F. Dilution Modeling

WEM
WATER ENGINEERING & MODELING
766 North Mentor Avenue
Pasadena, CA 91104
(818) 398-9735 (Tel. & FAX)

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Mr. Rick Ware
Coastal Resources Management
3334 East Coast Highway #434
Corona del Mar, CA 92625

Dear Rick,

I enclose the report of my analysis of brine dilution for the proposed Cambria Desalination Plant. Please contact me if you have any questions.

Sincerely,

Gib Bogle
Principal

Cambria Desalination Plant Brine Discharge: Dilution Modeling

Introduction

The proposed Cambria Desalination Plant will discharge reject brine through a multiport diffuser located in about 9 m (30 ft) of water. The diffuser will have 21 ports, spaced at regular 1.52 m (5 ft) intervals on alternate sides. Each port will be mounted on a riser approximately 0.9 m (3 ft) off the bottom, and oriented at a 45 degree angle above the horizontal. The port diameter will be 3.61 cm (1.42 in).

The plant may be operated in several different modes, depending on the reverse osmosis recovery rate (40% or 50%), and on the production level. Eight different plant operation modes were analyzed in this study, corresponding to four levels of production with 40% and 50% recovery. The San Simeon only option will process an intake flow of 250 gpm, Phase I operation will process 750 gpm, Phase II operation will process 1375 gpm, and full operation will process 2000 gpm.

Dilution modeling was conducted in order to determine both initial dilution (i.e. nearfield dilution) and farfield dilution under a range of conditions, for the different plant operation modes. In the farfield, attention was focused on two kelp beds in the vicinity of the outfall. There is a kelp bed to the north of the outfall site, at a closest distance of about 100 m, and another kelp bed to the south, at a distance of 200 m. The model was run with longshore current values ranging from very low to very high, in order to find the worst case salinity elevation at the kelp beds.

Field Data

Current data from an extensive field monitoring program off San Simeon Creek lasting almost one year was provided by Marine Resource Consultants. The data were provided in the form of time series plots of current speed and current direction, for 5 periods of measurement, spanning the interval from September 94 to June 95. These measurements show that while the current speed in the neighborhood of the proposed outfall is typically between 2 and 7 cm/s, currents as high as 40 cm/s can occur for short periods during severe storms.

Marine Resource Consultants also supplied temperature, density and salinity profile data from the site.

Dilution Modeling

The EPA PLUMES model (Edition 3) was used in this study to predict both initial dilutions and farfield dilutions, and the associated salinity levels. The brine discharge from the outfall is denser than the ambient seawater, and therefore it tends to sink to the bottom. The 45 degree inclination of the diffuser ports causes the effluent jet/plume to follow a roughly parabolic trajectory - the jet rises to a maximum elevation of about 1.2 m above the level of the port, then falls back under the influence of gravity, eventually impinging on the sea floor. The zone of initial dilution (ZID) is usually defined by the point at which a plume becomes neutrally buoyant. In the case of dense brine plumes, this equilibrium state is not reached, and a different definition of the ZID must be used. The point at which the jet/plume reaches the bottom does correspond to a sharp reduction in the rate of dilution, and could be used as the limit of the ZID, but because this approach would fail to account for the presence of a layer of elevated salinity near the bottom (i.e. previously discharged brine), it could overestimate dilution. The conservative approach adopted here is to assume that the initial dilution phase ends when the jet/plume reaches the maximum rise.

The PLUMES model was configured so that the farfield model (using the Brooks procedure) is started at the point of maximum plume elevation, i.e. the plume width and dilution at the start of the farfield phase have the values that were attained at maximum rise. The ambient current carries the plume away from the outfall, with additional dilution resulting only from the lateral spreading of the plume, i.e. the plume vertical thickness does not change. In the cases analyzed here, the farfield locations of interest are so close to the outfall that significant additional dilution occurs only at low current speeds, i.e. less than 2 cm/s. At higher current speeds the short travel time to the kelp beds does not permit much plume spreading. Conservative farfield model assumptions were employed in two respects. First, a low value of the diffusion parameter of 0.0001 $m^{2/3}/s$ was used to account for reduced mixing near the bottom. Second, the constant eddy diffusivity formulation was used, since this yields lower dilutions than the 4/3 power law formulation. An additional reason that the farfield model may underestimate dilution and overestimate salinity is the fact that the model assumes that the jets have merged before the farfield phase begins. That is usually not the case here, and the centerline salinity in an individual jet/plume, which is the initial condition for the farfield modeling, is an overestimate of the centerline salinity for the combined plume.

For plant operation that generates a brine discharge of less than 1200 gpm (0.0757 m^3/s), it will be necessary to close some of the diffuser ports, in order to maintain the jet velocity at the ports at the design level of approximately 3.5 m/s. The number of ports to be left open was selected to yield a port velocity as close as possible to this value.

An ambient salinity of 33 ppt was used in all simulations.

Results

The two cases of full plant utilization were analyzed in detail. Initial and farfield dilutions (at 100 m and 200 m) were computed for the following current speeds (all cm/s):

0.1, 0.5, 1.0, 1.5, 2, 3, 4, 6, 8, 10, 20, 30, 40.

This range of current speeds covers the conditions observed during the 1994-95 field program. It is assumed that these current speeds could occur in either the upcoast or the downcoast direction, although in fact the downcoast direction occurs much more frequently. The 0.1 cm/s case is included to represent the no-current condition that is the worst case for initial dilution. Farfield results for the lowest current case are included for completeness, but with the understanding that the travel time for the effluent to reach the farfield locations is much longer than the maximum duration of this current condition.

Dilution of the brine plume is only affected by the part of the ambient temperature profile that the plume passes through, i.e. the bottom 2-3 m. Because the plume is dense, the worst case for dilution occurs when the temperature gradient is the greatest, and at the lowest temperature of the brine discharge. Since the plant intake is near the outfall, the brine temperature cannot be less than the ambient temperature at the bottom. The measured temperature profiles show a maximum gradient near the bottom of about 1 degree C in 3 m (measured in October 1994). Based on these observations, all the dilution modeling was conducted with a brine temperature of 12 degrees C, and an ambient temperature profile with 12 degrees C at the bottom and 13 degrees C at 3 m above the bottom. (In fact the initial dilution for a dense plume discharged near the bottom is very little affected by the ambient temperature profile.)

Table 1 shows the resulting dilution and salinities for the 2000 gpm case with 40% recovery. The 50% recovery case was analyzed first with 21 ports open, which gives a low port velocity of 2.94 m/s, yielding the results shown in Table 2. The analysis was then repeated with 17 ports open, giving a port velocity of 3.63 m/s, and the results are shown in Table 3.

Farfield dilutions and salinities are centerline values, i.e. the maximum values in the plume.

Table 1. Full Plant, 40% Recovery, 21 ports
Intake 2000 gpm, Discharge 1200 gpm (0.0757 m^3/s),
Brine salinity 54.4 ppt

Current Speed (cm/s)	Dilution			Salinity (ppt)		
	ZID	100 m	200 m	ZID	100 m	200 m
40	90	90	90	33.2	33.2	33.2
30	81	81	81	33.3	33.3	33.3
20	69	69	69	33.3	33.3	33.3
15	61	61	61	33.4	33.4	33.4
10	50	50	51	33.4	33.4	33.4
8	46	46	47	33.5	33.5	33.5
6	41	41	43	33.5	33.5	33.5
4	37	38	41	33.6	33.6	33.5
3	35	37	42	33.6	33.6	33.5
2	33	37	45	33.7	33.6	33.5
1.5	32	39	48	33.7	33.6	33.5
1.0	32	43	55	33.7	33.5	33.4
0.5	31	53	72	33.7	33.4	33.3
0.1	30	108	151	33.7	33.2	33.1

Table 2. Full Plant, 50% Recovery, 21 ports
Intake 2000 gpm, Discharge 1000 gpm (0.0631 m^3/s),
Brine salinity 65.6 ppt

Current Speed (cm/s)	Dilution			Salinity (ppt)		
	ZID	100 m	200 m	ZID	100 m	200 m
40	57	57	57	33.6	33.6	33.6
30	51	51	51	33.7	33.7	33.7
20	43	43	43	33.8	33.8	33.8
15	38	38	38	33.9	33.9	33.9
10	32	32	32	34.1	34.1	34.0
8	29	29	30	34.2	34.1	34.1
6	26	27	28	34.3	34.3	34.2
4	24	25	27	34.4	34.3	34.2
3	23	25	28	34.4	34.4	34.2
2	22	25	30	34.5	34.3	34.1
1.5	22	26	33	34.5	34.3	34.0
1.0	21	29	38	34.6	34.1	33.9
0.5	21	37	50	34.6	33.9	33.7
0.1	21	75	105	34.6	33.4	33.3

the ambient salinity of this magnitude translate directly into changes in the modeled salinities, with no effect on the modeled dilutions or ZID dimensions. For example, if the ambient salinity was 34 ppt instead of 33 ppt, the predicted ZID salinity for the 40% recovery case would be 34.7 ppt instead of 33.7 ppt.

The size of the ZID is conservatively calculated by assuming that it is a rectangular region bisected by the axis of the diffuser. This is correct at low current speeds, but at higher speeds the effluent is pushed to one side, and the size calculated in this way overstates the extent of the ZID. Table 4 shows the width computed in this way for the three modes of operation. The length of the ZID is approximately the diffuser length, i.e. 30.5 m (100 ft) if 21 ports are in use, 24.4 m (80 ft) if 17 ports are in use.

Table 4. Width of the ZID (m) with Full Plant Utilization

Current Speed (cm/s)	40% recovery (21 ports)	50% recovery (21 ports)	50% recovery (17 ports)
40	14.0	8.0	10.0
30	11.0	6.4	8.2
20	8.6	5.2	6.4
15	7.4	4.6	5.6
10	6.2	4.0	5.0
8	6.0	3.8	4.8
6	5.6	3.6	4.6
4	5.2	3.6	4.4
3	5.0	3.4	4.2
2	4.8	3.2	4.0
1.5	4.8	3.2	4.0
1.0	4.8	3.2	4.0
0.5	4.6	3.2	3.8
0.1	4.6	3.0	3.8

Several other modes of plant operation were analyzed. In Phase I operation, intake flow will be 750 gpm (0.0473 m^3/s), in Phase II the intake flow will be 1375 gpm (0.868 m^3/s), and under the San Simeon only option intake flow will be 250 gpm (0.0158 m^3/s). The modes were analyzed with both 40% recovery and 50% recovery. Rather than displaying detailed results for a wide range of current speeds, for these cases we present ZID results for the zero current case (actually 0.1 cm/s), which is the worst case for nearfield salinity, and farfield results for the current speed (3 or 4 cm/s) that yields the worst case farfield salinities. Table 5 is for the 40% recovery cases, Table 6 is for 50% recovery.

In each case, the number of ports used was chosen to give a port velocity as close as possible to 3.5 m/s.

Table 3. Full Plant, 50% Recovery, 17 ports
Intake 2000 gpm, Discharge 1000 gpm (0.0631 m^3/s),
Brine salinity 65.6 ppt

Current Speed (cm/s)	Dilution			Salinity (ppt)		
	ZID	100 m	200 m	ZID	100 m	200 m
40	71	71	71	33.5	33.5	33.5
30	63	63	63	33.5	33.5	33.5
20	53	53	53	33.6	33.6	33.6
15	47	47	47	33.7	33.7	33.7
10	39	39	40	33.9	33.9	33.8
8	36	36	37	33.9	33.9	33.9
6	33	33	35	34.0	34.0	34.0
4	30	31	35	34.1	34.1	34.0
3	29	31	36	34.2	34.1	33.9
2	28	32	39	34.2	34.0	33.8
1.5	27	34	43	34.2	34.0	33.8
1.0	26	37	49	34.3	33.9	33.7
0.5	26	48	65	34.3	33.7	33.5
0.1	26	98	138	34.3	33.3	33.2

Initial dilution decreases and salinity at the edge of the ZID increases with current speed. The worst case nearfield salinity is 33.7 ppt in the 40% recovery mode, and 34.6 ppt (21 ports) and 34.3 ppt (17 ports) in the 50% recovery mode. As expected, the 50% recovery scenario yields higher salinities than the 40% recovery scenario because of the higher discharge salinity. Closing 4 of the ports improves nearfield dilution somewhat, reducing the worst case salinity by 0.3 ppt. In all cases, it is only at low current speeds (less than 3 cm/s) that the farfield salinities are significantly less than the initial dilution.

Since field measurements indicate that current speed at the site is usually in the range 2 - 7 cm/s, these results imply that the nearfield salinity in the 40% recovery mode will generally be about 33.6 ppt, while in the 50% recovery mode it will be about 34.4 ppt (21 ports) or 34.2 ppt (17 ports). The worst case conditions yield only marginally higher nearfield salinities. In the farfield, the worst case salinity levels are 33.6 ppt (100 m) and 33.5 ppt (200 m) in the 40% recovery mode, 34.4 ppt (100 m) and 34.2 ppt (200 m) in the 50% recovery mode with 21 ports open, and 34.1 ppt (100 m) and 34.0 ppt (200 m) in the 50% recovery mode with 17 ports open. These maximum salinity levels occur under normal current conditions, provided the current direction is such that the plume is carried over the kelp beds. Since these conditions could occur in any season (although with different frequencies), there is no pattern of seasonal variation in the worst cases.

The ambient salinity at the discharge site fluctuates seasonally, exhibiting a variation of approximately one degree C. Changes in

Table 5. Nearfield and farfield worst case salinities under several modes of operation at 40% recovery.

	San Simeon	Phase I	Phase II
Discharge (m^3/s)	0.00947	0.0284	0.0521
Number of ports	3	8	14
Port velocity (m/s)	3.08	3.47	3.64
Zero current salinity (ppt)	33.8	33.7	33.7
ZID width (m)	4.0	4.4	4.6
Max. salinity 100 m (ppt)	33.5	33.5	33.6
Max. salinity 200 m (ppt)	33.4	33.5	33.5

Table 6. Nearfield and farfield worst case salinities under several modes of operation at 50% recovery.

	San Simeon	Phase I	Phase II
Discharge (m^3/s)	0.00789	0.0237	0.0434
Number of ports	2	7	12
Port velocity (m/s)	3.85	3.31	3.53
Zero current salinity (ppt)	34.2	34.4	34.3
ZID width (m)	4.0	3.6	3.8
Max. salinity 100 m (ppt)	33.7	34.0	34.1
Max. salinity 200 m (ppt)	33.5	33.8	33.9

Conclusions

In the 40% recovery operating mode, all the cases analyzed yielded salinities below 34 ppt, both at the edge of the ZID and in the farfield. With 50% recovery operation, salinity as high as 34.4 ppt is estimated at the edge of the ZID (for Phase I), and as high as 34.1 ppt (for Phase II) at the 100 m farfield location. The modeled salinity levels are not very sensitive to the current speed over the normal range of variation of current speed at the outfall site. The higher currents generated by severe storms cause increased dilution and decreased salinity levels.

Predicted farfield salinities are only slightly lower than the ZID values. This is partly because mixing (i.e. dilution) is greatly suppressed in a dense plume that is forming a bottom layer. Also, the close proximity of the kelp beds to the outfall leads to short travel times from the outfall to the farfield locations, limiting the amount of plume spreading that can occur. In addition, conservative assumptions were used in the model at every opportunity, in an attempt to compensate for the limitations in the model when treating dense discharges.

The results reported herein can be applied to scenarios with an ambient salinity that differs from 33 ppt, simply by adding the ambient salinity increment to the predicted salinity levels.