Appendix C:
Brine Plume Modeling of Strategic Petroleum Reserve Expansion Sites

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Appendix C
Brine Plume Modeling of Strategic Petroleum Reserve Expansion Sites

C.1 INTRODUCTION

The Department of Energy (DOE) is evaluating development of new Strategic Petroleum Reserve (SPR) sites and expansion of existing sites to increase the overall SPR capacity. At each of the sites, brine would be generated from cavern formation and during oil drawdown events over the operational life of the facility. Brine from three of these sites (Bruinsburg, Bayou Choctaw, and West Hackberry) would be injected into the deep subsurface through injection wells. At the remaining four sites in the following list, brine would be discharged into the Gulf of Mexico through diffusers. Brine discharge to the Gulf of Mexico would occur at the following proposed sites:

- Richton, MS (new site);
- Chacahoula, LA (new site);
- Big Hill, TX (expansion of existing SPR site; brine would be discharged through an existing diffuser); and
- Stratton Ridge, TX (new site).

The impacts of brine discharge into the Gulf of Mexico have been studied at operating sites including Bryan Mound, TX, and West Hackberry, LA. Based on field measurements of elevated salinity around these diffuser sites, an empirical model was developed. The model was run for the four above-listed proposed brine diffuser sites to estimate the impacts of brine discharge to the Gulf of Mexico for each of the proposed sites. Take note that West Hackberry is an existing SPR facility that in the past discharged brine to the Gulf of Mexico, but the diffuser is no longer being used; the proposed plan for expansion would use injection wells to dispose of brine. In addition to this modeling effort, EPA will require use of the CORMIX model to further predict the extent of the brine plume as part of the permitting process prior to operation of a brine diffuser.

C.1.1 Objectives

The objective of this study is to predict the areal extent of the brine plumes, the above-ambient salinity contours, and the vertical extent of the brine jets emanating from the proposed diffuser locations at the proposed new and expansion sites. The empirical brine plume model developed by Randall and Price (1985a, 1985d), which is described later, was used to estimate potential impacts of the proposed sites. Figure C.1.1-1 shows the proposed locations of the brine diffuser sites for the new and expansion sites.

C.1.2 Description of Proposed Diffusers

Brine from the SPR sites would be pumped to the Gulf of Mexico through a buried pipeline to a multiport diffuser. A schematic of the diffuser system is provided in figure C.1.2-1. The brine lines would range up to 4.0 inches (10 centimeters) with up to 75 proposed diffuser ports, 3.0 inches (7.6 centimeters) in diameter, spaced 60 feet (18 meters) apart at each diffuser location. A flexible hose extending 4.0 feet (1.2 meters) above the mudline would be attached to each port. The water depths at the proposed diffuser locations range from 30 feet (9.1 meters) to 47 feet (14 meters). As the brine exits from the diffuser ports, it is diluted as a result of jet mixing. Subsequently, it sinks to the bottom as a result of its greater density,

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Figure C.1.1-1: Proposed Locations of SPR Brine Diffusers in the Gulf of Mexico

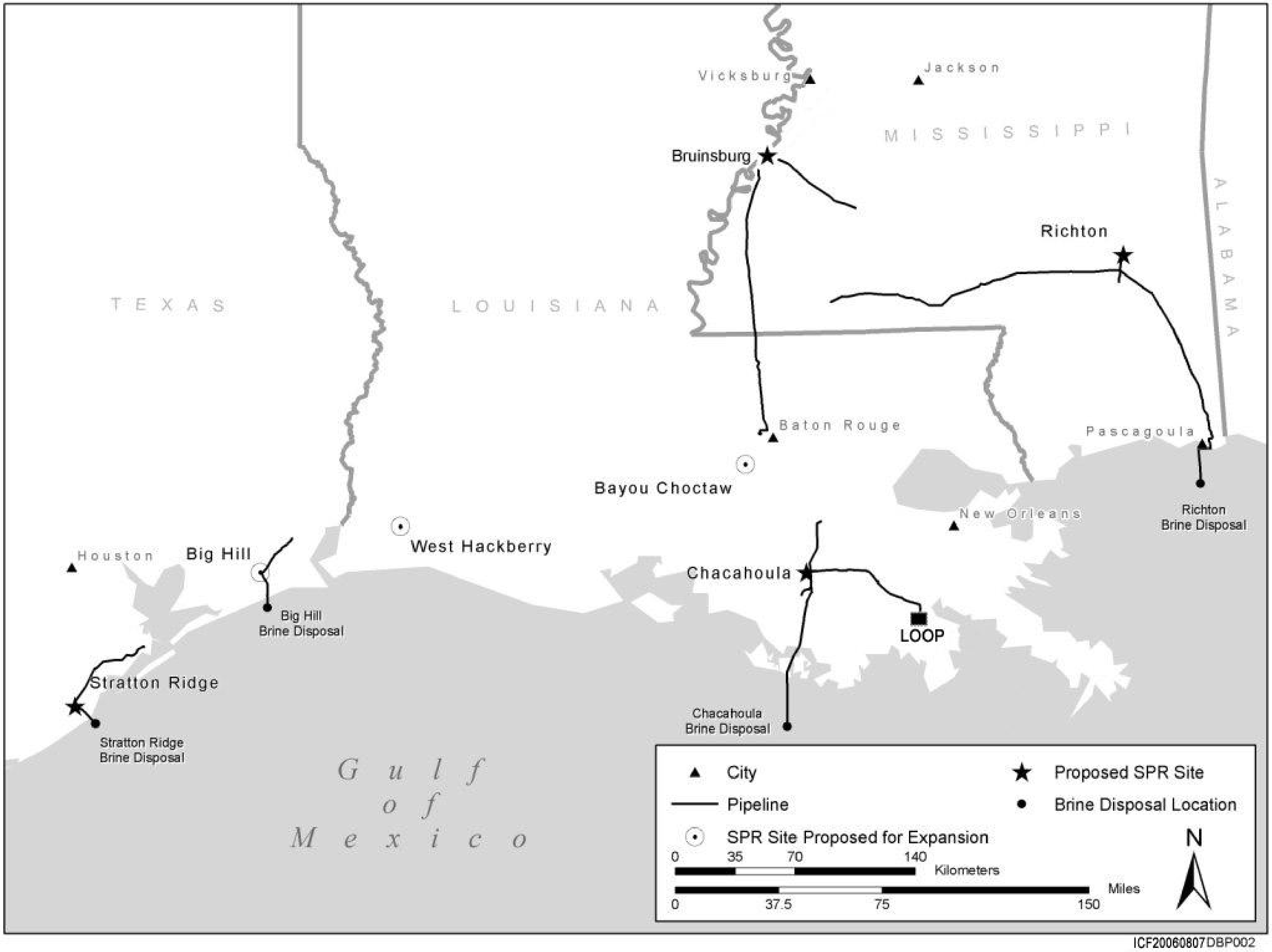
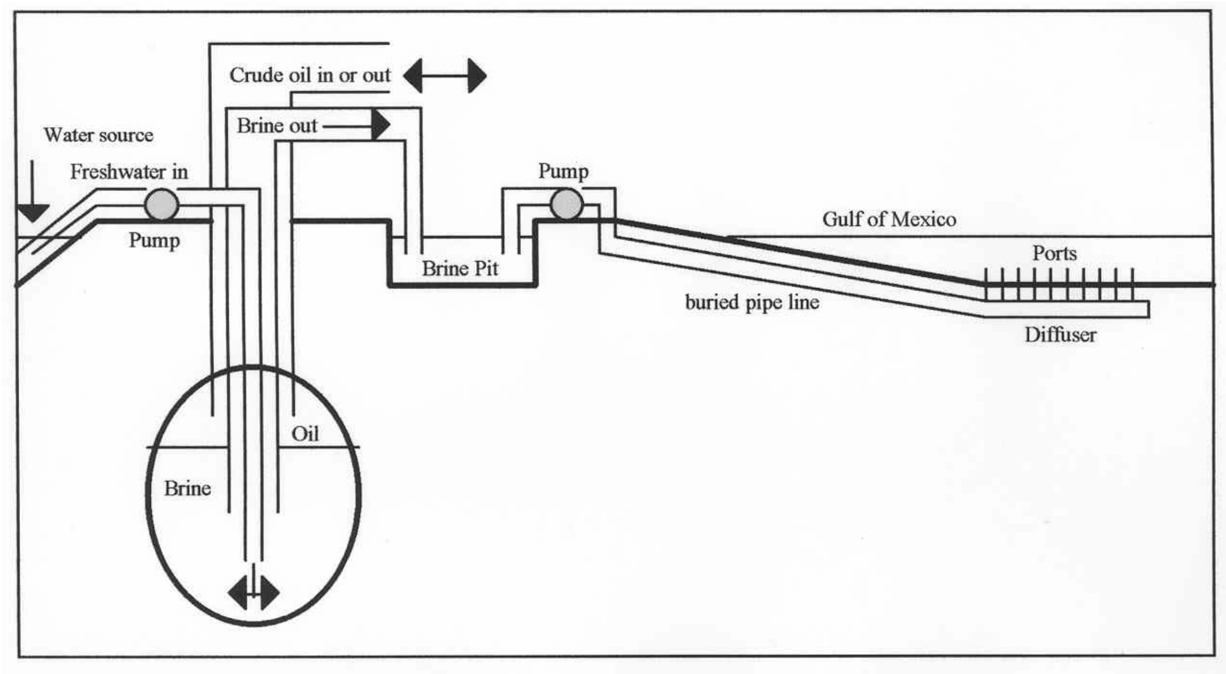


Figure C.1.2-1: Example Brine Diffuser Site and Schematic of the Brine Discharge Operation



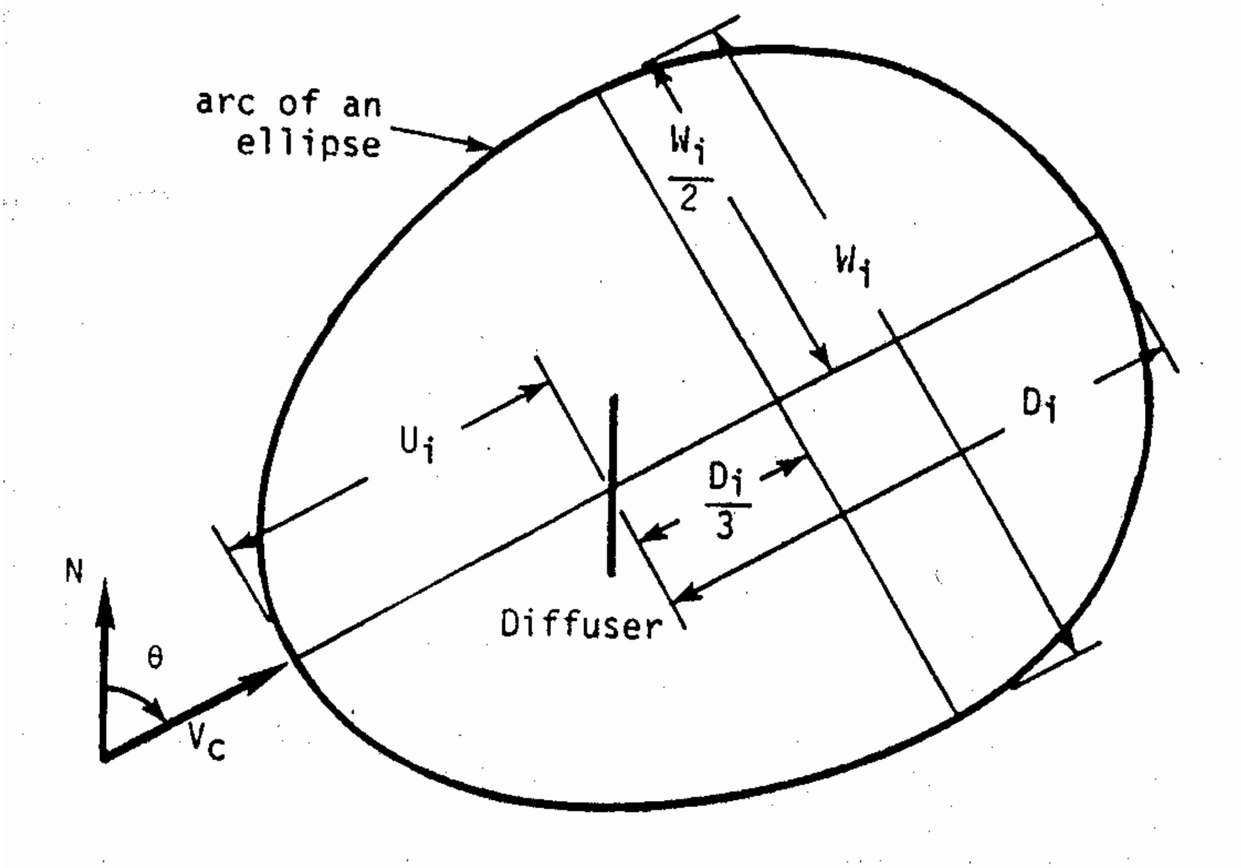
and it simultaneously spreads laterally. The plume is then dispersed by advection due to currents and diffusion due to turbulence.

C.2 DESCRIPTION OF BRINE PLUME MODEL

Experimental results of Tong and Stolzenbach (1979), a numerical model by Adams et al. (1975), and field measurements at Bryan Mound and West Hackberry diffuser sites, indicated there were certain parameters that are important in describing the plume behavior. These parameters are bottom-current speed (V_c) and direction, brine salinity (S_b), ambient bottom salinity (S_a), brine exit velocity (V_e), and brine discharge rate (Q). Empirical equations using dimensionless groupings of the above parameters were developed to estimate the brine plume areal extent, general dimensions (downstream length, width, and upstream length), maximum above-ambient bottom salinity, and the number of above-ambient salinity contours.

During field investigations at operating SPR brine diffusers, the brine plume was measured using a conductivity sensor mounted 10 inches (25 centimeters) above the sea floor in a towed sled. The measured brine plume data indicated that an ellipse was a reasonable estimate of the above-ambient bottom salinity contours. Therefore, empirical equations were determined to relate the upstream length (U_i), downstream length (D_i), and maximum width (W_i) of the plume to the dimensionless groups of physical parameters affecting the plume formation. The two lengths and the width define the axes of an ellipse as illustrated in figure C.2-1. The upstream length (U_i) is measured from the center of the diffuser in the opposite direction of the average bottom current to the desired above-ambient bottom salinity contour. The downstream length (D_i) is the distance measured in the direction of the bottom current from the center of the diffuser to the desired above-ambient bottom salinity contour. The width (W_i) is measured normal to the direction of the bottom current, and it is bisected by the line extending through the center of the diffuser in the direction of the bottom current. Plume measurements indicate that the

Figure C.2-1: Schematic of the Ellipse Used to Predict the Areal Extent of the Brine Plume



maximum width of the plume is usually located approximately one-third of the distance downstream of the diffuser, and therefore, the width is displaced a distance $D_i/3$ from the diffuser center. The ends of the lines U_i, D_i, and W_i are then connected with arcs of an ellipse that define the estimated above-ambient bottom salinity contour.

Note: Where U_i is the upstream length, D_i is downstream length, and W_i is the maximum width. The empirical relationship that fits the data best is

$$D_i, U_i \text{ or } W_i = M\,(Q/V_c)^{1/2}(S_b/S_a) + B \quad (1)$$

where Q, V_c, S_b and S_a are the brine discharge rate in units of cubic feet per second (cubic meters per second), average bottom current in units of cubic feet per second (meters per second), and brine salinity and ambient bottom salinity in units of parts per thousand, respectively. An empirical equation of similar form,

$$A_i = (1/M)(Q/V_c)(S_b/S_a) + B \quad (2)$$

is the best fit for predicting the areal extent. The units of the plume dimensions (D_i, U_i, and W_i) are feet (meters) and acres (hectares) for the area (A_i).

DOE began discharging brine at the Bryan Mound SPR site through a multiport diffuser in 71 feet (22 meters) of water located 11 nautical miles (20 kilometers) offshore of Freeport, TX, in March 1980. Field measurements of the resulting brine plumes are described in several reports (Randall, 1981; Randall, 1982; Randall and McLellan, 1983; Randall and Price, 1984a, 1985b).

Brine discharge began in May 1981 through the West Hackberry multiport diffuser located in 32 feet (9.8 meters) of water and 5.4 nautical miles (10 kilometers) offshore of Holly Beach, LA (the West Hackberry brine diffuser is no longer operated). The West Hackberry brine plume was also measured and the results were reported (Randall, 1983; Randall and Price, 1984b, 1985c).

The brine plume field measurements from the Bryan Mound and West Hackberry sites were used to develop empirical models for predicting the brine plume areal extent, brine jet vertical extent, and the above-ambient salinity contours. The models are described in the reports mentioned earlier and by Randall and Price (1985a, 1985d).

The measured brine plume data and bottom-current data from the West Hackberry diffuser site location, and the West Hackberry brine diffuser site operating data for the period May 1981 through November 1983 were used to determine the coefficients (*M* and *B*) for equations 1 and 2. The resulting coefficients and the correlation coefficients for the resulting equations are tabulated in table C.2-1. The scatter of the data about the regression line as discussed by Randall and Price (1985a, 1985d), and the low correlation coefficients indicate that the predictive equations are a reasonable estimate. The natural variation of salinity in the vicinity of the brine discharge contributes to the scatter. Also, the bottom currents change in magnitude and direction over the approximate 8-hour period of the plume measurement. Variations in the brine discharge rate and salinity during the measurement period are also factors contributing to the data scatter. Randall and Price (1985a, 1985d) conclude that the empirical equations are a best estimate of the plume characteristics in a variable ocean environment.

In addition to the plume dimensions and areal extent, the number of above-ambient bottom salinity contours must be determined. The maximum above-ambient bottom salinity is a function of the brine salinity, ambient bottom salinity, bottom current, port exit velocity, port diameter, brine density, and ambient bottom water density. Laboratory experiments conducted by Tong and Stolzenbach (1979) showed the maximum above-ambient bottom salinity could be estimated by

$$\Delta S = 0.5\, \Delta S_m\, V_r\, (F^2)^{-0.67} \qquad (3)$$

where ΔS is the bottom salinity minus the ambient salinity in units of parts per thousand, ΔS_m is the brine salinity minus the ambient salinity in units of parts per thousand, $V_r = V_c/V_e$, V_c is the bottom current in units of feet per second (meters per second), V_e is the jet exit velocity in units of feet per second (meters per second), $F = V_c/[g((\rho_b - \rho_a)/\rho_a)D]^{0.5}$, g is 9.81 feet per second (meters per second), ρ_b is the brine density in units of pounds per cubic feet (grams per cubic centimeters), ρ_a is the ambient sea water density in units of pounds per cubic feet (grams per cubic centimeters), and *D* is the port inside diameter in units of feet (meters).

The brine plume, brine discharge, and physical oceanography current meter data collected from the Bryan Mound and West Hackberry brine disposal operations were used to determine an empirical relationship similar to equation 3 using linear regression techniques (Randall and McLellan, 1983). The result has a correlation coefficient of 0.89, indicating a good fit to the data. Equation 4 is used to estimate the

Table C.2-1: Coefficients for Brine Plume Prediction Equations Based on Data for West Hackberry Brine Diffuser Site

Equation Type	Coefficient M	Coefficient B	Correlation Coefficient
Area			
A_1	10.3	3.02	0.20
A_2	17.9	1.04	0.20
A_3	34.0	0.21	0.22
A_4	56.2	0	0.17
A_5	127.4	0	0.06
A_6	196.3	0	0.01
Width			
W_1	71.1	1804	0.47
W_2	59.9	1045	0.53
W_3	41.0	629	0.52
W_4	34.7	186	0.54
W_5	18.7	55	0.28
W_6	13.8	52	0.33
Downstream Length			
D_1	56.5	1051	0.26
D_2	41.3	683	0.16
D_3	32.5	406	0.1
D_4	27.0	332	0.42
D_5	22.3	289	0.36
D_6	19.7	177	0.62
Upstream Length			
U_1	39.7	0	0.66
U_2	28.0	0	0.75
U_3	20.5	0	0.74
U_4	15.1	0	0.74
U_5	13.0	0	0.52
U_6	12.4	0	0.82

Note: Subscripts indicate the above-ambient salinity contour.
Source note: Randall and Price 1985a, 1985d.

maximum above-ambient bottom salinity, and this value is truncated to the nearest part per thousand to determine the number of above-ambient bottom salinity contours for the plume prediction.

$$\Delta S = 0.444\ \Delta S_m\ V_r\ (F^2)^{-0.533} \qquad (4)$$

The prediction of the plume is for an 8-hour period because this is the approximate time required to measure the plumes. The prediction model does not account for a sloping bottom, but the West Hackberry data used to evaluate the coefficients for the plume prediction equations were taken from a site that has a small cross-shelf slope (1 to 2,500). A computer program has been developed that inputs the necessary physical data and uses these data to compute the plume physical dimensions, areal extent, and above-ambient bottom salinity contours for each 8-hour period. Comparisons of predicted and measured results are described by Randall and Price (1985a, 1985d).

The plume prediction model in equations 1 and 2 and the maximum above-ambient bottom salinity prediction in equation 4 assume the vertical salinity distribution is constant. Stable stratification (increasing salinity with increasing depth) frequently is observed at water depths ranging from 30 to 40 feet (9.1 to 12 meters) in this area of the Gulf of Mexico; however, vertical salinity gradients in the range of 5 to 10 parts per thousand have been observed (Kelly et al., 1982, Randall and Kelly, 1982). When these vertical salinity gradients are present, the dilution of the brine is greater, and consequently, the maximum above-ambient bottom salinity is less than that predicted by equation 4. There are also fewer above-ambient salinity contours and smaller areal extent, and consequently, the model is conservative when salinity stratification is present.

The vertical extent of negatively buoyant jets has been investigated using laboratory and field experiments as reported by Tong and Stolzenbach (l979), Turner (1966), and Randall and McLellan (1983). The vertical extent of the brine jets depends on the exit velocity, port diameter, brine density, and ambient density of the receiving waters. A relationship has been determined by experimental procedures as reported by previously mentioned researchers. The general form of the equation developed is

$$Z/D = C\ V_e/[g((\rho_b - \rho_a) / \rho_a)D]^{1/2} \qquad (5)$$

where Z is maximum height of brine jet above the port , D is inside port diameter, V_e is port exit velocity, g is gravitational acceleration constant, ρ_b is the brine density, ρ_a is the ambient sea water density, and C is a proportional constant. Randall and McLellan (1983) determine a value of C equal to 2.2.

C.3 MODEL APPROACH

The empirical brine plume prediction model described earlier was used to predict the negatively buoyant brine plumes for the proposed new and expansion diffuser locations. Input parameters representative of baseline oceanographic conditions at each of the proposed brine diffuser sites were estimated based on available data from various field studies at similar depths and distances from shore in the Gulf of Mexico.

The direction and magnitude of bottom currents at the diffuser sites are primary determinants of the extent of the resultant brine plumes. The resultant high salinity plume is largest at low bottom-current velocities; thus, analyses are limited to the low bottom-current velocity of 1.2 inches per second (3.0 centimeters per second) (identified as the "maximum plume" scenario) and moderate bottom-current velocity 3.5 inches per second (9.0 centimeters per second) (identified as the "typical plume" scenario). These bottom-current velocities were chosen based on review of monitoring data from the operating Big Hill and West Hackberry SPR sites and other available data from the proposed Richton diffuser location area.

For each site, analyses and maps represent the following three scenarios:

1. The first map depicts the maximum potential impact area showing the plume extent resulting from the low bottom-current velocity of 1.2 inches per second (3.0 centimeters per second), and it shows the predominant current direction along the shoreline.

2. The second map depicts the area of impact assuming a "typical" bottom-current velocity of 3.5 inches per second (9.0 centimeters per second), and it shows the predominant current direction.

3. The third map depicts the area of impact also assuming a "typical" bottom-current velocity of 3.5 inches per second (9.0 centimeters per second), but it shows the second most predominant current direction.

Probable bottom-current velocities and directions are based on available oceanographic data for the diffuser sites and surrounding areas. This background information is summarized as follows.

Representative data from the Big Hill site is provided in tables C.3.1-1 and C.3.1-2. Table C.3.1-1 shows that bottom-current velocities may range from below 1.2 inches per second (3.0 centimeters per second) up to greater than 15.7 inches per second (40 centimeters per second) over the course of a 9-month monitoring program at the Big Hill diffuser location. At Big Hill, bottom-current velocities between 2.4 and 4.7 inches per second (6.0 and 12 centimeters per second) were most prevalent (table C.3.1-1). For the modeling effort, 3.5 inches per second (9.0 centimeters per second) was identified as typical bottom-current velocity. Table C.3.1-2 shows bottom-current direction in terms of percentage of time over a 9-month period. The direction of bottom currents in these areas has been recorded in all directions, but the predominant direction is along and parallel to the coastline.

Table C.3-1: Summary of Percentage of Occurrence of Bottom-Current Magnitudes at Big Hill Site

Month	Bottom-Current Magnitude Range (cm/s)								
	0–3	3–6	6–12	12–15	15–20	20–25	25–30	30–40	40+
DEC 77	3.8	14.4	25.9	12.8	18.6	13.4	5.4	5.7	0.0
JAN 78	2.6	7.7	25.6	13.8	19.4	12.5	9.3	6.9	2.3
FEB 78	1.0	8.9	24.0	13.8	20.8	15.0	9.2	5.1	2.1
MAR 78	7.1	16.9	42.4	13.6	11.0	5.5	3.1	0.4	0.0
APR 78	4.6	10.6	25.2	15.6	23.9	10.3	4.9	4.7	0.4
MAY 78	15.3	16.7	23.3	12.0	14.9	9.9	5.8	1.9	0.1
JUN 78	10.1	18.2	36.7	13.3	12.5	5.6	2.2	1.4	0.0
JUL 78	15.1	20.8	41.5	12.4	7.9	2.0	0.3	0.0	0.0
AUG 78	14.5	22.3	42.7	7.3	6.6	1.5	1.2	1.2	2.7
AVERAGE	8.2	15.2	31.9	12.7	15.1	8.4	4.6	3.0	0.8

Note: Based on current joint frequency distribution of Big Hill secondary site bottom-current data for December 1977 through August 1978.

cm/s = centimeter/second

Source note: Randall and Kelly (1982).

Table C.3-2: Summary of Percentage of Occurrence of Bottom-Current Directions at Big Hill Site

Month	N	NE	E	SE	S	SW	W	NW
DEC 77	1.8	22.5	8.8	2.6	8.4	30.4	21.6	3.9
JAN 78	4.8	16.8	5.5	1.7	11.0	16.1	38.4	5.5
FEB 78	6.4	20.8	9.2	3.9	11.3	16.2	24.7	7.4
MAR 78	9.0	21.6	7.0	6.2	7.4	18.1	21.8	8.9
APR 78	3.1	11.7	8.3	5.8	11.9	34.2	18.2	6.8
MAY 78	2.8	19.0	15.9	2.7	4.7	26.6	25.5	2.7
JUN 78	6.8	15.6	23.6	9.6	12.8	18.1	8.69	5.0
JUL 78	12.8	25.0	15.7	7.5	8.9	9.9	10.9	9.3
AUG 78	5.9	18.4	16.4	6.9	9.8	16.8	18.3	7.5
AVERAGE	5.9	19.0	12.3	5.2	9.6	20.7	20.9	6.3

Note: Based on current joint frequency distribution of Big Hill secondary site bottom-current data for December 1977 through August 1978.

Source note: Randall and Kelly (1982).

Data for the West Hackberry diffuser site (Kelly et al., 1982) show that the predominant bottom-current velocity during the year is 2.0 to 5.9 inches (5.0 to 15 centimeters) per second, representing the modeled “typical plume.” The low velocities resulting in the modeled “maximum plume” occur only 10.4 percent of the year. The bottom-current direction is in all directions, and the preferred bottom-current direction is to the west (parallel to the coastline) 26 percent of the time.

Oceanographic data from the area of the proposed Richton diffuser location are available in Dinnel (1988), Eleuterius (1973), Kjerfve and Sneed (1984), and Vittor and Associates (1985). In addition, an environmental impact statement by the U.S. Army Corps of Engineers and the U.S. Navy (1991), a feasibility report (USACE, 1984) for a nearby dredged material disposal area offshore Horn Island, and a U.S. Army Corps of Engineers study of the Mississippi Sound (USACE, 1980) were used to evaluate values for ambient bottom salinity, ambient bottom temperature and bottom-current velocities.

Table C.3.1-3 shows bottom-current magnitudes for the typical and maximum case plumes and the preferred bottom-current direction, based on data from Kjerfve and Sneed (1984). The data show that bottom currents representing the maximum plume extent, in the range of 0 to 1.6 inches per second (0 to 4 centimeters per second), occurred 34 percent of the time. Bottom currents representing typical plumes, in the range of 3.2 to 5.5 inches per second (8.0 to 14 centimeters per second), occurred 22 percent of the time. Bottom currents in the north-northeast direction occurred 19 percent of the time, and those in the northeast-east direction occurred 26 percent of the time.

Table C.3-3: Summary of Percentage of Occurrence of Bottom-Current Magnitudes and Directions at Richton Area

	Bottom-Current Magnitude (cm/s)							
Range	0–4	4–8	8–14	14–22				
Percentage of Time	34	34	22	10				
	Bottom-Current Direction							
Range	N-NE	NE-E	E-SE	SE-S	S-SW	SW-W	W-NW	NW-N
Percentage of Time	19	26	13	6	6	7	9	14

Note: Based on joint frequency distribution of offshore Mississippi sound site bottom-current data.

cm/s = centimeters/second

Source note: Kjerfve and Sneed, 1984.

C.4 DEFINITION OF MODEL INPUT PARAMETERS

Ambient conditions for the "typical" and "maximum" oceanographic conditions were determined to be similar at each of the proposed brine diffuser locations, based on review of the existing body of oceanographic data for this area, as described earlier. These conditions are summarized in table C.4-1. Salinity and water temperature are expected to be similar for typical and maximum conditions because the diffusers will be placed at similar water depths. The resultant plumes for a "typical" scenario and a low bottom-current velocity "maximum" scenario were evaluated for each diffuser location. The potential impacts of all current directions, in addition to just the two most prevalent current directions, were evaluated.

Table C.4-1: Environmental Conditions for SPR Expansion Sites

Parameter	Big Hill, TX		Stratton Ridge, TX		Chacahoula, LA		Richton, MS	
	Typical	**Max.**	**Typical**	**Max.**	**Typical**	**Max.**	**Typical**	**Max.**
Ambient Bottom Salinity (ppt)	31	25	31	25	31	25	31	25
Ambient Surface Salinity (ppt)	31	25	31	25	31	25	31	25
Ambient Bottom Temperature (°C)	20	15	20	15	20	15	20	15
Ambient Surface Temperature (°C)	20	15	20	15	20	15	20	15
Water Depth (ft)	33	33	30	30	30	30	47	47
Ambient Bottom Current (m/s)	0.09	0.03	0.09	0.03	0.09	0.03	0.09	0.03

ppt = parts per thousand; °C = degrees Celsius; ft = feet; m/s = meters/second
1 foot = 0.3048 meters

Table C.4-2 summarizes the input parameters including specific characteristics of the brine diffuser and discharge volume. The number of open diffuser ports is determined by assuming an exit velocity of 30 feet per second (9.1 meters per second) and the maximum brine discharge rate. The maximum brine salinity is chosen as 263 parts per thousand that corresponds to a saturated condition for 68 °Fahrenheit (20 °Celsius).

Table C.4-2: Characteristics of Brine and Brine Diffuser for SPR Expansion Sites

Parameter	Big Hill, TX	Stratton Ridge, TX	Chacahoula, LA	Richton, MS
Brine Salinity (ppt)	263	263	263	263
Brine Temperature (°C)	20	20	20	20
Maximum Number of Ports	75	75	75	75
Number of Open Ports resulting in maximum brine discharge rate	57	53	45	45
Port Height above Bottom (ft)	4	4	4	4
Port Exit Velocity (ft/s)	30	30	30	30
Maximum Brine Discharge Rate (MMBD)	1.3	1.2	1.0	1.0
Port Diameter (inches)	3	3	3	3
Port Spacing (ft)	60	60	60	60

ppt = parts per thousand; °C = degrees Celsius; ft = feet; ft/s = feet/second; MMBD = million barrels per day
1 foot = 0.3048 meters; 1 inch = 2.54 centimeters

C.5 DISCUSSION

Table C.5-1 summarizes model results for the existing (Big Hill) and proposed (Chacahoula, Richton, Stratton Ridge) brine diffuser location. Additional data appear in attachment C-1.

Table C.5-1: Results of Brine Plume Prediction for SPR Expansion Sites

Parameter	Big Hill, TX	Stratton Ridge, TX	Chacahoula, LA	Richton, MS
Brine Salinity (ppt)	263	263	263	263
Brine Temperature (°C)	20	20	20	20
Maximum Number of Ports	75	75	75	75
Number of Open Ports needed to reach maximum brine discharge rate	57	53	45	45
Port Height above Bottom (ft)	4	4	4	4
Port Exit Velocity (ft/s)	30	30	30	30
Maximum Brine Discharge Rate (MMBD)	1.3	1.2	1.0	1.0
Port Diameter (inch)	3	3	3	3
Port Spacing (ft)	60	60	60	60
Maximum Above-ambient Salinity (ppt)	4.3 (Typical) 4.7 (Maximum)	4.3 (Typical) 4.7 (Maximum)	4.3 (Typical) 4.7 (Maximum)	4.3 (Typical) 4.7 (Maximum)
Maximum Vertical Extent of Brine Jets (ft)	18.5 (Typical) 18.4 (Maximum)	18.5 (Typical) 18.4 (Maximum)	18.5 (Typical) 18.4 (Maximum)	18.5 (Typical) 18.4 (Maximum)
Water Depth	33	30	30	47
Downstream Length (nm) T – typical plume M – maximum plume	+1 – 1.9 T 3.4 M +2 – 1.3 T 2.5 M +3 – 1.0 T 1.9 M +4 – 0.8 T 1.5 M	+1 – 1.8 T 3.3 M +2 – 1.3 T 2.4 M +3 – 1.0 T 1.8 M +4 – 0.8 T 1.5 M	+1 – 1.7 T 3.1 M +2 – 1.2 T 2.2 M +3 – 0.9 T 1.7 M +4 – 0.7 T 1.4 M	+1 – 1.7 T 3.1 M +2 – 1.2 T 2.2 M +3 – 0.9 T 1.7 M +4 – 0.7 T 1.4 M

ppt = parts per thousand; °C = degrees Celsius; ft = feet; ft/s = feet/second; MMBD = million barrels per day; nm = nautical miles
1 foot = 0.3048 meters; 1 inch = 2.54 centimeters; 1 nautical mile = 1.85 kilometers

The typical plume assumes a moderate bottom-current velocity, resulting in the highest salinity, which would be 4.3 parts per thousand above ambient conditions. The typical plume would extend 0.8 nautical miles (1.5 kilometers) out from the diffuser, and the salinity rate would increase to 1.0 part per thousand for 1.9 nautical miles (3.5 kilometers) out from the diffuser.

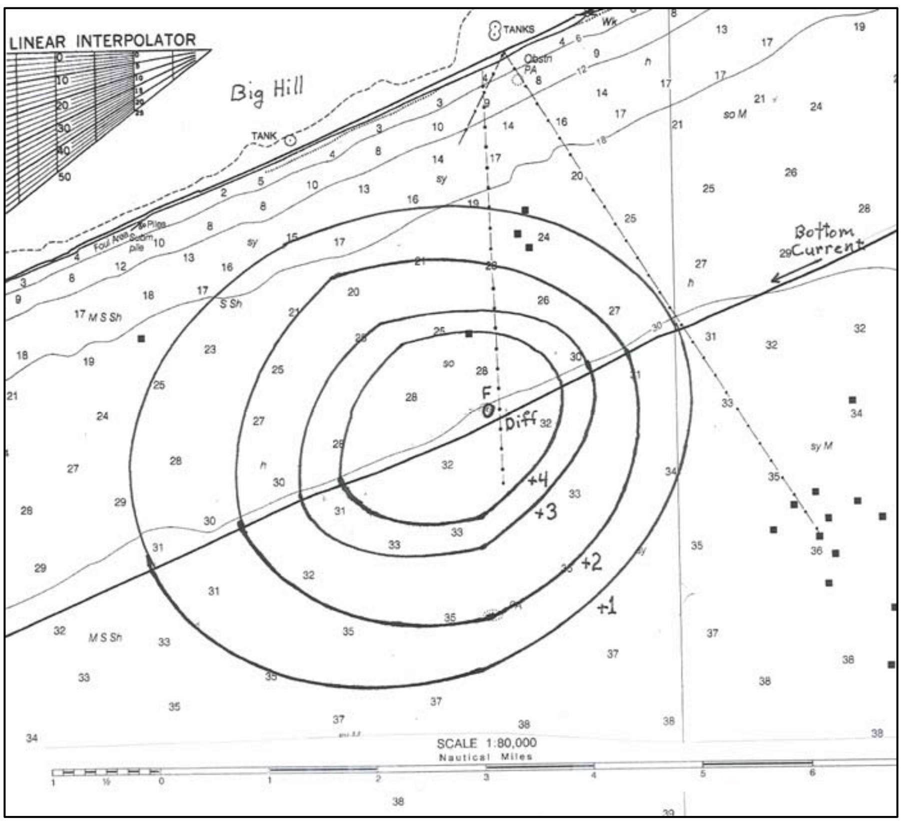
The maximum-plume scenario, which assumes a low bottom-current velocity, would have the highest increase of salinity above ambient conditions. The result would be 4.7 parts per thousand extending 1.5 nautical miles (2.8 kilometers) out from the diffuser. There would be an increase in salinity of 1.0 part per thousand extending out 3.4 nautical miles (6.3 kilometers) from the diffuser.

The maximum vertical extent of the brine jet would be approximately 19 feet (5.8 meters) for the typical plume and 18 feet (5.5 meters) for the large plume. For the Big Hill site, the maximum downstream length of the plume would be 3.4 nautical miles (6.3 kilometers) for the maximum plume scenario and 1.9 nautical miles (3.5 kilometers) for the typical plume scenario, which is the result of the largest brine maximum discharge rate of 1.3.

C.5.1 Big Hill

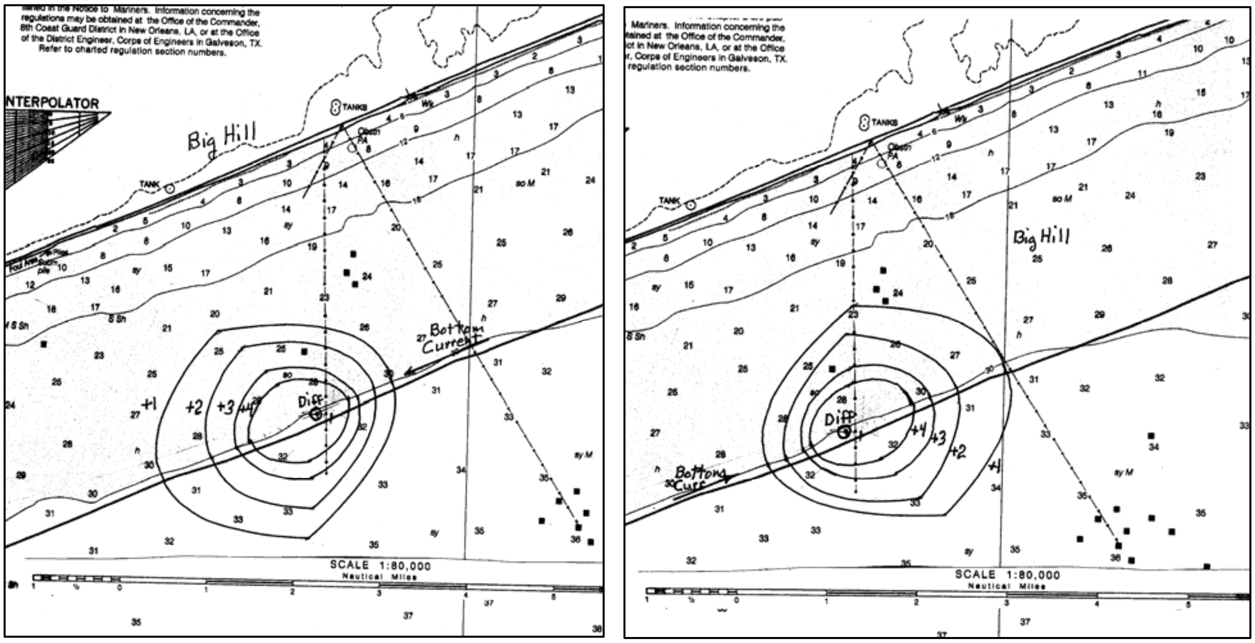
Figure C.5.1-1 shows the extent of the maximum elevated salinity plume showing the +1 through +4 parts per thousand contours for the proposed Big Hill site. Based on a review of the data presented in table C.3.1-2, this figure shows maximum plume conditions and assumes a low bottom-current velocity of 1.2 inches per second (3 centimeters per second) along the shore to the southwest.

Figure C.5.1-1: Big Hill - Empirical Brine Plume Prediction for Maximum Plume



The elliptical above-ambient salinity contours for the typical plume scenario assumes a bottom-current velocity of 3.5 inches per second (9 centimeters per second), shown on figure C.5.1-2 for the two most predominant current directions.

Figure C.5.1-2: Big Hill - Empirical Brine Plume Prediction for Typical Case Conditions for Bottom Currents Downcoast (left) and Upcoast (right)



The brine plume model estimates that the area inside the typical elliptical contour plumes is 7.2 square nautical miles (13 square kilometers) for the +1 parts per thousand contour, 4.0 square nautical miles (7.4 square kilometers) for the +2 parts per thousand contour, 2.0 square nautical miles (3.7 square kilometers) for the +3 parts per thousand, and 1.2 square nautical miles (2.2 square kilometers) for the +4 parts per thousand contour. For the maximum plume, estimated to occur on the average of 8 percent of the year, the model predicts the area inside the elliptical contours as 24, 14, 7.2, and 4.3 square nautical miles (45, 26, 13, and 8.0 square kilometers) for the +1, +2, +3, and +4 parts per thousand contours, respectively.

C.5.2 Stratton Ridge

The above-ambient salinity contours for +1 to +4 parts per thousand are shown on figure C.5.2-1 for the maximum plume scenario, which assumes a bottom-current velocity of 1.2 inches per second (3.0 centimeters per second) for the Stratton Ridge site. The bottom current is shown propagating down and parallel to the coast, which is the predominant current direction. The +1 part per thousand above-ambient contour overlaps the Freeport ship channel and thus some of the brine plume is predicted to enter the ship channel. The typical brine plume contours, which assume a bottom current of 3.5 inches per second (9.0 centimeters per second), are shown in figure C.5.2-2. Resultant plumes for the two most prevalent bottom currents are shown parallel to the shoreline. The predicted area inside the elliptical maximum plume contours are 22.8 square nautical miles (42 square kilometers) for the +1 parts per thousand contour, 14 square nautical miles (26 square kilometers) for the +2 contour, 6.7 square nautical miles (12 square kilometers) for the +3 parts per thousand, and 4.0 square nautical miles (7.4 square kilometers) for the +4 parts per thousand contour. The typical plume scenario predicts areas of 6.8, 3.7, 1.8, and 1.1 square nautical miles (13, 6.9, 3.3, and 2.0 square kilometers) respectively. The depth of the diffuser is 30 feet (9.14 meters) on the navigation chart. The diffuser for this proposed SPR expansion site is parallel to the brine line and nearly perpendicular to the coastline.

Figure C.5.2-1: Stratton Ridge - Empirical Brine Plume Prediction for Maximum Case Conditions for Downcoast Bottom Currents

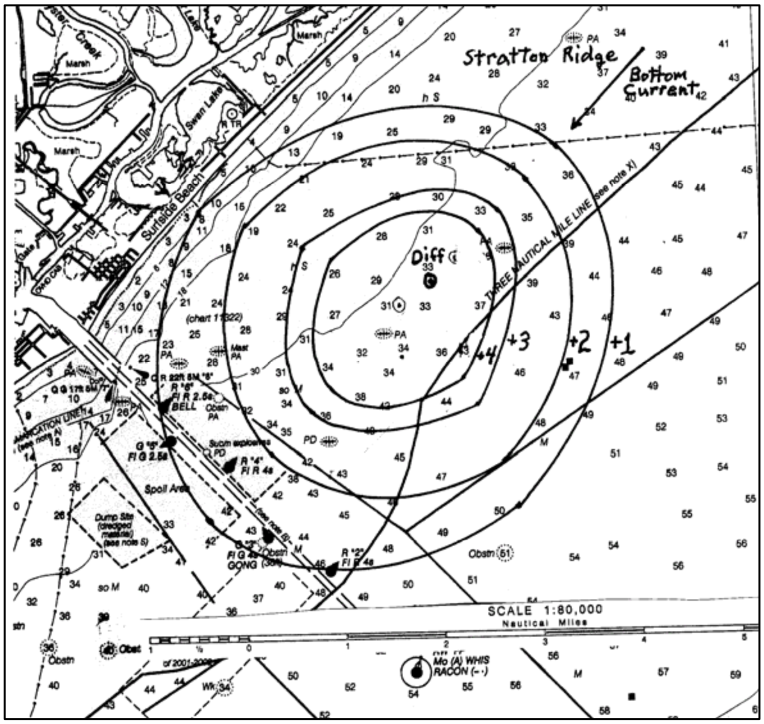
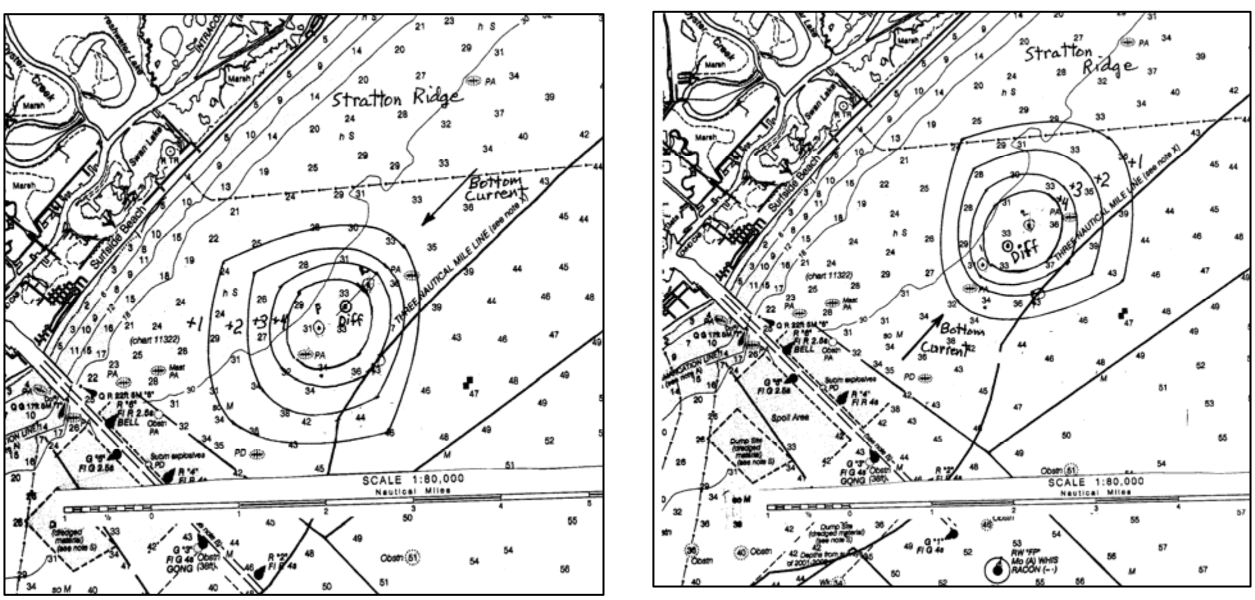


Figure C.5.2-2: Stratton Ridge - Empirical Brine Plume Prediction for Typical Case Conditions for Bottom Currents Downcoast (left) and Upcoast (right)



C.5.3 Chacahoula

The Chacahoula site's maximum plume, which assumes a bottom-current velocity of 1.2 inches per second (3 centimeters per second) above-ambient salinity contours for +1 to +4 parts per thousand, are illustrated in figure C.5.4-1. The diffuser for this expansion site is perpendicular to the brine line. Figure C.5.4-2 shows the typical plume, which assumes a bottom-current velocity of 3.5 inches per second (9 centimeters per second).

Figure C.5.3-1: Chacahoula - Empirical Brine Plume Prediction for Maximum Case Conditions for Westerly Bottom Currents

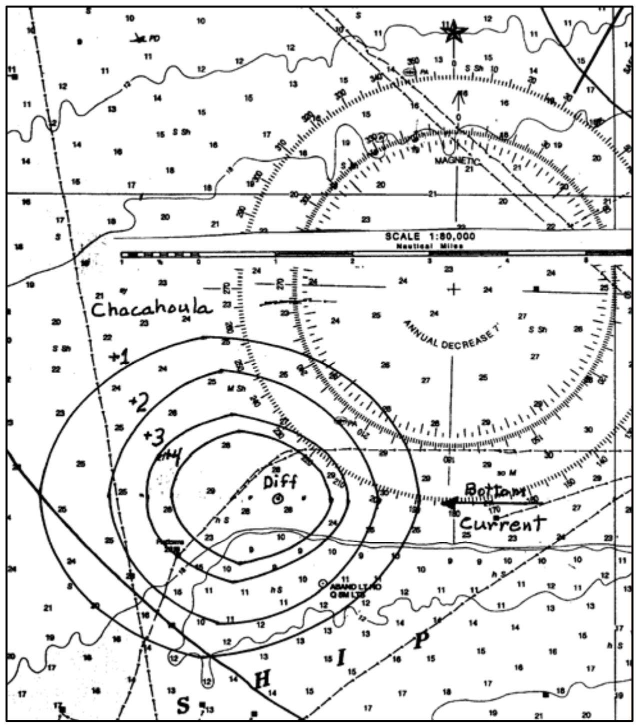
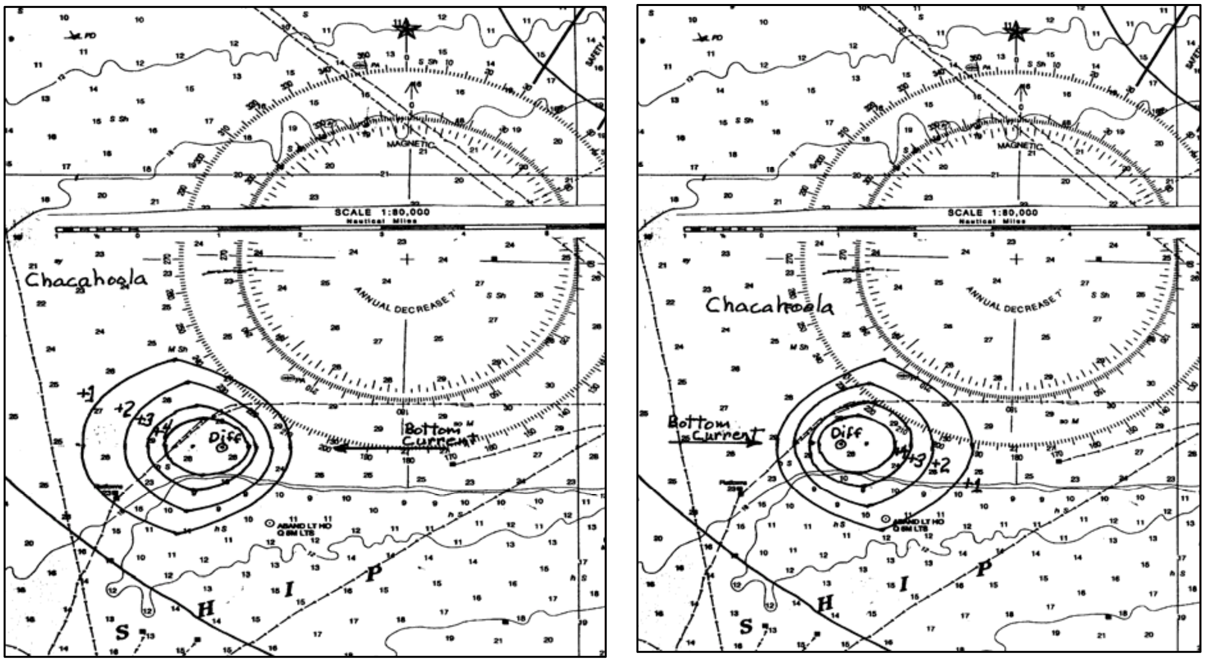


Figure C.5.3-2: Chacahoula - Empirical Brine Plume Prediction for Typical Case Conditions for Bottom Currents to the West (left) and East (right)



The diffuser is located at a depth of approximately 30 feet (9.1 meters), very close to Ship Shoal, which rises vertically from a depth of 20 feet (6.1 meters) to a depth of 10 feet (3.1 meters). Although the predicted above-ambient salinity contours for the maximum plume are shown to move onto Ship Shoal, the model is based on a nearly flat bottom, which cannot account for the bathymetry encounter at Ship Shoal. At Chacahoula, the brine plume movement is restricted by the increasing depth to the north (shoreward), west, and south (Ship Shoal). Flow along the bottom contours to the east is possible; however, the depth increases slightly in the easterly direction along Ship Shoal. The bottom bathymetry at the Chacahoula diffuser could lead to pooling of above-ambient salinity water near the bottom (approximately 2.0 feet (0.6 meters) thick), and inhibit dilution of brine. The bottom currents may not be strong enough to move the brine up the slopes shown on the chart.

C.5.4 Richton

The above-ambient salinity contours for +1 to +4 parts per thousand for the maximum plume case, which assumes a bottom-current velocity of 1.2 inches per second (3 centimeters per second) at the proposed Richton diffuser site, are shown in figure C.5.5-1. Figure C.5.5-2 shows the above-ambient plume contours for the typical case plume, which assumes an upshore and downshore direction bottom-current velocity of 3.5 inches per second (9 centimeters per second).

In the maximum case scenario, the model predicts the area inside the contours would be 19.5 square nautical miles (36 square kilometers) for the +1 parts per thousand contour, 11 square nautical miles (20.4 square kilometers) for the +2 contour, 5.7 square nautical miles (11 square kilometers) for the +3 parts per thousand, and 3.4 square nautical miles (6.3 square kilometers) for the +4 parts per thousand contour. The typical case scenario is predicted to have areas of 5.9, 3.2, 1.6, and 0.9 square nautical miles (11, 5.9, 3.0, and 1.7 square kilometers) respectively.

Figure C.5.4-1: Richton - Empirical Brine Plume Prediction for Maximum Case Conditions for North-Northeast Bottom Currents

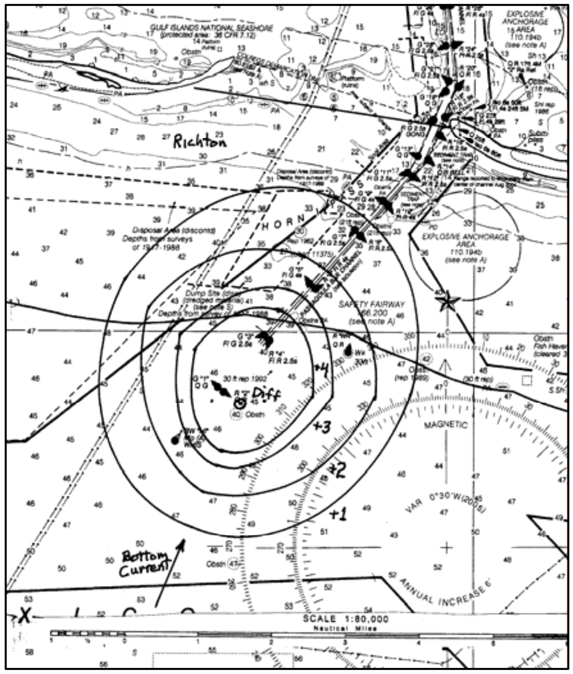
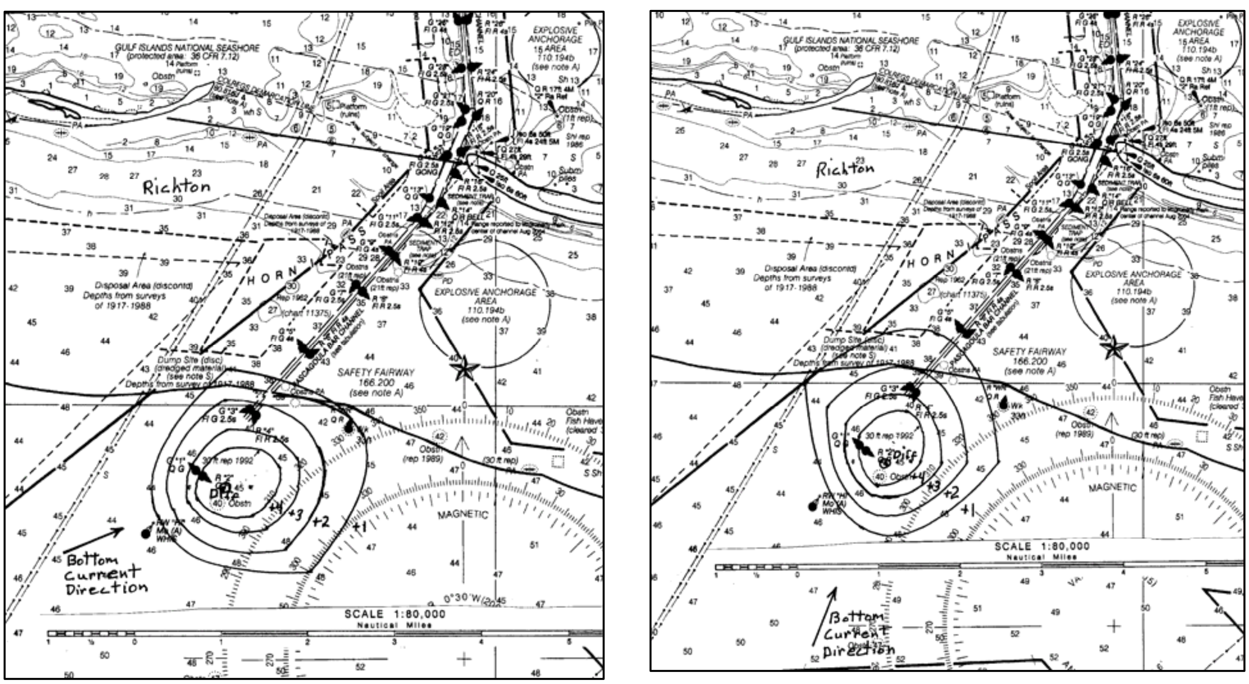


Figure C.5.4-2: Richton - Empirical Brine Plume Prediction for Typical Case Conditions



The diffuser location is approximately 1.0 nautical mile (1.9 kilometers) south of the entrance to the Pascagoula ship channel. The diffuser for this expansion site is parallel to the brine line and nearly perpendicular to the coastline. The maximum case plume, depicted in figure C.5.5-1, shows all of the above-ambient salinity contours located inside the ship channel. Figure C.5.5-2 shows the typical case contours of +1 and +2 parts per thousand entering the ship channel for two predominant bottom-current directions.

C.6 CONCLUSIONS

DOE used the empirical brine plume prediction model developed from the measured brine plume data from operating SPR brine diffuser sites to predict the plume characteristics for the SPR expansion diffuser sites at Big Hill, Stratton Ridge, Chacahoula, and Richton. The model was applied to five selected scenarios representing a range of expected environmental and disposal operational conditions. This report includes the results for typical and maximum case conditions.

Results show the maximum above-ambient salinity would be 4.3 parts per thousand and 4.7 parts per thousand for the typical and maximum case conditions. These above ambient salinity values are the same for all expansion sites because they all have the same brine salinity (263 parts per thousand) exit velocity of 30 feet (9.1 meters) per second, port diameter (3.0 inches [7.6 centimeters]), and ambient salinity and temperature profiles. The maximum vertical extent of the brine jets is approximately 19 and 18 feet (5.8 and 5.5 meters) for the typical and maximum case scenarios, respectively, and these are the same for all sites for the same reason described for the maximum above-ambient salinities. The maximum areal extent of the above-ambient contours is affected by the brine discharge rate, and the maximum areas occur for the Big Hill site, which has the largest brine discharge rate (1.3 maximum brine discharge rate). The Big Hill site appears to provide the best dilution and dispersion area for the brine discharge. The Stratton Ridge site plume predictions show portions of the brine plume entering the Freeport ship channel when the bottom current is downcoast, which is a common occurrence. The Chacahoula site shows the diffuser within 0.5 nautical miles (0.93 kilometers) of Ship Shoal. This bathymetry feature is not modeled by the empirical plume model, but it is expected that the brine plume dilution will be reduced due to shallower water depths to the south, west, and north of Ship Shoal. The proposed location of the Richton diffuser is approximately 1.0 nautical mile (1.9 kilometers) south of the entrance of the Pascagoula ship channel, and the model predicts the typical and maximum brine plumes would enter the ship channel.

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ATTACHMENT C-1: Model Predictions for Brine Discharge Scenarios for the Strategic Petroleum Reserve Expansion Sites

Table C-1-1: Predicted Characteristics of Typical and Large Scenario Brine Plume at Big Hill Expansion Diffuser Site

	Big Hill (typical)	Big Hill (Maximum)
Amb. Bottom Sal.(o/oo)	31.00	25.00
Amb. Bottom Temp.(oC)	22.00	15.00
Depth(ft.)	33.00	33.00
Amb. Bottom Cur.(m/s)	.09	.03
Amb. Top of Sal.(o/oo)	31.00	23.00
Brine Sal.(o/oo)	263.00	263.00
Brine Temp.(oC)	20.00	20.00
Num. open ports	57.00	57.00
Jet Exit Vel.(ft/s)	30.00	30.00
Port Dia(in)	3.00	3.00
Brine discharge rate(m3/s) =	2.4	2.4
Brine discharge rate(barrel/day x 10-6)=	1.3	1.3
Maximum above ambient bottom salinity (o/oo)=	4.3	4.7
Vertical extent(m) =	5.7	5.6
Vertical extent(ft) =	18.5	18.4

Plume Areal Extent	Typical (km2)	Typical (nm2)	Typical (acresx10e-3)	Maximum (km2)	Maximum (nm2)	Maximum (acresx10e-3)
+1o/oo contour	24.8	7.2	6.1	83.9	24.4	20.7
+2o/oo contour	13.6	3.9	3.4	47.6	13.9	11.8
+3o/oo contour	6.8	2.0	1.7	24.7	7.2	6.1
+4o/oo contour	4.0	1.2	1.0	14.8	4.3	3.7

Plume Width	Typical (km)	Typical (nm)	Maximum (km)	Maximum (nm)
+1o/oo contour	4.9	2.6	8.5	4.6
+2o/oo contour	3.7	2.0	6.7	3.6
+3o/oo contour	2.4	1.3	4.5	2.4
+4o/oo contour	1.7	.9	3.4	1.9

Plume Downstream Length	Typical (km)	Typical (nm)	Maximum (km)	Maximum (nm)
+1o/oo contour	3.5	1.9	6.3	3.4
+2o/oo contour	2.5	1.3	4.6	2.5
+3o/oo contour	1.8	1.0	3.4	1.9
+4o/oo contour	1.5	.8	2.9	1.5

Plume Upstream Length	Typical (km)	Typical (nm)	Maximum (km)	Maximum (nm)
+1o/oo contour	1.7	.9	3.7	2.0
+2o/oo contour	1.2	.7	2.6	1.4
+3o/oo contour	.9	.5	1.9	1.0
+4o/oo contour	.7	.4	1.4	.8

°C = degrees Celsius; ft = feet; m/s = meters/second; ft/s = feet/second; in = inches; m^3/s = cubic meters/second; m = meters; km = kilometer; km^2 = square kilometers; 0/00 = parts per thousand; nm = nautical miles; nm^2 = square nautical miles

Table C-1-2: Predicted Characteristics of Typical Scenario Brine Plume at Stratton Ridge Expansion Diffuser Site

Strattom Ridge (typical)		Strattom Ridge (Maximum)	
Amb. Bottom Sal.(o/oo)	31.00	Amb. Bottom Sal.(o/oo)	25.00
Amb. Bottom Temp.(oC)	22.00	Amb. Bottom Temp.(oC)	15.00
Depth(ft.)	30.00	Depth(ft.)	30.00
Amb. Bottom Cur.(m/s)	.09	Amb. Bottom Cur.(m/s)	.03
Amb. Top of Sal.(o/oo)	31.00	Amb. Top of Sal.(o/oo)	25.00
Brine Sal.(o/oo)	263.00	Brine Sal.(o/oo)	263.00
Brine Temp.(oC)	20.00	Brine Temp.(oC)	20.00
Num. open ports	53.00	Num. open ports	53.00
Jet Exit Vel.(ft/s)	30.00	Jet Exit Vel.(ft/s)	30.00
Port Dia(in)	3.00	Port Dia(in)	3.00
Brine discharge rate(m3/s) =	2.2	Brine discharge rate(m3/s) =	2.2
Brine discharge rate(barrel/day x 10-6)=	1.2	Brine discharge rate(barrel/day x 10-6)=	1.2
Maximum above ambient bottom salinity (o/oo)=	4.3	Maximum above ambient bottom salinity (o/oo)=	4.7
Vertical extent(m) =	5.7	Vertical extent(m) =	5.6
Vertical extent(ft) =	18.5	Vertical extent(ft) =	18.4

Plume Areal Extent	(km2)	(nm2)	(acresx10e-3}	Plume Areal Extent	(km2)	(nm2)	(acresx10e-3}
+1o/oo contour	23.2	6.8	5.7	+1o/oo contour	78.3	22.8	19.3
+2o/oo contour	12.7	3.7	3.1	+2o/oo contour	44.4	12.9	11.0
+3o/oo contour	6.3	1.8	1.6	+3o/oo contour	23.0	6.7	5.7
+4o/oo contour	3.7	1.1	.9	+4o/oo contour	13.8	4.0	3.4

Plume Width	(km)	(nm)	Plume Width	(km)	(nm)
+1o/oo contour	4.8	2.6	+1o/oo contour	8.2	4.4
+2o/oo contour	3.6	1.9	+2o/oo contour	6.5	3.5
+3o/oo contour	2.4	1.3	+3o/oo contour	4.3	2.3
+4o/oo contour	1.6	.9	+4o/oo contour	3.3	1.8

Plume Downstream Length	(km)	(nm)	Plume Downstream Length	(km)	(nm)
+1o/oo contour	3.4	1.8	+1o/oo contour	6.2	3.3
+2o/oo contour	2.4	1.3	+2o/oo contour	4.4	2.4
+3o/oo contour	1.8	1.0	+3o/oo contour	3.3	1.8
+4o/oo contour	1.5	.8	+4o/oo contour	2.8	1.5

Plume Upstream Length	(km)	(nm)	Plume Upstream Length	(km)	(nm)
+1o/oo contour	1.7	.9	+1o/oo contour	3.6	1.9
+2o/oo contour	1.2	.6	+2o/oo contour	2.5	1.4
+3o/oo contour	.9	.5	+3o/oo contour	1.9	1.0
+4o/oo contour	.6	.3	+4o/oo contour	1.4	.7

°C = degrees Celsius; ft = feet; m/s = meters/second; ft/s = feet/second; in = inches; m^3/s = cubic meters/second; m = meters; km = kilometer; km^2 = square kilometers; 0/00 = parts per thousand; nm = nautical miles; nm^2 = square nautical miles

Table C-1-3: Predicted Characteristics of Typical and Large Case Scenarios of Brine Plume Contours at Chacahoula Expansion Diffuser Site

Chacahoula (typical)

Amb. Bottom Sal.(o/oo)	31.00
Amb. Bottom Temp.(oC)	22.00
Depth(ft.)	30.00
Amb. Bottom Cur.(m/s)	.09
Amb. Top of Sal.(o/oo)	31.00
Brine Sal.(o/oo)	263.00
Brine Temp.(oC)	20.00
Num. open ports	45.00
Jet Exit Vel.(ft/s)	30.00
Port Dia(in)	3.00
Brine discharge rate(m3/s) =	1.9
Brine discharge rate(barrel/day x 10-6)=	1.0
Maximum above ambient bottom salinity (o/oo)=	4.3
Vertical extent(m) =	5.7
Vertical extent(ft) =	18.5

Plume Areal Extent	(km2)	(nm2)	(acresx10e-3)
+1o/oo contour	20.2	5.9	5.0
+2o/oo contour	10.9	3.2	2.7
+3o/oo contour	5.4	1.6	1.3
+4o/oo contour	3.1	.9	.8

Plume Width	(km)	(nm)
+1o/oo contour	4.6	2.5
+2o/oo contour	3.4	1.8
+3o/oo contour	2.2	1.2
+4o/oo contour	1.5	.8

Plume Downstream Length	(km)	(nm)
+1o/oo contour	3.2	1.7
+2o/oo contour	2.3	1.2
+3o/oo contour	1.7	.9
+4o/oo contour	1.4	.7

Plume Upstream Length	(km)	(nm)
+1o/oo contour	1.5	.8
+2o/oo contour	1.1	.6
+3o/oo contour	.8	.4
+4o/oo contour	.6	.3

Chacahoula

Amb. Bottom Sal.(o/oo)	25.00
Amb. Bottom Temp.(oC)	15.00
Depth(ft.)	30.00
Amb. Bottom Cur.(m/s)	.03
Amb. Top of Sal.(o/oo)	25.00
Brine Sal.(o/oo)	263.00
Brine Temp.(oC)	20.00
Num. open ports	45.00
Jet Exit Vel.(ft/s)	30.00
Port Dia(in)	3.00
Brine discharge rate(m3/s) =	1.9
Brine discharge rate(barrel/day x 10-6)=	1.0
Maximum above ambient bottom salinity (o/oo)=	4.7
Vertical extent(m) =	5.6
Vertical extent(ft) =	18.4

Plume Areal Extent	(km2)	(nm2)	(acresx10e-3)
+1o/oo contour	66.9	19.5	16.5
+2o/oo contour	37.8	11.0	9.3
+3o/oo contour	19.6	5.7	4.8
+4o/oo contour	11.7	3.4	2.9

Plume Width	(km)	(nm)
+1o/oo contour	7.7	4.2
+2o/oo contour	6.0	3.3
+3o/oo contour	4.0	2.2
+4o/oo contour	3.1	1.7

Plume Downstream Length	(km)	(nm)
+1o/oo contour	5.8	3.1
+2o/oo contour	4.1	2.2
+3o/oo contour	3.1	1.7
+4o/oo contour	2.6	1.4

Plume Upstream Length	(km)	(nm)
+1o/oo contour	3.3	1.8
+2o/oo contour	2.3	1.3
+3o/oo contour	1.7	.9
+4o/oo contour	1.3	.7

°C = degrees Celsius; ft = feet; m/s = meters/second; ft/s = feet/second; in = inches; m^3/s = cubic meters/second; m = meters; km = kilometer; km^2 = square kilometers; 0/00 = parts per thousand; nm = nautical miles; nm^2 = square nautical miles

Table C-1-4: Predicted Characteristics of Typical Scenario Brine Plume Contours at Richton Expansion Diffuser Site

```
Richton Dome (typical)
Amb. Bottom Sal.(o/oo)      31.00
Amb. Bottom Temp.(oC)       22.00
Depth(ft.)                  47.00
Amb. Bottom Cur.(m/s)         .09
Amb. Top of Sal.(o/oo)      31.00
Brine Sal.(o/oo)           263.00
Brine Temp.(oC)             20.00
Num. open ports             45.00
Jet Exit Vel.(ft/s)         30.00
Port Dia(in)                 3.00
Brine discharge rate(m3/s) =        1.9
Brine discharge rate(barrel/day x 10-6)=    1.0
Maximum above ambient bottom salinity (o/oo)=        4.3
Vertical extent(m) =             5.7
Vertical extent(ft) =            18.5
```

Plume Areal Extent	(km2)	(nm2)	(acresx10e-3}
+1o/oo contour	20.2	5.9	5.0
+2o/oo contour	10.9	3.2	2.7
+3o/oo contour	5.4	1.6	1.3
+4o/oo contour	3.1	.9	.8

Plume Width	(km)	(nm)
+1o/oo contour	4.6	2.5
+2o/oo contour	3.4	1.8
+3o/oo contour	2.2	1.2
+4o/oo contour	1.5	.8

Plume Downstream Length	(km)	(nm)
+1o/oo contour	3.2	1.7
+2o/oo contour	2.3	1.2
+3o/oo contour	1.7	.9
+4o/oo contour	1.4	.7

Plume Upstream Length	(km)	(nm)
+1o/oo contour	1.5	.8
+2o/oo contour	1.1	.6
+3o/oo contour	.8	.4
+4o/oo contour	.6	.3

```
Richton Dome
Amb. Bottom Sal.(o/oo)      25.00
Amb. Bottom Temp.(oC)       15.00
Depth(ft.)                  47.00
Amb. Bottom Cur.(m/s)         .03
Amb. Top of Sal.(o/oo)      25.00
Brine Sal.(o/oo)           263.00
Brine Temp.(oC)             20.00
Num. open ports             45.00
Jet Exit Vel.(ft/s)         30.00
Port Dia(in)                 3.00
Brine discharge rate(m3/s) =        1.9
Brine discharge rate(barrel/day x 10-6)=    1.0
Maximum above ambient bottom salinity (o/oo)=        4.7
Vertical extent(m) =             5.6
Vertical extent(ft) =            18.4
```

Plume Areal Extent	(km2)	(nm2)	(acresx10e-3}
+1o/oo contour	66.9	19.5	16.5
+2o/oo contour	37.8	11.0	9.3
+3o/oo contour	19.6	5.7	4.8
+4o/oo contour	11.7	3.4	2.9

Plume Width	(km)	(nm)
+1o/oo contour	7.7	4.2
+2o/oo contour	6.0	3.3
+3o/oo contour	4.0	2.2
+4o/oo contour	3.1	1.7

Plume Downstream Length	(km)	(nm)
+1o/oo contour	5.8	3.1
+2o/oo contour	4.1	2.2
+3o/oo contour	3.1	1.7
+4o/oo contour	2.6	1.4

Plume Upstream Length	(km)	(nm)
+1o/oo contour	3.3	1.8
+2o/oo contour	2.3	1.3
+3o/oo contour	1.7	.9
+4o/oo contour	1.3	.7

°C = degrees Celsius; ft = feet; m/s = meters/second; ft/s = feet/second; in = inches; m^3/s = cubic meters/second; m = meters; km = kilometer; km^2 = square kilometers; 0/00 = parts per thousand; nm = nautical miles; nm^2 = square nautical miles