely match the large variation in the data for most times. The high tide salinities (green dots) are sometimes over predicted early in the record when river flow is high and under predicted late in the record when river flow is lower, but the general agreement is good.

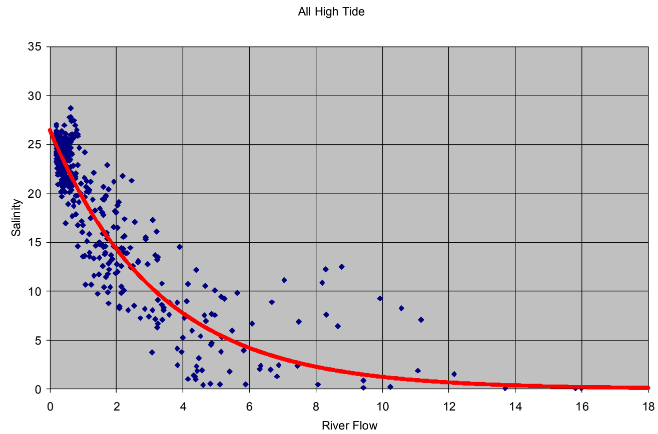

Figure 7. Variation of high tide averaged salinities as a function of river flow.

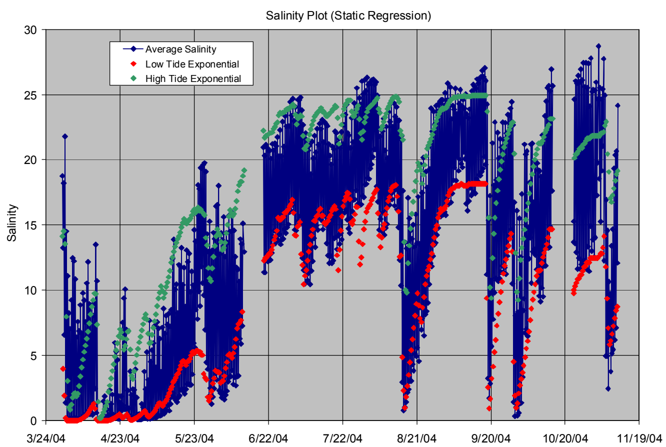

Figure 8. Low and high tide salinities predicted from the exponential regression equations overlain on the long term 6-hr block averaged data.

Intake and Discharge Salinity Analysis

The vertical profile data were then used to estimate the salinity at the intake and discharge. The intake is to be located approximately 4 m below MTL so the salinity at that depth from each profile taken during the 6-hr period centered on low tide was extracted. These salinities are shown in Figure 9 plotted against the corresponding salinity taken at the same time from the long term time series. There were nine profiles at this site. At higher levels both salinities are similar. At low long term salinities the intake salinity is higher since it is deeper in the water column and is less affected by river flow. A linear regression was developed between the intake and long term salinity and is also shown in the figure. The correlation coefficient, r^2, for this relationship, 0.82, is good.

This process was repeated for the 17 profiles taken at the discharge site that were acquired during the 6-hr period centered on high tide. Figure 10 shows the 1-m salinity taken from the profiles along with the long term salinities. This depth was chosen because the discharge plume extends over much of the water column and the 1 m level was thought more representative. The discharge salinity is higher than the long term salinity since its location is further downstream and more affected by higher ocean salinities. The correlation coefficient, r^2, for this relationship, 0.81, is also good.

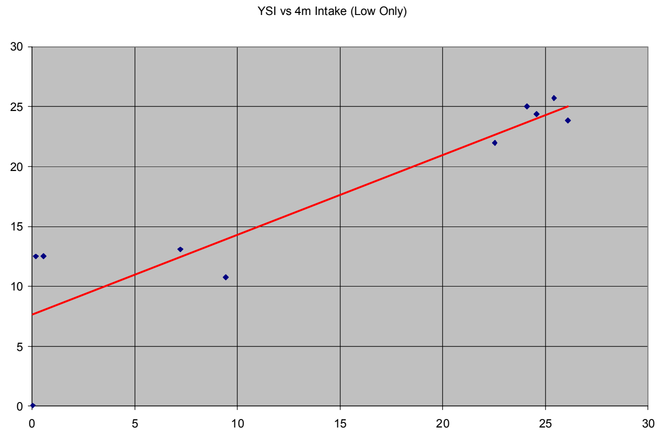

Figure 9. Variation of salinity at intake as a function of long term salinity

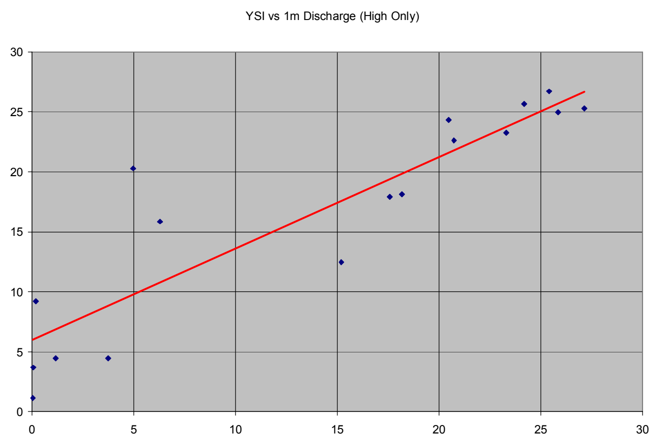

Figure 10. Variation of salinity at discharge as a function of long term salinity

Using the linear regressions, the intake and discharge salinities were calculated from the low tide and high tide salinities from the exponential regressions described earlier. These results are shown in Figure 11. For the intake, with generally low salinities, the offset from the long term salinities is small (difference between red and orange dots), typically less than 1 psu. During high flow events at the beginning of the record, however, when the salinity is low, there is a larger difference, approximately 3 psu. For the discharge a similar response is seen, with larger offsets (difference between dark and light green dots) at higher river flows that occur early in the record.

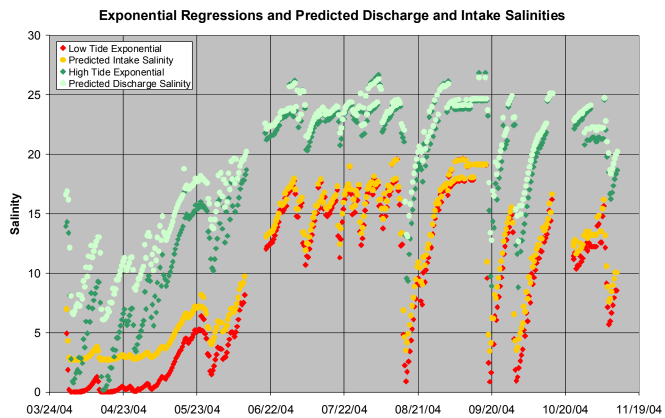

Figure 11. Predicted intake and discharge salinities with results of low and high tide exponential predictions.

Application to Palmer River Flows

The regression analysis can then be used to assess different ambient conditions under which the plant may be operating. Of biological concern are the spring and fall anadromous fish migrations up and down the Palmer River, respectively. Another period of general biological concern is summer when peak facility production is expected to occur.

To assess these periods the river flow rate is required. The long term USGS Wading River data set (1925 through 2004) was used to provide estimates of flow during these periods having been shown [1] that the Wading River is a good analog for the Palmer River. Monthly data for the period of record was downloaded from the USGS website.

The seasonal period flows were calculated from this table and results shown in Table 1. Definitions of the seasons are based on regulatory agency actions. Spring has the highest minimum, mean and maximum flows followed by summer and then fall.

Table 1. Seasonal flow variation for Palmer River.

Period	Min Flow	Max Flow	Mean Flow
	(m^3/s)	(m^3/s)	(m^3/s)
Spring (15 Mar – 15 June)	1.00	8.94	3.32
Summer (16 Jun – 30 Aug)	0.12	6.69	0.91
Fall (1 Sep – 30 Oct)	0.08	3.84	0.78

The flows presented in Table 1 were then used in the regression models to predict intake and discharge salinities. Results from the analysis based on river flow rate are shown in Table 2. Typical conditions (mean river flow) show that for spring the intake salinity is 8.4 psu and the discharge salinity is 13.2. The range for all flows in spring varies from 7.6 to 13.6 psu for intake and 7.3 to 20.8 psu for discharge. For summer the intake salinity is 14.1 psu and the discharge salinity is 21.2. The range for all flows in summer varies from 7.7 to 20.5 psu for intake and 8.5 to 25.4 psu for discharge. For the fall season the intake salinity is 14.8 psu and the discharge salinity is 21.8. The range for all flows conditions in fall varies from 8.1 to 21.1 psu for intake and 12.2 to 25.7 psu for discharge.

Table 6. Predicted intake and discharge salinities from seasonal flow rates.

	Salinity @ Min Flow	Salinity @ Max Flow	Salinity @ Mean Flow
	(psu)	(psu)	(psu)
INTAKE			
Spring	13.6	7.6	8.4
Summer	20.5	7.7	14.1
Fall	21.1	8.1	14.8
DISCHARGE			
Spring	20.8	7.3	13.2
Summer	25.4	8.5	21.2
Fall	25.7	12.2	21.8

IV. CONCLUSIONS

A desalination facility has been proposed by the Town of Swansea, Massachusetts to supply additional fresh water for its citizens. The facility has been designed to withdraw water from the Palmer River during the six-hour period around low tide while the brine discharge is scheduled during the 6-hr period around high tide. These time periods minimize the discharge salinity relative to ambient conditions.

An extensive field data set was acquired as part of this project. The data were analyzed to determine the likely intake and discharge salinities for use in the evaluation of both the operations of the desalination facility and its potential environmental effects. The regression analysis successfully showed that the salinities at both the intake and discharge are strong functions of river flow. Therefore with knowledge of the river flow the intake and discharge salinity can be predicted.

Once the analysis was completed the monthly flow averages for the Palmer River (adapted from the USGS Wading River long term information) were used to estimate likely salinities at the intake and discharge. These salinity estimates, which are based on long term river flow data as well as the results of the field survey, provide a solid understanding of conditions at the intake and discharge points. The minimum and maximum monthly mean flows can be used to provide a range of flow conditions, along with the typical mean flows, for use in subsequent environmental and plant operation analyses.

REFERENCES

[1] C. Swanson, P. Hall, S. Subbayya, and K. Knee, "Palmer River field and modeling study for the Swansea Desalination Project," Report 03-150 by Applied Science Associates, Inc., Narragansett, RI, 22 November 2004.

[2] Epsilon Associates, Inc., "Draft environmental impact report, Swansea Desalination Project, EOEA #13183", Maynard, MA, November 2004.

[3] Epsilon Associates, Inc., "Supplemental final environmental impact report, Swansea Desalination Project, EOEA #13183, Maynard, MA, 15 February 2006.