Final Environmental Impact Statement

(Final Statement to FEA-DES-77-8)

STRATEGIC PETROLEUM RESERVE

Texoma Group Salt Domes

(West Hackberry Expansion, Black Bayou, Vinton, Big Hill)

Cameron and Calcasieu Parishes, Louisiana and Jefferson County, Texas

U.S. DEPARTMENT OF ENERGY

November 1978
Volume 4 of 5
Appendices D–T

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Responsible Official

Ruth C. Clusen

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Assistant Secretary for Environment

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Appendices D–T

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APPENDIX D

PRECIPATION DATA, WATER, SEDIMENT, AND ELUTRIATE QUALITY DATA, WATER, SEDIMENT, AND ELUTRIATE STANDARDS AND CRITERIA, HYDROLOGIC DATA, WATER UTILIZATION DATA, SUBSURFACE WATER DATA, WATER WITHDRAWAL MODELS, SEDIMENT TRANSPORT CALCULATIONS, AQUIFER PRESSURE CALCULATIONS, AND THE BRINE INJECTION ANALYSES FOR THE TEXOMA REGION

APPENDIX D.1

PRECIPITATION DATA FOR AREAS INCLUDED IN THE TEXOMA CLUSTER

This appendix contains four figures and one table concerning precipitation in the areas of Texas and Louisiana in which primary and secondary sites would be located. Figure D.1-1 presents the distribution of average winter-spring precipitation in southern Louisiana based on monthly water balances for the 24-year period from 1945 to 1968. The corresponding summer-autumn precipitation surplus is given in Figure D.1-2. The average seasonal precipitation deficits for the same area are provided in Figure D.1-3. The recorded average monthly precipitation at Lake Charles, Louisiana is presented in Table D.1-1. Precipitation data for the area of interest in Texas is presented in Figure D.1-4.

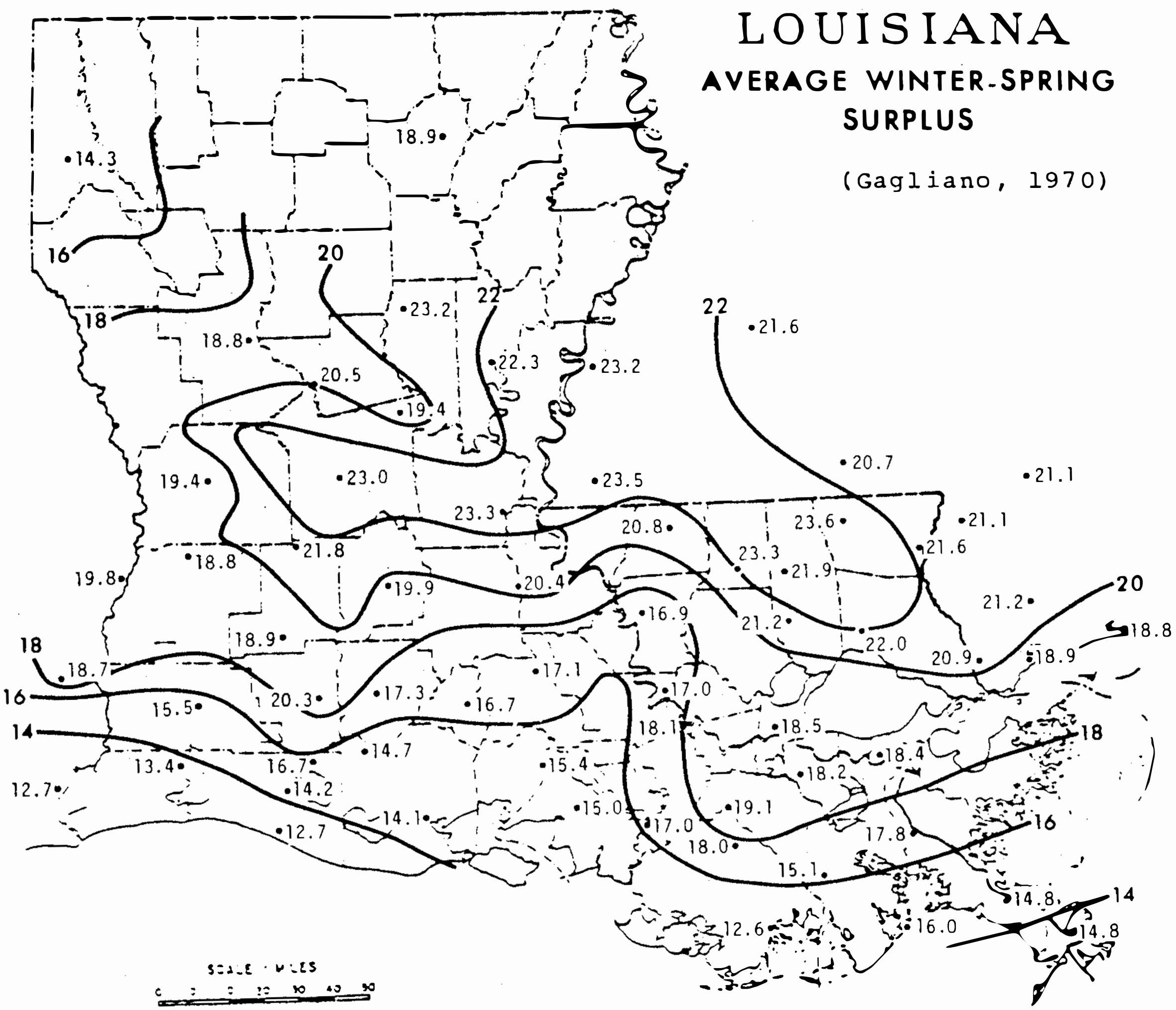

Figure D.1-1. Distribution of average winter-spring precipitation surplus in southern Louisiana. Station averages were determined from monthly water balances for the 24-year period between 1945 and 1968. Surplus values are given in inches.

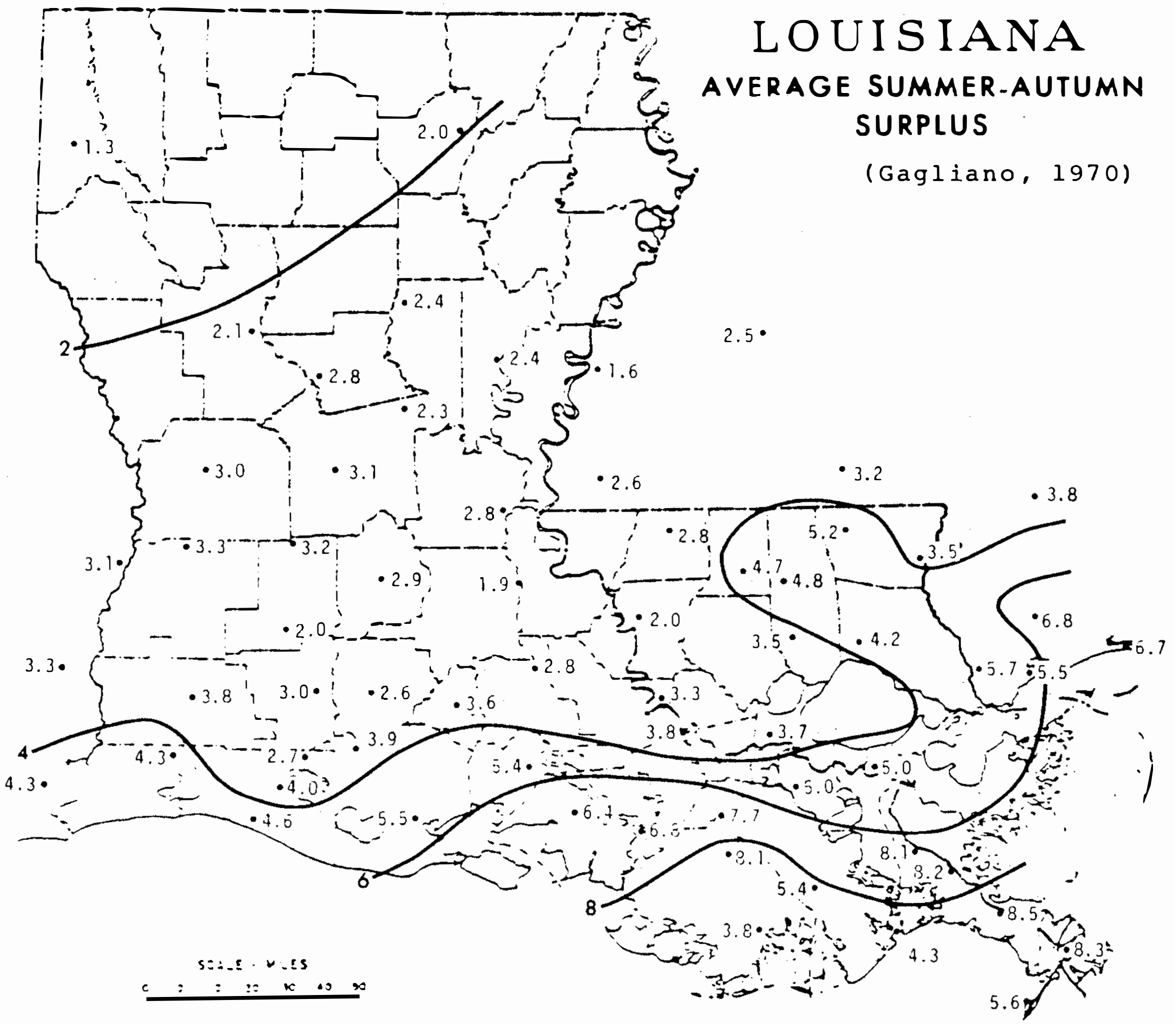

Figure D.1-2. Distribution of average summer-autumn precipitation surplus in south and central Louisiana. Station averages were determined from monthly water balances for the 24-year period between 1945 and 1968. Surplus values are given in inches.

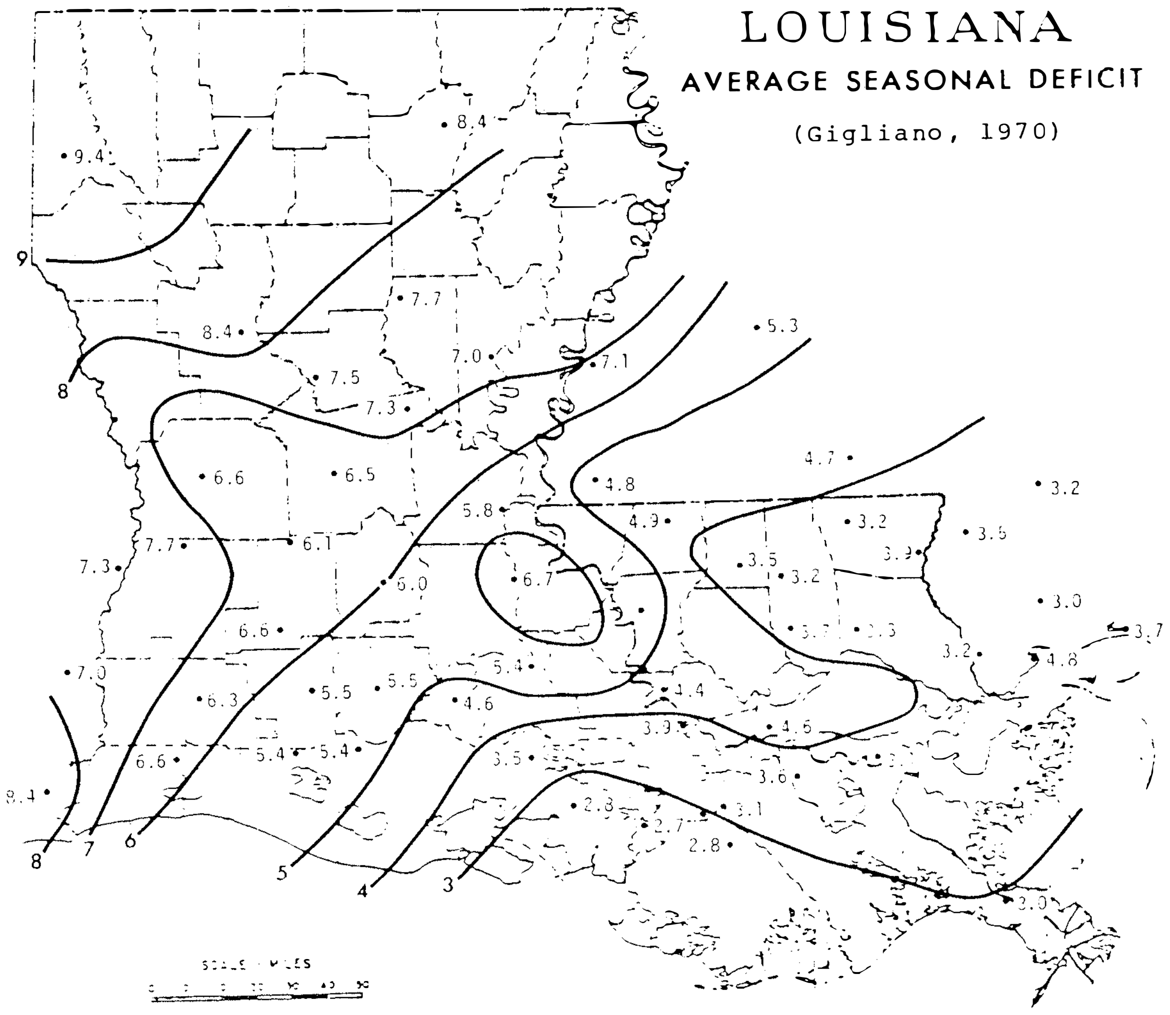

Figure D.1-3. Average seasonal precipitation deficits in south and central Louisiana. Station averages were determined from monthly water balances for the 24-year period between 1945 and 1968. Deficit values are given in inches.

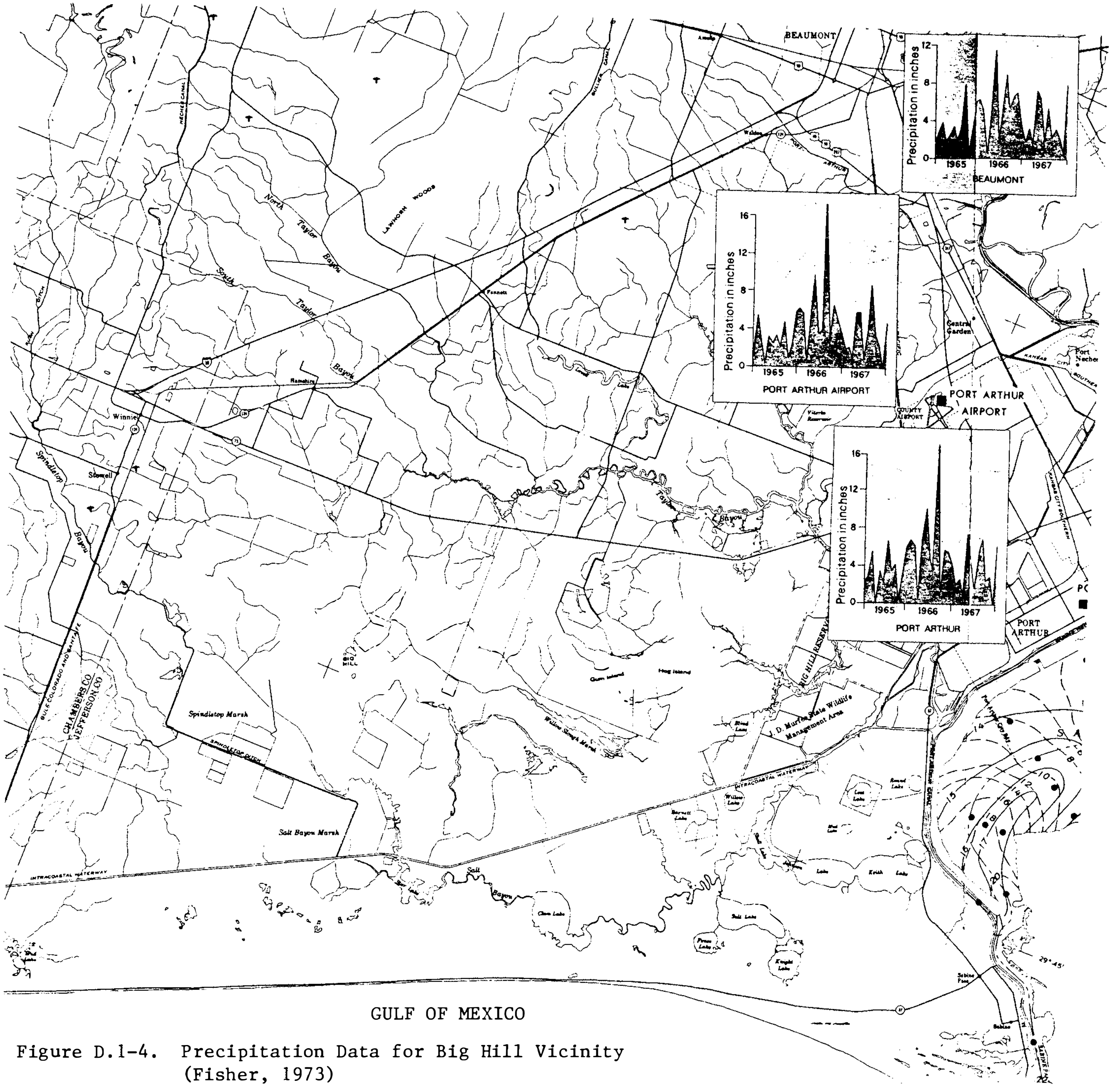

Figure D.1-4. Precipitation Data for Big Hill Vicinity (Fisher, 1973)

Table D.1-1. Recorded Average Monthly Precipitation at Lake Charles, Louisiana Meteorological Station. Latitude N30°07'; Longitude W93°12'.

(U.S. Dept. Commerce, 1974)

(in inches)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1934	6.62	7.04	9.21	3.62	3.19	0.45	8.31	3.29	6.44	2.47	7.84	2.67	61.35
1935	2.37	3.44	6.84	3.29	4.48	8.87	6.72	5.69	2.87	1.44	4.60	7.85	58.46
1936	3.09	3.93	1.27	1.77	4.65	0.02	6.24	6.46	4.73	1.96	3.99	4.68	42.79
1937	8.06	1.43	3.76	1.16	1.57	4.11	2.73	6.38	4.03	5.60	1.66	2.22	42.71
1938	6.47	1.78	2.89	5.95	2.78	3.99	5.32	4.37	3.98	2.11	3.08	2.49	45.21
1939	3.75	2.82	1.61	1.56	1.75	2.03	6.68	2.25	3.34	1.41	1.93	2.53	31.66
1940	1.71	4.57	1.89	15.30	0.85	8.22	4.97	14.56	2.44	1.54	8.54	8.24	72.83
1941	3.34	2.69	3.99	1.92	12.24	5.57	9.56	3.52	8.09	5.97	1.92	11.68	70.49
1942	1.14	3.70	5.30	5.30	4.51	10.93	8.66	6.98	4.02	3.00	0.76	6.67	60.97
1943	4.79	7.72	8.74	1.73	2.71	5.19	9.99	1.95	11.83	1.03	6.38	6.95	69.01
1944	8.37	2.30	4.61	5.89	6.99	0.68	1.92	6.58	5.17	4.75	9.97	4.83	62.06
1945	2.61	3.98	4.10	3.21	4.93	5.01	12.72	5.85	3.67	5.11	2.80	7.54	61.51
1946	9.44	3.64	4.99	2.62	14.28	5.12	7.20	2.68	6.63	4.98	5.97	2.26	69.81
1947	6.07	3.27	6.65	4.32	6.17	17.90	2.82	4.53	1.19	0.63	5.06	6.45	65.06
1948	6.07	4.97	2.86	3.04	2.48	1.68	1.18	4.52	3.71	0.93	5.99	2.52	39.95
1949	3.62	8.03	9.67	4.98	1.94	8.38	9.21	2.09	3.64	11.15	0.88	5.77	69.36
1950	3.17	5.22	4.84	3.59	7.53	12.87	5.98	2.73	5.45	2.35	1.45	4.19	59.37
1951	7.28	2.18	7.75	1.18	0.87	1.61	1.94	1.00	4.63	0.65	2.21	6.08	37.38
1952	2.32	7.96	3.56	9.75	6.48	3.28	17.83	1.36	1.77	T	4.90	8.79	68.01
1953	1.95	5.03	1.03	6.33	11.13	1.18	11.73	3.25	0.65	2.66	4.82	5.74	55.50
1954	2.26	0.44	2.37	1.65	4.05	1.78	3.65	2.43	0.70	3.62	4.25	2.88	30.08
1955	5.74	7.35	0.12	6.43	3.42	4.85	6.57	8.81	1.57	2.49	4.09	3.89	55.33
1956	2.94	4.56	4.68	1.27	5.25	1.94	0.48	3.77	0.07	1.69	2.29	10.43	39.37
1957	0.96	2.13	7.08	13.71	1.59	11.46	2.92	2.35	6.35	5.21	10.35	4.05	68.16
1958	3.51	3.87	4.01	4.94	4.57	3.58	9.02	9.41	10.04	1.45	1.57	3.22	59.19
1959	4.89	10.67	1.97	4.16	5.85	3.49	17.94	4.72	1.21	4.62	2.98	5.55	68.05
1960	3.79	4.35	0.84	5.92	0.42	1.44	5.05	6.25	2.58	5.17	4.32	7.83	27.96
1961	4.39	7.75	2.58	3.47	4.11	5.31	8.43	4.04	3.48	1.92	14.09	4.03	63.60
1962	4.01	0.80	1.39	3.11	1.73	5.33	0.48	17.36	1.01	2.70	4.40	4.01	46.33
1963	5.07	4.13	0.55	0.64	0.57	4.60	5.28	1.87	8.78	T	4.70	3.36	39.55
1964	5.49	3.05	4.02	1.84	2.12	5.87	4.86	5.58	6.14	0.30	2.06	5.84	47.17
1965	2.49	3.86	3.34	0.96	4.05	1.49	1.85	6.79	3.43	0.32	1.22	5.00	34.80
1966	6.48	6.17	0.75	8.59	6.30	5.10	4.90	6.63	3.54	2.96	4.45	3.78	59.65
1967	1.70	2.26	1.05	5.63	8.59	1.64	5.47	6.21	4.21	4.57	0.11	13.27	54.71
1968	3.89	2.68	2.76	2.39	3.16	8.90	7.82	3.59	3.11	2.38	5.83	4.73	51.24
1969	1.13	6.75	4.27	9.53	6.65	0.84	10.06	1.97	3.23	4.42	0.70	5.57	55.12
1970	2.16	2.68	5.25	1.81	7.11	4.28	0.97	3.56	4.13	17.28	1.78	4.10	55.20
1971	0.78	3.45	0.27	0.93	5.78	2.23	4.45	6.31	5.38	2.64	1.64	9.90	43.76
1972	7.73	2.24	2.23	1.58	4.53	0.93	7.75	6.64	5.82	6.44	4.30	5.47	55.66
1973	4.14	2.94	7.40	10.95	7.48	3.86	2.96	3.29	19.96	4.12	3.01	4.80	75.03
RECORD MEAN	3.95	4.29	3.68	4.58	4.92	4.82	6.38	5.01	4.59	3.44	3.99	5.71	55.36

APPENDIX D.2

STATE WATER QUALITY STANDARDS

This appendix contains two tables taken from the Louisiana and Texas State Water Quality Standards. These standards are legal codes (Vernons Texas Code Annotated, Water Code, Section 21.002 and Louisiana Revised Statutes, Title 56:1439), as opposed to existing criteria which have no regulatory authority.

Footnote: Although Louisiana uses the word "criteria" in its water quality document, the word is used in such a context that "standard" is the actual meaning. (EPA, 1976)

Table D.2-1. Louisiana Water Quality Standards (Louisiana Stream Control Commission, 1973)

SABINE BASIN

SEGMENT AGENCY I.D. NUMBER	SEGMENT DESCRIPTION	WATER USES: PRIMARY CONTACT RECREATION	WATER USES: SECONDARY CONTACT RECREATION	WATER USES: PROPAGATION OF FISH AND WILDLIFE	WATER USES: DOMESTIC RAW WATER SUPPLY	CRITERIA: CHLORIDE (mg/l) Not to exceed	CRITERIA: SULPHATE (mg/l) Not to exceed	CRITERIA: DISSOLVED OXYGEN (mg/l) Not less than	CRITERIA: pH RANGE	CRITERIA: Bacteria Standard	CRITERIA: TEMPERATURE °C	CRITERIA: TOTAL DISSOLVED SOLIDS (mg/l) Not to exceed
100080	Sabine Lake (Tidal)	X	X	X		--	--	4.0	6.0 to 8.5	4	35*	--
100081	Sabine Pass (Tidal)	X	X	X		--	--	5.0	6.5 to 9.0	4	35*	--
100090	Black Bayou - Intracoastal Waterway to Sabine Lake (Tidal)		X	X		--	--	4.0	6.0 to 8.5	2	35*	--
100100	Vinton Waterway - Vinton to Intracoastal Waterway (Tidal)		X	X		--	--	4.0	6.0 to 8.5	2	35*	--

CALCASIEU BASIN

SEGMENT AGENCY I.D. NUMBER	SEGMENT DESCRIPTION	PRIMARY CONTACT RECREATION	SECONDARY CONTACT RECREATION	PROPAGATION OF FISH AND WILDLIFE	DOMESTIC RAW WATER SUPPLY	CHLORIDE (mg/l) Not to exceed	SULPHATE (mg/l) Not to exceed	DISSOLVED OXYGEN (mg/l) Not less than	pH RANGE	Bacteria Standard	TEMPERATURE °C	TOTAL DISSOLVED SOLIDS (mg/l) Not to exceed
030150	Calcasieu River - Moss Lake to the Gulf of Mexico (Tidal)	X	X	X		--	--	4.0	6.0 to 8.5	4	35*	--
030160	Intracoastal Waterway (East - West) - Sabine River to Calcasieu Lock (Tidal)		X	X		--	--	4.0	6.0 to 8.5	2	35*	--
030170	Black Lake (Tidal'		X	X		--	--	4.0	6.0 to 8.5	2	35*	--

Table D.2-2. TEXAS WATER QUALITY STANDARDS - FRESH AND TIDAL WATERS

(Texas Water Quality Board, 1976)

NECHES RIVER BASIN

NECHES-TRINITY COASTAL BASIN

SABINE RIVER BASIN

SEGMENT		WATER USES DEEMED DESIRABLE				CRITERIA					COLIFORM	
NUMBER	DESCRIPTION	CONTACT RECREATION	NONCONTACT RECREATION	PROPAGATION OF FISH & WILDLIFE	DOMESTIC RAW WATER SUPPLY	CHLORIDE (mg/1) avg. not to exceed	SULFATE (mg/1) avg. not to exceed	TOTAL DISSOLVED SOLIDS (mg/1) avg. not to exceed	DISSOLVED OXYGEN (mg/1) not less than	pH RANGE	FECAL/ (100ml) - log. avg. not more than (see Gen. Statement)	TEMPERATURE °F (see Gen. Statement)
0601	Neches River Tidal		X	X					2.5*	6.0-8.5	2,000	95
0701	Taylor Bayou - above tidal	X	X	X		100	75	600	5.0	6.5-8.5	200	95
0702	Intracoastal Waterway - Port Bolivar to Sabine-Neches Canal		X	X					4.0	6.5-8.5	2,000	95
0501	Sabine River Tidal	X	X	X					4.0	6.0-8.5	200	95

SABINE-NECHES ESTUARY

● BAY & GULF WATERS

SEGMENT							COLIFORM	TEMP.
NUMBER	DESCRIPTION	CONTACT RECREATION	NONCONTACT RECREATION	PROPAGATION OF FISH & WILDLIFE	DISSOLVED OXYGEN (mg/1) not less than	pH RANGE	TOTAL/ (100 ml) - median not more than (see Gen. Statement)	FALL, WINTER & SPRING not to exceed 4°F rise SUMMER not to exceed a 1.5°F rise
2411	Sabine Pass - U. S. Coast Guard Station to end of jetties	X	X	X	5.0	7.0-9.0	70	95
2412	Sabine Lake	X	X	X	4.0	6.5-9.0	70	95

APPENDIX D.3

WATER AND SEDIMENT QUALITY CRITERIA

This appendix contains both the Environmental Protection Agency 1976 criteria in summary form and unofficial criteria for sediment quality. Table D.3-1 presents a summary form of the EPA criteria. Table D.3-2 contains the unofficial criteria used to evaluate sediment quality. Table D.3-3* consists of guidelines used in assessment of existing water quality. These guidelines are applied to the evaluation of presently available water quality information.

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*It should be noted that the EPA criteria do not represent legal entities as defined by state or federal authority. They do however "represent a concentration or level associated with a degree of environmental effect upon which scientific judgement may be based." (EPA, 1976)

These EPA criteria are in response to the Federal Water Pollution Control Act Amendments of 1972 and will be updated as compliance with that law requires.

Table D.3-1. Summary Table for Water Quality Criteria

(EPA, 1976)

PARAMETERS	CRITERIA		
	Domestic Water Supply	Freshwater Aquatic Life	Marine Aquatic Life
Ammonia	-	20 μg/l (un-ionized)	-
Alkalinity	-	$\geq$20 mg/l as $CaCO_3$ (except where normally less)	
Arsenic	50 g/l		
Beryllium	-	11 μg/l	-
Barium	1000 μg/l	-	-
Cadmium	10 μg/l	0.4 μg/l	5 μg/l
Chlorine	-	2.0 μg/l	2 μg/l
Chromium	50 μg/l	100 μg/l	100 μg/l
Copper	1000 μg/l	0.1 x 96h LC 50	0.1 x 96h LC 50
Cyanide	-	5 μg/l	5.0 μg/l
Gases (Total Dissolved)	-	<110 percent of saturation at STP	<110 percent of saturation at STP
Iron	300 μg/l	1.0 mg/l	-
Lead	50 μg/l	0.1 x 96h LC 50	0.1 x 96h LC 50
Manganese	50 μg/l	-	-
Mercury	2 μg/l	0.05 μg/l	0.10 μg/l
Nickel	-	0.01 x 96h LC 50	0.01 x 96h LC 50
Nitrates/Nitrites	10,000 μg/l	-	-
Oil & Grease	-	0.01 x lowest 96 h LC 50 (cont. flow)	0.01 x lowest cont. flow 96 h LC 50
Oxygen,Dissolved	-	5.0 g/l	-
pH	5-9	6.5 - 9	6.5 - 8.5

Table D.3-1. Summary Table for Water Quality Criteria (Continued)

	Domestic Water Supply	Freshwater Aquatic Life	Marine Aquatic Life
Phenol	1 μg/l	1 μg/l	1 μg/l
Phosphorus	-	0.10 μg/l	0.10 μg/l
PCB's	-	0.001 μg/l	0.001 μg/l
Phthalate Esters	-	3 μg/l	-
Selenium	10 μg/l	-	0.01 x 96h LC 50
Silver	50 μg/l	0.01 x 96h LC 50	0.01 x 96h LC 50
Sulfides - H_2S	-	2 μg/l (undis-(sociated H_2S)	2 μg/l (undis H_2S)
Solids (Dissolved) & Salinity	250 mg/l	-	-
Aldrin	1 μg/l	0.003 μg/l	0.003 μg/l
Chlordane	(any level is suspect)	0.01 μg/l	0.004 μg/l
Dieldrin	1 μg/l	0.003 μg/l	0.003 μg/l
Zinc	5,000 μg/l	0.01 x 96 h LC 50	-
Chlorophenoxy			
Herbicides:			
2, 4-D	100 μg/l	-	-
2,4,5-TP	10 μg/l	-	-
DDT	(any level is suspect)	0.001 μg/l	0.001 μg/l
Demeton	-	0.1 μg/l	0.1 μg/l
Endosulfan	-	0.003 μg/l	0.001 μg/l
Endrin	0.2 μg/l	0.004 μg/l	0.004 μg/l
Guthion	-	0.01 μg/l	0.01 μg/l
Heptachlor	-	0.001 μg/l	0.001 μg/l

Table D.3-1. Summary Table for Water Quality Criteria (Concluded)

	Domestic Water Supply	Fresh Aquatic Life	Marine Aquatic Life
Lindane	4.0 μg/l	0.01 μg/l	0.004 μg/l
Mathation	0.1 μg/l	0.1 μg/l	0.1 μg/l
Methoxyclor	100 μg/l	0.03 μg/l	0.03 μg/l
Mirex	-	0.001 μg/l	0.001 μg/l
Parathion	-	0.04 μg/l	0.04 μg/l
Toxaphene	5 μg/l	0.005 μg/l	0.005 μg/l

Table D.3-2. Recommended Concentration Limits of Selected Sediment Parameters

	Units (dry weight basis)	Non-Polluted		Polluted	
		mean	range	mean	range
COD[a]	mg/kg	21,000	2,000-48,000	177,000	39,000-395,000
TKN[a]	mg/kg	550	10-1,310	2,640	580-6,800
grease - oil[a]	mg/kg	560	110-1,310	7,150	1,380-32,100
sulfide[a]	mg/kg			50,000	
TKN[b]	mg/kg			1,000	
grease - oil[b]	mg/kg			1,500	
mercury[b]	mg/kg			1	
lead[b]	mg/kg			50	
zinc[b]	mg/kg			50	

a) (O'Neal G. and J. Scerva, 1971)

b) (Slotta, L. S. and K. J. Williamson, 1974)

Table D.3-3. Guidelines Used in the Detection of Water Quality Problems

Superscript	Definition of Superscript
a	Violates state water quality standards.
b	Exceeds 1976 EPA drinking water criteria.
c	Exceeds 1976 EPA criteria for freshwater aquatic life.
d	Exceeds 1976 EPA criteria for marine life.
e	Either (1) appears excessive, but no precise numerical criteria exist (LC criteria only) or (2) exceeds formerly existing criteria not updated in 1976 EPA criteria.
f	No known criteria exist at this time.
g	Exceeds unofficial criteria.

These superscripts appear often in tabulated water quality data sheets. They indicate possible problem areas in water quality.

APPENDIX D.4

CALCASIEU RIVER, CALCASIEU LAKE
AND
CALCASIEU SHIP CHANNEL HYDROLOGIC DATA

This appendix contains one figure and 25 tables. The figure is a map of the area with sampling stations. Tables are listed below. Tables one through four contain flow data, the remaining tables are water quality data.

Table D.4-1 Average Discharge Rates, Calcasieu River. Water Years 1974, 1975 and 1976.
Table D.4-2 Monthly Calcasieu River Flows near Kinder, Louisiana. Water Years 1975 and 1976.
Table D.4-3 Daily Water Flows Calcasieu River near Kinder Louisiana. Water Year 1976. (2 pages)
Table D.4-4 Monthly Stream Flow in Acre-Feet, Calcasieu River Basin, 1976.
Table D.4-5 Calcasieu River Mile 19.0
Table D.4-6 Calcasieu River Mile 17.7
Table D.4-7 Calcasieu River Mile 17.6
Table D.4-8 Calcasieu River Mile 17.5
Table D.4-9 Calcasieu River Mile 16.5
Table D.4-10 Calcasieu River Mile 15.0
Table D.4-11 Calcasieu River Mile 14.5
Table D.4-12 Calcasieu River Mile 13.4
Table D.4-13 Calcasieu River Mile 13.0
Table D.4-14 Calcasieu River Mile 12.6
Table D.4-15 Calcasieu River Mile 12.1
Table D.4-16 Calcasieu River Mile 11.5
Table D.4-17 Calcasieu River Mile 11.3

Table D.4-18 Calcasieu River Mile 10.0
Table D.4-19 Calcasieu River at Rabbit Island
Table D.4-20 Calcasieu River Mile 1.0
Table D.4-21 Water Quality for Stations 8, 9, 10 and 11, Calcasieu Ship Channel
Table D.4-22 Sediment Quality for Stations 8, 9, 10 and 11, Calcasieu Ship Channel
Table D.4-23 Elutriate Data, Stations8, 9, 10, 11 Calcasieu Ship Channel
Table D.4-24 Water, Elutriate and Sediment Data for Station 7, Calcasieu River at Hackberry
Table D.4-25 Water, Elutriate and Sediment Data for Station 8A, Calcasieu River at Mile 15.0

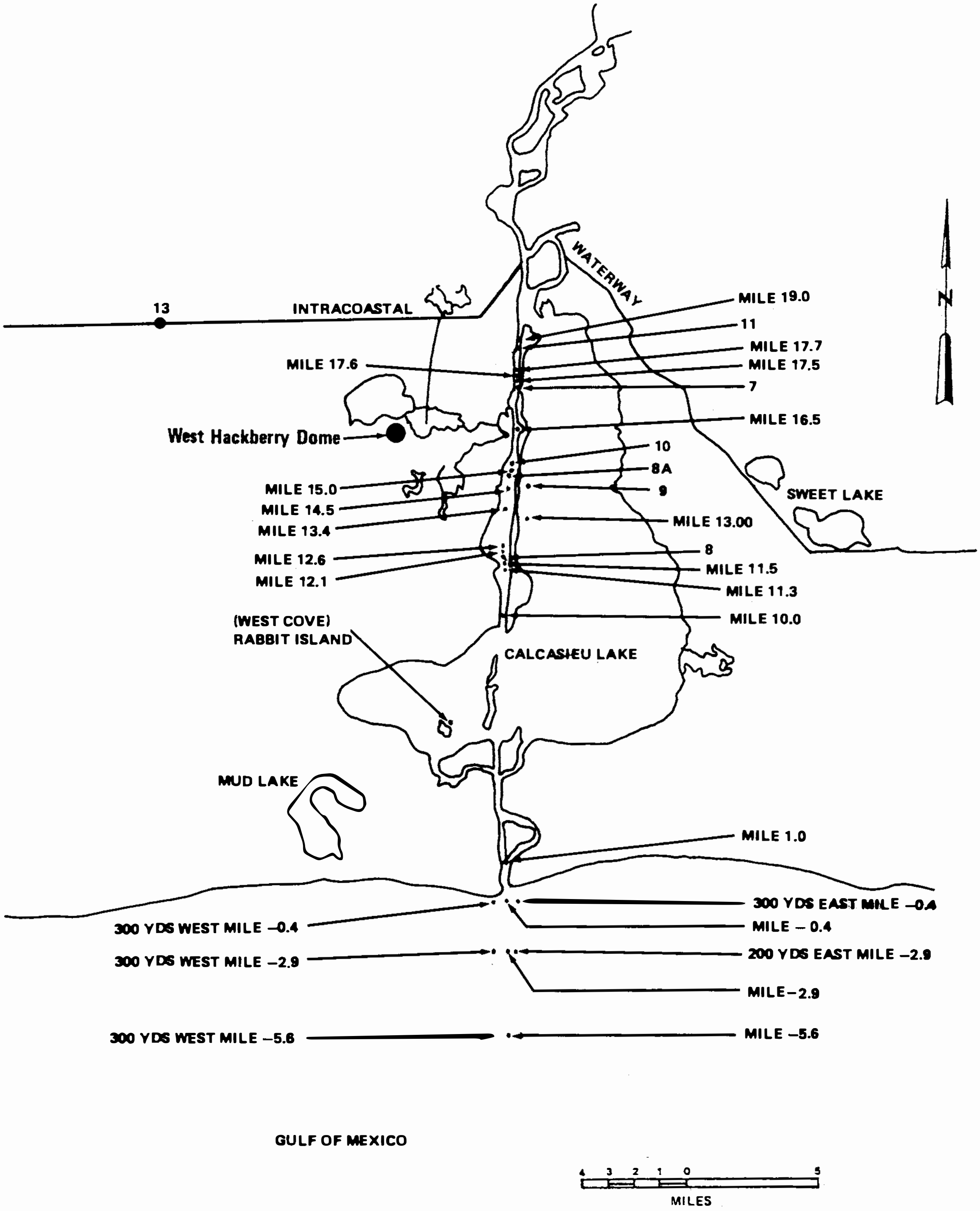


Figure D.4-1. Location of Sample Stations near the West Hackberry Site

Table D.4-1. Average Discharge Rate, Calcasieu River Water Years 1974, 1975, 1976

(USGS, Louisiana, 1974, 1975, 1976)

Location	Flow Rate (cfs) 1974	1975	1976	AVG
Glenmore, Louisiana (Rapides Parish)	805	1,267	535	869
Oberlin, Louisiana (Allen Parish)	1,381	1,822	779	1,327
Kinder, Louisiana (Allen Parish)	3,407	3,832	1,963	3,067

Table D.4-2. Monthly Calcasieu River Flow at Kinder, Louisiana (USGS Louisiana; 1975, and 1976)

		Flow Rate (cfs)	
Year	Month	Mean	Maximum
1974	OCT	400	470
	NOV	1,384	3,160
	DEC	4,415	16,000
1975	JAN	6,944	15,100
	FEB	2,440	3,700
	MAR	3,100	5,220
	APR	2,951	5,130
	MAY	10,330	29,100
	JUN	4,313	9,600
	JUL	3,585	7,130
	AUG	4,534	14,000
	SEP	1,281	2,450
	OCT	2,541	10,500
	NOV	1,878	5,640
	DEC	1,761	4,270
1976	JAN	2,668	9,650
	FEB	1,819	3,730
	MAR	3,937	10,100
	APR	2,548	8,650
	MAY	2,631	8,180
	JUN	1,797	4,420
	JUL	1,044	1,710
	AUG	490	691
	SEP	389	551

Table D.4-3. Daily Water Flows, Calcasieu River Near Kinder, Louisiana, Water Year 1976 (USGS, Louisiana; 1976)

LOCATION.--Lat 30°30'10", long 92°54'55", in NW¼SE¼ sec.30, T.6 S., R.5 W., Allen Parish, on left bank on downstream side of bridge on U. S. Highway 190, 0.5 mi (0.8 km) downstream from Whisky Chitto Creek, and 4.0 mi (6.4 km) west of Kinder.

DRAINAGE AREA.--1,700 mi^2 (4,403 km^2).

PERIOD OF RECORD.--August 1922 to January 1925, October 1938 to September 1957, October 1961 to current year. October 1957 to Septebmer 1961 (annual maximums) from U. S. Weather Bureau records.

GAGE.--Water-stage recorder. Datum of gage is 11.95 ft (3.642 m) above mean sea level (Louisiana Geodetic Survey bench mark). August 1922 to January 1925, water-stage recorder 400 ft (122 m) downstream at datum 1.77 ft (0.539 m) higher. October 1938 to July 9, 1939, nonrecording gage at present site and datum.

REMARKS.--Records good. Paper mill at Elizabeth pumps about 11 ft^3/s (0.31 m^3/s) from wells which is later discharged into Mill Creek 36 mi (58 km) above station. This discharge is continuous and fairly constant. Water is diverted during period April to September at points just above station and 5.0 mi (8.0 km) above station for the irrigation of about 7,500 acres (30.4 km^2) of rice, part of which is below station. The maximum rate of withdrawal is about 100 ft^3/s (2.83 m^3/s) and this diversion results in marked regulation of the low-water flow. Records of water temperatures for water year 1976 are published under miscellaneous water-quality sites in this report.

AVERAGE DISCHARGE.--36 years (1922-24, 1938-57, 1961-76), 2,573 ft^3/s (72.86 m^3/s), 1,860,000 acre-ft/yr (2.30 km^3/yr).

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 182,000 ft^3/s (5,154 m^3/s) May 19, 1953, gage height, 32.00 ft (9.754 m); minimum, 136 ft^3/s (3.85 m^3/s) Aug. 15, 1956; minimum gage height, 1.99 ft (0.606 m) Aug. 17, 1951, Oct. 20, 1973.

EXTREMES FOR CURRENT YEAR.--Maximum discharge, 10,700 ft^3/s (303 m^3/s) Oct. 30, gage height, 15.77 ft (4.807 m); minimum, 307 ft^3/s (8.69 m^3/s) Sept. 26, gage height, 2.25 ft (0.686 m).

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	681	5640	2000	2870	3070	1720	7860	675	1790	1320	691	551
2	661	4130	2130	2570	3690	1770	8650	653	3890	1430	661	470
3	643	3860	2120	2440	3730	1720	8140	632	4360	1180	634	404
4	631	3630	1860	2740	3590	1450	8020	624	4420	1050	608	397
5	623	3260	1540	2720	3010	1170	6310	579	4160	1350	598	508
6	612	2670	1390	2400	2400	1050	4600	537	3220	1710	602	475
7	607	2010	1320	2080	2090	1090	4040	664	2450	1240	595	431
8	600	1560	1310	1880	1830	1870	3430	1280	2200	941	586	413
9	593	1340	1280	1880	1680	2690	2910	2190	2200	921	560	409
10	588	1210	1240	1860	1570	3360	2410	2650	2280	948	551	381
11	582	1140	1130	1760	1440	3140	1950	3140	2220	879	548	375
12	575	1080	1050	1670	1330	2730	1580	2960	1850	806	532	427
13	569	1030	1010	1650	1260	2160	1320	2280	1320	786	487	423
14	563	982	970	1640	1220	1990	1190	2280	1060	852	435	427
15	1050	930	939	1560	1180	3440	1100	3180	957	843	420	412
16	1970	897	929	1430	1140	5440	1030	4740	883	849	410	414
17	2120	871	935	1310	1090	5950	975	6900	839	894	390	400
18	2240	852	953	1200	1050	5850	942	8180	818	886	410	356
19	2140	837	1070	1120	1030	5190	904	6800	900	1680	394	339
20	1700	857	1110	1070	1010	4290	877	5660	1090	1570	390	338
21	1220	1570	1040	1040	1070	3520	890	4860	1100	1060	390	333
22	1020	2530	982	1000	1250	3060	931	4090	1260	937	394	322
23	907	2320	944	990	1630	2820	950	3550	1280	902	435	315
24	833	1780	935	986	1940	2800	900	2960	1170	937	416	312
25	1220	1350	2020	1400	1870	6780	858	2380	1140	1020	410	310
26	5240	1430	3880	6090	1680	9660	795	1770	1130	1070	440	308
27	8660	1680	4270	9650	1620	10100	738	1400	1110	1010	413	315
28	10300	1520	4190	9570	1620	7600	736	1140	1030	951	412	337
29	10500	1590	3750	6550	1650	5840	719	1000	900	856	427	390
30	10200	1790	3240	4560	---	5500	681	910	874	760	476	380
31	8920	---	3060	3020	---	6290	---	903	---	727	476	---
TOTAL	78768	56346	54597	82706	52740	122040	76436	81567	53901	32365	15191	11672
MEAN	2541	1878	1761	2668	1819	3937	2548	2631	1797	1044	490	389
MAX	10500	5640	4270	9650	3730	10100	8650	8180	4420	1710	691	551
MIN	563	837	929	986	1010	1050	681	537	818	727	390	308
AC-FT	156200	111800	108300	164000	104600	242100	151600	161800	106900	64200	30130	23150

CAL YR 1975 TOTAL 1397725 MEAN 3829 MAX 29100 MIN 563 AC-FT 2772000
WTR YR 1976 TOTAL 718329 MEAN 1963 MAX 10500 MIN 308 AC-FT 1425000

Table D.4-3 Daily Water Flows, Calcasieu River Near Kinder, Louisiana, Water Year 1976 (Concluded) (USGS, Louisiana; 1976)

GAGE HEIGHT, IN FEET, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976
MEAN VALUES

DAY	OCT.	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.46	13.55	6.89	8.85	9.23	6.16	14.48	3.52	6.29	5.10	3.44	3.06
2	3.40	11.49	7.20	8.23	10.36	6.31	14.89	3.50	10.25	5.41	3.36	2.80
3	3.34	10.63	7.18	7.96	10.42	6.16	14.63	3.46	11.36	4.71	3.28	2.59
4	3.31	10.25	6.52	8.57	10.20	5.45	14.57	3.48	11.43	4.34	3.21	2.57
5	3.29	9.61	5.71	8.53	9.12	4.68	13.91	3.37	11.08	5.18	3.18	2.92
6	3.25	8.43	5.28	7.85	7.87	4.32	12.20	3.28	9.99	6.13	3.19	2.81
7	3.24	6.90	5.11	7.08	7.12	4.45	10.90	3.64	7.96	4.87	3.17	2.67
8	3.22	5.76	5.08	6.59	6.44	6.56	9.92	5.28	7.37	4.01	3.14	2.61
9	3.19	5.15	4.99	6.57	6.07	8.46	8.93	7.40	7.37	3.95	3.06	2.60
10	3.18	4.82	4.88	6.53	5.78	9.81	7.86	8.39	7.57	4.03	3.04	2.51
11	3.16	4.60	4.57	6.28	5.43	9.37	6.77	9.38	7.43	3.83	3.03	2.48
12	3.14	4.42	4.33	6.05	5.12	8.56	5.83	9.03	6.49	3.61	2.98	2.65
13	3.12	4.27	4.22	5.99	4.95	7.28	5.19	7.57	5.10	3.55	2.85	2.63
14	3.10	4.13	4.10	5.96	4.84	6.85	4.86	7.57	4.36	3.75	2.70	2.64
15	4.47	3.98	4.01	5.75	4.74	9.41	4.63	9.16	4.06	3.72	---	2.60
16	6.87	3.88	3.98	5.39	4.60	12.25	4.44	11.36	3.84	3.74	---	2.59
17	7.23	3.81	4.00	5.08	4.45	13.16	4.29	13.54	3.71	3.87	---	2.55
18	7.51	3.75	4.05	4.78	4.33	13.06	4.20	14.65	3.65	3.85	2.63	2.41
19	7.29	3.70	4.41	4.55	4.26	12.38	4.10	14.18	3.89	6.05	2.58	2.36
20	6.22	3.76	4.51	4.39	4.22	11.25	4.03	13.21	4.47	5.78	2.57	2.35
21	5.00	5.73	4.30	4.29	4.41	10.06	4.06	12.33	4.49	4.45	2.57	2.33
22	4.45	8.13	4.13	4.19	4.90	9.23	4.17	11.30	4.94	4.13	2.58	2.30
23	4.14	7.68	4.02	4.16	5.94	8.75	4.22	10.12	5.01	4.04	2.70	2.28
24	3.92	6.31	3.99	4.14	6.72	8.69	4.09	9.01	4.69	4.13	2.65	2.27
25	4.92	5.19	6.88	5.25	6.56	12.90	3.98	7.79	4.61	4.36	2.63	2.26
26	11.38	5.40	10.30	12.19	6.07	15.35	3.80	6.30	4.59	4.50	2.63	2.25
27	14.59	6.07	11.23	15.23	5.90	15.55	3.64	5.31	4.51	4.33	2.64	2.27
28	15.61	5.64	11.12	15.31	5.90	14.70	3.63	4.61	4.27	4.17	2.64	2.34
29	15.68	5.83	10.44	14.10	5.99	13.50	3.59	4.19	3.89	3.91	2.67	---
30	15.60	6.35	9.58	12.40	---	12.71	3.51	3.92	3.81	3.64	2.83	---
31	15.01	---	9.22	9.60	---	13.18	---	3.90	---	3.54	2.83	---
MAX	15.68	13.55	11.23	15.31	10.42	15.55	14.89	14.65	11.43	6.13	3.44	3.06
MIN	3.10	3.70	3.98	4.14	4.22	4.32	3.51	3.28	3.65	3.54	---	2.25

Table D.4-4. Monthly Stream Flow in Acre-Feet, Calcasieu River Basin, (Jones, et al, 1956)

Month	Beckwith Creek	Hickory Branch	Bundick Creek	Whiskey Chitto Creek	Calcasieu River at Oberlin	Ungaged area *A*	Ungaged area *B*	Ungaged area *C*	Total
1947									
October	100	30	4,300	10,000	3,100	9,500	300	4,000	31,300
November	2,300	1,300	18,400	37,100	26,200	37,000	37,800	40.600	201,000
December	12,800	7,700	36,100	71,900	136,000	71,900	46,700	39,500	423,000
1948									
January	14,200	13,000	27,700	53,900	92,400	54,300	79,000	46,500	381,000
February	26,500	19,700	45,500	94,700	198,000	93,400	123,000	100,000	701,000
March	8,600	6,800	20,400	56,400	111,000	51,100	39,400	28,400	322,000
April	2,600	800	8,500	21,500	40,500	19,900	11,800	13,100	119,000
May	500	50	7.400	20,000	11,900	18,200	1,700	3,600	63,400
June	200	30	4,600	11,100	4,300	10,400	800	600	32,000
July	900	100	4,700	11,100	4,200	10,500	5,400	7,700	44,600
August	100	10	4,000	8,800	3,000	8,500	1,400	8,200	34.000
September	80	20	4,800	10,200	3,200	10,000	600	9,300	38,200
October	200	10	4,300	7,900	2,800	8,100	300	2,400	26,000
November	12,200	6,600	45,500	90,300	106,000	90,400	30,200	6,600	388,000
December	8,500	6,600	20,200	60,100	120,000	53,400	32,900	34,400	330,000
1949									
January	23,500	19,100	41,300	95,500	157,000	91,100	93,200	42,400	563,000
February	38.300	26,200	45,600	90,900	189,000	90,800	170,000	126,000	777,000
March	51,900	36,800	66,200	130,000	228,000	130,000	241,000	77,000	961,000
April	61,500	34,000	83,300	216,000	348,000	199,000	186,000	91,800	1,220,000
May	9,100	2,900	25,900	37,300	77,700	42,000	25,200	22,900	243,000
June	5,500	1,200	10,100	22,400	9,300	21,600	22,600	12,300	105,000
July	5,900	3,700	10,600	32,300	31,100	28,600	25,200	53,200	190,600
August	500	200	7,400	20,000	24,600	18.200	2,300	17,200	90,400
September	200	400	6,500	13,500	5,600	13,300	1,400	11,400	52,300
October	12,100	11,000	20,200	37,700	30.700	38,500	99,800	99,500	350,000
November	600	500	6,600	17,000	11,100	15,700	4.400	4,600	60,500
December	21,700	14,800	36,000	65,400	98,400	67,500	97,800	39,300	441,000
1950									
January	17,800	8,500	35,700	81,400	158.000	78,600	56.600	59,300	495.000
February	48,400	28.800	98,700	165,000	329,000	176,000	133,000	66,400	1,065,000
March	28,500	23,000	41,300	94,400	180,000	90,300	122,000	86,600	666,000
April	8,000	7,100	15,500	51,500	33,100	44,600	23.200	2,300	185,000
May	27,400	9,400	53,100	137,000	192,000	127,000	85,100	45,000	676,000
June	50,200	26,900	77,700	151,000	257,000	152,000	274,000	98,800	1.088,000
July	3,800	2,000	15.200	33,900	23,900	32,700	19,400	13,700	145,000
August	1,000	90	6,400	19,400	11,700	17,100	2,800	13,400	71.900
September	1,000	200	6,500	17,900	11,600	16,200	3,000	12,700	69,100
October	400	20	5,700	13,900	6,400	13,100	1,800	4,700	46,000
November	600	50	6,100	14,500	14,600	13,800	2,300	7,300	59.200
December	700	70	7,000	18,200	14,600	16,800	4,000	12.700	74.000
1951									
January	8,100	6,100	24,300	60,400	166,000	56,400	10,200	29,700	361,000
February	8,200	5,100	16,900	48,000	91,200	43,200	48,600	53,800	315,000
March	7,900	3,500	15,700	37,400	42,400	35,300	41,000	27,400	211,000
April	4,900	400	12,600	33,200	113,000	30,500	14,900	26,600	236,000
May	400	50	5,800	15,900	46,800	14,400	1,200	2,800	87,400
June	200	10	4,600	11,300	8,000	10,600	400	7,500	42,600
July	1,100	2,400	5,000	12,500	8,000	11,700	11,800	10,500	63,000
August	400	200	4,100	8,700	4,700	8.500	2,200	7,200	36,000
September	6,200	9,200	14,900	17,400	4,600	21,500	29,800	15,500	119,000
October	1,000	200	4,800	10,700	6,400	10,300	2,500	3,400	39,300

Table D.4-5. Analysis of Samples Collected at Calcasieu River Mile 19.0 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
MAR. 04...	1005	80	40^f	140^f	420^f	3400^f	130^f	50^f	0	820^f	6200^f	.21

DATE	DISSOLVED NITRITE (N) (MG/L)	TOTAL AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)
MAR. 04...	.02	.58^d	.45^f	.97^f	.90^f	.02^d	28^f	8^f	34^f	<1.0^f	2100^f	2100^f

DATE	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
MAR. 04...	18000^f	7.6	25^f	10^f	8.7	120^f	5.2^f	<5^f	<5^f	4.4^f	.00

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)
MAR. 04...	1	0	.00	.0	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR (UG/L)	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
MAR. 04...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)
MAR. 04...	.00	.00	.00	1	1	1	1	<10	0

DATE	TOTAL COPPER (CU) (UG/L)	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
MAR. 04...	3	2	0	0	.1	.1	1	0	40

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-6. Analysis of Samples Collected at Calcasieu River Mile 17.7 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)
JUNE											
29...	0840	40^f	20^f	110^f	280^f	2600^f	110^f	65^f	0^f	560^f	4700^f
30...	1345	120^f	20^f	120^f	320^f	2800^f	100^f	70^f	0^f	700^f	4900^f

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)
JUNE											
29...	.02	.01	.36^f	--	.96^f	--	.00^d	2^f	1^f	16^f	<1.0^f
30...	.09	.01	.42^f	.36^f	1.3^f	.95^f	.01	5^f	3^f	--	--

DATE	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
JUNE											
29...	1400^f	1400^f	13300^f	7.1	5^f	15^f	5.1^e	80^f	.6^f	4.2^f	.00^f
30...	1600^f	1600^f	14800^f	7.5	10^f	10^f	6.0	110^f	1.1^f	5.7^f	.00^f

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)
JUNE											
29...	6^d	0	.00	.0	.00	.00	.00	.00	.00	.00	.00
30...	1	0	.00	.0	.00	.00	.00	.01	.00	.00	.00

DATE	TOTAL HEPTACHLOR (UG/L)	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
JUNE											
29...	.00	.00	.00	.00	.00	.00	.00	.0	.00^f	0	.00
30...	.00	.00	.00	.00	.00	.00	.00	.0	.00^f	0	.00

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-6. Analysis of Samples Collected at Calcasieu River Mile 17.7 (Concluded) (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE										
29...	.04^f	.01^f	.00^f	2	2	0	0	20	0	
30...	.03^f	.03^f	.00^f	1	1	0	0	20	0	6

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
JUNE									
29...	7	6	0	.2^d	.1	6	6	40	0
30...	5	4	0	.1	.1	2	0	30	20

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-7. Analysis of Samples Collected at Calcasieu River Mile 17.6 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED NITRATE (N) (MG/L)
MAR. 31...	0900	90[f]	250[f]	17[f]	36[f]	330[f]	15[f]	27[f]	0	81[f]	580[f]	.32[f]

DATE	DIS-SOLVED NITRITE (N) (MG/L)	AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	DIS-SOLVED KJEL. NITRO-GEN (N) (MG/L)	DIS-SOL-VED-PHOS-PHORUS (P) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	VOL. NON-FILT-RABLE RESIDUE (MG/L)	SUS-PENDED SOLIDS (MG/L)	SETTLE-ABLE MATTER (ML/L /HR)	HARD-NESS (CA,MG) (MG/L)
MAR. 31...	.01[f]	.25[f]	.31[f]	.94[f]	.94[f]	.01[d]	121[f]	15[f]	113[f]	<1.0[f]	190[f]

DATE	NON-CAR-BONATE HARD-NESS (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	COLOR (PLAT-INUM-COBALT UNITS)	TUR-BID-ITY (JTU)	DIS-SOLVED OXYGEN (MG/L)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)	FECAL COLI-FORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
MAR. 31...	170[f]	2020[f]	7.1	50[f]	90[f]	5.9[e]	28[f]	1.5[f]	15000[f]	12[f]	.00

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLOR-DANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DI-AZINON (UG/L)	TOTAL DI-ELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)
MAR. 31...	0	0	.00	.0	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTA-CHLOR (UG/L)	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALA-THION (UG/L)	TOTAL METHYL PARA-THION (UG/L)	TOTAL METHYL TRI-THION (UG/L)	TOTAL PARA-THION (UG/L)	TOTAL PCB (UG/L)	POLY-CHLO-RINATED NAPH-THA-LENES (UG/L)	TOTAL TOX-APHENE (UG/L)	TOTAL TRI-THION (UG/L)
MAR. 31...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
MAR. 31...	.03[f]	.00	.00	3	0	0	0	10	0	4

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
MAR. 31...	3[f]	10	0	.1	.0	7	0	50[f]	0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-8. Analysis of Samples Collected at Calcasieu River Mile 17.5 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
FEB. 18...	1015	40^f	110^f	310^f	2600^f	120^f	52^f	0	640^f	4500^f	.19^f

DATE	DISSOLVED NITRITE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)
FEB. 18...	.01^f	1.0^f	.84^f	.26^d	34^f	3^f	19^f	<1.0^f	1600^f	1600^f	13800^f

DATE	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
FEB. 18...	7.7	25^f	20^f	7.8	200^f	1.7^f	10^f	<5^f	9.4^f	.00	3^d

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTACHLOR (UG/L)
FEB. 18...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
FEB. 18...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
FEB. 18...	.00	.00	.00	1	0	1	1^f	<10	0	3

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
FEB. 18...	3^f	0	0	.1	.0	6	0	10^f	0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-9. Analysis of Samples Collected at Calcasieu River Mile 16.5 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
FEB. 04...	1015	60^f	58^f	170^f	1500^f	56^f	42^f	0	370^f	2600^f	.10^f

DATE	DISSOLVED NITRITE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)
FEB. 04...	.01^f	1.7^f	1.6^f	.04^d	30^f	5^f	27^f	<1.0^f	840^f	810^f	8200^f

DATE	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
FEB. 04...	7.5	30^f	20^f	7.9	80^f	3.0^f	70^f	60^f	7.2^f	.00	8^d

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTACHLOR (UG/L)
FEB. 04...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
FEB. 04...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)
FEB. 04...	.00	.00	.00	1	0	0	0	20	0

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
FEB. 04...	6^f	9	0	.1	.1^f	3	0	10^f	10^f

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-10. Analysis of Samples Collected at Calcasieu River Mile 15.0 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)
JUNE											
29...	0845	150^f	30^f	120^f	350^f	3000^f	120^f	73^f	0	680^f	5400^f
30...	1400	50^f	20^f	130^f	360^f	3100^f	120^f	70^f	0	800^f	5800^f

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)
JUNE											
29...	.02^f	.01^f	.29^f	.20^f	--	.95^f	.01^d	25^f	14^f	23^f	<1.0^f
30...	.03^f	.01^f	.26^f	.23^f	1.1^f	.74^f	.01^d	3^f	2^f	3^f	--

DATE	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
JUNE											
29...	1700^f	1700^f	16100^f	7.4	5^f	10^f	5.6$^{\bullet}$	80^f	1.1^f	4.7^f	.00
30...	1800^f	1800^f	16100^f	7.7	5^f	6^f	7.6	120^f	2.7^f	11^f	.00

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)
JUNE											
29...	0	0	.00	.0	.00	.00	.00	.00	.00	.00	.00
30...	0	0	.00	.0	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR (UG/L)	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
JUNE											
29...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00
30...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-10. Analysis of Samples Collected At Calcasieu River Mile 15.0 (Concluded) (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE										
29...	.00^f	.00^f	.00	2	1^f	0	0	20	0	6
30...	.03^f	.03^f	.00	1	1^f	0	0	20	0	23

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
JUNE									
29...	6^f	9	0	.3^d	.1^f	6	4^f	20^f	10^f
30...	5^f	5	0	.1	.1^f	2	0	20^f	10^f

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.4-11. Analysis of Samples Collected at Calcasieu River Mile 14.5 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED NITRATE (N) (MG/L)
FEB. 11...	1115	50^f	120^f	340^f	2900^f	120^f	67^f	0	660^f	5000^f	.13^f

DATE	DIS-SOLVED NITRITE (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	DIS-SOLVED KJEL. NITRO-GEN (N) (MG/L)	DIS-SOL-VED-PHOS-PHORUS (P) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	VOL. NON-FILT-RABLE RESIDUE (MG/L)	SUS-PENDED SOLIDS (MG/L)	SETTLE-ABLE MATTER (ML/L /HR)	HARD-NESS (CA,MG) (MG/L)	NON-CAR-BONATE HARD-NESS (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)
FEB. 11...	.01^f	1.3^f	.03^f	.03^d	48^f	12^f	48^f	<1.0^f	1700^f	1600^f	15000^f

DATE	PH (UNITS)	COLOR (PLAT-INUM-COBALT UNITS)	TUR-BID-ITY (JTU)	DIS-SOLVED OXYGEN (MG/L)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)	IMME-DIATE COLI-FORM (COL. PER 100 ML)	FECAL COLI-FORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
FEB. 11...	7.6	20^f	20^f	7.9	340^f	.9^f	300^f	20^f	7.8^f	.00	9^d

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLOR-DANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DI-AZINON (UG/L)	TOTAL DI-ELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTA-CHLOR (UG/L)
FEB. 11...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALA-THION (UG/L)	TOTAL METHYL PARA-THION (UG/L)	TOTAL METHYL TRI-THION (UG/L)	TOTAL PARA-THION (UG/L)	TOTAL PCB (UG/L)	POLY-CHLO-RINATED NAPH-THA-LENES (UG/L)	TOTAL TOX-APHENE (UG/L)	TOTAL TRI-THION (UG/L)
FEB. 11...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
FEB. 11...	.00	.00	.00	1	0^f	0	0^f	10	0^f	3

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
FEB. 11...	2^f	0	0^f	.0	.0^f	5	0^f	40	10

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-12. Analysis of Samples Collected at Calcasieu River Mile 13.4 (USGS, Louisiana, 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
JAN. 15...	0800	60^{f}	220^{f}	680^{f}	5700^{f}	370^{f}	153^{f}	0^{f}	1300^{f}	10000^{f}	.16^{f}

DATE	DISSOLVED NITRITE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)
JAN. 15...	.01^{f}	.79^{f}	.28^{f}	.03^{d}	67^{f}	10^{f}	53^{f}	<1.0^{f}	3400^{f}	3200^{f}	28600^{f}

DATE	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	PHENOLS (UG/L)	OIL AND GREASE (MG/L)
JAN. 15...	7.9	10^{f}	15^{f}	10.2	3.4^{f}	<5^{f}	<5^{f}	6.0^{f}	1	1

DATE	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTACHLOR (UG/L)
JAN. 15...	.00	.0	.00	.00	.00	.00	.00	.05	.00	.00

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
JAN. 15...	.00	.00	.00	.00	.00	.00	.0	.05	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)
JAN. 15...	.65^{f}	.00	.00	1	0	0	0	<10	0

DATE	TOTAL COPPER (CU) (UG/L)	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
JAN. 15...	2	0	5	0	.0	.0	3	0	20

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-13. Analysis of Samples Collected at Calcasieu River Mile 13.0 (USGS, Louisiana, 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)
JUNE 29...	0950	50^{f}	20^{f}	110^{f}	330^{f}	2800^{f}	110^{f}	52^{f}	0	630^{f}	5000^{f}
30...	1327	270^{f}	20^{f}	120^{f}	340^{f}	3000^{f}	110^{f}	56^{f}	0	720^{f}	5600^{f}

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)
JUNE 29...	.00	.01^{f}	.09^{f}	.00	.63^{f}	.62^{f}	.01^{d}	10^{f}	4^{f}	12^{f}	<1.0^{f}
30...	.00	.00^{f}	.10^{f}	.02^{f}	.74^{f}	.53^{f}	.01^{d}	4^{f}	2^{f}	7^{f}	--

DATE	HARDNESS (CA+MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
JUNE 29...	1600^{f}	1600^{f}	15000^{f}	7.2	5^{f}	6^{f}	6.9	120^{f}	4.7^{f}	5.1^{f}	.00
30...	1700^{f}	1700^{f}	15800^{f}	7.5	5^{f}	5^{f}	8.4	110^{f}	4.8^{f}	7.8^{f}	.00

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)
JUNE 29...	0	0	.00	.0	.00	.00	.00	.00	.00	.00	.00
30...	0	0	.00	.0	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR (UG/L)	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
JUNE 29...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00
30...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-13. Analysis of Samples Collected at Calcasieu River Mile 13.0 (Concluded) (USGS, Louisiana, 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE										
29...	.28^f	.05^f	.00	1	1^f	1	1^f	20	0	8
30...	.08^f	.03^f	.00	1	1^f	0	0	30	0	--

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
JUNE									
29...	8^f	8	0	.1	.1^f	6	5^f	20^f	0^f
30...	7^f	8	0	.1	.0	2	0	--	30

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-14. Analysis of Samples Collected at Calcasieu River Mile 12.6 (USGS, Louisiana, 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
JAN. 15...	0900	70^{f}	240^{f}	710^{f}	5900^{f}	230^{f}	116^{f}	0^{f}	1400^{f}	10000^{f}	.00

DATE	DISSOLVED NITRITE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)
JAN. 15...	.01	.78^{f}	.42^{f}	.03^{d}	82^{f}	5^{f}	66^{f}	<1.0^{f}	3500^{f}	3400^{f}	28800^{f}

DATE	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
JAN. 15...	7.8	20^{f}	25^{f}	10.0	150^{f}	3.5^{f}	20^{f}	8^{f}	5.4^{f}	.00	1

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTACHLOR (UG/L)
JAN. 15...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
JAN. 15...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)	DISSOLVED COPPER (CU) (UG/L)
JAN. 15...	1	1^{f}	0	0	20	0	4	2^{f}

DATE	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
JAN. 15...	3	0	.2^{d}	.0	0	0	40^{f}

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.4-15. Analysis of Samples Collected at Calcasieu River Mile 12.1 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)
JUNE 29...	1034	80^f	30^f	150^f	420^f	3600^f	120^f	80^f	0	820^f	6600^f
30...	1252	60^f	10^f	170^f	480^f	4000^f	150^f	86^f	0	950^f	7500^f

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L/HR)
JUNE 29...	.00^f	.01^f	.05^f	.04^f	.87^f	.78^f	.01^d	14^f	8^f	14^f	<1.0^f
30...	.02^f	.01^f	.12^f	.04^f	1.1^f	.53^f	.00	15^f	8^f	--	--

DATE	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
JUNE 29...	2100^f	2000^f	18400^f	7.8	5^f	5^f	6.7	110^f	1.8^f	4.5^f	.00
30...	2400^f	2300^f	20100^f	7.9	4^f	5^f	6.9	78^f	2.6^f	5.4^f	.00

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)
JUNE 29...	0	0	.00	.0	.00	.00	.00	.00	.00	.00	.00
30...	0	0	.00	.0	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR (UG/L)	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
JUNE 29...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00
30...	.00	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.4-15. Analysis of Samples Collected at Calcasieu River Mile 12.1 (Concluded) (USGS, Louisiana; 1976)

ANALYSES OF SAMPLES COLLECTED BY MISCELLANEOUS SITES

DREDGING OPERATIONS STUDY--Continued

295631093201900 CALCASIEU RIVER AT MILE 12.1, NEAR HACKBERRY, LA (CE 73656)--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE										
29...	.15^{f}	.02^{f}	.00	2	2^{f}	2	2^{f}	10	0	6
30...	.03^{f}	.02^{f}	.00	1	1^{f}	0	0^{f}	20	0	39

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
JUNE									
29...	6^{f}	0	0	.2^{d}	.1^{f}	9	5^{f}	20^{f}	20^{f}
30...	4^{f}	4	0	.1	.0	2	0	20^{f}	20^{f}

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-16. Analysis of Samples Collected at Calcasieu River Mile 11.5 (USGS, Louisiana, 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
FEB. 06...	1120	100[f]	83[f]	240[f]	2100[f]	74[f]	53[f]	0	510[f]	3600[f]	.35[f]

DATE	DISSOLVED NITRITE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)	HARDNESS (CA+MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)
FEB. 06...	.00	1.3[f]	.89[f]	.03[d]	49[f]	9[f]	52[f]	<1.0[f]	1200[f]	1200[f]	11200[f]

DATE	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
FEB. 06...	7.5	20[f]	20[f]	8.3	930[f]	1.4[f]	110[f]	32[f]	7.6[f]	.00	6[d]

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTACHLOR (UG/L)
FEB. 06...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
FEB. 06...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
FEB. 06...	.00	.00	.00	1	0	0	0	<10	0	2

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
FEB. 06...	2[f]	0	0	.0	.0	2	0	20[f]	0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-17. Analysis of Samples Collected at Calcasieu River Mile 11.3 (USGS, Louisiana, 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
FEB. 11...	0945	40^f	140^f	420^f	3500^f	140^f	79^f	0	880^f	6000^f	.10^f

DATE	DISSOLVED NITRITE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L /HR)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)
FEB. 11...	.01^f	1.4^f	1.3^f	.02^d	35^f	4^f	22^f	<1.0^f	2100^f	2000^f	18800^f

DATE	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
FEB. 11...	7.6	25^f	7^f	9.4	190^f	1.6^f	100^f	20^f	6.0^f	.00	15^d

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTACHLOR (UG/L)
FEB. 11...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
FEB. 11...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
FEB. 11...	.00	.00	.00	1	1^f	0	0	10	0	1

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
FEB. 11...	0	0	0	.0	.0	6	0	20^f	0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-18. Analysis of Samples Collected at Calcasieu River Mile 10.0 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED NITRATE (N) (MG/L)
APR. 07...	1010	70[f]	120[f]	74[f]	190[f]	1800[f]	6.5[f]	65[f]	0	430[f]	3100[f]	.11[f]

DATE	DISSOLVED NITRITE (N) (MG/L)	AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	SETTLEABLE MATTER (ML/L/HR)	HARDNESS (CA+MG) (MG/L)
APR. 07...	.01[f]	.27[f]	.20[f]	.64[f]	.56[f]	.07[d]	76[f]	17[f]	22[f]	<1.0[f]	970[f]

DATE	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
APR. 07...	930[f]	9510[f]	7.2	20[f]	30[f]	6.7	110[f]	1.4[f]	40[f]	15[f]	.00

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLORDANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DIAZINON (UG/L)	TOTAL DIELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)
APR. 07...	2[d]	0	.00	.0	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTACHLOR (UG/L)	TOTAL HEPTACHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL METHYL TRITHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL PCB (UG/L)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOTAL TRITHION (UG/L)
APR. 07...	.00	.00	.00	.01	.00	.00	.00	.0	.00	0	.00

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
APR. 07...	.03[f]	.00	.00	1	1[f]	0	0	<10	0	4

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
APR. 07...	3[f]	3	0	.0	.0	4	0	20[f]	10[f]

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-19. Analysis of Samples Collected at Calcasieu River at Rabbit Island (USGS, Louisiana; 1976)

ANALYSES OF SAMPLES COLLECTED AT MISCELLANEOUS SITES

DREDGING OPERATIONS STUDY--Continued

295100093222500 CALCASIEU LAKE (WEST COVE) AT RABBIT ISLAND, NEAR CAMERON, LA (CE 73651)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)
JUNE 29...	1050	60^f	40^f	190^f	570^f	4600^f	130^f	89^f	0	1100^f	8400^f
30...	1240	70^f	30^f	190^f	570^f	4600^f	180^f	90^f	0	1200^f	8600^f

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	DIS-SOLVED KJEL. NITRO-GEN (N) (MG/L)	DIS-SOL-VED-PHOS-PHORUS (P) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	VOL. NON-FILT-RABLE RESIDUE (MG/L)	SUS-PENDED SOLIDS (MG/L)	HARD-NESS (CA,MG) (MG/L)
JUNE 29...	.01^f	.00	.05^f	.02^f	.68^f	.68^f	.01^d	11^f	8^f	--^{f}	2800^f
30...	.01^f	.00	.09^f	.04^f	--	.98^f	.01^d	46^f	8^f	36	2800^f

DATE	NON-CAR-BONATE HARD-NESS (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	COLOR (PLAT-INUM-COBALT UNITS)	TUR-BID-ITY (JTU)	DIS-SOLVED OXYGEN (MG/L)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
JUNE 29...	2700^f	23200^f	7.7	5^f	7^f	6.5	110^f	--^{f}	5.1^f	.00	0^d
30...	2700^f	23700^f	7.8	3^f	15^f	7.6	110^f	2.3	5.7^f	.00	2

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLOR-DANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DI-AZINON (UG/L)	TOTAL DI-ELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTA-CHLOR (UG/L)
JUNE 29...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00
30...	0	.00	.0	.00	.00	.00	.01^f	.00	.00	.00	.00

DATE	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALA-THION (UG/L)	TOTAL METHYL PARA-THION (UG/L)	TOTAL METHYL TRI-THION (UG/L)	TOTAL PARA-THION (UG/L)	TOTAL PCB (UG/L)	POLY-CHLO-RINATED NAPH-THA-LENES (UG/L)	TOTAL TOX-APHENE (UG/L)	TOTAL TRI-THION (UG/L)
JUNE 29...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00
30...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-19. Analysis of Samples Collected at Calcasieu River at Rabbit Island (Concluded) (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE										
29...	.01^{f}	.00	.00	2	2^{f}	1	0	20	0	--
30...	--	--	--	2	1^{f}	0	0	20	0	7

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
JUNE									
29...	10^{f}	0	0	.1	.1^{f}	10	2^{f}	20^{f}	20^{f}
30...	3^{f}	4	0	.1	.0	7	0	30^{f}	20^{f}

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-20. Analysis of Samples Collected at Calcasieu River Mile 1.0 (USGS, Louisiana; 1976)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)
JUNE											
29...	1123	50^f	50^f	240^f	710^f	5800^f	210^f	134^f	0	1300^f	11000^f
30...	0937	320^f	40^f	250^f	760^f	6300^f	240^f	132^f	0	1500^f	11000^f

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	DIS-SOLVED KJEL. NITRO-GEN (N) (MG/L)	DIS-SOL-VED-PHOS-PHORUS (P) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	VOL. NON-FILT-RABLE RESIDUE (MG/L)	SUS-PENDED SOLIDS (MG/L)	HARD-NESS (CA,MG) (MG/L)
JUNE											
29...	$.01^f$	$.01^f$	$.06^f$	$.06^f$	$.53^f$	$.49^f$	$.01^d$	14^f	12^f	--	3500^f
30...	$.02^f$	$.01^f$	.08	$.05^f$	$.73^f$	$.40^f$	$.01^d$	86^f	13^f	73^f	3800^f

DATE	NON-CAR-BONATE HARD-NESS (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	COLOR (PLAT-INUM-COBALT UNITS)	TUR-BID-ITY (JTU)	DIS-SOLVED OXYGEN (MG/L)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
JUNE											
29...	3400^f	28200^f	8.3	0	8^f	6.5	200^f	1.5^f	3.9^f	.00	0
30...	3600^f	30000^f	8.2	3^f	35^f	5.8	160^f	2.3^f	4.3^f	.00	0

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	TOTAL CHLOR-DANE (UG/L)	TOTAL DDD (UG/L)	TOTAL DDE (UG/L)	TOTAL DDT (UG/L)	TOTAL DI-AZINON (UG/L)	TOTAL DI-ELDRIN (UG/L)	TOTAL ENDRIN (UG/L)	TOTAL ETHION (UG/L)	TOTAL HEPTA-CHLOR (UG/L)
JUNE											
29...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00
30...	0	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00

DATE	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	TOTAL LINDANE (UG/L)	TOTAL MALA-THION (UG/L)	TOTAL METHYL PARA-THION (UG/L)	TOTAL METHYL TRI-THION (UG/L)	TOTAL PARA-THION (UG/L)	TOTAL PCB (UG/L)	POLY-CHLO-RINATED NAPH-THA-LENES (UG/L)	TOTAL TOX-APHENE (UG/L)	TOTAL TRI-THION (UG/L)
JUNE										
29...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00
30...	.00	.00	.00	.00	.00	.00	.0	.00	0	.00

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-20. Analysis of Samples Collected at Calcasieu River Mile 1.0 (Concluded) (USGS, Louisiana; 1976)

ANALYSES OF SAMPLES COLLECTED AT MISCELLANEOUS SITES

DREDGING OPERATIONS STUDY--Continued

294630093204600 CALCASIEU RIVER AT MILE 1.0, NEAR CAMERON, LA (CE 73650)--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL 2,4-D (UG/L)	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE										
29...	$.07^f$	.00	.00	2	1^f	2	0	30	0	6
30...	$.01^f$	.00	.00	2	1^f	1	0	30	0	11

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
JUNE									
29...	6^f	15	0	$.2^d$	$.0^f$	10	3^f	20^f	20^f
30...	4^f	9	0	$.3^d$	$.3^f$	8	0	--	40^f

Note: Sample station locations are shown in Figure D.4-1. Explanation of the superscripts is found in Table D.3-3.

Table D.4-21. Water Quality of Stations 8, 9, 10, and 11, Calcasieu Ship Channel

(US Army CE, New Orleans, 1976)

Results of Water Quality Field Sampling

	Temp. °C	pH	D.O. mg/L	COD mg/L	SS mg/L	VSS mg/L	TKN mg/L	T-P mg/L	Oil and Grease mg/L
Station 8	23.8	7.8	5.5^{e}	675^{f}	15^{f}	3^{f}	1.0^{f}	0.054^{d}	7.9
Station 9	20.0	4.1^{e}	3.9^{e}	51^{f}	120^{f}	11^{f}	0.78^{f}	0.220^{d}	8.8
Station 10	23.4	6.6	13.9	169^{f}	18^{f}	2^{f}	1.1^{f}	0.072^{d}	26.8
Station 11	24.6	6.8	7.0	684^{f}	22^{f}	3^{f}	2.2^{f}	0.052^{d}	<0.5

Results of Water Quality Field Sampling Heavy Metals*

	Hg µg/L	Pb mg/L	Zn mg/L	As mg/L	Cd mg/L	Cu mg/L	Cr (Total) mg/L	Ni mg/L
Station 8	38^{d}	0.11^{e}	0.073	<0.025	<0.05	<0.05	0.05	<0.10
Station 9	<0.2^{e}	<0.10	0.250^{e}	<0.025	<0.05	<0.05	<0.05	0.12^{e}
Station 10	90^{d}	<0.10	0.055	<0.025	<0.05	<0.05	0.07	<0.10
Station 11	56^{d}	<0.10	0.063	<0.025	<0.05	<0.05	<0.05	<0.10

*Detection limits for Weston's equipment: Hg, 0.2 µg/L; Pb and Ni, 0.1 mg/L; Zn and As, 0.025 mg/L; Cd, Cr, and Cu, 0.05 mg/L.

Source: Roy F. Weston Inc.

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.4-21. Water Quality of Stations 8, 9, 10, and 11, Calcasieu Ship Channel (Continued)

(US Army, New Orleans, 1976)

Results of Field Sampling Survey
Pesticides in Water

	Parameter	Concentration µg/L
Station 8	2,4 D	0.01[f]
Station 9	2,4 D	0.02[f]
Station 10	2,4 D	0.01[f]
Station 11	Diazinon	0.02[f]
	2,4 D	0.01[f]

Source: Roy F. Weston Inc.

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.4-22. Sediment Quality for Stations 8, 9, 10 and 11, Calcasieu Ship Channel

(US Army CE, New Orleans, 1976)

Results of Field Sampling Sediments

	COD mg/kg	TS % Solids	TVS % Solids-Dry Weight	TKN mg/kg	Oil mg/kg
Station 8	12,177	38.0[f]	3.4[f]	504	621
Station 9	11,000	36.0[f]	4.0[f]	386	335
Station 10	16,919	32.0[f]	3.5[f]	366	100
Station 11	16,945	34.0[f]	3.7[f]	522	175

Results of Field Sampling Heavy Metals in Sediments

	Hg mg/kg	Pb mg/kg	Zn mg/kg	As mg/kg	Cd mg/kg	Cu mg/kg	Cr (Total) mg/kg	Ni mg/kg
Station 8	0.666	10.0	40.0	0.63[f]	1.0[f]	5.0[f]	8.0[f]	12.0[f]
Station 9	6.5[g]	<1.0	32.0	2.07[f]	<1.0[f]	<5.0[f]	10.0[f]	<5.0[f]
Station 10	1.11[g]	10.0	48.0	1.02[f]	2.0[f]	5.0[f]	11.0[f]	12.0[f]
Station 11	0.070	10.0	38.0	0.97[f]	1.0[f]	5.0[f]	9.0[f]	8.0[f]

Source: Roy F. Weston Inc.

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.4-23. Elutriate Data, Stations 8, 9, 10, 11, Calcasieu Ship Channel (U.S. Army Corps of Engineers, New Orleans, 1976)

Results of Field Sampling Elutriate Tests
Inland Stations

	Hg µg/L	Pb mg/L	Zn mg/L	As mg/L	Cd mg/L	Cr (Total) mg/L	Ni mg/L	Cu mg/L
Station 8	0.85	0.22	0.100	<0.025	<0.05	< 0.05	0.11	<0.05
Station 9	0.60	<0.10	0.120	<0.025	<0.05	< 0.05	<0.10	<0.05
Station 10	<0.20	0.20	0.060	<0.025	<0.05	< 0.05	<0.10	<0.05
Station 11	0.45	0.25	0.115	<0.025	<0.05	< 0.05	0.19	0.08

Source: Roy F. Weston Inc.

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.4-24. Elutriate, Surface Water, and Bottom Sediment Data for Station 7, Calcasieu River at Hackberry.

(U.S. Army CE, New Orleans, 1975)

Sample No.:	1	1	1
Lab I.D. No.:	101090	101053	101053
Record No.:	2044	1970	1970
Date:	04-04-75	04-04-75	04-04-75
Time:	1031	1030	1030

	WATER QUALITY		BOTTOM SEDIMENT	
SOURCE	ELUTRIATE	SURFACE WATER	SAMPLE CONCENTRATION	
UNITS	(ug/l)	(ug/l)	(mg/kg*)	
As	3	0	8 >[f]	
Cd	0	0	4 >[f]	
Cr	10	0	18[f]	
Cu	1	3	23[f]	
Pb	0	2	30[e]	
Hg	0.0	0.0	0.10	
Ni	2	0	15[f]	
Zn	20[f]	30[f]	56[f]	
Phenols	4[d]	6[e]	--	
UNITS	(mg/l)	(mg/l)		
Cn	0.00	0.00	0[f]	
COD	500[f]	290[f]	59,000 >[e]	
TKN	3.6[f]	0.56[f]	2,300 >[e]	
TVS	--	1[f]	81,900 >[f]	
Oil & Grease	--	2[e]	< 1	

*dry weight

Table D.4-24. Elutriate, Surface Water, and Bottom Sediment Data for Station 7, Calcasieu River at Hackberry. (Continued)

(US Army CE, New Orleans, 1975)

Sample No.:	2	2	2
Lab I.D. No.:	105063	105047	105047
Record No.:	3219	3187	3187
Date:	04-06-75	04-06-75	04-06-75
Time:	1001	1000	1000
	WATER QUALITY		BOTTOM SEDIMENT
SOURCE	ELUTRIATE	SURFACE WATER	SAMPLE CONCENTRATION
UNITS	(ug/1)	(ug/1)	(mg/kg*)
As	6	1	8 >[f]
Cd	0	0	1[f]
Cr	10	10	15[f]
Cu	3	3	15[f]
Pb	0	1	30
Hg	0.0	0.02[d]	0.14
Ni	1	2	10[f]
Zn	30[f]	10[f]	53[e]
Phenols	9[e]	6[e]	--
UNITS	(mg/1)	(mg/1)	
Cn	0.00	0.00	0[f]
COD	520[f]	320[f]	60,000 >[e]
TKN	4.6[f]	0.57[f]	2,300 >[e]
TVS	----	12[f]	86,800 >[e]
Oil & Grease	----	2[e]	1

*dry weight

Table D.4-24. Elutriate, Surface Water, and Bottom Sediment Data for Station 7, Calcasieu River at Hackberry. (Continued)

(US Army CE, New Orleans, 1975)

PESTICIDE ANALYSIS

Sample Location:	Calcasieu River at Hackberry - Station 7	
Sample No.:	1	1
Date:	04-04-75	04-04-75
Time:	1030	1030

Parameter	Concentration		
	Surface Water ug/l		Bottom Sediment ug/kg
Aldrin	0.00		0.0[f]
Chlordane	0.0		0[f]
DDT	0.00[f]		1.7[f]
DDE	0.00[f]		0.0[f]
Dieldrin	0.00		0.6[f]
Endrin	0.00		0.0[f]
Heptachlor epoxide	0.00[f]		0.0[f]
Heptachlor	0.00		0.0[f]
Lindane	0.00		0.0[f]
PCB	0.0		4[f]
PCN	0.0[f]		0[f]
Toxaphene	0		0[f]

Table D.4-24. Elutriate, Surface Water, and Bottom Sediment Data for Station 7, Calcasieu River at Hackberry. (Concluded)

(US Army CE, New Orleans, 1975)

PESTICIDE ANALYSIS

Sample Location:	Calcasieu River at Hackberry - Station 7	
Sample No.:	2	2
Date:	04-06-75	04-06-75
Time:	1000	1000

Parameter	Concentration	
	Surface Water ug/l	Bottom Sediment ug/kg
Aldrin	0.00	0.0 f
Chlordane	0.0	0 f
DDD	0.00 f	0.0 f
DDE	0.00 f	0.0 f
DDT	0.00	0.0 f
Dieldrin	0.00	0.8 f
Endrin	0.00	0.0 f
Heptachlor epoxide	0.00 f	0.0 f
Heptachlor	0.00	0.0 f
Lindane	0.00	0.0 f
PCB	0.0	0 f
PCN	0.0 f	0 f
Toxaphene	0	0 f

Table D.4-25. Elutriate, Surface Water, and Bottom Sediment Data, Station 8A, Calcasieu River at Mile 15.0

(US Army CE, New Orleans, 1975)

Sample No.:	1	1	1
Lab I.D. No.:	101069	101048	101048
Record No.:	2002	1960	1960
Date:	04-04-75	04-04-75	04-04-75
Time:	1101	1100	1100

	WATER QUALITY		BOTTOM SEDIMENT	
SOURCE	ELUTRIATE	SURFACE WATER	SAMPLE CONCENTRATION	
UNITS	(ug/1)	(ug/1)	(mg/kg*)	
As	6	1	7 >[f]	
Cd	0	0	2 [f]	
Cr	10	0	12 [f]	
Cu	2	3	21 [f]	
Pb	0	1	30	
Hg	0.0	0.1	0.99	
Ni	0	0	150	
Zn	30 [f]	30 [f]	54 [e]	
Phenols	15 [e]	15 [d]	--	
UNITS	(mg/1)	(mg/1)		
Cn	0.00	0.00	0 [f]	
COD	250 [f]	400 [f]	45,000	
TKN	3.2 [f]	0.49 [f]	1,900 >[f]	
TVS	---	12 [f]	73,600 [f]	
Oil & Grease	---	2 [e]	<1	

*dry weight

Table D.4-25. Elutriate, Surface Water, and Bottom Sediment Data, Station 8A, Calcasieu River at Mile 15.0 (Continued)

(US Army CE, New Orleans, 1975)

Sample No.:	2	2	2	
Lab I.D. No.:	105062	105048	105048	
Record No.:	3217	3189	3189	
Date:	04-04-75	04-04-75	04-04-75	
Time:	0946	0945	0945	
	WATER QUALITY		BOTTOM SEDIMENT	
SOURCE	ELUTRIATE	SURFACE WATER	SAMPLE CONCENTRATION	
UNITS	(ug/1)	(ug/1)	(mg/kg*)	
As	2	1	9 >[f]	
Cd	0	2	<1[f]	
Cr	10	10	13[f]	
Cu	2	6	15[f]	
Pb	0	0	20	
Hg	0.1	0.2[d]	0.10[e]	
Ni	2	2	10[f]	
Zn	30[f]	30[f]	53[f]	
Phenols	8[e]	8[d]	--	
UNITS	(mg/1)	(mg/1)		
Cn	0.00	0.00	0[f]	
COD	410[f]	450[f]	57,000 >[e]	
TKN	2.4[f]	0.61[f]	2,300 >[e]	
TVS	--	8[f]	81,500 >[e]	
Oil & Grease	--	1	1[f]	

*dry weight

Table D. 4-25. Elutriate, Surface Water, and Bottom Sediment Data, Station 8A, Calcasieu River at Mile 15.0 (Continued)

(US Army CE, New Orleans, 1975)

PESTICIDE ANALYSIS

Sample Location:	Calcasieu River - Calcasieu Lake Mile 15.0 - Station 8A	
Sample No.:	1	1
Date:	04-04-75	04-04-75
Time	1100	1100

Parameter	Concentration	
	Surface Water ug/l	Bottom Sediment ug/kg
Aldrin	0.00	0.0[f]
Chlordane	0.0	0[f]
DDD	0.00[f]	0.0[f]
DDE	0.00[f]	0.0[f]
DDT	0.00	0.0[f]
Dieldrin	0.00	0.9[f]
Endrin	0.00	0.0[f]
Heptachlor epoxide	0.00[f]	0.0[f]
Heptachlor	0.00	0.0[f]
Lindane	0.00	0.0[f]
PCB	0.0	3[f]
PCN	0.0[f]	0[f]
Toxaphene	0	0[f]

Table D.4-25. Elutriate, Surface Water, and Bottom Sediment Data, Station 8A, Calcasieu River at Mile 15.0 (Concluded)

(US Army CE, New Orleans, 1975)

PESTICIDE ANALYSIS

Sample Location: Calcasieu River - Calcasieu Lake Mile 15.0 - Station 8A

Sample No.:	2	2
Date:	04-06-75	04-06-75
Time:	0945	0945

Parameter	Concentration	
	Surface Water ug/l	Bottom Sediment ug/kg
Aldrin	0.00	0.0[f]
Chlordane	0.0	0[f]
DDD	0.00[f]	1.3[f]
DDE	0.00[f]	0.0[f]
DDT	0.0	0.0[f]
Dieldrin	0.00	0.4[f]
Endrin	0.00	0.0[f]
Heptachlor epoxide	0.00[f]	0.0[f]
Heptachlor	0.00	0.0[f]
Lindane	0.00	0.0[f]
PCB	0.0	0[f]
PCN	0.0[f]	0[f]
Toxaphene	0	0[f]

APPENDIX D.5

SABINE-NECHES RIVER BASIN
INCLUDING
COW BAYOU HYDROLOGIC DATA

This appendix consists of volumetric flow data and water quality data for the Sabine-Neches River Basin. Figure D.5-1 is a map of this basin with sample stations. Tables are listed below.

Table D.5-1	Volumetric Flow Data, Sabine River near Ruliff, Texas
Table D.5-2	Volumetric Flow Data, Cow Bayou near Mauriceville, Texas
Table D.5-3	Volumetric Flow Data, Neches River at Evadale, Texas
Table D.5-4	Water Quality Data, Sabine River near Ruliff, Texas
Table D.5-5	Water Quality in Area of Dredging in Sabine River - SN 15
Table D.5-6	Sabine River Water and Sediment Quality Data SN-15, SN-16, and SN-17
Table D.5-7	Cow Bayou Water and Sediment Quality Data CB 3 and CB 4
Table D.5-8	Water Quality Data, Neches River, Evadale, Texas
Table D.5-9	Neches River Water and Sediment Quality Data NR-2, NR-3 and NR-4

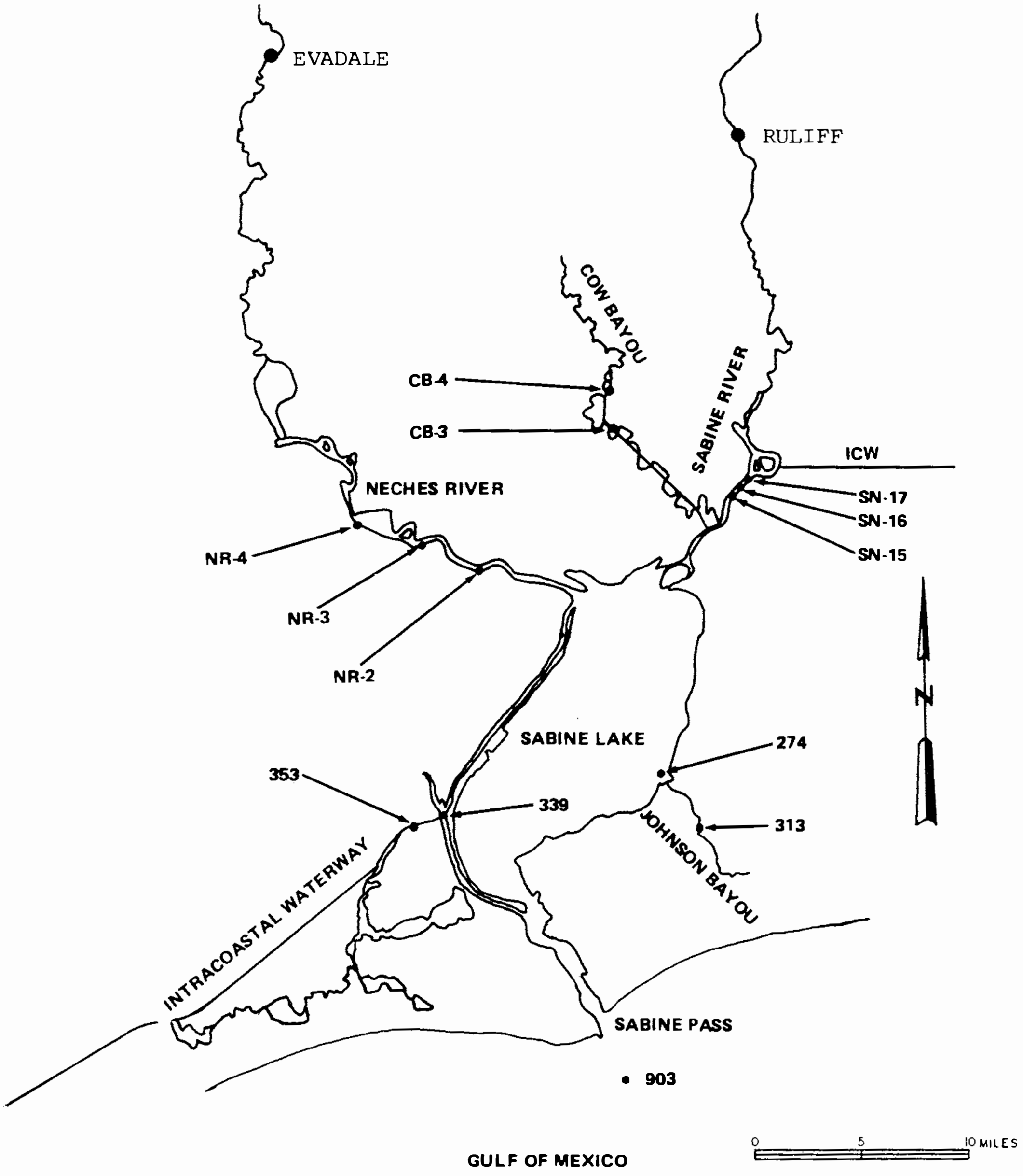


Figure D.5-1. Location of Sample Stations in the Sabine-Neches River Basin

Table D.5-1. Volumetric Flow Data, Sabine River near Ruliff, Texas

(USGS, Texas, 1975)

LOCATION.--Lat 30°18'13", long 93°44'37", Calcasieu Parish, La.-Newton County, Tex. State line, at downstream side of bridge on Texas State Highway 12, 2.4 miles (3.9 km) north of Ruliff, 4.2 miles (6.8 km) upstream from the Kansas City Southern Railway Co. bridge, 4.5 miles (7.2 km) downstream from Cypress Creek, and at mile 40.2 (64.7 km).

DRAINAGE AREA.--9,329 mi^2 (24,162 km^2).

PERIOD OF RECORD.--Discharge: October 1924 to current year.
Water quality: Chemical analyses: October 1945 to September 1946, October 1947 to current year. Chemical and biochemical analyses: October 1967 to current year. Pesticide analyses: January 1968 to current year. Water temperatures: October 1947 to current year.

GAGE.--Water-stage recorder. Datum of gage is 4.08 ft (1.244 m) above mean sea level. Prior to Mar. 1, 1941, nonrecording gage at Kansas City Southern Railway Co. bridge, 4.2 miles (6.8 km) downstream and at datum 2.02 ft (0.616 m) lower. Mar. 1, 1941, to Dec. 8, 1948, nonrecording gage at present site and datum.

AVERAGE DISCHARGE.--42 years (1924-56) prior to completion of Toledo Bend Reservoir, 8,422 ft^3/s (238.5 m^3/s), 6,102,000 acre-ft/yr (7.52 km^3/yr); 9 years (1966-75) regulated, 7,969 ft^3/s (225.7 m^3/s), 5,774,000 acre-ft/yr (7.12 km^3/yr).

EXTREMES.--Discharge: Current year: Maximum discharge, 40,700 ft^3/s (1,150 m^3/s) May 14 (gage height, 15.33 ft or 4.673 m); minimum daily, 774 ft^3/s (21.9 m^3/s) Oct. 14.
Period of record: Maximum discharge, 121,000 ft^3/s (3,430 m^3/s) May 22, 1953 (gage height, 19.98 ft or 6.090 m); minimum, 270 ft^3/s (7.65 m^3/s) Sept. 27-30, Oct. 1-3, 17-20, 1956.
Historic: Maximum stage since at least 1835, 22.2 ft (6.77 m) in May or June 1884 (adjusted to present site and datum on basis of slope of flood of June 8, 9, 1950); flood of Apr. 26-29, 1913, reached a stage of 19.5 ft (5.94 m), present site and datum, from information by local resident.
Water quality: Current year: Maximum daily specific conductance, 165 micromhos Jan. 31, Feb. 17; minimum daily, 63 micromhos Aug. 8. Maximum water temperatures, 31.0°C July 24; minimum, 9.0°C Jan. 13-16.
Period of record: Maximum daily specific conductance, 779 micromhos Aug. 31, 1966; minimum daily, 28 micromhos Sept. 19, 1963. Maximum water temperatures, 36.0°C Aug. 14, 1962; minimum, 1.0°C Jan. 28, 1948.

REMARKS.--Discharge records fair. Flow is partly regulated by Toledo Bend Reservoir (station 08025350) 116.3 miles (187.1 km) upstream.

REVISIONS (WATER YEARS).--WSP 1282: 1941(M), 1942. WSP 1442: 1925-29, 1937-39, 1943. WSP 1732: Drainage area.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3,460	3,600	14,600	32,100	17,500	25,200	17,100	9,520	24,200	12,400	7,260	7,060
2	2,550	3,210	13,600	30,800	17,200	24,100	17,100	11,500	25,700	12,800	9,910	5,380
3	2,740	2,910	12,700	29,800	17,000	23,500	17,100	14,400	24,100	13,000	10,600	4,130
4	1,940	3,020	12,700	27,400	16,900	22,600	17,100	16,000	21,400	13,400	11,000	5,160
5	1,310	3,090	13,300	26,200	16,900	21,600	17,100	16,300	18,300	13,800	11,100	6,430
6	1,100	2,610	14,300	26,200	17,800	20,200	16,900	16,200	16,700	14,400	9,670	7,130
7	1,000	2,200	15,100	29,100	19,500	19,200	16,600	18,000	15,500	14,400	8,580	7,350
8	926	2,120	15,800	31,400	21,500	18,500	17,600	24,700	14,400	14,000	9,070	7,180
9	888	2,160	17,200	29,100	22,200	18,400	18,200	33,000	14,600	13,300	9,660	5,370
10	850	2,260	19,200	28,000	21,500	18,200	17,900	34,800	13,400	12,400	9,380	4,000
11	822	2,400	20,500	27,200	20,500	17,800	17,800	36,100	10,300	11,000	8,700	5,030
12	807	2,700	19,600	25,800	19,500	17,600	17,900	38,000	11,400	9,760	7,930	5,860
13	792	3,440	18,300	26,000	18,900	17,400	18,400	39,300	14,400	9,300	6,690	6,370
14	774	3,740	17,500	26,700	18,600	17,500	18,400	40,600	18,600	9,300	6,710	6,550
15	786	3,150	17,800	25,700	18,900	18,500	18,200	39,500	20,700	8,400	7,260	6,280
16	816	2,500	17,700	23,400	19,000	19,600	16,900	35,300	19,700	6,800	7,470	4,320
17	1,230	2,120	17,700	22,200	19,000	22,100	15,900	28,600	18,500	6,480	7,650	3,440
18	1,620	2,010	17,900	20,800	19,100	22,600	14,800	22,900	17,400	6,730	7,830	5,380
19	1,400	2,220	20,800	20,100	21,500	22,600	13,800	19,800	16,200	6,860	7,750	6,950
20	1,130	4,410	24,400	19,700	26,800	22,900	12,500	18,400	14,500	6,860	6,850	7,950
21	1,000	7,360	26,500	20,200	33,400	24,700	11,600	17,400	12,900	6,380	6,740	8,160
22	909	9,760	25,400	20,300	37,300	25,500	11,200	16,100	11,400	4,600	7,190	7,620
23	864	11,900	24,900	20,300	38,400	24,400	11,200	13,900	11,000	3,910	7,750	5,190
24	822	14,100	24,900	19,700	38,000	22,100	12,100	11,200	10,600	5,570	7,860	2,860
25	798	15,500	24,700	19,000	35,900	20,300	13,300	9,940	10,400	7,200	7,320	2,780
26	813	15,400	24,400	18,500	32,800	19,200	13,700	9,760	10,600	8,490	6,840	4,460
27	920	14,200	24,200	17,800	29,400	18,600	13,200	10,200	11,200	9,210	5,610	5,420
28	895	14,200	26,200	17,800	26,700	18,000	11,900	11,700	11,600	9,080	5,810	5,870
29	920	15,000	29,600	17,800	------	17,800	9,000	14,800	11,700	7,310	6,710	5,680
30	1,140	15,600	32,500	17,600	------	17,500	7,820	18,000	12,200	5,590	7,280	3,810
31	2,920	------	33,400	17,400	------	17,200	------	21,000	------	6,240	7,270	------
TOTAL	38,942	188,890	637,400	734,100	661,700	635,400	452,320	666,920	463,600	288,970	247,450	169,170
MEAN	1,256	6,296	20,560	23,680	23,630	20,500	15,080	21,510	15,450	9,322	7,982	5,639
MAX	3,460	15,600	33,400	32,100	38,400	25,500	18,400	40,600	25,700	14,400	11,100	8,160
MIN	774	2,010	12,700	17,400	16,900	17,200	7,820	9,520	10,300	3,910	5,610	2,780
AC-FT	77,240	374,700	1,264M	1,456M	1,312M	1,260M	897,200	1,323M	919,600	573,200	490,800	335,500

CAL YR 1974 TOTAL 4,268,862 MEAN 11,700 MAX 84,000 MIN 774 AC-FT 8,467,000
WTR YR 1975 TOTAL 5,184,862 MEAN 14,210 MAX 40,600 MIN 774 AC-FT 10,280,000

Table D.5-2. Volumetric Flow Data, Cow Bayou near Mauriceville, Texas

(USGS, Texas~~,—~~1975)

LOCATION.--Lat 30°11'10", long 93°54'30", Orange County, near center of span at downstream side of bridge on State Highway 12, 0.4 mile (0.6 km) upstream from Kansas City Southern Railway Co. bridge, and 2.7 miles (4.3 km) southwest of Mauriceville.

DRAINAGE AREA.--83.3 mi² (215.7 km²).

PERIOD OF RECORD.--March 1952 to current year (October 1956 to September 1957, monthly discharge only).

GAGE.--Water-stage recorder. Datum of gage is 4.73 ft (1.442 m) above mean sea level. Prior to Oct. 23, 1957, nonrecording gage at same site and datum.

AVERAGE DISCHARGE.--23 years, 96.6 ft³/s (2.736 m³/s), 15.75 in/yr (400 mm/yr), 69,990 acre-ft/yr (86.3 hm³/yr).

EXTREMES.--Current year: Maximum discharge, 2,060 ft³/s (58.3 m³/s) June 10 (gage height, 15.77 ft or 4.807 m); minimum, 0.05 ft³/s (0.001 m³/s) Oct. 18-22.
Period of record: Maximum discharge, 4,600 ft³/s (130 m³/s) Sept. 19, 1963 (gage height, 18.15 ft or 5.532 m); no flow at times. Maximum stage since at least 1940, 18.16 ft (5.535 m) Oct. 28, 1970.

REMARKS.--Records fair. No large diversion above station. Base flow is partly sustained by springs.

REVISIONS.--WSP 1732: Drainage area.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	.08	2.3	38	406	17	11	7.7	481	999	200	100	31
2	.08	2.1	28	319	22	9.2	6.6	391	1,040	250	153	20
3	.08	1.4	21	281	34	7.9	5.6	434	980	300	245	13
4	.10	48	15	227	260	30	4.8	446	822	320	451	37
5	.11	63	12	170	249	43	3.8	394	525	300	643	228
6	.11	25	16	128	212	35	3.1	303	282	250	649	375
7	.11	11	23	468	188	38	2.5	214	152	150	469	392
8	.11	22	20	883	161	40	99	275	62	70	461	408
9	.11	15	21	830	131	37	243	226	719	40	445	404
10	.09	12	26	870	102	35	297	184	2,020	25	316	348
11	.06	25	43	937	77	32	422	205	1,780	15	269	263
12	.06	17	49	942	60	27	353	242	1,420	10	227	173
13	.07	16	47	894	45	34	260	226	1,120	8.0	165	92
14	.06	15	53	772	35	53	550	194	869	12	83	54
15	.17	10	221	586	26	73	659	156	551	25	45	30
16	.09	6.7	147	413	47	93	625	127	283	35	32	20
17	.06	74	122	297	106	95	610	89	141	31	29	26
18	.05	53	129	353	87	116	545	86	43	17	17	23
19	.05	47	145	269	74	124	415	103	15	10	10	17
20	.05	111	134	143	53	136	291	112	13	8.6	7.0	13
21	.05	102	111	96	36	144	205	97	28	7.5	5.7	9.9
22	.05	98	85	71	27	143	152	63	25	7.2	5.3	8.0
23	.06	119	65	53	25	126	108	36	28	39	5.9	6.7
24	.06	137	53	57	21	93	83	19	79	125	18	5.1
25	.06	143	82	76	17	63	61	13	73	178	30	3.6
26	.06	115	310	56	14	42	39	8.9	145	184	60	2.7
27	.06	91	484	43	12	28	23	5.9	154	152	104	1.8
28	.33	79	509	33	12	20	15	148	137	147	102	1.3
29	2.2	65	531	27	------	15	12	750	120	143	75	.86
30	1.5	51	523	22	------	12	249	848	150	110	58	.59
31	1.1	------	484	18	------	9.6	------	933	------	92	46	------
TOTAL	7.23	1,576.5	4,547	10,740	2,150	1,764.7	6,350.1	7,809.8	14,775	3,261.3	5,325.9	3,007.55
MEAN	.23	52.6	147	346	76.8	56.9	212	252	493	105	172	100
MAX	2.2	143	531	942	260	144	659	933	2,020	320	649	408
MIN	.05	1.4	12	18	12	7.9	2.5	5.9	13	7.2	5.3	.59
CFSM	.003	.63	1.76	4.15	.92	.68	2.55	3.03	5.92	1.26	2.06	1.20
IN.	.003	.70	2.03	4.80	.96	.79	2.84	3.49	6.60	1.46	2.38	1.34
AC-FT	14	3,130	9,020	21,300	4,260	3,500	12,600	15,490	29,310	6,470	10,560	5,970

CAL YR 1974 TOTAL 29,774.55 MEAN 81.6 MAX 1,240 MIN .05 CFSM .98 IN 13.30 AC-FT 59,060
WTR YR 1975 TOTAL 61,315.08 MEAN 168 MAX 2,020 MIN .05 CFSM 2.02 IN 27.38 AC-FT 121,600

PEAK DISCHARGE (BASE, 900 FT³/S)

DATE	TIME	G.HT.	DISCHARGE
1-12	1300	12.13	946
6- 2	0900	12.56	1,040
6-10	0500	15.77	2,060

Table D.5-3 Volumetric Flow Data, Neches River at Evadale, Texas (USGS, Texas, 1975)

NECHES RIVER BASIN

08041000 Neches River at Evadale, Tex.
(National stream-quality accounting network)

LOCATION.--Lat 30°21'22", long 94°05'36", Jasper-Hardin County line, near center of channel on downstream side of pier of bridge on U.S. Highway 96 at Evadale, 0.8 mile (1.3 km) upstream from Mill Creek, 16 miles (26 km) upstream from Village Creek, and at mile 55.6 (89.5 km).

DRAINAGE AREA.--7,951 mi^2 (20,593 km^2).

PERIOD OF RECORD.--Discharge: July 1904 to December 1906, April 1921 to current year. Monthly discharge only for some periods, published in WSP 1312.

Water quality: Chemical and biochemical analyses: October 1947 to current year. Pesticide analyses: January 1968 to current year. Water temperatures: October 1947 to current year. Sediment records: October 1974 to September 1975.

GAGE.--Water-stage recorder. Datum of gage is 8.25 ft (2.515 m) above mean sea level. July 1, 1904, to Dec. 31, 1906, nonrecording gage on Gulf, Colorado, and Santa Fe Railway Co. bridge at site 1.2 miles (1.9 km) downstream at datum 5.50 ft (1.676 m) lower; Apr. 1, 1921, to Dec. 7, 1948, nonrecording gages at site 1.2 miles (1.9 km) downstream at present datum; Dec. 8, 1948, to Nov. 8, 1963, water-stage recorder at site 1.2 miles (1.9 km) downstream at present datum.

AVERAGE DISCHARGE.--45 years (1904-6, 1921-64) prior to regulation by Sam Rayburn Reservoir, 6,308 ft^3/s (178.6 m^3/s), 4,570,000 acre-ft/yr (5.63 km^3/yr); 11 years (1964-75) regulated, 5,184 ft^3/s (146.8 m^3/s), 3,756,000 acre-ft/yr (4.63 km^3/yr).

EXTREMES.--Discharge: Current year: Maximum discharge, 19,800 ft^3/s (561 m^3/s) Jan. 26, 27 (gage height, 16.74 ft or 5.102 m); minimum daily, 1,780 ft^3/s (50.4 m^3/s) Sept. 19.

Period of record: Maximum discharge, 92,100 ft^3/s (2,610 m^3/s) May 11, 1944 (gage height, 23.58 ft or 7.187 m, from floodmark), at site then in use; minimum daily, 63 ft^3/s (1.78 m^3/s) Nov. 26-28, 1956.

Historic: Flood in May 1884 (stage 26.2 ft or 7.99 m at former site, discharge about 125,000 ft^3/s or 3,540 m^3/s) and flood in August 1915 (stage 24.5 ft or 7.47 m at former site, discharge about 102,000 ft^3/s or 2,890 m^3/s) are the highest since at least 1884. Stages by Gulf, Colorado, and Santa Fe Railway Co.

Water quality: Current year: Maximum daily specific conductance, 177 micromhos Sept. 30; minimum daily, 98 micromhos June 1. Maximum water temperatures, 30.0°C on several days during August; minimum, 8.0°C Dec. 4, Jan. 13, 15.

Period of record: Maximum daily specific conductance, 422 micromhos Jan. 25, 1957; minimum daily, 23 micromhos Sept. 19, 1963. Maximum water temperatures, 34.0°C June 29, 1953; minimum, 3.0°C Jan. 30, 31, 1948, Jan. 31, 1949, and Jan. 24, 1963.

REMARKS.--Discharge records fair. Flow regulated by B. A. Steinhagen Lake (station 08040000) 58.1 miles (93.5 km) upstream (capacity, 124,700 acre-ft or 154 hm^3) and Sam Rayburn Reservoir (station 08039300) 95.7 miles (154.0 km) upstream (capacity, 4,442,000 acre-ft or 5.48 km^3). Some diversions upstream for municipal use.

REVISIONS (WATER YEARS).--WSP 718: 1929. WSP 1342: 1905-7, 1924. WSP 1732: Drainage area at former site.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4,710	3,050	7,650	9,540	13,800	18,900	9,630	8,420	16,600	8,290	8,020	8,470
2	4,190	3,250	7,610	8,410	11,300	18,800	9,210	9,050	16,200	8,770	7,990	8,900
3	3,150	4,520	7,570	7,640	10,500	18,700	8,710	9,860	15,900	9,450	7,960	8,190
4	2,610	6,310	7,470	7,080	12,700	18,800	8,520	10,500	15,000	9,470	8,040	6,790
5	2,470	7,410	7,030	6,850	15,700	19,200	8,690	10,700	12,200	8,930	8,220	6,000
6	2,350	7,840	6,750	7,380	16,500	19,200	8,930	10,800	7,790	8,560	8,090	5,650
7	2,310	7,670	7,250	9,220	16,400	19,500	8,970	11,700	7,400	8,370	8,100	5,490
8	2,290	7,380	8,540	11,700	16,000	19,500	9,020	14,600	7,360	8,260	8,510	5,420
9	2,270	7,150	9,470	13,900	15,600	18,400	8,770	16,600	7,360	8,210	8,910	5,390
10	2,120	6,840	9,630	16,400	15,300	16,700	8,120	17,300	8,190	8,160	9,050	5,370
11	2,080	6,630	9,580	17,600	15,400	15,100	6,520	17,800	9,340	8,200	9,040	5,370
12	2,240	6,100	10,000	18,200	15,600	14,100	5,490	18,600	11,200	8,240	8,530	5,390
13	2,300	5,520	11,300	17,200	15,900	14,100	6,160	18,800	13,400	8,240	7,900	5,540
14	2,310	5,630	13,200	17,500	16,900	14,200	7,350	18,800	12,400	8,290	7,550	5,570
15	2,390	5,650	15,400	16,100	18,000	14,200	7,750	19,000	8,120	8,250	7,380	5,050
16	2,420	5,650	16,400	15,000	18,800	14,800	8,470	19,200	6,920	8,010	6,930	3,270
17	2,410	5,850	16,800	14,400	19,300	15,700	9,260	19,100	6,160	7,100	6,440	2,130
18	2,370	6,230	16,600	14,200	19,400	16,300	9,750	19,000	6,080	6,310	6,200	1,850
19	2,330	7,130	15,600	14,500	19,400	14,800	10,300	18,800	6,430	6,190	6,150	1,780
20	2,310	7,770	14,400	14,900	19,400	13,200	10,500	18,600	7,230	6,330	6,520	1,920
21	2,290	8,420	13,500	15,500	19,400	12,000	10,300	18,300	8,480	6,330	6,870	3,280
22	2,280	8,970	12,200	15,900	19,500	11,000	10,300	17,500	9,520	6,090	6,330	3,920
23	2,280	9,200	10,500	16,000	19,600	10,300	10,000	16,900	10,100	5,810	5,420	4,090
24	2,270	8,970	8,670	17,000	19,500	10,000	10,100	16,600	10,300	5,720	4,920	4,040
25	2,270	8,500	7,420	18,400	19,600	9,830	10,100	16,700	9,750	5,830	4,690	3,810
26	2,270	8,180	7,170	19,500	19,400	9,720	9,300	16,300	8,860	6,550	4,600	3,580
27	2,260	8,100	7,460	19,800	19,200	9,690	8,210	15,400	8,370	7,540	4,570	3,170
28	2,330	7,980	8,370	19,300	18,900	9,690	7,740	15,000	8,210	8,290	4,550	2,810
29	2,660	7,840	9,280	18,200	------	9,690	7,330	16,000	8,180	8,370	4,730	2,730
30	3,090	7,700	9,820	17,000	------	9,690	7,620	17,000	8,190	8,060	5,920	2,680
31	3,250	------	10,100	15,700	------	9,690	------	17,000	------	7,990	7,410	------
TOTAL	78,880	207,440	322,740	450,020	477,000	445,500	261,120	489,930	291,240	238,210	215,540	137,650
MEAN	2,545	6,915	10,410	14,520	17,040	14,370	8,704	15,800	9,708	7,684	6,953	4,588
MAX	4,710	9,200	16,800	19,800	19,600	19,500	10,500	19,200	16,600	9,470	9,050	8,900
MIN	2,080	3,050	6,750	6,850	10,500	9,690	5,490	8,420	6,080	5,720	4,550	1,780
AC-FT	156,500	411,500	640,200	892,600	946,100	883,600	517,900	971,800	577,700	472,500	427,500	273,000

CAL YR 1974 TOTAL 3,327,030 MEAN 9,115 MAX 26,900 MIN 2,080 AC-FT 6,599,000
WTR YR 1975 TOTAL 3,615,270 MEAN 9,905 MAX 19,800 MIN 1,780 AC-FT 7,171,000

Note: Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-4. Water Quality Data, Sabine River near Ruliff. Texas

(USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	TIME	DISSOLVED ALUMINUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	DISSOLVED BORON (B) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	DISSOLVED CHROMIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)
OCT. 23...	1645	100^{f}	2	2	50	$<10^{\bullet}$	0	0	0	$<50^{f}$
FEB. 12...	0900	30^{f}	0	0	40	20^{c}	0	0	10	$<50^{f}$
APR. 09...	1420	20^{f}	0	0	30	10^{c}	0	0	10	$<50^{f}$
AUG. 06...	1300	40^{f}	1	1	50	$<10^{\bullet}$	0	0	0	$<50^{f}$

DATE	DISSOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DISSOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DISSOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	DISSOLVED LITHIUM (LI) (UG/L)	TOTAL MANGANESE (MN) (UG/L)
OCT. 23...	1^{f}	<10	0	1700^{c}	250	$<100^{\bullet}$	8^{f}	0	400^{f}
FEB. 12...	0	<10	2	,960	10	100^{c}	4^{f}	0	70^{f}
APR. 09...	0	<10	4	1300^{c}	120	$<100^{\bullet}$	1^{f}	10^{f}	90^{f}
AUG. 06...	0	<10	2	1800^{c}	140	$<100^{\bullet}$	0	10^{f}	130^{f}

DATE	DISSOLVED MANGANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL SELENIUM (SE) (UG/L)	DISSOLVED SELENIUM (SE) (UG/L)	DISSOLVED STRONTIUM (SR) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
OCT. 23...	380^{f}	.0	.0	1	0	0	100^{f}	$190^{\bullet}$	$120^{\bullet}$
FEB. 12...	10^{f}	$.1^{c}$	$.1^{c}$	1	0	0	130^{f}	10	100
APR. 09...	20^{f}	.0	.0	0	0	0	120^{f}	30	30
AUG. 06...	20^{f}	.0	.0	11	0	0	70^{f}	20	30

DATE	TIME	INSTANTANEOUS DISCHARGE (CFS)	TEMPERATURE (DEG C)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MATERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDT (UG/L)	DDT IN BOTTOM MATERIAL (UG/KG)
OCT. 23...	1645	857	22.5	.00	.0	.00	.0	.00	.0	.00	.0
FEB. 12...	0900	16000	12.5	.00	.0	.00	.0	.00	.0	.00	.0
APR. 09...	1420	17500	17.5	.00	.0	.00	.0	.00	.0	.00	.0
AUG. 06...	1300	8400	27.0	.00	.0	.00	.0	.00	.0	.00	.0

DATE	TOTAL DIELDRIN (UG/L)	DIELDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL HEPTACHLOR (UG/L)	HEPTACHLOR IN BOTTOM MATERIAL (UG/KG)	TOTAL HEPTACHLOR EPOXIDE (UG/L)	HEPTACHLOR EPOXIDE IN BOTTOM MATERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL CHLORDANE (UG/L)
OCT. 23...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0
FEB. 12...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0
APR. 09...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0
AUG. 06...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0

DATE	CHLORDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MATERIAL (UG/KG)	TOTAL DIAZINON (UG/L)	TOTAL MALATHION (UG/L)	TOTAL METHYL PARATHION (UG/L)	TOTAL PARATHION (UG/L)	TOTAL 2,4-D (UG/L)	TOTAL SILVEX (UG/L)	TOTAL 2,4,5-T (UG/L)
OCT. 23...	0	.0	0	.00	.00	.00	.00	$.08^{f}$	.00	.00
FEB. 12...	0	.0	0	.00	.00	.00	.00	.00	.00	.00
APR. 09...	0	.0	0	.00	.00	.00	.00	.00	.00	.00
AUG. 06...	0	.0	0	.00	.00	.00	.00	.00	.00	$.01^{f}$

Note: Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-4 Water Quality Data, Sabine River near Ruliff, Texas (Continued)

(USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	TIME	INSTANTANEOUS DISCHARGE (CFS)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)
OCT.										
01...	0702	3700	7.4^{f}	8.0^{f}	2.2^{f}	12^{f}	2.6^{f}	23^{f}	0	13
08...	0700	850	--	--	--	--	--	--	--	7.2
14...	0608	760	--	--	--	--	--	--	--	3.2
22...	0705	890	--	--	--	--	--	--	--	4.0
23...	1645	857	15^{f}	7.5^{f}	1.3^{f}	12^{f}	2.1^{f}	28^{f}	0	10
NOV.										
07...	0650	2200	11^{f}	5.0^{f}	1.0^{f}	10^{f}	2.2^{f}	17^{f}	0	12
13...	1330	4450	11^{f}	4.5^{f}	1.1^{f}	11^{f}	2.4^{f}	16^{f}	0	11
15...	0640	3100	--	--	--	--	--	--	--	7.2
22...	0700	8500	--	--	--	--	--	--	--	7.6
30...	0610	15500	--	--	--	--	--	--	--	12
DEC.										
07...	0630	16200	6.4^{f}	7.5^{f}	2.8^{f}	13^{f}	3.4^{f}	23^{f}	0	13
11...	0945	18000	7.0^{f}	6.6^{f}	1.7^{f}	11^{f}	2.2^{f}	19^{f}	0	11
14...	0635	22500	--	--	--	--	--	--	--	11
21...	0605	25500	--	--	--	--	--	--	--	12
30...	0700	33000	--	--	--	--	--	--	--	10
JAN.										
07...	0644	26000	5.8^{f}	7.5^{f}	2.9^{f}	13^{f}	3.1^{f}	24^{f}	0	12
08...	1700	29000	6.4^{f}	7.3^{f}	2.1^{f}	11^{f}	2.5^{f}	22^{f}	0	10
14...	0645	27000	--	--	--	--	--	--	--	9.6
21...	0657	21000	--	--	--	--	--	--	--	12
29...	0655	18500	--	--	--	--	--	--	--	13
FEB.										
07...	0700	18000	6.8^{f}	7.7^{f}	3.0^{f}	13^{f}	1.5^{f}	24^{f}	0	11
12...	0900	16000	6.5	8.5^{f}	2.7^{f}	15^{f}	2.5^{f}	28^{f}	0	15
14...	0700	17800	--	--	--	--	--	--	--	13
21...	0700	29000	--	--	--	--	--	--	--	8.8
28...	0645	25000	--	--	--	--	--	--	--	15
MAR.										
07...	0700	18500	--	--	--	--	--	--	--	17
14...	0700	17000	--	--	--	--	--	--	--	16
19...	0830	20000	7.8^{f}	5.0^{f}	2.2^{f}	12^{f}	2.6^{f}	18^{f}	0	13
21...	0700	22000	--	--	--	--	--	--	--	13
28...	0700	17500	--	--	--	--	--	--	--	13
APR.										
08...	0645	16500	--	--	--	--	--	--	--	13
09...	1420	17500	7.3^{f}	7.1^{f}	2.8^{f}	12^{f}	1.6^{f}	21^{f}	0	15
15...	0645	17200	--	--	--	--	--	--	--	14
22...	0645	12000	--	--	--	--	--	--	--	18
29...	0640	10200	--	--	--	--	--	--	--	14
MAY										
07...	0638	16750	--	--	--	--	--	--	--	9.2
13...	1330	38000	5.0^{f}	5.9^{f}	2.0^{f}	10^{f}	2.4^{f}	15^{f}	0	14
14...	0643	40520	--	--	--	--	--	--	--	16
21...	0643	17330	--	--	--	--	--	--	--	18
28...	0640	11250	--	--	--	--	--	--	--	13
JUNE										
01...	0648	23750	--	--	--	--	--	--	--	12
04...	1345	19000	6.4^{f}	5.7^{f}	2.2^{f}	9.9^{f}	1.8^{f}	14^{f}	0	12
08...	0617	14350	--	--	--	--	--	--	--	14
14...	0613	18350	--	--	--	--	--	--	--	10
21...	0650	14100	--	--	--	--	--	--	--	14
JULY										
07...	0643	15000	--	--	--	--	--	--	--	10
09...	1245	13700	7.4^{f}	6.2^{f}	3.2^{f}	11^{f}	2.0^{f}	19^{f}	0	14
14...	0644	10400	--	--	--	--	--	--	--	10
21...	0643	6900	--	--	--	--	--	--	--	23
21...	1715	--	--	--	--	--	--	--	--	--
28...	0644	10300	--	--	--	--	--	--	--	13
AUG.										
06...	1300	8400	8.3^{f}	4.3^{f}	1.2^{f}	7.1^{f}	1.4^{f}	13^{f}	0	9.4
07...	0611	8460	--	--	--	--	--	--	--	6.0
14...	0642	6680	--	--	--	--	--	--	--	15
21...	0640	6590	--	--	--	--	--	--	--	16
28...	0640	5440	--	--	--	--	--	--	--	22
SEP.										
07...	0700	7360	--	--	--	--	--	--	--	15
10...	1315	4010	10^{f}	7.0^{f}	3.0^{f}	12^{f}	2.0^{f}	24^{f}	0	11
14...	0645	6560	--	--	--	--	--	--	--	17
21...	0703	7720	--	--	--	--	--	--	--	16
29...	0645	6000	--	--	--	--	--	--	--	18

Note: Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-4 Water Quality Data, Sabine River near Ruliff, Texas (Continued) (USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED FLUO-RIDE (F) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	AMMONIA NITRO-GEN (N) (MG/L)	TOTAL ORGANIC NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	TOTAL PHOS-PHORUS (P) (MG/L)	DIS-SOLVED SOLIDS (RESI-DUE AT 180 C) (MG/L)
OCT.									
01...	16	.1^{f}	--	--	--	--	--	--	--
08...	20	--	--	--	--	--	--	--	--
14...	18	--	--	--	-	--	--	--	--
22...	14	--	--	--		--	--^{f}	--^{c}	--^{f}
23...	11	--	.01	.00		.76^{f}	.87	.05	91
NOV.									
07...	11	.0^{f}	--	--	- ●	--^{f}	--^{f}	--^{c}	--^{f}
13...	11	--	.06	.00	.09	1.1	1.2	.07	77
15...	14	--	--	--	--	--	--	--	--
22...	20	--	--	--	--	--	--	--	--
30...	22	--	--	--	--	--	--	--	--
DEC.									
07...	19	.1^{f}	--	--	- ●	--^{f}	--^{f}	--^{c}	--^{f}
11...	16	.1^{f}	.08	.00	.1	.43	.61	.06	82
14...	23	--	--	--	-	--	--	--	--
21...	25	--	--	--	-	--	--	--	--
30...	21	--	--	--	--	--	--	--	--
JAN.									
07...	19	.1^{f}	--	--	-- ●	--^{f}	--^{f}	--^{c}	--^{f}
08...	18	.0^{f}	.12	.01	.08	.68	.76	.07	84
14...	20	--	--	--	--	--	--	--	--
21...	25	--	--	--	--	--	--	--	--
29...	29	--	--	--	--	--	--	--	--
FEB.									
07...	20	.1^{f}	--	--	--	--^{f}	--^{f}	--^{c}	--^{f}
12...	22	.1^{f}	.18	.00	.03	.62	.65	.01	105
14...	27	--	--	--	--	--	--	--	--
21...	25	--	--	--	--	--	--	--	--
28...	26	--	--	--	--	--	--	--	--
MAR.									
07...	25	--	--	--	--	--	--	--	--
14...	23	--^{f}	--	--	--	--^{f}	--^{f}	--^{c}	--^{f}
19...	16	.1	.11	.00	.02	.38	.40	.04	88
21...	18	--	--	--	--	--	--	--	--
28...	21	--	--	--	--	--	--	--	--
APR.									
08...	21	--^{f}	--	--	--	--^{f}	--^{f}	--^{c}	--^{f}
09...	19	.1	.14	.00	.03	.53	.56	.04	81
15...	17	--	--	--	--	--	--	--	--
22...	19	--	--	--	--	--	--	--	--
29...	18	--	--	--	--	--	--	--	--
MAY									
07...	13	--^{f}	--	--	--	--^{f}	--^{f}	--^{c}	--^{f}
13...	15	.0	.11	.00	.03	.60	.63	.03	75
14...	16	--	--	--	--	--	--	--	--
21...	'20	--	--	--	--	--	--	--	--
28...	19	--	--	--	--	--	--	--	--
JUNE									
01...	15	--^{f}	--	--	--	--^{f}	--^{f}	--^{c}	--^{f}
04...	13	.1	.04	.00	.01	.64	.65	.04	77
08...	18	--	--	--	--	--	--	--	--
14...	13	--	--	--	--	--	--	--	--
21...	18	--	--	--	--	--	--	--	--
JULY									
07...	18	--^{f}	--	--	--	--^{f}	--^{f}	--^{c}	--^{f}
09...	15	.1	.02	.01	.03	.47	.50	.04	81
14...	12	--	--	--	--	--	--	--	--
21...	19	--	--	--	--	--^{f}	--^{f}	--^{c}	--
21...	--	--	.02	.00	.02	.38	.40	.03	--
28...	17	--	--	--	--	--	--	--	--
AUG.									
06...	9.2	.1^{f}	.09	.01	.04	1.1^{f}	1.1^{f}	.03^{c}	72^{f}
07...	10	--	--	--	--	--	--	--	--
14...	17	--	--	--	--	--	--	--	--
21...	19	--	--	--	--	--	--	--	--
28...	19	--	--	--	--	--	--	--	--
SEP.									
07...	20	--^{f}	--	--	--	--^{f}	--^{f}	--^{c}	--^{f}
10...	16	.1	.04	.00	.03	.64	.67	.04	79
14...	20	--	--	--	--	--	--	--	--
21...	18	--	--	--	--	--	--	--	--
29...	21	--	--	--	--	--	--	--	--

Note: Sample station locations are shown in Figure D.5-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.5-4. Water Quality Data, Sabine River near Ruliff, Texas (Continued)

(USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	DIS-SOLVED SOLIDS (SUM OF CONSTI-TUENTS) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	VOL. NON-FILT-RABLE RESIDUE (MG/L)	HARD-NESS (CA,MG) (MG/L)	NON-CAR-BONATE HARD-NESS (MG/L)	SODIUM AD-SORP-TION RATIO	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	TEMPER-ATURE (DEG C)
OCT.									
01...	73	--	--	29^{f}	10^{f}	1.0^{f}	136	6.7	24.0
08...	--	--	--	--	--	--	155	--	24.0
14...	--	--	--	--	--	--	141	--	24.0
22...	--	--	--	--	--	--	96	--	19.0
23...	74	43^{f}	15^{f}	24^{f}	1^{f}	1.1^{f}	119	6.7	22.5
NOV.									
07...	61	--	--	17^{f}	3^{f}	1.1^{f}	95	6.3^{c}	18.0
13...	60	86^{f}	40^{f}	16^{f}	3^{f}	1.2^{f}	98	6.8	17.5
15...	--	--	--	--	--	--	82	--	14.0
22...	--	--	--	--	--	--	102	--	18.0
30...	--	--	--	--	--	--	132	--	15.0
DEC.									
07...	77	--	--	30^{f}	11^{f}	1.0^{f}	141	6.7	13.0
11...	65	48^{f}	21^{f}	23^{f}	8	1.0^{f}	119	6.6	10.5
14...	--	--	--	--	--	--	128	--	11.0
21...	--	--	--	--	--	--	138	--	12.0
30...	--	--	--	--	--	--	108	--	14.0
JAN.									
07...	75	--	--	31^{f}	11^{f}	1.0^{f}	137	7.1	13.0
08...	68	24^{f}	4^{f}	27^{f}	9^{f}	.9^{f}	121	6.9	14.5
14...	--	--	--	--	--	--	113	--	9.0
21...	--	--	--	--	--	--	144	--	12.0
29...	--	--	--	--	--	--	162	--	16.0
FEB.									
07...	75	--	--	32^{f}	12^{f}	1.0^{f}	141	6.8	14.0
12...	86	15^{f}	9^{f}	33^{f}	10^{f}	1.1^{f}	156	7.0	12.5
14...	--	--	--	--	--	--	162	--	13.0
21...	--	--	--	--	--	--	148	--	14.0
28...	--	--	--	--	--	--	159	--	13.0
MAR.									
07...	--	--	--	--	--	--	157	--	11.0
14...	--	--	--	--	--	--	157	--	17.0
19...	68	87^{f}	36^{f}	22^{f}	7^{f}	1.1^{f}	128	7.0	15.0
21...	--	--	--	--	--	--	115	--	14.0
28...	--	--	--	--	--	--	141	--	17.0
APR.									
08...	--	--	--	--	--	--	142	--	17.0
09...	76	44^{f}	16^{f}	29^{f}	12^{f}	1.0^{f}	139	7.1	17.5
15...	--	--	--	--	--	--	117	--	14.0
22...	--	--	--	--	--	--	134	--	18.0
29...	--	--	--	--	--	--	123	--	22.0
MAY									
07...	--	--	--	--	--	--	88	--	24.0
13...	62	53^{f}	9^{f}	23^{f}	11^{f}	.9^{f}	117	6.7	22.5
14...	--	--	--	--	--	--	115	--	23.0
21...	--	--	--	--	--	--	129	--	26.0
28...	--	--	--	--	--	--	129	--	26.0
JUNE									
01...	--	--	--	--	--	--	94	--	24.0
04...	58	189^{f}	167^{f}	23^{f}	12^{f}	.9^{f}	106	6.6	24.5
08...	--	--	--	--	--	--	119	--	26.0
14...	--	--	--	--	--	--	80	--	26.0
21...	--	--	--	--	--	--	114	--	26.0
JULY									
07...	--	--	--	--	--	--	117	--	26.0
09...	68	66^{f}	3^{f}	29^{f}	13^{f}	.9^{f}	124	6.6	29.5
14...	--	--	--	--	--	--	86	--	29.0
21...	--	--	--	--	--	--	131	--	30.0
21...	--	--	--	--	--	--	--	--	29.5
28...	--	--	--	--	--	--	105	--	28.0
AUG.									
06...	48	140^{f}	3^{f}	16^{f}	5^{f}	.8^{f}	75	6.4^{c}	27.0
07...	--	--	--	--	--	--	76	--	26.0
14...	--	--	--	--	--	--	123	--	28.0
21...	--	--	--	--	--	--	134	--	29.0
28...	--	--	--	--	--	--	152	--	27.0
SEP.									
07...	--	--	--	--	--	--	142	--	28.0
10...	73	57^{f}	10^{f}	30^{f}	10^{f}	1.0^{f}	133	6.7	27.5
14...	--	--	--	--	--	--	141	--	27.0
21...	--	--	--	--	--	--	123	--	25.0
29...	--	--	--	--	--	--	147	--	22.0

Note: Sample station locations are shown in Figure D.5-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.5-4 Water Quality Data, Sabine River near Ruliff, Texas (Concluded)

(USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	PERCENT SATURATION	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	STREPTOCOCCI (COLONIES PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)
OCT.									
01...	30^f	--	--	--	--	--	--	--	--
08...	40^f	--	--	--	--	--	--	--	--
14...	40^f	--	--	--	--	--	--	--	--
22...	70^f	--	--	--	--	--	--	--	--
23...	80^f	20^f	9.4	107	1.6^f	150^f	60	29^f	10^f
NOV.									
07...	80^f	--	--	--	--	--	--	--	--
13...	40^f	45^f	10.2	106	1.8^f	1800^f	450^a	820^f	10^f
15...	90^f	--	--	--	--	--	--	--	--
22...	80^f	--	--	--	--	--	--	--	--
30...	50^f	--	--	--	--	--	--	--	--
DEC.									
07...	60^f	--	--	--	--	--	--	--	--
11...	50^f	20^f	7.9	71	1.0^f	3100^f	270^a	350^f	12^f
14...	40^f	--	--	--	--	--	--	--	--
21...	50^f	--	--	--	--	--	--	--	--
30...	70^f	--	--	--	--	--	--	--	--
JAN.									
07...	60^f	--	--	--	--	--	--	--	--
08...	60^f	20^f	10.0	97	1.2^f	1400^f	820^a	110^f	9.0^f
14...	100^f	--	--	--	--	--	--	--	--
21...	60^f	--	--	--	--	--	--	--	--
29...	55^f	--	--	--	--	--	--	--	--
FEB.									
07...	100^f	--	--	--	--	--	--	--	--
12...	20^f	15^f	9.0	84	.7^f	190^f	97	78^f	8.8^f
14...	60^f	--	--	--	--	--	--	--	--
21...	100^f	--	--	--	--	--	--	--	--
28...	70^f	--	--	--	--	--	--	--	--
MAR.									
07...	80^f	--	--	--	--	--	--	--	--
14...	70^f	--	--	--	--	--	--	--	--
19...	60^f	50^f	8.5	83	1.2^f	620^f	130	130^f	10^f
21...	80^f	--	--	--	--	--	--	--	--
28...	70^f	--	--	--	--	--	--	--	--
APR.									
08...	70^f	--	--	--	--	--	--	--	--
09...	60^f	20^f	8.9	93	1.0^f	1400^f	310^a	2000^f	6.9^f
15...	80^f	--	--	--	--	--	--	--	--
22...	70^f	--	--	--	--	--	--	--	--
29...	80^f	--	--	--	--	--	--	--	--
MAY									
07...	120^f	--	--	--	--	--	--	--	--
13...	70^f	30^f	6.9	78	1.4^f	7100^f	110	130^f	6.4^f
14...	70^f	--	--	--	--	--	--	--	--
21...	60^f	--	--	--	--	--	--	--	--
28...	70^f	--	--	--	--	--	--	--	--
JUNE									
01...	70^f	--	--	--	--	--	--	--	--
04...	60^f	20^f	6.8	81	1.1^f	550^f	207^a	50^f	9.9^f
08...	70^f	--	--	--	--	--	--	--	--
14...	100^f	--	--	--	--	--	--	--	--
21...	80^f	--	--	--	--	--	--	--	--
JULY									
07...	70^f	--	--	--	--	--	--	--	--
09...	70^f	25^f	6.5	84	1.0^f	400^f	210^a	62^f	7.2^f
14...	110^f	--	--	--	--	--	--	--	--
21...	50^f	--	--	--	--	--	--	--	--
21...	--	--	--	--	--	--	--	--	--
28...	70^f	--	--	--	--	--	--	--	--
AUG.									
06...	120^f	45^f	6.4	79	1.3^f	2100^f	130	150^f	11^f
07...	140^f	--	--	--	--	--	--	--	--
14...	60^f	--	--	--	--	--	--	--	--
21...	50^f	--	--	--	--	--	--	--	--
28...	60^f	--	--	--	--	--	--	--	--
SEP.									
07...	30^f	--	--	--	--	--	--	--	--
10...	60^f	35^f	6.2	78	1.0^f	1800^f	64	78^f	13^f
14...	50^f	--	--	--	--	--	--	--	--
21...	70^f	--	--	--	--	--	--	--	--
29...	40^f	--	--	--	--	--	--	--	--

Note: Sample station locations are shown in Figure D.5-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.5-5 Water Quality in Area of Dredging in Sabine River - SN 15

(US Army CE, Galveston, 1975)

PART (A)

	Sample No.	Date Sampled	Dist-Ft From C	Water Depth MLT-Ft	Water Temp °C	Dissolved Oxygen mg/l	pH	Salinity ppt	Conductivity umhes/cm	Air Temp °C	Wind Direction	Moisture Content % Dry Wt	Total Solids mg/l	Total Solids % By Wt	Total Volatile Solids mg/l	Total Volatile Solids % Dry Wt	Total Kjeldahl Nitrogen mg/l	Total Kjeldahl Nitrogen mg/kg
								AREA NO. 12										
								Before Dredging-Channel Area										
Sediment	SN15	3/27/75	0	39.3								56		64		3.4		1000
Water	SN15	3/27/75	0	39.3	21.0	9	8.5	5.0^f	$8,700^f$	24.5	SE		4130^f		640^f		0.2^f	
								During Dredging-Channel Area										
Water	SNW-75B-15W	7/24/75	570+00 0	41.5	31.0	5	8.5	14.0^f	$23,000^f$	29.0	NW		$14,200^f$		2520^f		2.1^f	

PART (B)

	Sample No.	Oil & Grease mg/l	Oil & Grease mg/kg	Chemical Oxygen Demand mg/l	Chemical Oxygen Demand mg/kg	Chlorides mg/l	Arsenic µg/l	Arsenic mg/kg	Cadmium mg/l	Cadmium mg/kg	Chromium (Total) mg/l	Chromium (Total) mg/kg	Copper mg/kg	Lead mg/l	Lead mg/kg	Mercury mg/l	Mercury mg/kg	Nickel mg/l	Nickel mg/kg	Zinc mg/kg
								AREA NO. 12												
								Before Dredging-Channel Area												
Sediment	SN15		590		$32,000^f$			3.3		0.4		14	9		24		<0.1		9	34
Water	SN15	0		81^f		$1,830^a$	5		0.003		0.01			0.02		0.49		0.05		
								During Dredging-Channel Area												
Water	SN15	0.0		69^f		$7,600^a$	5^f		<0.002		0.03			0.01		0.3^d		0.11		

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-6 Sabine River Water and Sediment Quality Data SN-15, SN-16, and SN-17

(US Army CE, Galveston, 1975)

RESULTS OF TESTS OF WATER

Field Sample No.	Total Residue	Total Volatile Residue	Chlorides Cl	Total Kjedahl Nitrogen	Ammonia Nitrogen	Total Organic Nitrogen	Total Carbon	Total Inorganic Carbon	Chemical Oxygen Demand	Oil & Grease
SN-15	11,400	2,500	5,400	0.43^f	0.25^e	0.18^f	31^f	15^f	52^f	13^e
SN-16	8,500	1.700	4,000	0.45^f	0.20^e	0.25^f	31^f	13^f	31^f	12^e
SN-17	7,900	1,500	3,600	0.62^f	0.38^e	0.24^e	32^f	14^f	47^f	12^e

Field Sample No.	(a) Arsenic as µg/1	(b) Cadmium Cd	Chromimum (Total) Cr	(a) Copper Cu	(a) Lead Pb	(a) Mercury Hg µg/1	(a) Nickel Ni	(a) Zinc Zn
SN-15	2	0.012^d	0.03	0.30^e	0.01^e	0.9^d	0.07	0.13
SN-16	1	0.011^d	0.04	0.34^e	0.01^e	0.7^d	0.06	0.19
SN-17	0	0.012^d	0.05	0.61^e	0.01^e	0.2^d	0.03	0.15

RESULTS OF TESTS OF BOTTOM SEDIMENT

Field Sample No.	Moisture Content % Dry Wt.	Total Solids % by Wt.	Total Volatile Solids % Dry Wt.	Total Kjeldahl Nitrogen	Ammonia Nitrogen	Total Organic Nitrogen	Total Organic Carbon	Oil & Grease	Chemical Oxygen Demand	(a) Arsenic As
SN-15	222	31^f	7.3^f	2180(b)^g	200^f	1980^f	11,000^f	3100^g	73,000^g	4.1^f
SN-16	72	58^f	3.1^f	800	85^f	795^f	9,400^f	1100	32,000	4.3^f
SN-17	257	28^f	8,5^f	2360(b)^g	200^f	2160^f	10,000^f	2400^g	74,000^g	4.5^f

Field Sample No.	(a) Cadmium Cd	Chromium (Total) Cr	Copper Cu	(a) Lead Pb	(a) Mercury Hg	(a) Nickel Ni	(a) Zinc Zn
SN-15	1.7^f	45^f	40^f	39^f	0.25^f	29^f	102^g
SN-16	0.9^f	10^f	6^f	14^f	$<0.1^f$	10^f	29
SN-17	1.4^f	27^f	23^f	39^f	0.22^f	23^f	77^g

(a) Retested

(b) Insufficient sample available for retest.

Notes: All results are in mg/l except as noted.

Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-7 Cow Bayou Water and Sediment Quality Data CB 3 and CB 4 (US Army CE, Galveston, 1975)

RESULTS OF TEST OF WATER

Field Sample No.	Total Residue	Total Volatile Residue	Chlorides Cl	Total Kjeldahl Nitrogen	Ammonia Nitrogen	Total Organic Nitrogen	Total Carbon	Total Inorganic Carbon	Total Organic Carbon
CB-3	2,300[f]	460[f]	1,100[f]	0.35[f]	0.28[e]	0.07[f]	48[f]	8[f]	40[f]
CB-4	3,400[f]	830[f]	1,700[f]	0.70[f]	0.45[e]	0.25[f]	51[f]	7[f]	44[f]

Field Sample No.	Chemical Oxygen Demand	Oil & Grease	(a) Arsenic As µg/l	(a) Cadmium Cd	Chromium (Total) Cr	(a) Copper Cu	(a) Lead Pb	(a) Mercury Hg µg/l	(a) Nickel Ni	(a) Zinc Zn
CB-3	17[f]	13[f]	1	0.010[d]	0.05	0.39	0.01	0.6[d]	0.03	0.10
CB-4	39[f]	12[f]	2	0.013[d]	0.03	0.36	0.01	0.3[d]	0.04	0.18

RESULTS OF TESTS OF BOTTOM SEDIMENT

Field Sample No.	Moisture Content % Dry Wt.	Total Solids % by Wt.	Total Volatile Solids % Dry Wt.	Total Kjeldahl Nitrogen	Ammonia Nitrogen	Total Organic Nitrogen	Total Organic Carbon	Oil & Grease	Chemical Oxygen Demand	(a) Arsenic As
CB-3	244[f]	29[f]	10.4[f]	3700[g]	200[f]	3500[f]	13,000[f]	2600[r]	110,000[g]	7.1
CB-4	316[f]	24[f]	13.2[f]	4310[g]	370[f]	3940[f]	16,000[f]		130,000[g]	6.8

Field Sample No.	(a) Cadmium Cd	Chromium (Total) Cr	Copper Cu	(a) Lead Pb	(a) Mercury Hg	(a) Nickel Ni	(a) Zinc Zi
CB-3	0.8	46	14	78[g]	0.28	18	72[g]
CB-4	0.8	34	13	52[g]	0.16	35	62[g]

(a) Retested

Notes: All results are in mg/l except as noted.

No state criteria available for this water body.

Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-8 Water Quality Data, Neches River, Evadale, Texas (USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	TIME	INSTANTANEOUS DISCHARGE (CFS)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)
OCT. 23...	1845	2200	11^{f}	8.5^{f}	2.9^{f}	14^{f}	2.7^{f}	26^{f}	0	15
NOV. 13...	1515	5200	11^{f}	6.8^{f}	2.6^{f}	9.7^{f}	2.5^{f}	14^{f}	0	13
DEC. 11...	1130	10000	12^{f}	7.5^{f}	1.7^{f}	11^{f}	2.5^{f}	16^{f}	0	15
JAN. 09...	0930	13000	11^{f}	7.6^{f}	2.5^{f}	12^{f}	2.7^{f}	22^{f}	0	17
FEB. 12...	1045	15000	7.7^{f}	7.1^{f}	2.5^{f}	11^{f}	2.5^{f}	19^{f}	0	15
MAR. 19...	1030	14500	6.9^{f}	6.5^{f}	2.9^{f}	13^{f}	2.5^{f}	20^{f}	0	17
APR. 09...	1640	8600	6.4^{f}	8.3^{f}	3.0^{f}	16^{f}	3.0^{f}	22^{f}	0	21
MAY 14...	0915	19000	14^{f}	6.2^{f}	2.0^{f}	9.5^{f}	2.5^{f}	18^{f}	0	14
JUNE 04...	1530	9600	8.9^{f}	7.6^{f}	2.8^{f}	12^{f}	2.1^{f}	23^{f}	0	14
JULY 09...	1430	8300	9.8^{f}	7.7^{f}	2.7^{f}	13^{f}	2.3^{f}	22^{f}	0	18
AUG. 06...	1530	8100	9.7^{f}	7.0^{f}	3.2^{f}	12^{f}	2.3^{f}	20^{f}	0	16
SEP. 10...	1515	5400	10^{f}	8.2^{f}	3.3^{f}	14^{f}	2.4^{f}	25^{f}	0	17

DATE	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	AMMONIA NITROGEN (N) (MG/L)	TOTAL ORGANIC NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)
OCT. 23...	21	--	.00	.00	.03	$.62^{f}$	$.65^{f}$	$.07^{e}$	112
NOV. 13...	16	--	.04	.00	$.07^{e}$	1.0^{f}	1.1^{f}	$.07^{e}$	87
DEC. 11...	17	.0	.01	.00	$.09^{e}$	1.4^{f}	1.5^{f}	$.05^{e}$	102
JAN. 09...	18	.0	.03	.01	$.05^{e}$	$.79^{f}$	$.84^{f}$	$.05^{e}$	101
FEB. 12...	17	$.1^{f}$	.04	.00	.03	$.64^{f}$	$.67^{f}$	$.04^{e}$	139
MAR. 19...	18	$.2^{f}$	.05	.00	.03	$.36^{f}$	$.39^{f}$	$.04^{e}$	95
APR. 09...	20	$.1^{f}$	.05	.00	$.04^{e}$	$.42^{f}$	$.46^{f}$	$.05^{e}$	106
MAY 14...	13	$.1^{f}$	.14	.00	$.05^{e}$	1.0^{f}	1.1^{f}	$.05^{e}$	--
JUNE 04...	17	$.1^{f}$	.07	.00	.00	$.57^{f}$	$.57^{f}$	$.07^{e}$	98
JULY 09...	17	$.1^{f}$	.05	.01	$.08^{e}$	$.67^{f}$	$.75^{f}$	$.05^{e}$	98
AUG. 06...	16	$.1^{f}$	.08	.00	.01	$.56^{f}$	$.57^{f}$	$.02^{e}$	96
SEP. 10...	20	$.1^{f}$	.01	.01	.00	$.55^{f}$	$.55^{f}$	$.04^{e}$	83

Note: Sample station locations are shown in Figure D.5-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.5-8 Water Quality Data, Neches River, Evadale, Texas (Continued)
(USGS, Texas, 1975)

NECHES RIVER BASIN

08041000 Neches River at Evadale, Tex.--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	SODIUM ADSORPTION RATIO	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (DEG C)
OCT. 23...	89	45^f	15^f	33^f	12^f	1.1^f	162	6.6	21.5
NOV. 13...	68	99^f	35^f	28^f	16^f	$.8^f$	109	6.9	16.5
DEC. 11...	75	64^f	23^f	26^f	13^f	$.9^f$	131	6.3^c	11.0
JAN. 09...	82	45^f	4^f	29^f	11^f	1.0^f	137	6.6	14.5
FEB. 12...	73	56^f	19^f	28^f	13^f	$.9^f$	123	7.1	12.0
MAR. 19...	77	110^f	30^f	26^f	12^f	1.1^f	145	7.0	15.5
APR. 09...	89	53^f	23^f	33^f	15^f	1.2^f	163	6.9	19.0
MAY 14...	70	53^f	4^f	24^f	9^f	$.8^f$	115	6.6	23.5
JUNE 04...	76	50^f	8^f	31^f	12^f	$.9^f$	139	6.6	26.5
JULY 09...	81	52^f	7^f	30^f	12^f	1.0^f	147	6.7	29.5
AUG. 06...	76	49^f	15^f	31^f	14^f	$.9^f$	134	6.6	28.0
SEP. 10...	87	33^f	3^f	34^f	14^f	1.0^f	154	6.7	27.5

DATE	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	PERCENT SATURATION	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	STREPTOCOCCI (COLONIES PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)
OCT. 23...	60^f	30^f	9.6	108	1.2^f	270^f	73	47^f	10^f
NOV. 13...	100^f	40^f	10.2	104	2.0^f	1700^f	190	550^f	16^f
DEC. 11...	80^f	35^f	8.8	79	1.2^f	7000^f	210^a	270^f	20^f
JAN. 09...	100^f	25^f	9.4	91	1.1^f	700^f	280^a	160^f	11^f
FEB. 12...	100^f	25^f	9.2	85	1.1^f	820^f	120	110^f	14^f
MAR. 19...	60^f	35^f	8.7	86	$.5^f$	850^f	230^a	120^f	3.2^f
APR. 09...	120^f	30^f	8.8	94	$.6^f$	780^f	150	1400^f	9.5^f
MAY 14...	120^f	35^f	6.2	72	1.9^f	19000^f	260^a	140^f	3.2^f
JUNE 04...	100^f	35^f	6.3	77	1.6^f	2100^f	190	74^f	9.7^f
JULY 09...	160^f	35^f	6.8	88	$.9^f$	150^f	130	52^f	--
AUG. 06...	80^f	40^f	6.8	86	1.0^f	3500^f	78	170^f	5.8^f
SEP. 10...	80^f	25^f	7.0	88	$.8^f$	2000^f	56	370^f	11^f

Note: Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-8 Water Quality Data, Neches River, Evadale, Texas (Continued) (USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	TIME	DIS-SOLVED ALUM-INUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	DIS-SOLVED BORON (B) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	DIS-SOLVED CHRO-MIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)
OCT. 23...	1845	100^{f}	2	2	50^{f}	<10$^{\bullet}$	<1$^{\bullet}$	0	0	<50^{f}
FEB. 12...	1045	220^{f}	1	0	70^{f}	20^{c}	0	0	0	<50^{f}
APR. 09...	1640	20^{f}	2	1	70^{f}	10^{c}	0	0	0	<50^{f}
MAY 14...	1915	--	--	--	30^{f}	--	--	--	--	--
AUG. 06...	1530	20^{f}	2	0	30^{f}	<10$^{\bullet}$	0	0	0	<50^{f}

DATE	DIS-SOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	DIS-SOLVED LITHIUM (LI) (UG/L)	TOTAL MAN-GANESE (MN) (UG/L)
OCT. 23...	1^{f}	<10	2^{f}	1300^{c}	110$^{\bullet}$	<100$^{\bullet}$	7^{f}	0	0
FEB. 12...	0	10	8^{f}	1900^{c}	210$^{\bullet}$	<100$^{\bullet}$	4^{f}	0	90^{f}
APR. 09...	0	<10	3^{f}	2000^{c}	120$^{\bullet}$	100$^{\bullet}$	0	10^{f}	150^{f}
MAY 14...	--	--	--	--	--	--	--	--	--
AUG. 06...	0	<10	4^{f}	2000^{c}	90$^{\bullet}$	<100$^{\bullet}$	0	0	180^{f}

DATE	DIS-SOLVED MAN-GANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL SELE-NIUM (SE) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED STRON-TIUM (SR) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
OCT. 23...	10^{f}	.0	.0	3	1^{f}	0	110^{f}	220$^{\bullet}$	210$^{\bullet}$
FEB. 12...	20^{f}	.0	.0	2	0	0	90^{f}	40	100$^{\bullet}$
APR. 09...	20^{f}	.0	.0	2	0	0	120^{f}	20	30
MAY 14...	--	--	--	--	--	--	--	--	--
AUG. 06...	10^{f}	.0	.0	0	0	0	110^{f}	30	40

DATE	TIME	INSTAN-TANEOUS DIS-CHARGE (CFS)	TEMPER-ATURE (DEG C)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDT (UG/L)	DDT IN BOTTOM MA-TERIAL (UG/KG)
OCT. 23...	1845	2200	21.5	.00	.0	.00	.0	.00	.0	.00	.0
FEB. 12...	1045	15000	12.0	.00	.0	.00	.0	.00	.0	.00	.0
APR. 09...	1640	8600	19.0	.00	.0	.00	.0	.00	.0	.00	.0
AUG. 06...	1530	8100	28.0	.00	.0	.00	.0	.00	.0	.00	.0

DATE	TOTAL DI-ELDRIN (UG/L)	DI-ELDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL HEPTA-CHLOR (UG/L)	HEPTA-CHLOR IN BOTTOM MA-TERIAL (UG/KG)	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	HEPTA-CHLOR EPOXIDE IN BOT-TOM MA-TERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL CHLOR-DANE (UG/L)
OCT. 23...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0
FEB. 12...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0
APR. 09...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0
AUG. 06...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0	.0

DATE	CHLOR-DANE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DI-AZINON (UG/L)	TOTAL MALA-THION (UG/L)	TOTAL METHYL PARA-THION (UG/L)	TOTAL PARA-THION (UG/L)	TOTAL 2,4-D (UG/L)	TOTAL SILVEX (UG/L)	TOTAL 2,4,5-T (UG/L)
OCT. 23...	0	.0	0	.00	.00	.00	.00	.00	.00	.00
FEB. 12...	0	.0	0	.00	.00	.00	.00	.02^{f}	.00	.00
APR. 09...	0	.0	0	.00	.00	.00	.00	.00	.00	.00
AUG. 06...	0	.0	0	.00	.00	.00	.00	.01^{f}	.00	.01^{f}

Note: Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-8 Water Quality Data, Neches River, Evadale, Texas (Concluded) (USGS, Texas, 1975)

WATER QUALITY DATA, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DATE	TIME	INSTANTANEOUS DISCHARGE (CFS)	TEMPERATURE (DEG C)	SUSPENDED SEDIMENT (MG/L)	SUSPENDED SEDIMENT DISCHARGE (T/DAY)	SUS. SED. SIEVE DIAM. % FINER THAN .062 MM
OCT. 23...	1845	2200	21.5	21	125	100
NOV. 13...	1515	5200	16.5	23	323	92
DEC. 11...	1130	10000	11.0	44	1190	90
JAN. 09...	0930	13000	14.5	22	772	98
FEB. 12...	1045	15000	12.0	38	1540	52
MAR. 19...	1030	14500	15.5	25	979	76
APR. 09...	1640	8600	19.0	27	627	90
MAY 14...	0915	19000	23.5	16	821	95
JUNE 04...	1530	9600	26.5	48	1240	82
JULY 09...	1430	8300	29.5	26	583	96
AUG. 06...	1530	8100	28.0	38	831	93
SEP. 10...	1515	5400	27.5	17	248	97

MONTHLY AND ANNUAL MEANS AND LOADS FOR WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

MONTH	DISCHARGE (CFS-DAYS)	SPECIFIC CONDUCTANCE (MICRO-MHOS)	DISSOLVED SOLIDS (MG/L)	DISSOLVED SOLIDS (TONS)	DISSOLVED CHLORIDE (MG/L)	DISSOLVED CHLORIDE (TONS)	DISSOLVED SULFATE (MG/L)	DISSOLVED SULFATE (TONS)	HARDNESS (CA,MG) (MG/L)
OCT. 1974.....	78880	158	88	15700	21	4470	16	3410	31
NOV. 1974.....	207440	114	63	35300	13	7280	14	7840	25
DEC. 1974.....	322740	126	70	61000	15	13100	14	12200	27
JAN. 1975.....	450020	126	70	85100	15	18200	14	17000	27
FEB. 1975.....	477000	129	72	92700	16	20600	15	19300	27
MAR. 1975.....	445500	143	80	96200	18	21700	15	18000	29
APR. 1975.....	261120	155	86	60600	20	14100	16	11300	31
MAY 1975.....	489930	130	72	95200	16	21200	15	19800	27
JUNE 1975.....	291240	131	73	57400	16	12600	15	11800	27
JULY 1975.....	238210	145	81	52100	19	12200	16	10300	29
AUG. 1975.....	215540	140	78	45400	18	10500	15	8730	29
SEPT 1975.....	137650	149	83	30800	19	7060	16	5950	30
TOTAL	3615270	**	**	730000	**	163000	**	146000	**
WTD.AVG.	9904.85	135	75	**	17	**	15	**	28

Note: Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.5-9. Neches River Water and Sediment Quality Data NR-2, NR-3 and NR-4 (US Army CE, Galveston, 1975)

RESULTS OF TESTS OF WATER

Field Sample No.	Total Residue	Total Volatile Residue	Chlorides Cl	Total Kieldahl Nitrogen	Ammonia Nitrogen	Total Organic Nitrogen	Total Carbon	Total Inorganic Carbon	Chemical Oxygen Demand	Oil & Grease
NR-2	$12,600^f$	$2,400^f$	6,600	0.58	0.38^e	0.20^f	56^f	15^f	56^f	10^e
NR-3	$11,200^f$	$2,100^f$	5,600	0.85	0.22^e	0.63^f	62^f	13^f	37^f	11^e
NR-4	$10,800^f$	$2,000^f$	5,300	1.0	0.30^e	0.70^f	51^f	14^f	29^f	16^e

Field Sample No.	(a) Arsenic As μg/l	(a) Cadmium Cd	Chromium (Total) Cr	(a) Copper Cu	(a) Lead Pb	(a) Mercury Hg μg/l	(a) Nickel Ni	(a) Zinc Zn
NR-2	1	0.014^e	0.04	0.50	0.02	0.2	0.06	0.23
NR-3	0	0.13^e	0.03	0.40	0.01	0.4	0.07	0.23
NR-4	(b)	(b)	0.03	0.54	0.02	0.2	0.07	0.18

RESULTS OF TESTS OF BOTTOM SEDIMENT

Field Sample No.	Moisture Content % Dry Wt.	Total Solids % By Wt.	Total Volatile Solids % Dry Wt.	Total Kjeldahl Nitrogen	Ammonia Nitrogen	Total Organic Nitrogen	Total Organic Carbon	Oil & Grease	Chemical Oxygen Demand	(a) Arsenic As
NR-2	170	37^f	6.4^f	1750^g	150^f	1600^f	$11,000^f$	2400^g	$62,000^g$	0.0^f
NR-3	222	31^f	8.2^f	2180^g	170^f	2010^f	$13,000^f$	2600^g	$82,000^g$	4.9^f
NR-4	244	29^f	9.3^f	2130^g	180^f	1950^f	$16,000^f$	3400^g	$96,000^g$	5.9^f

Field Sample No.	(a) Cadmium Cd	Chromium (Total) Cr	Copper Cu	(a) Lead Pb	(a) Mercury Hg	(a) Nickel Ni	(a) Zinc Zn
NR-2	0.6^f	38^f	37^f	53^g	0.17	22^f	67^g
NR-3	0.2^f	37^f	23^f	70^g	0.16	17^f	67^g
NR-4	0.3^f	59^f	19^f	116^g	0.20	20^f	85^g

(a) Retested

(b) Insufficient sample available for retest.

Notes: All results are in mg/l except as noted.

Sample station locations are shown in Figure D.5-1.

Explanation of the superscripts is found in Table D.3-3.

APPENDIX D.6

HYDROLOGIC DATA
FOR THE
INTRACOASTAL WATERWAY

This appendix contains water, sediment, and pesticide quality for the Intracoastal Waterway. Figures D.4-1, D.5-1, and D.8-1 give the sample station locations for these sites. The following tables are included in this appendix:

Table D.6-1. Water Quality Data for ICW at Junction of ICW with the Sabine-Neches Canal (Line 339) and (Line 353).

Table D.6-2. Water Quality for ICW near Black Lake

Table D.6-3. Pesticide Analysis for ICW near Black Lake

Table D.6-4. Water Quality Data for the ICW at Big Hill Road (Sample Station B)

Table D.6-5. Sediment Quality Data for the ICW at Big Hill Road (Sample Station B)

Table D.6-1. Water Quality Data for Intracoastal Waterway near the Junction with the Sabine-Neches Canal

(Texas Water Development Board, 1971)

TABLE 1A--QUALITY OF WATER IN THE SABINE-NECHES ESTUARY,

1971 WATER YEAR--CONTINUED

FIELD DETERMINATIONS

DATE OF COLLECTION	TIME	SITE	DEPTH (METERS)	SPECIFIC CONDUCTANCE (MICROMHOS) (FIELD)	TEMPERATURE (DEG. C)	PH	DISSOLVED OXYGEN (MG/L)	PERCENT SATURATION	TURBIDITY (JTU)	TRANSPARENCY SECCHI DISK (CM)
					LINE 339					
MAY 20, 71	1535	2	.3	23000	26.2	7.9	6.6	87	--	81[f]
			3.0	27000	26.0	7.8	5.6	76	--	--
			6.1	28000	26.0	7.8	5.3	72	--	--
			10.7	36000	26.0	7.9	5.4	75	--	--
					LINE 353					
MAY 20, 71	1545	2	.3	19000	27.5	7.2	.0●	0●	--	48[f]
			1.5	21000	26.6	7.3	2.5●	33	--	--
			3.0	23000	26.4	7.7	5.6	74	--	--
			4.9	24000	26.1	7.7	6.6	87	--	--

TABLE 1B--QUALITY OF WATER IN THE SABINE-NECHES ESTUARY,

1971 WATER YEAR

NUTRIENT AND OTHER ENVIRONMENTAL CHARACTERISTICS

DATE OF COLLECTION	TIME	SITE	DEPTH (METERS)	DISSOLVED SILICA (SIO2) (MG/L)	TOTAL NITRATE (N) (MG/L)	AMMONIA NITROGEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	DISSOLVED PHOSPHORUS ORTHO (P) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	BIOCHEMICAL OXYGEN DEMAND (BOD) (MG/L)	CHEMICAL OXYGEN DEMAND (COD) (MG/L)	TOTAL ORGANIC CARBON (MG/L)
						LINE 339						
MAY 20, 71	1535	2	.3	3.8[f]	.4	.62●	.12	.06[f]	.06[d]	1.1[f]	--	--
			10.7	2.8[f]	.2	.36●	.04	.04[f]	.04[d]	.1[f]	--	--

TABLE 1C--QUALITY OF WATER IN THE SABINE-NECHES ESTUARY,

1971 WATER YEAR

CHEMICAL ANALYSES

DATE OF COLLECTION	TIME	SITE	DEPTH (METERS)	SPECIFIC CONDUCTANCE (MICROMHOS) (LAB)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM + POTASSIUM (NA+K) (MG/L)	BICARBONATE (HCO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)
					LINE 339						
MAY 20, 71	1535	2	.3	22400	--	--	--	--	--	--	--
			10.7	35100	--	--	--	--	--	--	--

Table D.6-2. Analysis of Water Samples Taken From The Intracoastal Waterway During The Period 23 - 28 March 1975

(US Army CE, New Orleans, 1975)

Sample Station	Total COD (mg/l)	Dissolved COD (mg/l)	Total TKN (mg/l)	Dissolved TKN (mg/l)	NO_3 (mgN/l)	NO_3 (mgN/l)	Solluble Ortho P (mgP/l)	Tot. P (mgP/l)	Total P (mg/l)	Dissolved Organic Carbon (mg/l)	Grease & Oil (mg/l)	Tot. Susp. Solids (mg/l)	Volatile Susp. Solids (mg/l)
13	33.0[f]	33.0[f]	1.84[f]	0.89[f]	<0.10[f]	0.12[f]	<0.01[f]	0.24[f]	29.0[d]	29.0[f]	<5.0[e]	43[f]	30[f]

Sample Station	Tot. Zn (μg/l)	Sol. Zn (μg/l)	Tot. Cd (μg/l)	Sol. Cd (μg/l)	Tot. Cu (μg/l)	Sol. Cu (μg/l)	Tot. Cr (μg/l)	Sol. Cr (μg/l)	Tot. Ni (μg/l)	Sol. Ni (μg/l)	Tot. Pb (μg/l)	Sol. Pb (μg/l)	Tot. As (μg/l)	Sol. As (μg/l)	Tot. Hg (μg/l)	Sol. Hg (μg/l)
13	235[f]	13[f]	0.6	<0.2[f]	10	9[f]	6	<0.5[f]	91[e]	18[f]	2.0	1.0[f]	60[d]	60[f]	9.9[d]	9.9[f]

Sample Station*	Date	Depth (m)	Temp (°C)	DO (mg/l)	pH	Cond. (umho/cm)	Salinity (ppt)	ORP** (mv)	Sed. pH	Direction of Flow
13	3/25	5.6	19.5	8.05	6.75	270	0.17	+820	7.30	E

* In Situ parameters measured in the Gulf Intracoastal Waterway during the period 23-28 March 1975.

** Oxidation-reduction potential.

Table D.6-3. Pesticide Analysis of Water Samples Taken from the Intracoastal Waterway during the Period 23 - 29 March 1975 (All concentrations expressed as μg/l)

(US Army CE, New Orleans, 1975)

	Station 13 Near Black Lake
Toxaphene	<50[d]
Lindane	51[d]
Heptachlor	<1.0[d]
Heptachlor Epoxide	<1.0[e]
Aldrin	<1.0[d]
Chlordane	10[d]
Dieldrin	<2.0[d]
Ethion	ND
Methoxychlor	<1.0[e]
Endrin	<3.0[d]
O,P'-DDT	3.2[d]
P,P'-DDT	<3.0[e]
O,P'-DDE	<1.0[e]
P,P'-DDE	<2.0[e]
O,P'-DDD	<2.0[e]
P,P'-DDD	<3.0[e]

Table D.6-4. Water Quality Data for the ICW at Big Hill Road (Sample Station B)**

	Concentration⁺
Field Measurements	
pH	8.7[d]
Temp (°C)	20
DO (mg/l)	7.8
Conductivity (µmhos/cm)	1700
Turbidity (JTU)	55
Lab Measurements	
Phen. Alk. (mg/l)	0
TSS (mg/l)	62
T-Phos. (mg/l)	.07[d]
pH	7.6
VSS	11
Ortho-Phos. (mg/l)	.03
T. Alk. (mg/l)	59
Ammonia N (mg/l)	.21
Conductivity (µmhos/cm)	2300
Nitrate N (mg/l)	.17[f]
Chloride (mg/l)	6800
Total Coliform (#/100 ml)	1000
Fecal Coliform (#/100 ml)	73
TOC (mg/l)	9
Sulphate (mg/l)	876
BOD_5 (mg/l)	<3

Table D.6-4. Water Quality Data for the ICW at Big Hill Road (Sample Station B) (Continued)**

Metals (μg/l)	Concentration[+]
Arsenic	<20
Barium	<50
Boron	<1000
Cadmium	<20
Copper	<20
Chromium	<20
Iron	580[f]
Lead	40[e]
Magnanese	180[f]
Mercury	<.5*
Nickel	30
Selenium	<20
Silver	<20
Zinc	70

Table D.6-4. Water Quality Data for the ICW at Big Hill Road (Sample Station B)** (Concluded)

Pesticides (μg/l)	Concentration[+]
2,4-D	$<10^{f}$
2,4,5-T	$<10^{f}$
Silvex	$<10^{f}$
Heptachlor	$< 0.02^{*}$
Heptachlor Epoxide	$< 0.02^{*}$
Lindane	$<0.02^{*}$
Malathion	$<0.02^{*}$
Methoxychlor	$<0.02^{*}$
Parathion	<0.02
PCB	$<1.0^{*}$

* Judgment not possible with these "less than" values as detection limits were higher than EPA recommended criteria.

\+ Explanation of the superscripts is found in Table D.3-3.

** Sampling and analysis provided by Texas Water Quality Board upon FEA request.

Table D.6-5. Sediment Quality Data for the ICW at Big Hill Road (Sample Station B)**

Metals (mg/kg)	Concentration$^+$
Arsenic	10
Barium	26
Cadmium	<.69
Copper	17
Chromium	12
Lead	18
Mercury	.16
Manganese	270
Nickel	10
Selenium	<.69
Silver	2.4
Zinc	35
Other Parameters (mg/kg)	
T-Phosphorous	620
COD	46700^g
Kj-N	738^g
Volatile Solids	52000
Oil & Grease	880

Table D.6-5. Sediment Quality Data for the ICW at Big Hill Road (Sample Station B) (Concluded)**

Pesticides and Related Compounds (μg/kg)	Concentration+
Silvex	<20.0
Aldrin	< 1.0
Chlordane	<20.0
DDD	< 5.0
DDE	< 5.0
DDT	< 5.0
Diazinon	< 5.0
Dieldrin	< 3.0
Endrin	< 3.0
Heptachlor	< 1.0
Heptachlor Expxide	< 1.0
Lindane	< 1.0
Methoxychlor	<20.0
Methyl Parathion	< 5.0
Parathion	< 5.0
Toxaphene	<50.0
PCB	<20.0

\+ Explanation of the superscripts is found in Table D.3-3.

** Sampling and analysis provided by Texas Water Quality Board upon FEA request.

APPENDIX D.7

GULF OF MEXICO HYDROLOGIC DATA

Appendix D.7 presents Hydrologic data for the Gulf of Mexico at the mouth of the Calcasieu River Basin. Sample locations are shown in Figure D.4-1.

Table D.7-1. Water Quality Data
Mile (-0.4) Calcasieu Ship Channel

Table D.7-2. Water Quality Data
Mile (-2.9) Calcasieu Ship Channel

Table D.7-3. Water Quality Data
Mile (-5.6) Calcasieu Ship Channel

Table D.7-1. Water Quality Data, Mile (-0.4) Calcasieu Ship Channel

(USGS, Louisiana, 1976)

294530093201200 GULF OF MEXICO 300 YARDS EAST OF CALCASIEU SHIP CHANNEL AT MILE -0.4

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)
SEP.											
08...	0945	50^f	30^f	320^f	980^f	8500^f	400^f	135^f	0	2000^f	16000^f
08...	1150	60^f	30^f	310^f	980^f	8300^f	340^f	133^f	0	2000^f	15000^f

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	HARDNESS (CA,MG) (MG/L)
SEP.											
08...	.00	.01^f	.12^f	.10^f	.42^f	.28^f	.03^d	24^f	0^f	32^f	4800^f
08...	.01^f	.01^f	.14^f	.14^f	.47^f	.46^f	.05^d	36^f	13^f	24^f	4800^f

DATE	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
SEP.											
08...	4700^f	39500^f	8.1	7.3	170^f	2.6^f	<5^f	<5^f	6.7^f	.00	1^d
08...	4700^f	38400^f	8.0	7.0	149^f	1.6^f	160^f	36^f	3.4^f	.00	2^d

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL CHLORDANE (UG/L)	CHLORDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MATERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDT (UG/L)	DDT IN BOTTOM MATERIAL (UG/KG)
SEP.											
08...	1	.00	--	.0	--	.00	--	.00	--	.00	--
08...	0	.00	.0	.0	0	.00	.0	.00	.0	.00	.0

DATE	TOTAL DIAZINON (UG/L)	DIAZINON IN BOTTOM MATERIAL (UG/KG)	TOTAL DIELDRIN (UG/L)	DIELDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ETHION (UG/L)	ETHION IN BOTTOM MATERIAL (UG/KG)	TOTAL HEPTACHLOR (UG/L)	HEPTACHLOR IN BOTTOM MATERIAL (UG/KG)
SEP.										
08...	.00	--	.00	--	.00	--	.00	--	.00	--
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-1. Water Quality Data, Mile (-0.4) Calcasieu Ship Channel (Continued)

(USGS, Louisiana, 1976)

294530093201200 GULF OF MEXICO 300 YARDS EAST OF CALCASIEU SHIP CHANNEL AT MILE -0.4--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	HEPTACHLOR EPOXIDE IN BOTTOM MATERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL MALATHION (UG/L)	MALATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL METHYL PARATHION (UG/L)	METHYL PARATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL METHYL TRITHION (UG/L)	METHYL TRITHION IN BOTTOM MATERIAL (UG/KG)
SEP.										
08...	.00	--	.00	--	.00	--	.00	--	.00	--
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

DATE	TOTAL PARATHION (UG/L)	PARATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MATERIAL (UG/KG)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOXAPHENE IN BOTTOM MATERIAL (UG/KG)	TOTAL TRITHION (UG/L)	TRITHION IN BOTTOM MATERIAL (UG/KG)	TOTAL 2,4-D (UG/L)
SEP.										
08...	.00	--	.0	--	.00	0	--	.00	--	.00
08...	.00	.0	.0	0	.00	0	0	.00	.0	.00

DATE	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
SEP.									
08...	.00	.00	1	1^f	0	0	30	0	4
08...	.00	.00	1	1^f	0	0	20	0	3

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
SEP.									
08...	3^f	2	0	.0	.0	3	1^f	50^f	40^f
08...	3^f	3	1^f	.0	.0	3	1^f	50^f	50^f

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-1. Water Quality Data, Mile (-0.4) Calcasieu Ship Channel (Continued)

(USGS, Louisiana, 1976)

294524093203600 CALCASIEU RIVER SHIP CHANNEL AT MILE -0.4

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	ALDRIN IN BOTTOM MA-TERIAL (UG/KG)	CHLOR-DANE IN BOTTOM MA-TERIAL (UG/KG)	DDD IN BOTTOM MA-TERIAL (UG/KG)	DDE IN BOTTOM MA-TERIAL (UG/KG)	DDT IN BOTTOM MA-TERIAL (UG/KG)	DI-AZINON IN BOTTOM MA-TERIAL (UG/KG)	DI-ELDRIN IN BOTTOM MA-TERIAL (UG/KG)	ENDRIN IN BOTTOM MA-TERIAL (UG/KG)	ETHION IN BOTTOM MA-TERIAL (UG/KG)
SEP.										
08...	0915	.0	0	.0	.0	.0	.0	.0	.0	.0
08...	1215	.0	0	.0	.0	.0	.0	.0	.0	.0

DATE	HEPTA-CHLOR IN BOTTOM MA-TERIAL (UG/KG)	HEPTA-CHLOR EPOXIDE IN BOT-TOM MA-TERIAL (UG/KG)	LINDANE IN BOTTOM MA-TERIAL (UG/KG)	MALA-THION IN BOTTOM MA-TERIAL (UG/KG)	METHYL PARA-THION IN BOT-TOM MA-TERIAL (UG/KG)	METHYL TRI-THION IN BOT-TOM MA-TERIAL (UG/KG)	PARA-THION IN BOTTOM MA-TERIAL (UG/KG)	PCB IN BOTTOM MA-TERIAL (UG/KG)	TOX-APHENE IN BOTTOM MA-TERIAL (UG/KG)	TRI-THION IN BOTTOM MA-TERIAL (UG/KG)
SEP.										
08...	.0	.0	.0	.0	.0	.0	.0	0	0	.0
08...	.0	.0	.0	.0	.0	.0	.0	16●	0	.0

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.7-1. Water Quality Data, Mile (-0.4) Calcasieu Ship Channel (Continued)

(USGS, Louisiana, 1976)

294522093205900 GULF OF MEXICO 300 YARDS WEST OF CALCASIEU SHIP CHANNEL AT MILE -0.4

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)
SEP.											
08...	1000	90^{f}	30^{f}	320^{f}	990^{f}	8400^{f}	350^{f}	135^{f}	0	2000^{f}	15000^{f}
08...	1200	70^{f}	30^{f}	320^{f}	980^{f}	8400^{f}	340^{f}	144^{f}	0	2000^{f}	16000^{f}

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	DIS-SOLVED KJEL. NITRO-GEN (N) (MG/L)	DIS-SOL-VED-PHOS-PHORUS (P) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	VOL. NON-FILT-RABLE RESIDUE (MG/L)	SUS-PENDED SOLIDS (MG/L)	HARD-NESS (CA+MG) (MG/L)
SEP.											
08...	.00	$.01^{f}$	$.13^{f}$	$.13^{f}$	$.35^{f}$	$.35^{f}$	$.03^{d}$	21^{f}	11^{f}	28^{f}	4900^{f}
08...	.00	$.01^{f}$	$.08^{f}$	$.07^{f}$	$.47^{f}$	$.43^{f}$	$.03^{d}$	44^{f}	19^{f}	41^{f}	4800^{f}

DATE	NON-CAR-BONATE HARD-NESS (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	DIS-SOLVED OXYGEN (MG/L)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)	IMME-DIATE COLI-FORM (COL. PER 100 ML)	FECAL COLI-FORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
SEP.											
08...	4800^{f}	39000^{f}	8.1	7.8	139^{f}	2.9^{f}	$<5^{f}$	$<5^{f}$	6.4^{f}	.00	3^{d}
08...	4700^{f}	39300^{f}	8.0	8.1	173^{f}	3.6^{f}	$<5^{f}$	$<5^{f}$	4.8^{f}	.00	2^{d}

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL CHLOR-DANE (UG/L)	CHLOR-DANE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDT (UG/L)	DDT IN BOTTOM MA-TERIAL (UG/KG)
SEP.											
08...	0	.00	.0	.0	0	.00	.0	.00	.0	.00	.0
08...	0	.00	.0	.0	0	.00	.0	.00	.0	.00	.0

DATE	TOTAL DI-AZINON (UG/L)	DI-AZINON IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DI-ELDRIN (UG/L)	DI-ELDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL ETHION (UG/L)	ETHION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL HEPTA-CHLOR (UG/L)	HEPTA-CHLOR IN BOTTOM MA-TERIAL (UG/KG)
SEP.										
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-1. Water Quality Data, Mile (-0.4) Calcasieu Ship Channel (Concluded)

(USGS, Louisiana, 1976)

294522093205900 GULF OF MEXICO 300 YARDS WEST OF CALCASIEU SHIP CHANNEL AT MILE -0.4--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL HEPTACHLOR EPOXIDE (UG/L)	HEPTACHLOR EPOXIDE IN BOTTOM MATERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL MALATHION (UG/L)	MALATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL METHYL PARATHION (UG/L)	METHYL PARATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL METHYL TRITHION (UG/L)	METHYL TRITHION IN BOTTOM MATERIAL (UG/KG)
SEP.										
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

DATE	TOTAL PARATHION (UG/L)	PARATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MATERIAL (UG/KG)	POLYCHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOXAPHENE IN BOTTOM MATERIAL (UG/KG)	TOTAL TRITHION (UG/L)	TRITHION IN BOTTOM MATERIAL (UG/KG)	TOTAL 2,4-D (UG/L)
SEP.										
08...	.00	.0	.0	0	.00	0	0	.00	.0	.00
08...	.00	.0	.0	0	.00	0	0	.00	.0	.00

DATE	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
SEP.									
08...	.00	.00	1	1^f	0	0	20	0	4
08...	.00	.00	2	1^f	0	0	20	0	4

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
SEP.									
08...	4^f	3	3^f	.0	.0	3	1^f	50^f	40^f
08...	3^f	3	0	.0	.0	4	2^f	40^f	40^f

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.7-2. Water Quality Data, Mile (-2.9) Calcasieu Ship Channel

(USGS, Louisiana, 1976)

294320093200000 GULF OF MEXICO 200 YARDS EAST OF CALCASIEU SHIP CHANNEL AT MILE -2.9

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)
SEP.											
08...	0930	50^{f}	40^{f}	330^{f}	990^{f}	8600^{f}	350^{f}	176^{f}	0	2100^{f}	18000^{f}
08...	1130	60^{f}	40^{f}	320^{f}	940^{f}	8600^{f}	360^{f}	137^{f}	0	2100^{f}	16000^{f}

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	HARDNESS (CA,MG) (MG/L)
SEP.											
08...	.01^{f}	.00	.10^{f}	.10^{f}	.34^{f}	.26^{f}	.03^{d}	39^{f}	23^{f}	29^{f}	4900^{f}
08...	.00	.01^{f}	.16^{f}	.04^{f}	.26^{f}	.26^{f}	.03^{d}	14^{f}	1^{f}	10^{f}	4700^{f}

DATE	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
SEP.											
08...	4800^{f}	40200^{f}	8.2	7.7	173^{f}	1.7^{f}	<5^{f}	<5^{f}	3.6^{f}	.00	1
08...	4600^{f}	40200	8.2	7.9	134^{f}	2.3^{f}	<5^{f}	<5^{f}	3.6^{f}	.00	3^{d}

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL CHLORDANE (UG/L)	CHLORDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MATERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDT (UG/L)	DDT IN BOTTOM MATERIAL (UG/KG)
SEP.											
08...	2^{e}	.00	.0	.0	0	.00	.0	.00	.0	.00	.0
08...	0	.00	.0	.0	0	.00	.0	.00	.0	.00	.0

DATE	TOTAL DIAZINON (UG/L)	DIAZINON IN BOTTOM MATERIAL (UG/KG)	TOTAL DIELDRIN (UG/L)	DIELDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ETHION (UG/L)	ETHION IN BOTTOM MATERIAL (UG/KG)	TOTAL HEPTACHLOR (UG/L)	HEPTACHLOR IN BOTTOM MATERIAL (UG/KG)
SEP.										
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-2. Water Quality Data, Mile (-2.9) Calcasieu Ship Channel (Continued)

(USGS, Louisiana, 1976)

294320093200000 GULF OF MEXICO 200 YARDS EAST OF CALCASIEU SHIP CHANNEL AT MILE -2.9--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	HEPTA-CHLOR EPOXIDE IN BOTTOM MATERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL MALATHION (UG/L)	MALATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL METHYL PARATHION (UG/L)	METHYL PARATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL METHYL TRITHION (UG/L)	METHYL TRITHION IN BOTTOM MATERIAL (UG/KG)
SEP.										
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

DATE	TOTAL PARATHION (UG/L)	PARATHION IN BOTTOM MATERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MATERIAL (UG/KG)	POLY-CHLORINATED NAPHTHALENES (UG/L)	TOTAL TOXAPHENE (UG/L)	TOXAPHENE IN BOTTOM MATERIAL (UG/KG)	TOTAL TRITHION (UG/L)	TRITHION IN BOTTOM MATERIAL (UG/KG)	TOTAL 2,4-D (UG/L)
SEP.										
08...	.00	.0	.0	13	.00	0	0	.00	.0	.00
08...	.00	.0	.0	0	.00	0	0	.00	.0	.00

DATE	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	HEXAVALENT CHROMIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
SEP.									
08...	.00	.00	2	1^{f}	0	0	10	0	3
08...	.00	.00	3	1^{f}	0	0	20	0	2

DATE	DISSOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)
SEP.									
08...	3^{f}	2	2^{f}	.0	.0	3	1^{f}	50^{f}	40^{f}
08...	2^{f}	2	0	.0	.0	2	2^{f}	50^{f}	30^{f}

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-2. Water Quality Data, Mile (-2.9) Calcasieu Ship Channel (Continued)

(USGS, Louisiana, 1976)

294310093200500 GULF OF MEXICO AT CALCASIEU SHIP CHANNEL AT MILE -2.9 (CE 96142)

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)
JUNE											
29...	1319	60^f	40^f	230^f	650^f	5400^f	210^f	121^f	0	1300^f	9900^f
30...	0915	50^f	50^f	270^f	770^f	6500^f	250^f	130^f	0	1700^f	12000^f
SEP.											
08...	0915	--	--	--	--	--	--	--	--	--	--
08...	1120	--	--	--	--	--	--	--	--	--	--

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)	DIS-SOLVED KJEL. NITRO-GEN (N) (MG/L)	DIS-SOL-VED-PHOS-PHORUS (P) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	VOL. NON-FILT-RABLE RESIDUE (MG/L)	SUS-PENDED SOLIDS (MG/L)	HARD-NESS (CA,MG) (MG/L)
JUNE											
29...	.07^f	.01^f	--	.08^f	--	.43^f	.01^d	9^f	7^f	9^f	3300^f
30...	.02^f	.01^f	.06^f	.07^f	.45^f	.38^f	.05^d	34^f	18^f	24^f	3800^f
SEP.											
08...	--	--	--	--	--	--	--	--	--	--	--
08...	--	--	--	--	--	--	--	--	--	--	--

DATE	NON-CAR-BONATE HARD-NESS (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	COLOR (PLAT-INUM-COBALT UNITS)	TUR-BID-ITY (JTU)	DIS-SOLVED OXYGEN (MG/L)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
JUNE											
29...	3200^f	26600^f	8.4	5^f	4^f	6.5	160^f	1.2^f	3.2^f	.00	0
30...	3700^f	30800^f	8.3	2^f	20^f	6.7	360^f	1.7^f	4.2^f	.00	0
SEP.											
08...	--	--	--	--	--	--	--	--	--	--	--
08...	--	--	--	--	--	--	--	--	--	--	--

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL CHLOR-DANE (UG/L)	CHLOR-DANE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DDT (UG/L)	DDT IN BOTTOM MA-TERIAL (UG/KG)
JUNE											
29...	0	.00	--	.0	--	.00	--	.00	--	.00	--
30...	0	.00	--	.0	--	.00	--	.00	--	.00	--
SEP.											
08...	--	--	.0	--	0	--	.0	--	.0	--	.0
08...	--	--	.0	--	0	--	.0	--	.0	--	.0

DATE	TOTAL DI-AZINON (UG/L)	DI-AZINON IN BOTTOM MA-TERIAL (UG/KG)	TOTAL DI-ELDRIN (UG/L)	DI-ELDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MA-TERIAL (UG/KG)	TOTAL ETHION (UG/L)	ETHION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL HEPTA-CHLOR (UG/L)	HEPTA-CHLOR IN BOTTOM MA-TERIAL (UG/KG)
JUNE										
29...	.00	--	.00	--	.00	--	.00	--	.00	--
30...	.00	--	.00	--	.00	--	.00	--	.00	--
SEP.										
08...	--	.0	--	.0	--	.0	--	.0	--	.0
08...	--	.0	--	.0	--	.0	--	.0	--	.0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-2. Water Quality Data, Mile (-2.9) Calcasieu Ship Channel (Continued)

UUSGS, Louisiana, 1976)

294310093200500 GULF OF MEXICO AT CALCASIEU SHIP CHANNEL AT MILE -2.9 (CE 96142)--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	HEPTA-CHLOR EPOXIDE IN BOT-TOM MA-TERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL MALA-THION (UG/L)	MALA-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL METHYL PARA-THION (UG/L)	METHYL PARA-THION IN BOT-TOM MA-TERIAL (UG/KG)	TOTAL METHYL TRI-THION (UG/L)	METHYL TRI-THION IN BOT-TOM MA-TERIAL (UG/KG)
JUNE										
29...	.00	--	.00	--	.00	--	.00	--	.00	--
30...	.00	--	.00	--	.00	--	.00	--	.00	--
SEP.										
08...	--	.0	--	.0	--	.0	--	.0	--	.0
08...	--	.0	--	.0	--	.0	--	.0	--	.0

DATE	TOTAL PARA-THION (UG/L)	PARA-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MA-TERIAL (UG/KG)	POLY-CHLO-RINATED NAPH-THA-LENES (UG/L)	TOTAL TOX-APHENE (UG/L)	TOX-APHENE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL TRI-THION (UG/L)	TRI-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL 2,4-D (UG/L)
JUNE										
29...	.00	--	.0	--	.00	0	--	.00	--	.05^{f}
30...	.00	--	.0	--	.00	0	--	.00	--	.10^{f}
SEP.										
08...	--	.0	--	0	--	--	0	--	.0	--
08...	--	.0	--	0	--	--	0	--	.0	--

DATE	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE									
29...	.00	.00	2	2^{f}	1	0	10	0	7
30...	.00	.00	2	2^{f}	0	0	30	0	6
SEP.									
08...	--	--	--	--	--	--	--	--	--
08...	--	--	--	--	--	--	--	--	--

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
JUNE									
29...	4^{f}	4	3^{f}	.1	.0	10	0	20^{f}	20^{f}
30...	3^{f}	8	0	.1	.1^{f}	6	0	40^{f}	20^{f}
SEP.									
08...	--	--	--	--	--	--	--	--	--
08...	--	--	--	--	--	--	--	--	--

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-2. Water Quality Data, Mile (-2.9) Calcasieu Ship Channel (Continued)

(USGS, Louisiana, 1976)

294310093200600 GULF OF MEXICO 300 YARDS WEST OF CALCASIEU SHIP CHANNEL AT MILE -2.9

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	TOTAL NITRATE (N) (MG/L)
JUNE												
29...	1326	50^f	40^f	230^f	710^f	5700^f	210^f	208^f	0	1300^f	10000^f	.00^f
30...	0855	50^f	50^f	270^f	770^f	6500^f	250^f	130^f	0	1700^f	12000^f	.02
SEP.												
08...	0905	60^f	30^f	310^f	980^f	8600^f	360^f	136^f	0	2100^f	16000^f	.00
08...	1115	60^f	40^f	310^f	990^f	8600^f	360^f	216^f	0	2100^f	15000^f	.00

DATE	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)
JUNE											
29...	.01^f	.10^f	.37^f	--	.45^f	.01^d	5^f	4^f	14^f	3500^f	3300^f
30...	.01^f	--	.07^f	.45^f	.38^f	.05^d	34^f	18^f	24^f	3800^f	3700^f
SEP.											
08...	.01^f	.14^f	.11^f	.42^f	.31^f	.03^d	47^f	13^f	51^f	4800^f	4700^f
08...	.01^f	.16^f	.08^f	.33^f	.31^f	.03^d	52^f	10^f	50^f	4900^f	4700^f

DATE	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	COLOR (PLATINUM-COBALT UNITS)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)
JUNE											
29...	27900^f	8.3	0	6^f	6.0	--	--	--	--	3.7^f	.00
30...	30800^f	8.3	2^f	10^f	6.6	--	2.6^f	--	--	4.2^f	.00
SEP.											
08...	40200^f	8.2	--	--	7.8	134^f	1.2^f	<5^f	<5^f	2.5^f	.00
08...	39600^f	8.1	--	--	8.2	115^f	3.5^f	<5^f	<5^f	3.6^f	.00

DATE	PHENOLS (UG/L)	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL CHLORDANE (UG/L)	CHLORDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MATERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDT (UG/L)
JUNE											
29...	0	0	.00	--	.0	--	.00	--	.00	--	.00
30...	0	0	.00	--	.0	--	.00	--	.00	--	.00
SEP.											
08...	4^d	0	.00	.0	.0	0	.00	.0	.00	.0	.00
08...	5^d	0	.00	.0	.0	0	.00	.0	.00	.0	.00

DATE	DDT IN BOTTOM MATERIAL (UG/KG)	TOTAL DIAZINON (UG/L)	DIAZINON IN BOTTOM MATERIAL (UG/KG)	TOTAL DIELDRIN (UG/L)	DIELDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ETHION (UG/L)	ETHION IN BOTTOM MATERIAL (UG/KG)	TOTAL HEPTACHLOR (UG/L)	HEPTACHLOR IN BOTTOM MATERIAL (UG/KG)
JUNE											
29...	--	.00	--	.00	--	.00	--	.00	--	.00	--
30...	--	.01^f	--	.00	--	.00	--	.00	--	.00	--
SEP.											
08...	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-2. Water Quality Data, Mile (-2.9) Calcasieu Ship Channel (Concluded)

(USGS, Louisiana, 1976)

294310093200600 GULF OF MEXICO 300 YARDS WEST OF CALCASIEU SHIP CHANNEL AT MILE -2.9--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	HEPTA-CHLOR EPOXIDE IN BOT-TOM MA-TERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL MALA-THION (UG/L)	MALA-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL METHYL PARA-THION (UG/L)	METHYL PARA-THION IN BOT-TOM MA-TERIAL (UG/KG)	TOTAL METHYL TRI-THION (UG/L)	METHYL TRI-THION IN BOT-TOM MA-TERIAL (UG/KG)
JUNE										
29...	.00	--	.00	--	.00	--	.00	--	.00	--
30...	.00	--	.00	--	.00	--	.00	--	.00	--
SEP.										
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

DATE	TOTAL PARA-THION (UG/L)	PARA-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MA-TERIAL (UG/KG)	POLY-CHLO-RINATED NAPH-THA-LENES (UG/L)	TOTAL TOX-APHENE (UG/L)	TOX-APHENE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL TRI-THION (UG/L)	TRI-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL 2,4-D (UG/L)
JUNE										
29...	.00	--	.0	--	.00	0	--	.00	--	.13^f
30...	.00	--	.0	--	.00	0	--	.00	--	.06^f
SEP.										
08...	.00	.0	.0	0	.00	0	0	.00	.0	.00
08...	.00	.0	.0	0	.00	0	0	.00	.0	.00

DATE	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
JUNE									
29...	.00	.00	2	2^f	1	0	30	0	6
30...	.00	.00	2	2^f	0	0	30	0	6
SEP.									
08...	.00	.00	2	1^f	0	0	20	0	3
08...	.00	.00	3	0	0	0	20	0	3

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
JUNE									
29...	5^f	3	0	.2	.2^f	9	0	--	40^f
30...	3^f	8	0	.1	.1^f	6	0	40^f	20^f
SEP.									
08...	3^f	2	1^f	.0	.0	3	3^f	40^f	30^f
08...	3^f	3	1^f	.0	.0	5	2^f	40^f	20^f

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-3. Water Quality Data, Mile (-5.6) Calcasieu Ship Channel

(USGS, Louisiana, 1976)

294054093195000 GULF OF MEXICO AT CALCASIEU SHIP CHANNEL AT MILE -5.6

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	ALDRIN IN BOTTOM MATERIAL (UG/KG)	CHLORDANE IN BOTTOM MATERIAL (UG/KG)	DDD IN BOTTOM MATERIAL (UG/KG)	DDE IN BOTTOM MATERIAL (UG/KG)	DDT IN BOTTOM MATERIAL (UG/KG)	DIAZINON IN BOTTOM MATERIAL (UG/KG)	DIELDRIN IN BOTTOM MATERIAL (UG/KG)	ENDRIN IN BOTTOM MATERIAL (UG/KG)	ETHION IN BOTTOM MATERIAL (UG/KG)
SEP.										
07...	1545	.0	0	.0	.0	.0	.0	.0	.0	.0
08...	0850	.0	0	.0	.0	.0	.0	.0	.0	.0

DATE	HEPTACHLOR IN BOTTOM MATERIAL (UG/KG)	HEPTACHLOR EPOXIDE IN BOTTOM MATERIAL (UG/KG)	LINDANE IN BOTTOM MATERIAL (UG/KG)	MALATHION IN BOTTOM MATERIAL (UG/KG)	METHYL PARATHION IN BOTTOM MATERIAL (UG/KG)	METHYL TRITHION IN BOTTOM MATERIAL (UG/KG)	PARATHION IN BOTTOM MATERIAL (UG/KG)	PCB IN BOTTOM MATERIAL (UG/KG)	TOXAPHENE IN BOTTOM MATERIAL (UG/KG)	TRITHION IN BOTTOM MATERIAL (UG/KG)
SEP.										
07...	.0	.0	.0	.0	.0	.0	.0	0	0	.0
08...	.0	.0	.0	.0	.0	.0	.0	0	0	.0

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.7-3. Water Quality Data, Mile (-5.6) Calcasieu Ship Channel (Continued)

(USGS, Louisiana, 1976)

294054093202000 GULF OF MEXICO 300 YARDS WEST OF CALCASIEU SHIP CHANNEL AT MILE -5.6

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TIME	DISSOLVED IRON (FE) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)
SEP.											
07...	1530	70^{f}	30^{f}	320^{f}	1000^{f}	8600^{f}	400^{f}	136^{f}	0	2100^{f}	16000^{f}
08...	0840	40^{f}	40^{f}	320^{f}	990^{f}	8600^{f}	370^{f}	135^{f}	0	2100^{f}	16000^{f}

DATE	TOTAL NITRATE (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	DISSOLVED KJEL. NITROGEN (N) (MG/L)	DISSOLVED PHOSPHORUS (P) (MG/L)	TOTAL NONFILTRABLE RESIDUE (MG/L)	VOL. NONFILTRABLE RESIDUE (MG/L)	SUSPENDED SOLIDS (MG/L)	HARDNESS (CA,MG) (MG/L)
SEP.											
07...	.01^{f}	.00	.08^{f}	.08^{f}	.31^{f}	.19^{f}	.03^{d}	29^{f}	12^{f}	31^{f}	4900^{f}
08...	.00	.01^{f}	.10^{f}	.04^{f}	.40^{f}	.21^{f}	.06^{d}	39^{f}	11^{f}	47^{f}	4900^{f}

DATE	NONCARBONATE HARDNESS (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	DISSOLVED OXYGEN (MG/L)	CHEMICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	IMMEDIATE COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	TOTAL ORGANIC CARBON (C) (MG/L)	CYANIDE (CN) (MG/L)	PHENOLS (UG/L)
SEP.											
07...	4800^{f}	39900^{f}	8.1	8.0	134^{f}	.3^{f}	<5^{f}	<5^{f}	2.4^{f}	.00	1^{d}
08...	4800^{f}	39800^{f}	8.1	7.5	95^{f}	2.8^{f}	<5^{f}	<5^{f}	2.3^{f}	.00	5

DATE	OIL AND GREASE (MG/L)	TOTAL ALDRIN (UG/L)	ALDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL CHLORDANE (UG/L)	CHLORDANE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDD (UG/L)	DDD IN BOTTOM MATERIAL (UG/KG)	TOTAL DDE (UG/L)	DDE IN BOTTOM MATERIAL (UG/KG)	TOTAL DDT (UG/L)	DDT IN BOTTOM MATERIAL (UG/KG)
SEP.											
07...	0	.00	.0	.0	0	.00	.0	.00	.0	.00	.0
08...	0	.00	.0	.0	0	.00	.0	.00	.0	.00	.0

DATE	TOTAL DIAZINON (UG/L)	DIAZINON IN BOTTOM MATERIAL (UG/KG)	TOTAL DIELDRIN (UG/L)	DIELDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ENDRIN (UG/L)	ENDRIN IN BOTTOM MATERIAL (UG/KG)	TOTAL ETHION (UG/L)	ETHION IN BOTTOM MATERIAL (UG/KG)	TOTAL HEPTACHLOR (UG/L)	HEPTACHLOR IN BOTTOM MATERIAL (UG/KG)
SEP.										
07...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.04	.0	.00	.0	.00	.0	.00	.0	.00	.0

Note: Sample station locations are shown in Figure D.4-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.7-3. Water Quality Data, Mile (-5.6) Calcasieu Ship Channel (Concluded)

(USGS, Louisiana, 1976)

294054093202000 GULF OF MEXICO 300 YARDS WEST OF CALCASIEU SHIP CHANNEL AT MILE -5.6--Continued

WATER QUALITY DATA, WATER YEAR OCTOBER 1975 TO SEPTEMBER 1976

DATE	TOTAL HEPTA-CHLOR EPOXIDE (UG/L)	HEPTA-CHLOR EPOXIDE IN BOT-TOM MA-TERIAL (UG/KG)	TOTAL LINDANE (UG/L)	LINDANE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL MALA-THION (UG/L)	MALA-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL METHYL PARA-THION (UG/L)	METHYL PARA-THION IN BOT-TOM MA-TERIAL (UG/KG)	TOTAL METHYL TRI-THION (UG/L)	METHYL TRI-THION IN BOT-TOM MA-TERIAL (UG/KG)
SEP.										
07...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0
08...	.00	.0	.00	.0	.00	.0	.00	.0	.00	.0

DATE	TOTAL PARA-THION (UG/L)	PARA-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL PCB (UG/L)	PCB IN BOTTOM MA-TERIAL (UG/KG)	POLY-CHLO-RINATED NAPH-THA-LENES (UG/L)	TOTAL TOX-APHENE (UG/L)	TOX-APHENE IN BOTTOM MA-TERIAL (UG/KG)	TOTAL TRI-THION (UG/L)	TRI-THION IN BOTTOM MA-TERIAL (UG/KG)	TOTAL 2,4-D (UG/L)
SEP.										
07...	.00	.0	.0	16^{e}	.00	0	0	.00	.0	.00
08...	.00	.0	.0	0	.00	0	0	.00	.0	.00

DATE	TOTAL 2,4,5-T (UG/L)	TOTAL SILVEX (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	HEXA-VALENT CHRO-MIUM (CR6) (UG/L)	TOTAL COPPER (CU) (UG/L)
SEP.									
07...	.00	.00	2	2^{f}	0	0	20	0	3
08...	.00	.00	1	1^{f}	0	0	20	0	3

DATE	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
SEP.									
07...	3^{f}	3	1^{f}	.0	.0	3	1^{f}	60^{f}	40^{f}
08...	3^{f}	2	1^{f}	.0	.0	3	1^{f}	40^{f}	40^{f}

Note: Sample station locations are shown in Figure D.4-1.

Explanation of the superscripts is found in Table D.3-3.

APPENDIX D.8

TAYLOR BAYOU AND TRIBUTARIES, SALT BAYOU, AND SPINDLETOP DITCH

HYDROLOGIC DATA

Data in this appendix includes flow and water quality data for the area drained by Taylor Bayou and its tributaries plus Salt Bayou and Spindletop Ditch. Figure D.8-1 is a map of the area with water quality sampling stations. Table D.8-1 gives flow data for Hillebrandt Bayou, Table D.8-2 lists flow data for Taylor Bayou, and Table D.8-3 lists flow information for tributaries of Taylor Bayou. Table D.8-4 lists sample stations along Taylor Bayou and its tributaries by local landmarks.

Water quality data are provided in the following tables:

Table D.8-5. Field Water Quality Measurements for Taylor Bayou and Its Tributaries

Table D.8-6. Lab Water Quality Analyses and Other Miscellaneous Data for Taylor Bayou and Its Tributaries

Table D.8-7. Sediment Analyses, Physical-Chemical Parameters, Heavy Metals and Pesticides for Taylor Bayou

Table D.8-8. Water Quality Data for Salt Bayou

Table D.8-9. Sediment Quality Data for Salt Bayou

Table D.8-10. Water Quality Data for Spindletop Ditch (Sample Station D)

Table D.8-11. Sediment Quality Data for Spindletop Ditch (Sample Station D)

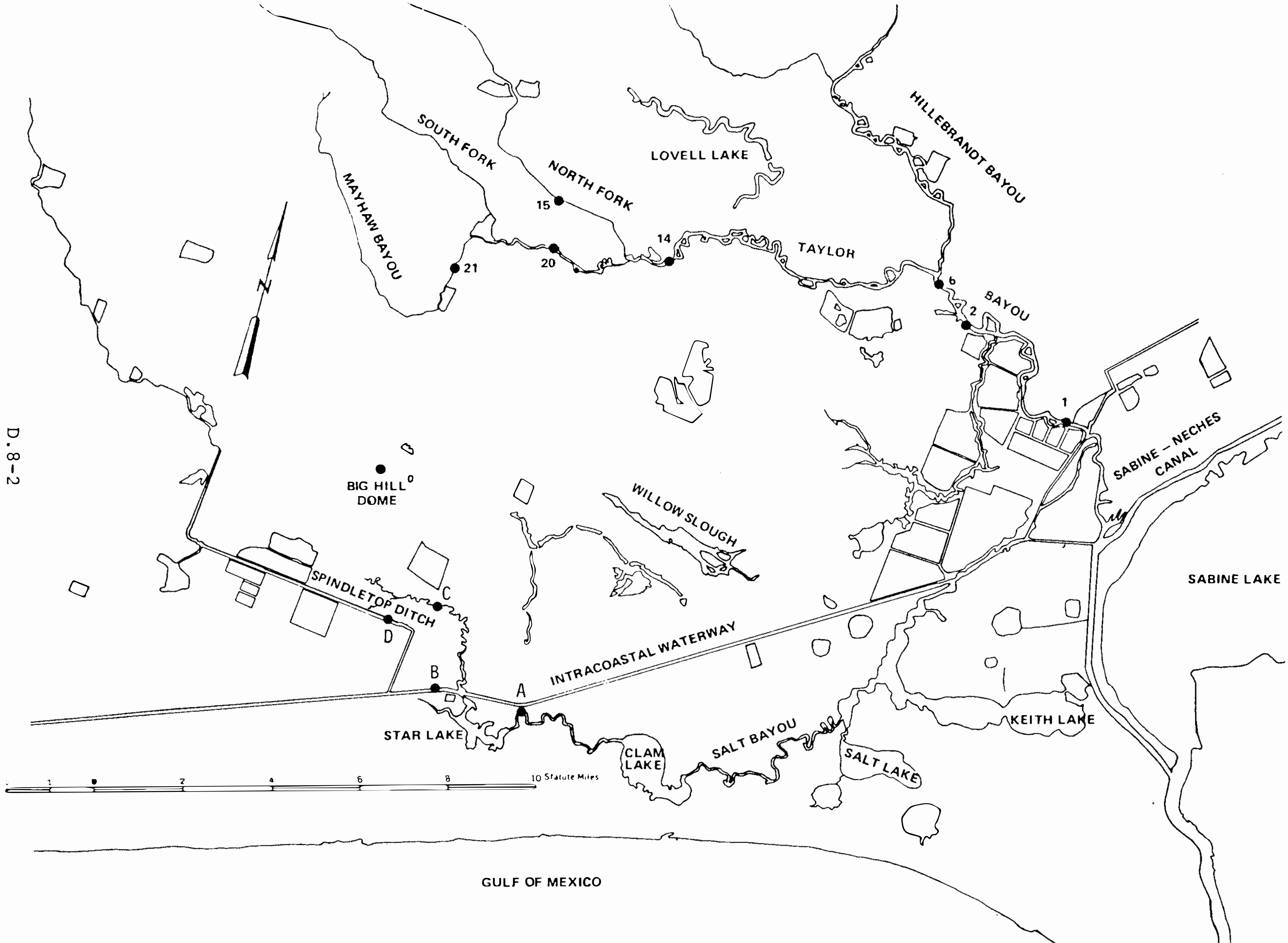


Figure D.8-1. Location of Sample Stations near the Big Hill Site

Table D.8-1. Flow Data for Taylor Bayou Near LaBelle (USGS, Texas, 1975)

TAYLOR BAYOU BASIN

08042000 Taylor Bayou near LaBelle, Tex.

LOCATION.--Lat 29°52'30", long 94°09'34", Jefferson County, near center of stream at downstream side of bridge on county road, 0.7 mile (1.1 km) south of LaBelle, 6.0 miles (9.7 km) upstream from Hillebrandt Bayou, 7.2 miles (11.6 km) upstream from State Highway 73, and 11.2 miles (18.0 km) upstream from salt-water gates and barge locks. Distances are measured along rectified channel.

DRAINAGE AREA.--262 mi^2 (679 km^2).

PERIOD OF RECORD.--April 1954 to current year, complete records for storms of 1.0 inch (25.4 mm) or more runoff, except for the period Sept. 10-22, 1961.

GAGE.--Water-stage recorder. Datum of gage is 4.63 ft (1.411 m) below mean sea level, determined by several comparisons of water surface with auxiliary water-stage recorder 7.2 miles (11.6 km) downstream during times of no flow and ideal weather conditions.

EXTREMES.--Current year: Maximum discharge, 5,520 ft^3/s (156 m^3/s) June 1; maximum gage height, 8.50 ft (2.591 m) May 31; minimum discharge not determined (affected by tides and pumping); minimum gage height, 3.20 ft (0.975 m) Dec. 1.

Period of record: Maximum discharge, 9,590 ft^3/s (272 m^3/s) Sept. 22, 1963; maximum gage height, 11.78 ft (3.591 m) Sept. 20, 1963 (backwater from Hillebrandt Bayou); minimum discharge not determined (affected by tides and pumping); minimum gage height, 2.31 ft (0.704 m) July 17, 1954.

Maximum stage since at least 1941, that of Sept. 20, 1963. Flood in 1941 reached a stage of 11.3 ft (3.44 m), from information by Corps of Engineers; flood in 1946 reached a stage of 10.4 ft (3.17 m), from county bridge plans; flood of Sept. 13, 1961 (Hurricane Carla), reached a stage of 11.51 ft (3.508 m).

REMARKS.--Records poor. Discharge is computed using fall as a factor. Discharge for recessions of large rises with insufficient fall are estimated. Small rises with insufficient fall are not computed. Low flow is regulated by drainage from ricefields and operation of salt-water gates and barge locks. An unknown amount of water is diverted above and below gage for rice irrigation.

REVISIONS.--WSP 1922: Drainage area.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	-	1,770	-	-				-	5,380	-	2,520	
2	-	800	-	-				-	5,260	-	3,040	
3	-	200	-	-				-	3,730	-	2,000	
4	-	-	-	-				-	1,600	-	1,000	
5	-	-	-	-				-	600	-	1,500	
6	-	-	-	-				-	-	-	1,000	
7	-	-	-	800				-	-	-	300	
8	-	-	-	3,520				-	-	-	-	
9	-	-	-	3,200				-	200	-	-	
10	-	-	-	2,500				-	2,400	-	-	
11	-	-	-	3,470				-	4,290	-	-	
12	-	-	-	2,220				-	4,740	-	-	
13	-	-	-	800				-	4,510	-	-	
14	-	-	-	200				-	3,900	-	-	
15	-	-	-	-				-	2,950	-	-	
16	-	100	-	-				-	1,500	-	-	
17	-	1,990	-	-				-	700	-	-	
18	-	2,870	-	-				-	-	-	-	
19	-	2,220	-	-				-	-	-	-	
20	-	2,370	-	-				-	-	-	-	
21	-	2,080	-	-				-	-	-	-	
22	-	1,000	-	-				-	-	-	-	
23	-	500	-	-				-	-	-	-	
24	-	-	-	-				-	-	-	-	
25	-	-	200	-				-	-	-	-	
26	-	-	1,490	-				-	-	-	-	
27	-	-	3,220	-				-	-	-	-	
28	500	-	3,410	-				200	-	-	-	
29	3,000	-	2,680	-	------			2,410	-	-	-	
30	3,650	-	1,000	-	------			4,070	-	-	-	
31	2,620	------	500	-	------		------	4,830	------	400	-	------
MAX	3,650	2,870	3,410	3,520				4,830	5,380	400	3,040	

CAL YR 1974............... MAX 5,810
WTR YR 1975............... MAX 5,380

Table D.8-2. Flow Data for Hillebrandt Bayou near Lovelle Lake (USGS, Texas, 1975)

TAYLOR BAYOU BASIN

08042500 Hillebrandt Bayou near Lovell Lake, Tex.

LOCATION.--Lat 29°55'44", long 94°06'35", Jefferson County, near center of stream at downstream side of bridge on county road, 1.3 miles (2.1 km) southeast of Lovell Lake, and 4.4 miles (7.1 km) upstream (along rectified channel) from Taylor Bayou.

DRAINAGE AREA.--128 mi² (332 km²).

PERIOD OF RECORD.--April 1954 to current year, complete records for storms of 1.0 inch (25.4 mm) or more runoff, except for the period Sept. 11-18, 1961.

GAGE.--Water-stage recorder. Auxiliary water-stage recorder 3.0 miles (4.8 km) downstream. Datum of gage is 4.63 ft (1.411 m) below mean sea level, determined by comparisons of water surface with Taylor Bayou near LaBelle, auxiliary gage, 5.6 miles (9.0 km) downstream, during times of no flow and ideal weather conditions. Prior to Aug. 28, 1963, auxiliary water-stage recorder on Taylor Bayou 1.2 miles (1.9 km) downstream from Hillebrandt Bayou, nonrecording gages on Taylor Bayou 2.3 and 5.2 miles (3.7 and 8.4 km) downstream from Hillebrandt Bayou.

EXTREMES.--Current year: Maximum discharge, 5,660 ft³/s (160 m³/s) June 10; maximum gage height, 8.48 ft (2.585 m) June 10; minimum discharge not determined (affected by tides and pumping); minimum gage height, 3.83 ft (1.167 m) Dec. 1.

Period of record: Maximum discharge, 15,000 ft³/s (425 m³/s) Sept. 18, 1963; maximum gage height, 12.34 ft (3.761 m) Sept. 19, 1963; minimum discharge not determined (affected by tides and pumping); minimum gage height, 2.33 ft (0.710 m) July 17, 1954.

Maximum stage since 1941, 12.34 ft (3.761 m) Sept. 19, 1963. A stage of 11.56 ft (3.523 m) occurred Sept. 13, 1961 (backwater caused by Hurricane Carla).

REMARKS.--Records fair. Discharge computed using fall as a factor. Discharge for recessions of large rises with insufficient fall are estimated. Small rises with insufficient fall are not computed. Low flow is regulated by drainage from ricefields and operation of salt-water gates and barge locks. An unknown amount of water is diverted above and below gage for rice irrigation.

REVISIONS.--WSP 1922: Drainage area.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	-	500		-				-	2,200	-	900	
2	-	100		-				-	1,000	-	3,350	
3	-	-		-				-	500	-	1,930	
4	-	-		-				-	200	-	900	
5	-	-		-				-	-	-	1,100	
6	-	-		-				-	-	-	800	
7	-	-		900				-	-	-	100	
8	-	-		2,750				-	-	-	-	
9	-	-		900				-	1,060	-	-	
10	-	-		1,470				-	5,310	-	-	
11	-	-		700				-	4,740	-	-	
12	-	-		100				-	2,870	-	-	
13	-	-		-				-	1,000	-	-	
14	-	-		-				-	200	-	-	
15	-	-		-				-	-	-	-	
16	-	-		-				-	-	-	-	
17	-	-		-				-	-	-	-	
18	-	-		-				-	-	-	-	
19	-	-		-				-	-	-	-	
20	-	-		-				-	-	-	-	
21	-	-		-				-	-	-	-	
22	-	-		-				-	-	-	-	
23	-	-		-				-	-	-	-	
24	-	-		-				-	-	-	-	
25	-	-		-				-	-	-	-	
26	-	-		-				-	-	-	-	
27	-	-		-				-	-	-	-	
28	100	-		-				200	-	-	-	
29	1,880	-		-	------			1,480	-	-	-	
30	1,760	-		-	------			3,040	-	-	-	
31	1,000	------		-	------		------	2,900	------	100	-	------
MAX	1,880	500		2,750				3,040	5,310	100	3,350	

CAL YR 1974............... MAX 4,790
WTR YR 1975............... MAX 5,310

Table D.8-3. Flow Data for Taylor Bayou Tributaties (Texas Water Quality Board, 1975)

Hydrological Data

Station Number	Location	Method	Date	Time	Discharge cfs
8	Pevitot Gulley	PM*	7/23/74	1650	4.47
9	Bayou Din	PM	7/23/74	1235	0.36
10	Kidd Gulley	PM	7/23/74	1140	17.09
11	Willow Marsh Bayou	PM	7/23/74	1035	31.86
16	Green Pond Gulley	PM	7/23/74	1250	146.86
17	Ground Gulley	PM	7/23/74	1140	97.18
19	Pignut Gulley	PM	7/23/74	1030	14.77
21	Mayhaw Bayou	PM	7/23/74	1410	10.45

* PM - Pigmy Meter

The data in Table 3 indicate that the majority of inflow to Taylor Bayou is supplied by Green Pond Gulley, Ground Gulley, Pignut Gulley, and Willow Marsh Bayou. The remaining tributaries were small and contributed less than 20 cfs each. All other tributaries feeding the bayou were observed in a non-discharging condition or at a level considered not significant.

Note: Sample station locations are shown in Figure D.8-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.8-4. Sample Station Locations for Taylor Bayou and Tributaries

(Texas Water Quality Board, 1975)

Survey Station Number	Station Reference Number	Location
1	0701.A001	Bayou - ¼ mile upstream from salt water barrier
2	0701.A002	Bayou - at Highway 73 bridge
6	0701.A006	Hillebrandt Bayou at Humble Road
8	0701.A008	Pevitot Gulley at La Belle Road
9	0701.A009	Bayou Din at Highway 124
10	0701.A010	Kidd Gulley at Highway 124
11	0701.A011	Willow Marsh Bayou at Highway 124
14	0701.A014	Bayou at La Belle Road
15	0701.A015	North Fork of Taylor Bayou at County Road south of Burrell
16	0701.A016	Green Pond Gulley at Gilbert Road
17	0701.A017	Ground Gulley at Johnson Road
19	0701.A019	Pignut Gulley at Pignut Road
20	0701.A020	South Fork of Taylor Bayou at County Road south of Burrell
21	0701.A021	Mayhaw Bayou at Highway 73

Note: Sample station locations are shown in Figure D.8-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.8-5. Flow Field Water Quality Measurements for Taylor Bayou and Its Tributaries

(Texas Water Quality Board, 1975)

Station 1 Time 0720

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	3.9[a,c]	50	84.6	6.8	315		
3	3.6[a,c]	47	85.1	6.85	310		
6	3.5[a,c]	45	84.6	6.85	315		
9	3.5[a,c]	45	84.2	6.85	310		
12	3.0[a,c]	38	84.2	6.8	350		
15	1.0[a,c]	13	84.2	6.8	3300		
18	1.0[a,c]	13	84.2	6.8	4000		

Station 1 Time 1035

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	3.8[a,c]	50	86	6.85	330	0	40
3	3.65[a,c]	48	86	6.85	330		
6	3.6[a,c]	47	86	6.85	330		
9	3.15[a,c]	41	86	6.85	340		
12	2.1[a,c]	27	85.7	6.8	1200		
14	1.8[a,c]	23	85.1	6.8	2000		

Station 1 Time 1430

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	5.9	80	89.6	6.8	350	0	41
3	3.5[a,c]	47	86.9	6.5	350		
6	3.4[a,c]	45	86	6.4	350		
9	3.4[a,c]	45	86	6.4	355		
12	2.9[a,c]	38	86	6.4	450		
15	1.8[a,c]	23	85.1	6.4	3000		

Station 1 Time 1700

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	5.4	73	89.6	6.7	330	0	44
3	5.1	69	89.6	7.0	330		
6	3.8[a,c]	51	88.7	6.85	330		
9	3.2[a,c]	43	87.8	6.8	340		
12	3.0[a,c]	39	86	6.8	340		
15	1.7[a,c]	22	86	6.7	1200		

Station 1 Time 1905

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	5.0	68	88.7	7.0	330	0	42
3	4.7[a,c]	64	88.7	7.0	330		
6	3.3[a,c]	44	87.8	6.85	330		
9	2.8[a,c]	37	86.9	6.8	345		
12	2.7[a,c]	36	86	6.8	345		
15	0.3[a,c]	4	85.1	6.8	3800		

Note: Sample station locations are shown in Figure D.8-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.8-5. Flow Field Water Quality Measurements for Taylor Bayou and Its Tributaries (Continued)

(Texas Water Quality Board, 1975)

Station 2 Time 0645

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	3.2^{ac}	42	85.1	6.7	280	0	38
3	3.2^{ac}	42	86	6.8	280		
6	2.8^{ac}	37	86	6.8	280		
9	0.8^{ac}	10	85.1	6.6	290		

Station 2 Time 1000

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	3.1^{ac}	41	86	6.8	290	0	41
3	3.0^{ac}	39	86	6.8	290		
6	2.7^{ac}	36	86	6.8	290		
9	1.5^{ac}	19	85.1	6.7	300		

Station 2 Time 1400

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	4.0^{ac}	54	89.6	6.7	340	0	44
3	3.0^{ac}	40	86.9	6.7	320		
6	2.5^{ac}	33	86	6.7	320		
9	2.0^{ac}	26	85.1	6.7	320		

Station 2 Time 1530

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	4.8^{ac}	66	91.4	6.9	315	0	44
3	2.8^{ac}	38	88.7	6.75	300		
6	1.7^{ac}	22	86	6.7	315		
9	1.3^{ac}	17	85.1	6.65	320		

Station 2 Time 2030

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	4.2^{ac}	56	87.8	6.9	290	0	42
3	3.7^{ac}	49	87.8	6.9	290		
6	2.0^{ac}	27	86.9	6.7	290		
9	1.2^{ac}	16	86	6.7	300		

Station 2 Time 0120

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	3.1^{ac}	41	86.9	6.85	290		
3	3.1^{ac}	41	86.9	6.85	290		
6	1.8^{ac}	24	86.9	6.75	295		
9	1.0^{ac}	13	85	6.75	310		

Station 2 Time 0700

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	2.7^{ac}	36	86	6.85	295		
3	2.7^{ac}	36	86	6.85	295		
6	2.7^{ac}	36	86	6.85	295		
9	1.3^{ac}	17	86	6.75	295		
12	0.95^{ac}	12	85.1	6.7	310		

Note: Sample station locations are shown in Figure D.8-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.8-5. Flow Field Water Quality Measurements for Taylor Bayou and Its Tributaries (Concluded) (Texas Water Quality Board, 1975)

Station 6 Time 0750

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	5.1	66	85.5	7.4	320	0	66
5	4.6^{ac}	60	85.5	7.4	325		
8	0.0^{ac}	0	82.4	7.25	380		

Station 6 Time 1100

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	6.2	82	86	7.5	320	0	62
5	3.9^{ac}	51	85.1	7.3	340		
8	0.1^{ac}	1	82.4	7.2	375		

Station 6 Time 1840

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	14.5	196	89.6	8.8	340	9	67
5	3.8^{ac}	50	86	7.4	355		
8	0.1^{ac}	1	84.2	7.2	375		

Station 6 Time 2025

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	9.6	130	88.7	8.6	340	1	65
5	4.2^{ac}	56	87.8	7.5	360		
8	1.2^{ac}	16	86	7.3	370		

Station 6 Time 1435

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	11.4	154	88.7	8.3	320	2	65
5	3.4^{ac}	44	85.1	7.3	355		
8	0.2^{ac}	3	82.4	7.2	380		

Station 14 Time 0900

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	4.15^{ac}	55	86	6.9	300	0	60
5	3.1^{ac}	46	86	6.8	300		
7.5	3.1^{ac}	40	84.2	6.8	300		

Station 14 Time 1130

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	4.8	63	86.9	7.6	260	0	60
5	3.6^{ac}	47	86	7.6	270		
7.5	3.0^{ac}	39	85.1	7.6	270		

Station 14 Time 1420

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	6.0	81	89.6	7.25	330	0	74
5	1.4^{ac}	18	86	6.9	330		
9	1.0^{ac}	13	85.1	6.75	330		

Station 14 Time 1755

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	6.7	91	89.1	7.4	270	0	54
5	2.9^{ac}	38	86.4	6.95	270		
10	2.1^{ac}	27	85.1	6.85	270		

Station 14 Time 2010

Depth ft.	D.O.		Temp. °F	pH	Cond. umhos /cm	Alk.	
	mg/l	% Sat.				Phen.	Tot.
1	7.8	105	88.7	7.2	270	0	56
5	4.3^{ac}	57	86.9	7.0	270		
10	2.2^{ac}	29	85.1	6.9	270		

Note: Sample station locations are shown in Figure D.8-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.8-6. Lab Water Quality Analyses and other Miscellaneous Data (Texas Water Quality Board, 1975)

Laboratory Water Analyses (mg/l)

Station	Station Number	Chloride	Sulfate	TDS	T-Phosphate	O-Phosphate	NH_3-N	NO_2-N	NO_3-N	Kjel-N	TOC	BOD_5	Filtered BOD_5	TSS	VSS
Taylor Bayou	1	46	27	156	0.61^c	0.38	<0.1	<0.05	0.04	1.0	18	1.5	0.5	35	6
Taylor Bayou	2	39	23	141	0.6^c	0.38	<.1	< .05	<.03	0.9	18	1.0	0.5	32	7
Hillebrandt Bayou	6	42	28	167	2.0^c	1.5	0.4	0.06	0.21	0.8	15	6.5	2.0	20	6
Taylor Bayou	14	29	23	129	0.74^c	0.33	<.1	<0.05	0.1	1.2	17	2.5	1.0	31	4
North Fork	15	26	21	122	0.38^c	0.07	<.1	< .05	0.04	0.8	16	3.0	1.0	39	11
South Fork	20	42	21	145	0.34^c	0.03	<.1	<0.05	<0.03	0.8	15	3.0	1.0	19	9
Mayhaw Bayou	21	56	29	196	0.33^c	0.08	<.1	<0.05	0.03	1.2	16	5.0	2.0	32	8

Tributary Field Measurements

Station Number	Tributary	Temperature °F	Dissolved Oxygen		pH	Time (hours)
			mg/l	% Saturation		
15	North Fork of Taylor	86	5.9^e	77	7.5	1015
21	Mayhaw Bayou	88	7.9	105	7.8	1410

Fecal Coliform Data

Station Number	1	2	6	14	15	0	21
Fecal Coliform No./100 ml	20	40	50	30	40	30	520^a

Note: Sample station locations are shown in Figure D.8-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.8-7. Sediment Analyses, Physico-Chemical Parameters, Heavy Metals and Pesticides

(Texas Water Quality Board, 1975)

Sediment Physico-chemical Analyses

Parameter	Station Number			
	1	2	6	14
COD (mg/kg)	11,700	40,500	74,200[g]	53,400[g]
IOD (mg/l)	369	191.5	--	367
Total Phosphate (mg/kg)	1,900	1,800	4,500	1,800
Kjel-Nitrogen (mg/kg)	1,730[g]	1,110[g]	2,370[g]	3,100[g]
Volatile Solids (%)	7.5	4.8	9.3	8.8
Oil & Grease (mg/kg)	13,200[g]	630	1,210	490

Sediment Heavy Metal Analyses (mg/kg)

Parameter	Station Number			
	1	2	6	14
Arsenic	2.5	3.1	2.2	2.0
Cadmium	<1	<1	<1	<1
Copper	6.9	11	23	8.3
Chromium	43	44	56	52
Lead	90[g]	39	75[g]	25
Mercury	0.11	0.08	0.36	0.06
Manganese	280	380	340	230
Nickel	15	18	18	17
Silver	1	1	3	2
Zinc	81[g]	68[g]	170[g]	66[g]

Note: Sample station locations are shown in Figure D.8-1.
Explanation of the superscripts is found in Table D.3-3.

Table D.8-7. Sediment Analyses, Physico-Chemical Parameters, Heavy Metals and Pesticides (Concluded)

(Texas Water Quality Board, 1975)

Sediment Pesticide Analyses (μg/kg)

Parameter	1	2	6	14
Silvex	*	0.0	0.0	0.0
Aldrin	*	0.0	0.0	0.0
Chlordane	*	0.0	0.0	0.0
DDD	*	0.0	3.9	0.0
DDE	*	0.0	3.1	0.0
DDT	*	0.0	0.0	0.0
Diazinon	*	0.0	0.0	0.0
Dieldrin	*	2.7	10.0	0.4
Endrin	*	0.0	0.0	0.0
Heptachlor	*	0.0	0.0	0.0
Heptachlor Expoxide	*	0.0	0.0	0.0
Lindane	*	0.0	0.0	0.0
Methoxychlor	*	0.0	0.0	0.0
Methyl Parathion	*	0.0	0.0	0.0
Parathion	*	0.0	0.0	0.0
Toxaphene	*	0.0	0.0	0.0
PCB	*	18.0^{g}	59.0^{g}	24.0^{g}

* Sample contaminated with oil residue - analysis not possible.

0.0 indicates none detected in sample.

Note: Sample station locations are shown in Figure D.8-1.

Explanation of the superscripts is found in Table D.3-3.

Table D.8-8. Water Quality Data for Salt Bayou**

	Concentration+	
	Sample Station C	Sample Station A
Field Measurements		
pH	7.0	8.6
Temp (°C)	24	25
DO (mg/l)	6.0	7.7
Conductivity (μmhos/cm)	1850	1700
Turbidity (JTU)	130	185
Lab Measurements		
Phen. AlK (mg/l)	0	0
TSS (mg/l)	74	139
T-Phos. (mg/l)	.19[c]	.24[c]
pH	7.0	7.9
VSS (mg/l)	23	26
O-Phos. (mg/l)	.03	.02
Total Alk. (mg/l)	48	48
Ammonia N (mg/l)	.08[c]	.01
Conductivity (μmhos/cm)	183	210
Nitrate N (mg/l)	.10[f]	.14[f]
Chloride (mg/l)	2600	750
TOC (mg/l)	27	32
Sulphate (mg/l)	82	56
Total Coliform (#/100 ml)	1700	1700
Fecal Coliform (#/100 ml)	136	<1
BOD_5 (mg/l)	8	4

Table D.8-8. Water Quality Data for Salt Bayou (Continued)**

	Concentration[+]	
Metals (µg/l)	Sample Station C	Sample Station A
Arsenic	<20	<20
Barium	<50	<50
Boron	<1000	<1000
Cadmium	<20[*]	<20[*]
Copper	50	20
Chromium	<20	<20
Iron	1200	5900
Lead	<20	<20
Manganese	200[f]	370[f]
Mercury	<.5[*]	<.5[*]
Nickel	<20	<20
Selenium	<20	<20
Silver	<20	<20
Zinc	70[e]	120[e]

Table D.8-8. Water Quality Data for Salt Bayou (Concluded)**

Pesticides and Related Compounds (μg/l)	Concentration+	
	Sample Station C	Sample Station A
2,4-D	<10[f]	<10[f]
2,4,5-T	<10[f]	<10[f]
Silvex	<10[f]	<10[f]
Heptachlor	< 0.02*	< 0.02*
Heptachlor Epoxide	< 0.02*	< 0.02*
Lindane	< 0.02*	< 0.02*
Malathion	< 0.02	< 0.02
Methoxychlor	< 0.02	< 0.02
Parathion	< 0.02	< 0.02
PCB	< 1.0*	< 1.0*

* Judgment not possible with these "less than" values as detection limits were higher than EPA recommended criteria.

\+ Explanation of the superscripts is found in Table D.3-3.

** Sampling and analysis provided by Texas Water Quality Board upon FEA request.

Table D.8-9. Sediment Quality Data for Salt Bayou**

	Concentration[+]	
Metals (mg/kg)	Sample Station C	Sample Station A
Arsenic	5.7	4.3
Barium	27	8.5
Cadmium	<.87	<.43
Copper	17	5.9
Chromium	15	5.1
Lead	14	10
Mercury	.18	<.05
Manganese	74	70
Nickel	7.4	4.9
Selenium	<.87	<.43
Silver	<.87	<.43
Zinc	28	23
Other Parameters (mg/kg)		
T-Phosphorus	170	430
COD	74000[g]	67000[g]
Kj-N	1238[g]	1267[g]
Volatile Solids	$6.9\text{x}10^4$	$7.1\text{x}10^5$
Oil & Grease	472	357

Table D.8-9. Sediment Quality Data for Salt Bayou (Concluded)**

Pesticides and Related Compounds (μg/kg)	Concentration+ Sample Station C	Sample Station A
Silvex	<20.0	<20.0
Aldrin	< 1.0	< 1.0
Chlordane	<20.0	<20.0
DDD	< 5.0	< 5.0
DDE	< 5.0	< 5.0
DDT	< 5.0	< 5.0
Diazinon	< 5.0	< 5.0
Dieldrin	< 3.0	< 3.0
Endrin	< 3.0	< 3.0
Heptachlor	< 1.0	< 1.0
Heptachlor Epoxide	< 1.0	< 1.0
Linane	< 1.0	< 1.0
Methoxychlor	<20.0	<20.0
Methyl Parathion	< 5.0	----
Parathion	< 5.0	----
Toxaphene	<50.0	<50.0
PCB	<20.0	<20.0

+ Explanation of superscripts is found in Table D.3-3.

** Sampling and analysis provided by Texas Water Quality Board upon FEA request.

Table D.8-10. Water Quality Data for Spindletop Ditch (Sample Station D)**

Field Measurements	Concentration[+]
pH	8.6
Temp (°C)	26
DO (mg/l)	8.9
Cond. (μmhos/cm)	8800
Turbidity (JTU)	32
Lab Measurements	
Phen. Alk. (mg/l)	0
TSS (mg/l)	22
T-Phos. (mg/l)	.07[c]
pH	7.5
VSS (mg/l)	8
Ortho-Phos (mg/l)	.02
T. Alk. (mg/l)	58
Ammonia N. (mg/l)	.04[c]
Cond. (μmhos/cm)	1000
Nitrate N (mg/l)	.44[f]
Chloride (mg/l)	2850
Total Coliform(#/100 ml)	2000
Fecal Coliform (#/100 ml)	10
TOC (mg/l)	11
Sulphate (mg/l)	401
BOD_5 (mg/l)	4

Table D.8-10. Water Quality Data for Spindletop Ditch (Sample Station D) (Continued)**

Metals (μg/l)	Concentration[+]
Arsenic	<20
Barium	<50[f]
Boron	<1000[f]
Cadmium	<20*
Copper	<20
Chromium	<20
Iron	580
Lead	40[e]
Manganese	180[f]
Mercury	<.5*
Nickel	30
Selenium	<20
Silver	<20
Zinc	70[e]

Table D.8-10. Water Quality Data for Spindletop Ditch (Sample Station D) (Concluded)**

Pesticides and Related Compounds (μg/l)	Concentration+
2,4-D	$<10^f$
2,4,5-T	$<10^f$
Silvex	$<10^f$
Heptachlor	< 0.02*
Heptachlor Epoxide	< 0.02*
Lindane	< 0.02*
Malathion	< 0.02
Methoxychlor	< 0.02
Parathion	< 0.02
PCB	< 1.0*

* Judgment not possible with these "less than values as detection limits were higher than EPA recommended criteria.

\+ Explanation of the superscripts is found in Table D.3-3.

** Sampling and analysis provided by Texas Water Quality Board upon FEA request.

Table D.8-11. Sediment Quality Data for Spindletop Ditch (Sample Station D)**

Metals (mg/kg)	Concentration[+]
Arsenic	2.9
Barium	26
Cadmium	<1.2
Copper	29
Chromium	22
Lead	29
Mercury	.28
Manganese	105
Nickel	14
Selenium	<1.2
Silver	<1.2
Zinc	55[g]
Other Parameters (mg/kg)	
T-Phosphorus	570
COD	1008200[g]
Kj-N	1585[g]
Volatile Solids	7.7×10^4
Oil and Grease	1659[g]

Table D.8-11. Sediment Quality Data for Spindletop Ditch (Sample Station D) (Concluded)**

Pesticides and Related Compounds (μg/kg)	Concentration+
Silver	<20.0
Aldrin	< 1.0
Chlordane	<20.0
DDD	< 5.0
DDE	< 5.0
DDT	< 5.0
Diazinon	< 5.0
Dieldrin	< 3.0
Endrin	< 3.0
Heptachlor	< 1.0
Heptachlor Epoxide	< 1.0
Linane	< 1.0
Methoxychlor	<20.0
Methyl Parathion	< 5.0
Parathion	< 5.0
Toxaphene	<50.0
PCB	<20.0

\+ Explanation of the superscripts is found in Table D.3-3.

** Sampling and analysis provided by water quality board upon FEA request.

APPENDIX D.9

WATER UTILIZATION

Appendix D.9 contains data on water pumpage in Calcasieu Parish and Cameron Parish in Louisiana and Jefferson County in Texas.

Table D.9-1. Water Pumpage in Calcasieu Parish Louisiana (mgd)

(Louisiana Geological Survey, 1970)

Use Category	Ground	Surface
Public Supplies	12.91	0
Industrial	120.28	642.28
Thermoelectric	5.44	0
Rural:		
Domestic	2.66	-
Livestock	.12	0.29
Irrigation:		
Rice	65.74	167.72
Other	0	0
TOTAL	207.15	809.80

Table D.9-2. Water Pumpage in Cameron Parish Louisiana (mgd)

(Louisiana Geological Survey, 1970)

Use Category	Ground	Surface
Public Supplies	0.70	0
Industrial	4.83	11.75
Thermoelectric	0	0
Rural:		
Domestic	.49	-
Livestock	.16	.34
Irrigation:		
Rice	5.10	29.32
Other	0	0
TOTAL	11.28	41.41

Table D.9-3. Approximate Ground Water Pumpage in Jefferson County, Texas

(Texas Water Development Board, 1971)

Use Category	Pumpage (mgd)
Industrial	3.1
Municipal	1.0
Irrigation	.5
TOTAL	4.6

APPENDIX D.10

DISCHARGE DATA
FOR
INDUSTRIAL AND MUNICIPAL WASTES

This appendix consists of two tables. Table D.10-1 points out discharge data for wastes emptying into the Calcasieu River estuarine region during 1969. Table D.10-2 presents similar data for wastes discharged into Taylor Bayou and its tributaries.

Table D.10-1 Quantity and Quality of Industrial Waste Emptying Into the Estuarine Part of the Calcasieu River - 1961

(Louisiana Wildlife and Fisheries Commission, 1971)

Source of Waste, Principal Products	Receiving Waters	Avg. Daily Discharge (mgd)	Sewerage Disposal Facilities[2]	Industrial Waste Facilities[3]	Estimated Pounds BOD Discharged Daily
Louisiana Menhaden-fish oil	Calcasieu River	Unk.	Unk.	C.B.	Unk.
Gulf Menhaden-fish oil	Calcasieu River	Unk.	Unk.	Unk.	Unk.
Ocean Protein, Lake Charles-fish oil	Calcasieu River	Unk.	Unk.	Unk.	Unk.
Olin Mathison-Chemicals	Calcasieu River	115.200	Unk.	I.R.	Unk.
Petroleum Chemicals, Inc.-petrochemicals	Bayou D'Inde to Calcasieu River	0.720	Unk.	C.S.R.	Unk.
Continental Oil Co.-complete refinery	Calcasieu River	12.960	Unk.	S.B.	Unk.
Tenneco Refinery - Naval stores products	Calcasieu River	Unk.	Unk.	I.B.S.	Unk.
Stauffer Chemicals - Vinyl clorides	Calcasieu River	0.720	Unk.	N.R.	Unk.
Columbia Southern - Chemicals	Calcasieu River	270.000	I.T.	R.T.	Unk.
Herculese Corporation - Petrochemicals	Calcasieu River	0.720	L.	F.R.S.	1,700
Firestone-synthetic rubber	Calcasieu River	0.820	I.T.	S.B.S.	750
Louisiana Polymer Corp.-Polyethylene	Calcasieu River	0.170	Unk.	S.G.	Unk.
Cities Service Refinery-Petrochemical and Petroleum refinery	Calcasieu River	288.000	O.P.	H.P.S.	1,750
Davidson Chemical-Inorganic chemicals	Calcasieu River	0.576	Unk.	Unk.	Unk.
Union Texas Petroleum-sulphur mine (Frasch process)	Bayou D'Inde to Calcasieu River	Unk.	Unk.	R.S.A.	Unk.

---

[1] Information on sources, amounts, and degree of treatment of waste obtained from the Pollution Control Division, Louisiana Wild Life and Fisheries Commission, 1969

[2] Symbols for degree of treatment: Unk.--Unknown; P.S.P.--Primary Settling Pond; I.T.--Imhoff Tank; L.--Lagoon; O.P.--Oxidation Pond.

[3] Symbols for degree of treatment: B.D.--Betz Dionodic water treatment; I.W.--Injection Wells, separaters, and skimmers; S.--Save, all solid removal; O.P.--Oxidation Pond; O.W.S.--Oil and water Separator; S.R.P.--Secondary Retention Ponds; C.B.--Cooling Basin; H.T.--Holding Tanks;

Table D.10-1.(Continued). Quantity and Quality of Industrial Waste

---

W.R.P.--Water Retention Ponds; I.R.--Impoundment Reservoir, solids removal; C.S.R.--through Cities Service Refinery; S.B.--Settling Basin and strippers; I.B.S.--Impoundment Basin and Skimmer; N.R.--Neutralization and Removal of dissolved solids; R.T.--Routine Testing of discharge water; R.F.S.--Facilities for Reduction in Solids; S.B.S.--Settling Basin and Skimmers; S.G.--Sump Gathering and burning of hydrocarbons; H.P.S.--Holding Ponds and Skimmers; R.S.A.--Reservoir, Spray Aeration--removal of H_2S.

Table D.10-1

Quantity and Quality of Domestic Waste Emptying into Estuarine Areas - 1969[1]

(Louisiana Wildlife and Fisheries Commission, 1971.)

Source of Waste	Receiving Waters	Average Daily Discharge (mgd)	Degree[2] of Treatment	Est. Average[3] ppm B.O.D. in Discharge	Estimated[4] Population Served
Cameron	Calcasieu River	0.20	P.T.	140	2,000
Hackberry	Calcasieu River	0.05	P.T.	140	500
Lake Charles - Greenwich Terrace	Calcasieu River	0.35	B.F.	30	3,500
Lake Charles - A & B Plant	Calcasieu River	7.70	A.S	30	71,300
Lake Charles - Firestone	Calcasieu River	0.05	B.F.	30	500
Westlake	Calcasieu River	0.44	B.F.	30	3,301
Maplewood	Calcasieu River	0.30	A.S.	30	275
Hollywood	Calcasieu River	0.05	B.F.	30	545
Lake Charles - Cities Service	Calcasieu River	0.60	O.P.	25	500
Sulphur	Bayou D'Inde to Calcasieu River	1.20	B.F.	30	12,800

[1] Information on sources, amounts, and degree of treatment of waste was obtained from the Louisiana Department of Health, 1969.

[2] Symbols for degree of treatment: B.F. - Biological Filtration; O.P. - Oxidation Pond; A.S. - Activated Sludge; P.T. - Primary Treatment.

[3] Based on an estimate that the average B.O.D. of untreated domestic sewerage is 200 ppm; primary treated is 140 ppm; and secondary treatment is 20 ppm unless known to be higher.

[4] Represents the actual number of domestic sewerage installations.

Table D.10-2. Wastewater Discharge in Taylor Bayou and Tributaries

(Texas Water Quality Board, 1975)

Wastewater Dischargers

Map Code	Name	BOD_5 lbs/day	Ammonia plus Nitrate Nitrogen	Ortho Phosphate
			lbs/day[3]	
A	City of Port Arthur (Lakeside Park STP)	8.9	5.6	22.7
B	City of Port Arthur (Port Acres STP)	75.0	43.0	48.0
C	Velsicol Chemical Co.	3.9	*	*
D	Country Side Estates STP	0.40	*	*
E	Jefferson County WCID 10 STP	18.6	46.4	71.4
F	City of Beaumont STP	1392.8	1267.4	2966.6
G	Goodyear Tire and Rubber Company	2.9	*	*
H	Country Club Park Estates STP	0.6	0.4	0.6
I	Texas Gulf, Incorporated	*	*	*
J	Union Texas Petroleum, Division of Allied Chemical Company	155.1	*	*
K	Texas A&M University Research Extension Center STP	3.5	2.3	1.7

* Nutrient Data Not Available

APPENDIX D.11

SUBSURFACE WATER DATA

Five figures and two tables pertaining to subsurface water quality comprise this appendix. Figures D.11-1 through D.11-3 consist of contour maps for the approximate altitude of the 1, 3, and 10 ppm dissolved solids surfaces. The potential water yield and aggregate sand thickness of the slightly saline water zone is presented in Figure D.11-4 while similar information for the moderately saline water zone is presented in Figure D.11-5. The results of chemical analysis of subsurface water taken from water wells in Cameron Parish are included in Table D.11-1. The 1974 salt water disposal report for that same parish is presented in Table D.11-2.

Figure D.11-1

Approximate Altitude of the 1000 mg/l Dissolved-Solids Surface

(Winslow, <u>et al</u>, 1968)

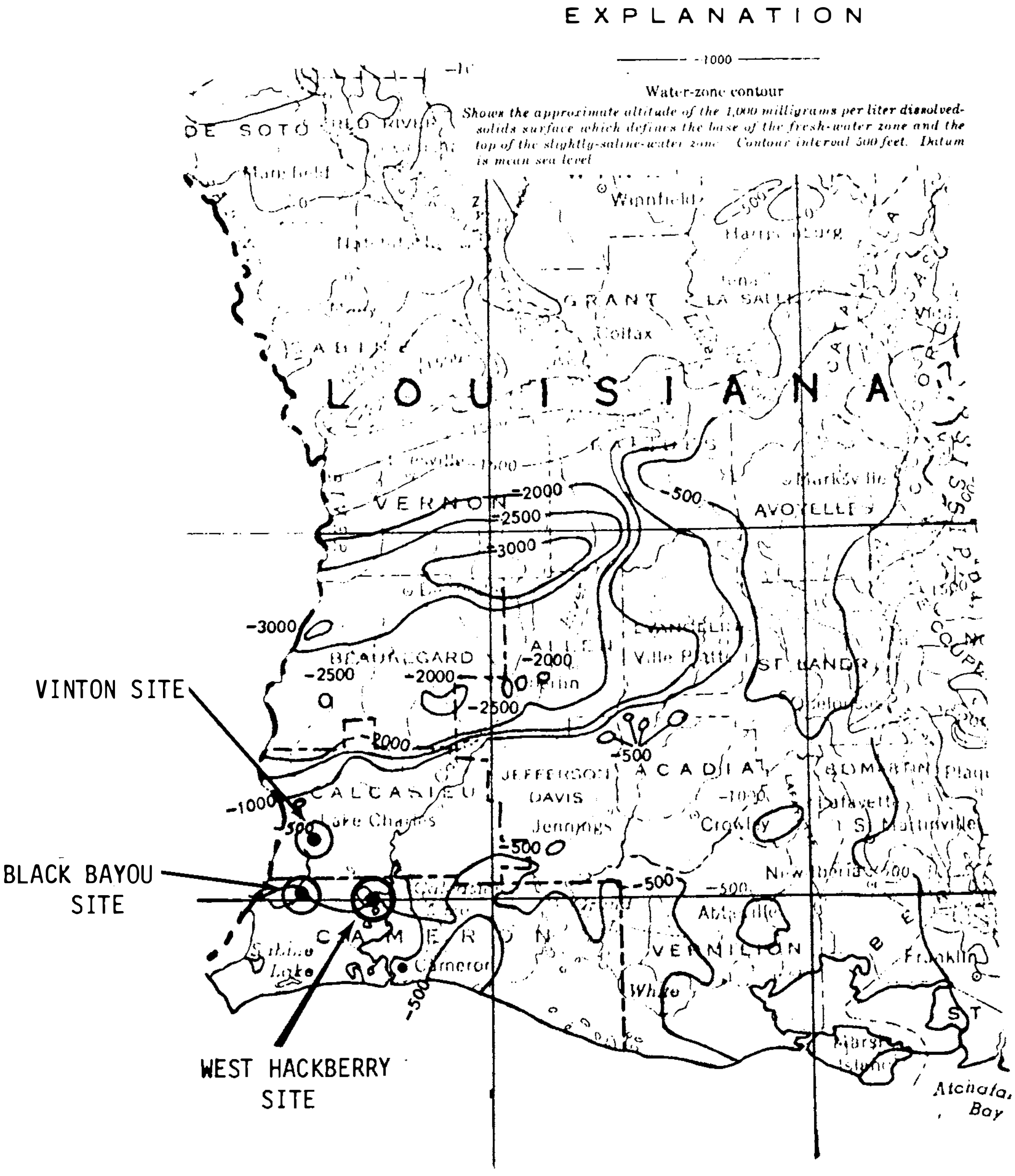
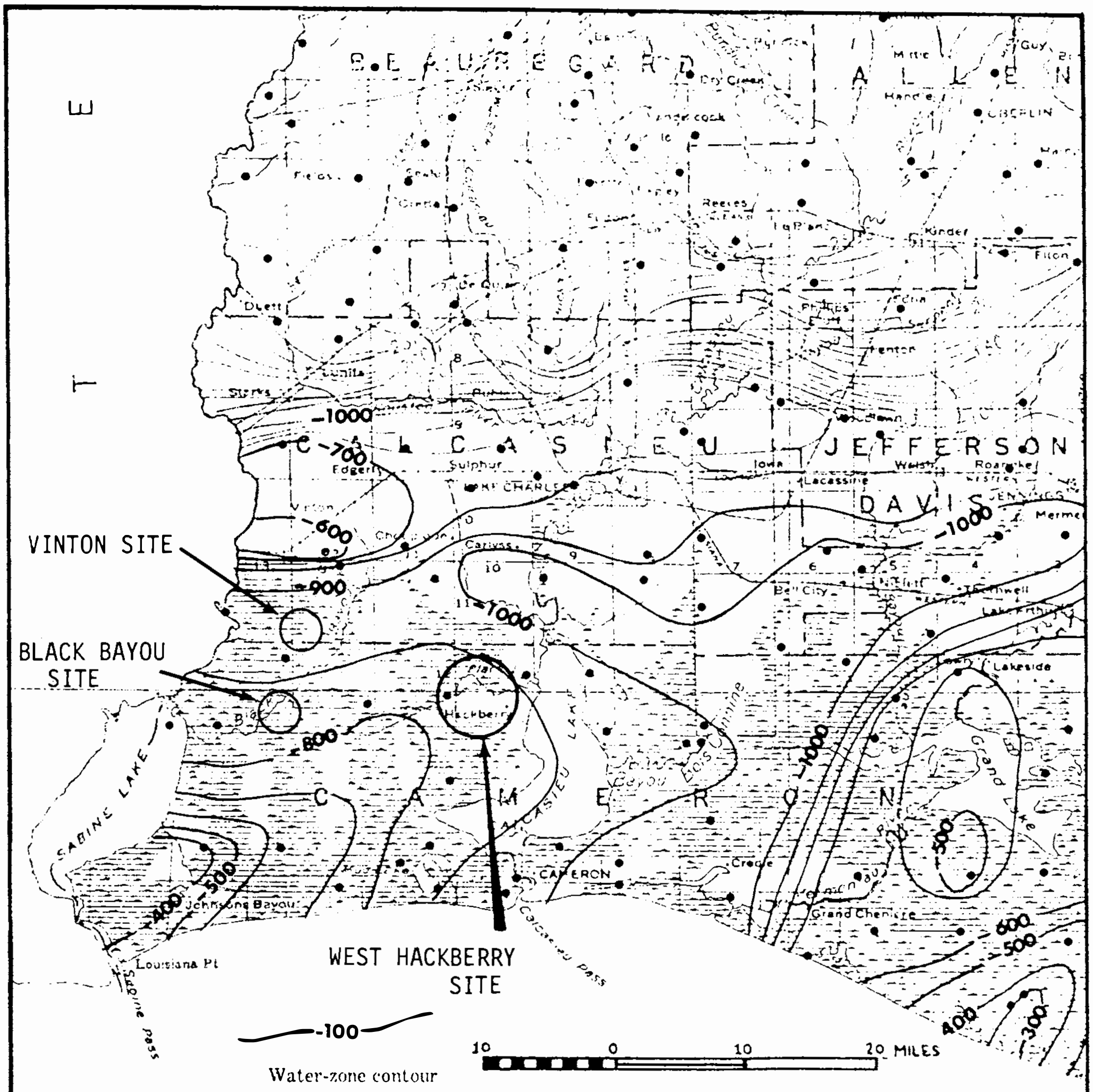


Figure D.11-2

Map Showing Approximate Altitude of the 3,000 Milligrams Per Liter Dissolved-Solids Surface

(Winslow, <u>et al</u>, 1968)

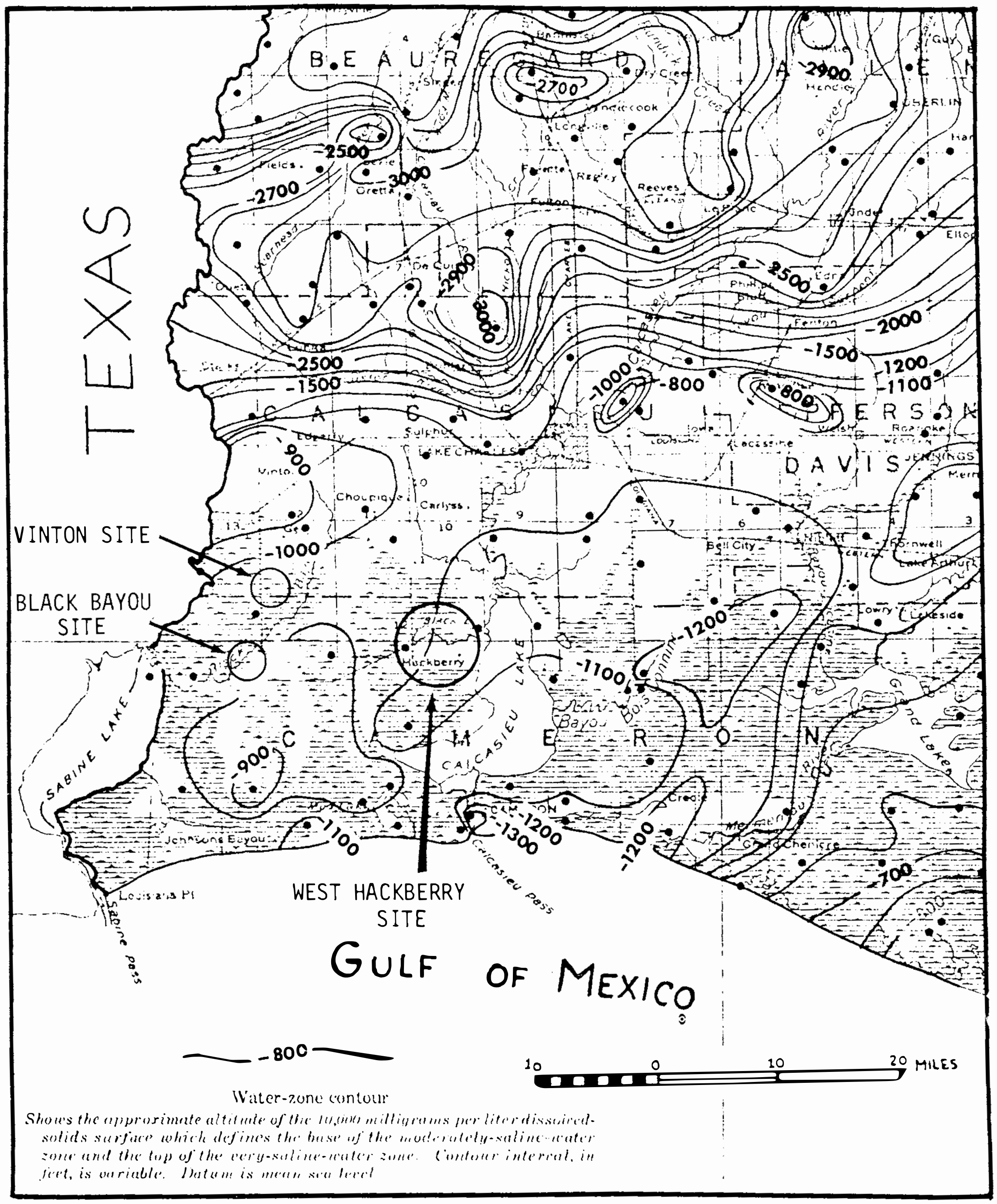


Shows the approximate altitude of the 3,000 milligrams per liter dissolved-solids surface which defines the base of the slightly-saline-water zone and the top of the moderately-saline-water zone. Contour interval, in feet, is variable. Datum is mean sea level

Figure D.11-3

Approximate Altitude of the 10,000 mg/l Dissolved-Solids Surface

(Winslow, et al, 1968)

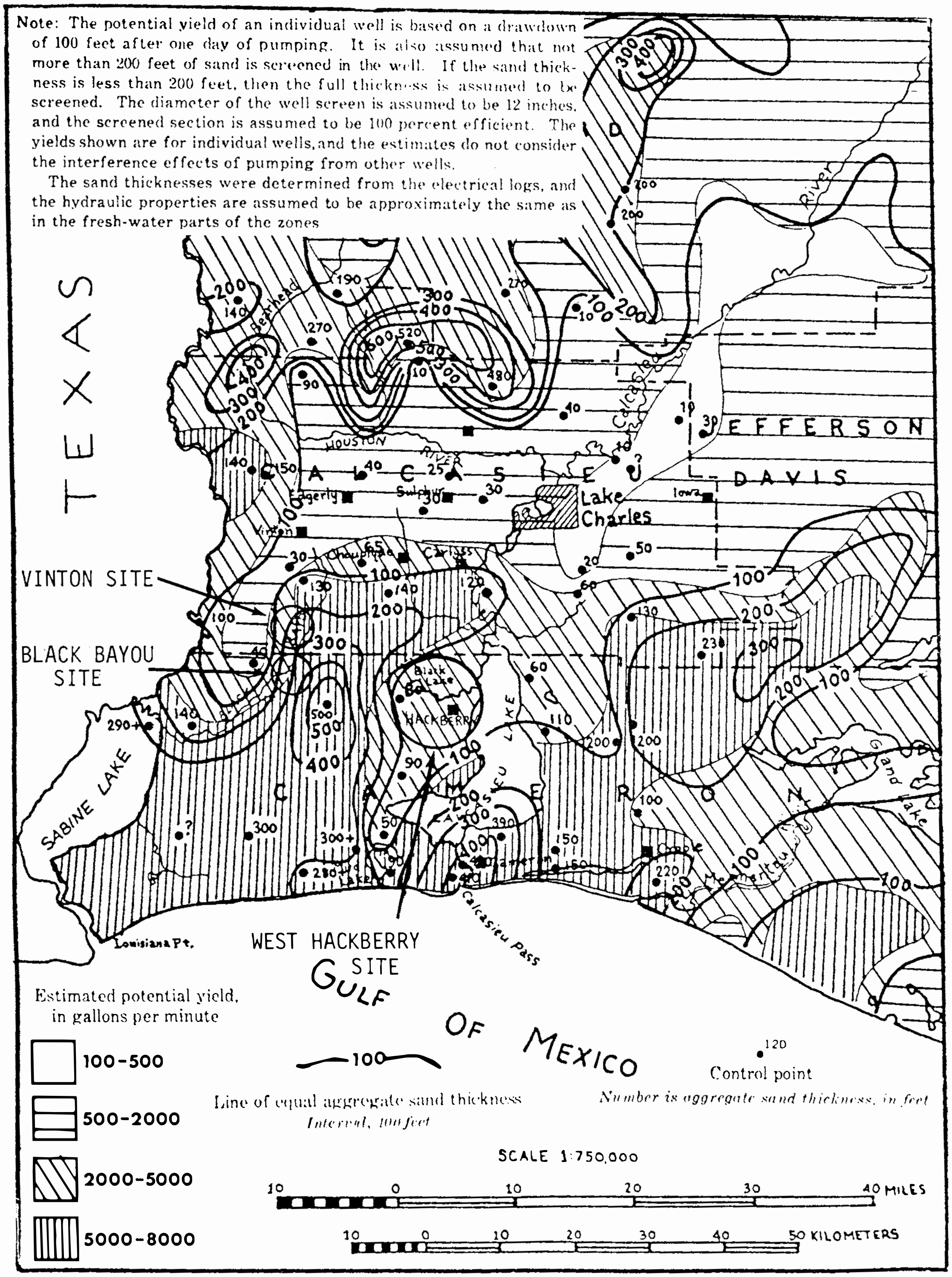


Water-zone contour

Shows the approximate altitude of the 10,000 milligrams per liter dissolved-solids surface which defines the base of the moderately-saline-water zone and the top of the very-saline-water zone. Contour interval, in feet, is variable. Datum is mean sea level

Figure D.11-4
Map Showing Estimated Potential Yield and Aggregate Sand Thickness of the Slightly-Saline-Water Zone (1,000-3,000 milligrams per liter dissolved solids)

(Winslow, et al, 1968)



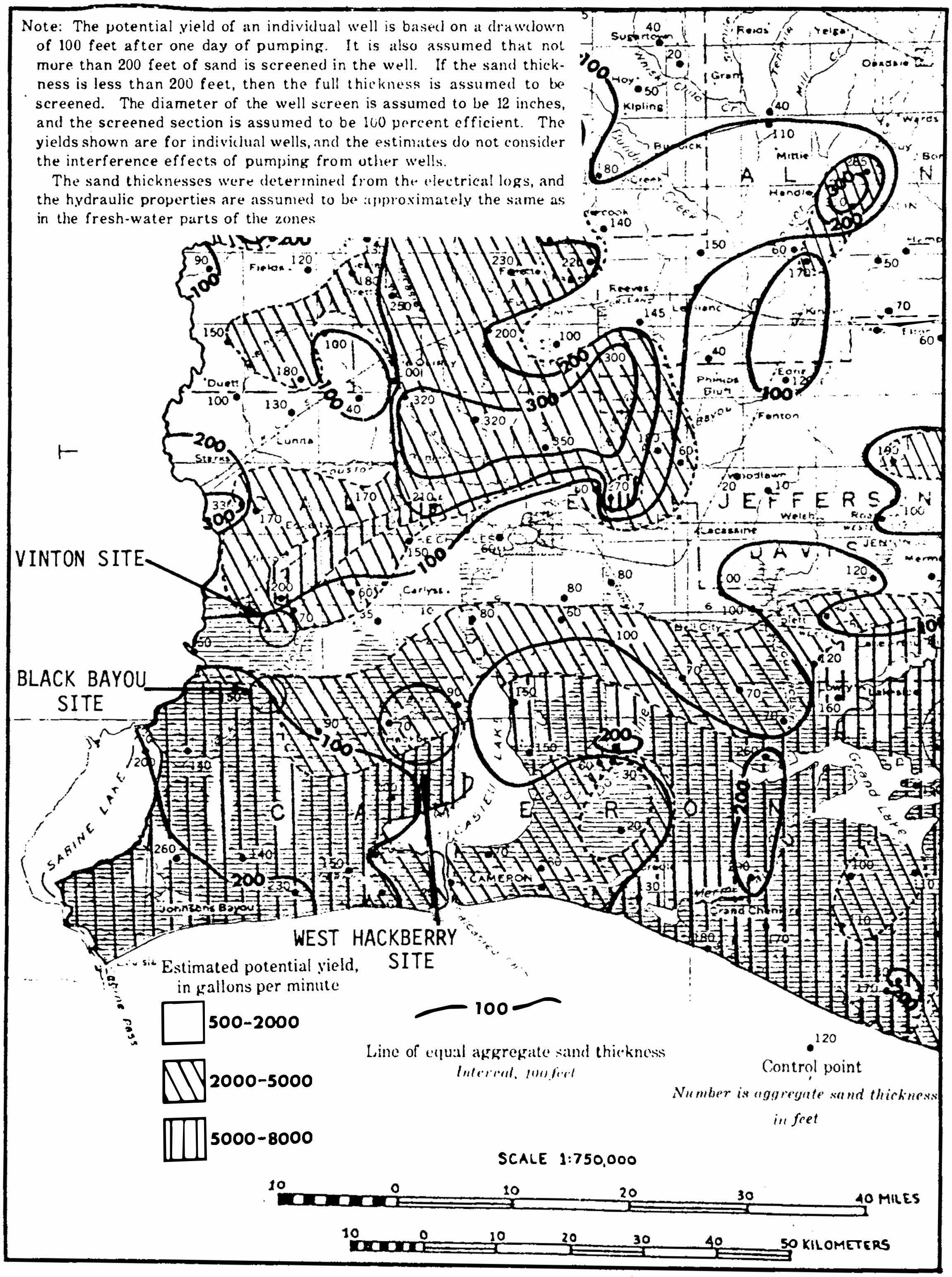
Note: The potential yield of an individual well is based on a drawdown of 100 feet after one day of pumping. It is also assumed that not more than 200 feet of sand is screened in the well. If the sand thickness is less than 200 feet, then the full thickness is assumed to be screened. The diameter of the well screen is assumed to be 12 inches, and the screened section is assumed to be 100 percent efficient. The yields shown are for individual wells, and the estimates do not consider the interference effects of pumping from other wells.

The sand thicknesses were determined from the electrical logs, and the hydraulic properties are assumed to be approximately the same as in the fresh-water parts of the zones

Figure D.11-5

Map Showing Estimated Potential Yield and Aggregate Sand Thickness of the Moderately-Saline-Water Zone (3,000 to 10,000 milligrams per liter dissolved solids)

(Winslow, <u>et al</u>, 1968)



Note: The potential yield of an individual well is based on a drawdown of 100 feet after one day of pumping. It is also assumed that not more than 200 feet of sand is screened in the well. If the sand thickness is less than 200 feet, then the full thickness is assumed to be screened. The diameter of the well screen is assumed to be 12 inches, and the screened section is assumed to be 100 percent efficient. The yields shown are for individual wells, and the estimates do not consider the interference effects of pumping from other wells.

The sand thicknesses were determined from the electrical logs, and the hydraulic properties are assumed to be approximately the same as in the fresh-water parts of the zones

Table D.11-1. Chemical and Physical Parameters of Several Wells in Cameron and Calcasieu Parishes*

(Winslow, et al, 1968)

Parish	Location	Depth or producing interval (feet)	Date of Collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
Cameron	T.13S.,R.12W	-	6-15-34	-	-	62	19	1,106	-	299	-	-
Do.	T.15S.,R.14W., sec. 14	530	4-17-32	-	-	214	86	2,215	-	345	-	-
Cameron	T.15S.,R.4W., sec. 41	460	2-2-55	30	.04	48	19	408	4.5	416	0	2.1
Do.	T.15S.,R.11W., sec. 41	836	9-20-51	33	1.5	32	14	769	2.8	340	0	3.3
Cameron	T.11S.,R.6W.	8,859-8,885	11-21-60	-	5	595	136	16,308	-	877	0	19
Do.	T.13S.,R.12W.	2,840-2,878	8-21-36	-	-	900	433	37,965	-	372	-	-
Cameron	T.12S.,R.3W., sec. 24	837-847	5-20-63	22	1.3	206	105	4,370	4.1	355	0	0.0
Do.	T.15S.,R.13W., sec. 8	1,112-1,117	5-30-65	28	3.4	660	212	7,240	39	287	0	40
Do.	T.15S.,R.15W., sec. 22	1,208	4-17-32	-	-	350	145	4,282	-	317	-	-
Calcasieu	T.10S.,R.11W., sec. 36	800-805	12-4-64	32	.18	29	22	391	4.0	316	0	0.0

*All concentrations in mg/l

Table D.11-1. Chemical and Physical Parameters of Several Wells in Cameron and Calcasieu Parishes (Concluded)

(Winslow, <u>et al</u>, 1968)

Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved Solids	Barium (Ba)	Strontium (Sr)	Iodine (I)	Bromine (Br)	Manganese (Mn)	Phosphate (PO_4)	Calcium Manganese	Hardness as $CaCO_3$		Specific conductance (Micromhos at 25°C)	pH	Temperature (°C)
												Non-Carbonate	Specific Gravity			
1,700	-	-	-	3,186	-	-	-	-	-	-	234	-	-	-	7.4	-
3,840	-	-	-	6,198	-	-	-	-	-	-	-	-	-	-	7.4	-
547	.1	.2	.05	1,260	-	-	-	-	.01	.19	198	0	-	2,270	7.5	22
1,080	.6	.5	.38	2,100	-	-	-	-	0.0	0.0	138	0	-	3,860	7.6	26
26,100	-	-	-	44,035	-	-	-	-	-	-	-	-	1.0305	-	7.6	-
61,251	-	-	-	100,920	-	-	-	-	-	-	-	-	-	-	7.4	-
7,130	0.2	-	0.54	12,000	-	-	-	-	0.30	0.07	947	656	-	20,400	7.6	24+
12,800	0.4	-	-	21,160	-	-	-	-	0.9	-	2,520	2,280	-	32,500	7.3	-
7,400	-	-	-	12,554	-	-	-	-	-	-	-	-	-	-	-	-
533	.3	.1	.19	1,180	-	-	-	-	.04	.08	164	0	-	2,110	7.6	21

Table D.11-2

SALT WATER DISPOSAL REPORT

CAMERON PARISH 1974

(Winslow, et al, 1968)

Field	Number of Wells	Average Depth (feet)	Pressure Range (psi)	Injection for Year	Cumulative Injection M (bbls)
CAMERON					
Big Lake	1	2,046	250-100	210,900	721.9
Cameron	1	3,320	700-400	3,738,236	8,302.2
Chalkley	3	2,550	575-50	1,788,789	13,849.7
Cheniere Perdue	1	1,515	600-0	945,600	3,590.0
Crab Lake	0	0	0	0	691.3
Deep Lake	1	2,370	55-Vac	1,223,433	15,168.1
E. Cheniere Perdue	1	2,496	0-0	54,750	86.7
Grand Cheniere	2	1,725	500-0	530,000	4,000.4
Grand Lake	4	2,200	450-Vac	2,946,979	24,214.8
High Island	1	10,314	90-0	15,680	353.6
Johnsons Bayou	2	1,450	125-25	12,775	670.6
Eings Bayou	1	1,455	50-0	14,840	2,289.1
Lacassine Refune	2	1,523	536-0	581,182	4,641.5
Lakeside	1	2,665	-Vac	50,653	1,596.1
Little Pecan Lake	3	2,750	450-0	1,399,833	7,661.4
Mallard Bay	1	1,900	300-250	364,028	5,003.1
Mud Lake	0	0	0	0	4,030.0
North Sweet Lake	2	3,250	350-0	147,455	707.4
Pecan Lake	1	3,900	-Vac	1,731,441	10,054.4
Sabine Lake	0	0	0	0	668.4
Second Bayou	0	0	0	0	2,906.8
S. Black Bayou	0	0	0	0	2,091.1
S. Grand Cheniere	1	3,022	8-0	7,076	7.1
S. Lake Misere	0	0	0	0	288.6
S. Pecan Lake	1	2,405	600-0	831,923	5,982.2
S. Thornwell	1	2,780	300-0	454,206	3,191.7
SW Lake Arthur	2	2,550	150-0	41,440	976.5
Sweet Lake	4	2,950	450-200	12,323,831	65,201.5
Twin Island	0	0	0	0	669.6
West Hackberry	0	0	0	0	732.0
PARISH TOTAL	37			29,415,055	190,447.6

APPENDIX D.12

WITHDRAWAL OF WATER FROM BLACK LAKE

1. Change of Surface Level of Black Lake During Leaching Operations in the Absence of Replenishment Water

If the lake is completely isolated from any source of replenishment water a simple conservation of mass model can be used to calculate the change in the surface level. The governing equation is:

$$A \frac{dh}{dt} = -Q_o \tag{1}$$

where

A = surface area of Black Lake
h = surface height of the lake
t = time
Q_o = volumetric withdrawal rate from lake

Now for leaching the withdrawal rate would be

$$Q_o = 30{,}000 \text{ gpm}$$
$$= 5.78 \times 10^6 \text{ ft}^3/\text{day}$$

The surface area of the lake is

$$A = 3.425 \text{ square miles}$$
$$= 95.5 \times 10^6 \text{ ft}^2$$

Thus

$$\frac{dh}{dt} = -Q_{o/A}$$

$$= -6.05 \times 10^{2} \text{ ft/day}$$

2. Change of Surface Level of Black Lake During Displacement Operations in the Absence of Replenishment Water

If the lake is completely isolated as before, Eq (1) applies. For this case

$$Q_o = 42{,}875 \text{ gpm}$$

$$= 8.25 \times 10^{6} \text{ ft}^{3}\text{/day}$$

Then

$$\frac{dh}{dt} = \frac{-Q_o}{A}$$

$$= -8.64 \times 10^{-2} \text{ ft/day}$$

3. Application of MIT Water Quality Network Model

If the lake is simultaneously supplied with replenishment water via Black Lake Bayou and Alkali Ditch, the governing equations can only be solved numerically. The MIT Water Quality Network Model which is described in Appendix D.14 has been used to provide such a solution. A network was developed consisting of Black Lake, Black Lake Bayou, and Alkali Ditch. The dimensions of each water body were consistent with those given in Table B.3-2. For the first test case boundary conditions were established as follows:

Location	Hydraulic	Water Quality
Junction of Alkali Ditch and Intracoastal Waterway	Sinusoidal variation of surface height with a range of .9 feet, a period of 12 hours, and a lag time of 69.38 minutes.	Constant salinity of .87 ppt.
Junction of Black Lake Bayou and Calcasieu Ship Channel	Sinusoidal variation of surface height with a range of .9 feet, a period of 12 hours, and zero lag time.	Constant salinity 11.44 ppt.
Withdrawal Point in Black Lake	Zero withdrawal for 90 days followed by withdrawal of 95.5 ft^3/sec for 150 days.	Zero diffusive flux

During an initial 90-day period no withdrawal of water took place and the network of water bodies was allowed to approach equilibrium. The resulting variation of water surface height and salinity in Black Lake during the last 30 days of this start-up period is presented in Figure D.12-1. The distribution of salinity in Black Lake, Black Lake Bayou, and Alkali Ditch, at the end of the 90-day start-up period, is shown in Figures D.12-2 and D.12-3. The corresponding distribution of flow velocities is included in Figures D.12-4 and D.12-5.

Following the start-up period, water was withdrawn from the lake for 150 days at a rate of 95.5 ft^3/sec corresponding to a displacement operation. The resulting variation of water surface height and salinity in Black Lake is also shown in Figure D.12-1. The distribution of salinity in Black Lake, Black Lake Bayou, and Alkaki Ditch, at the end of the 150-day withdrawal process, is included in Figures D.12-2 and D.12-3. The corresponding distribution of flow velocities is included in Figures D.12-4 and D.12-5.

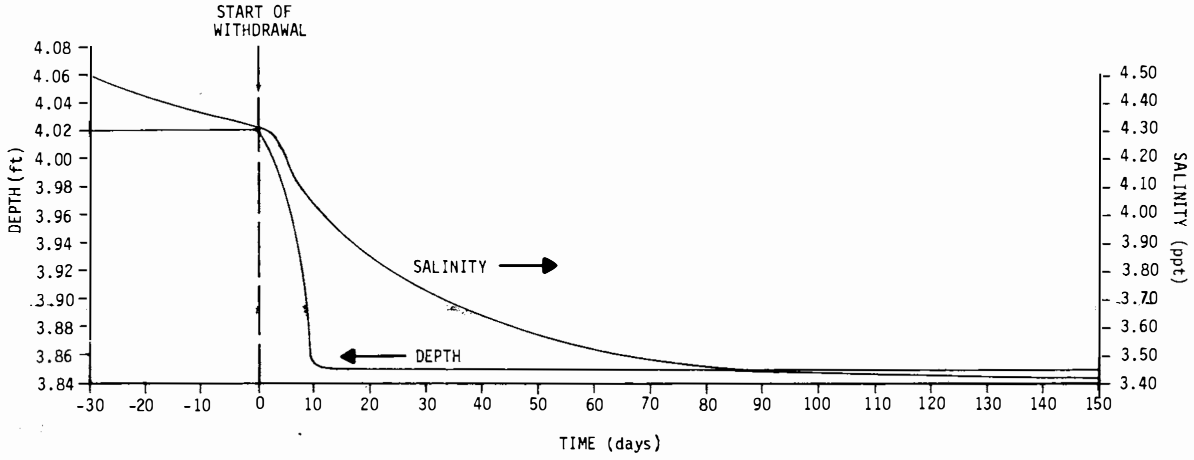


Figure D.12-1. Temporal Variation of Depth and Salinity of Black Lake (Without Wind-Driven Tidal Effects)

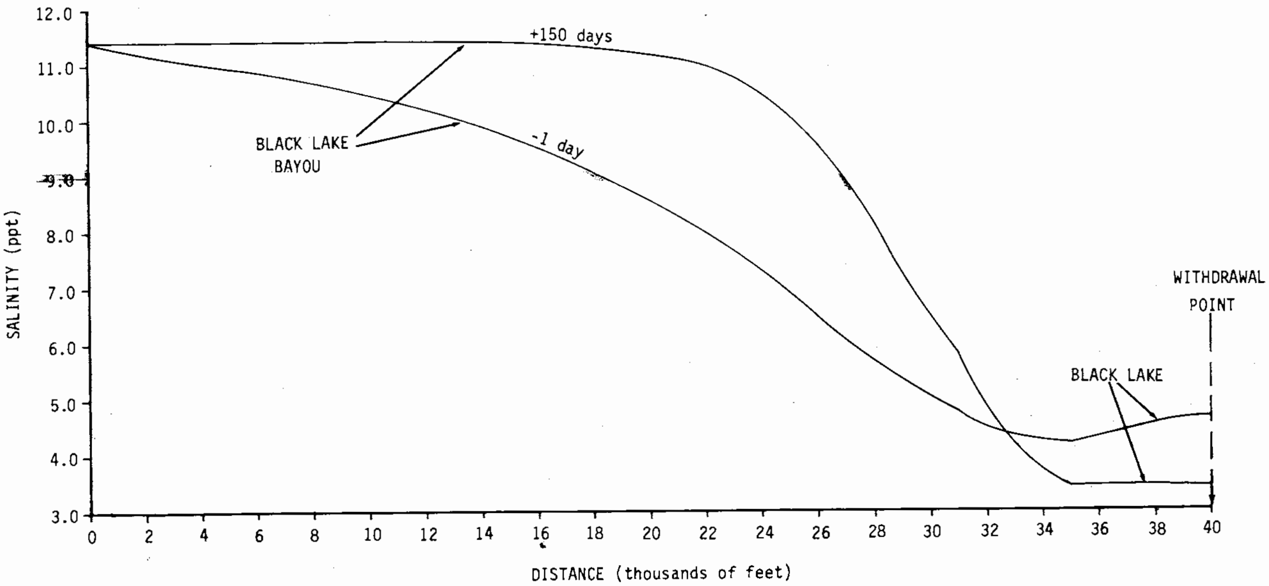


Figure D.12-2. Spatial Variation of Salinity in Black Lake and Black Lake Bayou (Without Wind-Driven Tidal Effects)

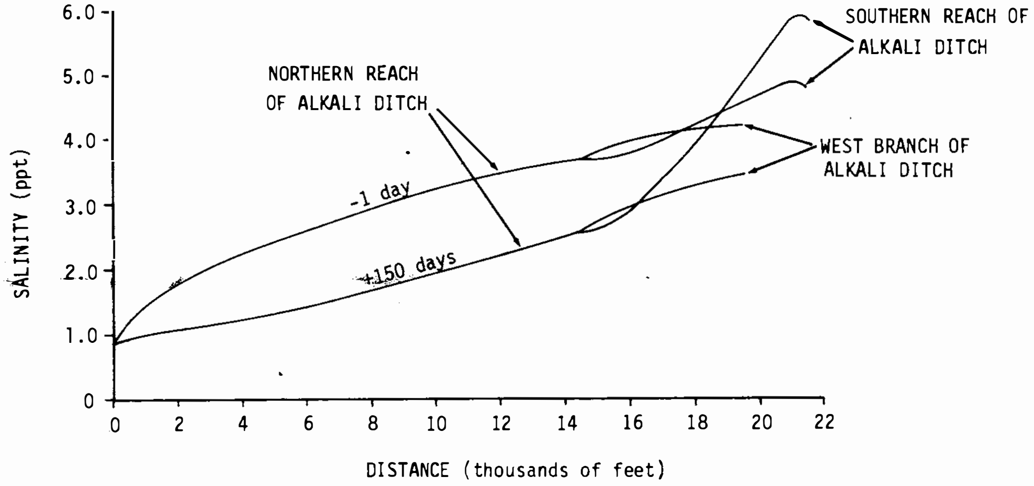


Figure D.12-3. Spatial Variation of Salinity in Alkali Ditch (Without Wind-Driven Tidal Effects)

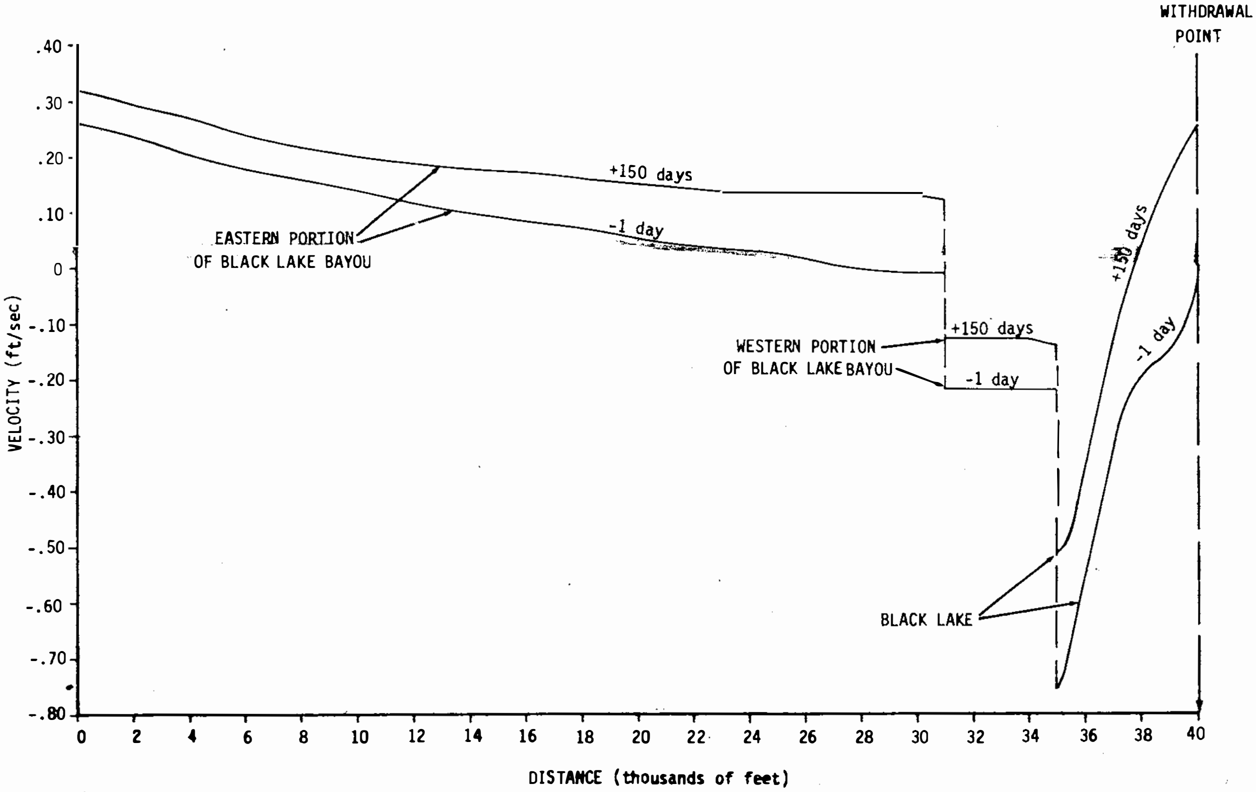


Figure D.12-4. Spatial Variation of Flow Velocity in Black Lake and Black Lake Bayou (Without Wind-Driven Tidal Effects)

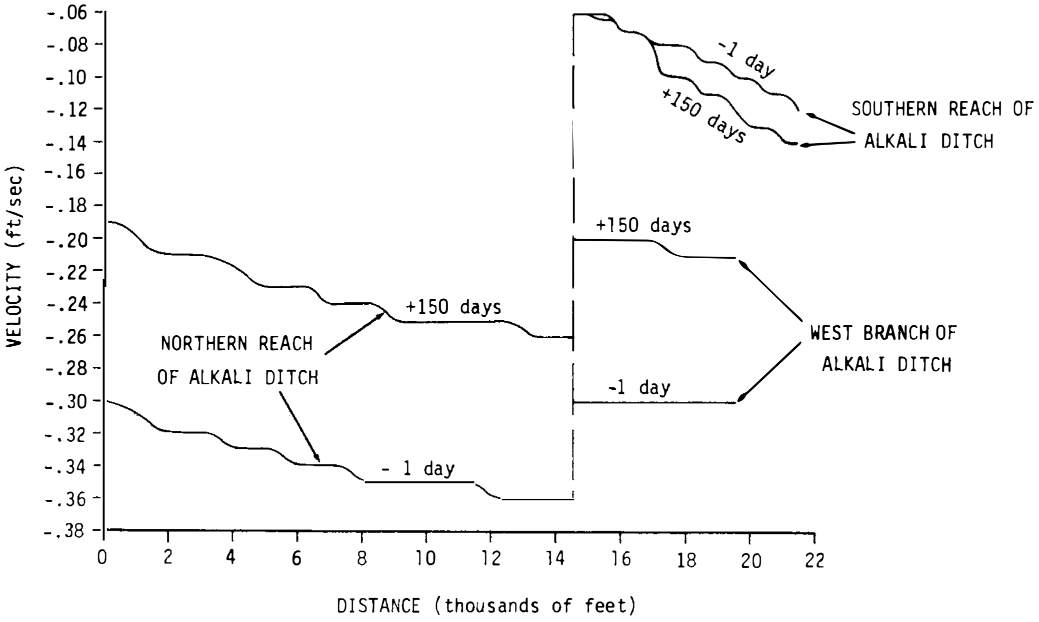


Figure D.12-5. Spatial Variation of Flow Velocity in Alkali Ditch (Without Wind-Driven Tidal Effects)

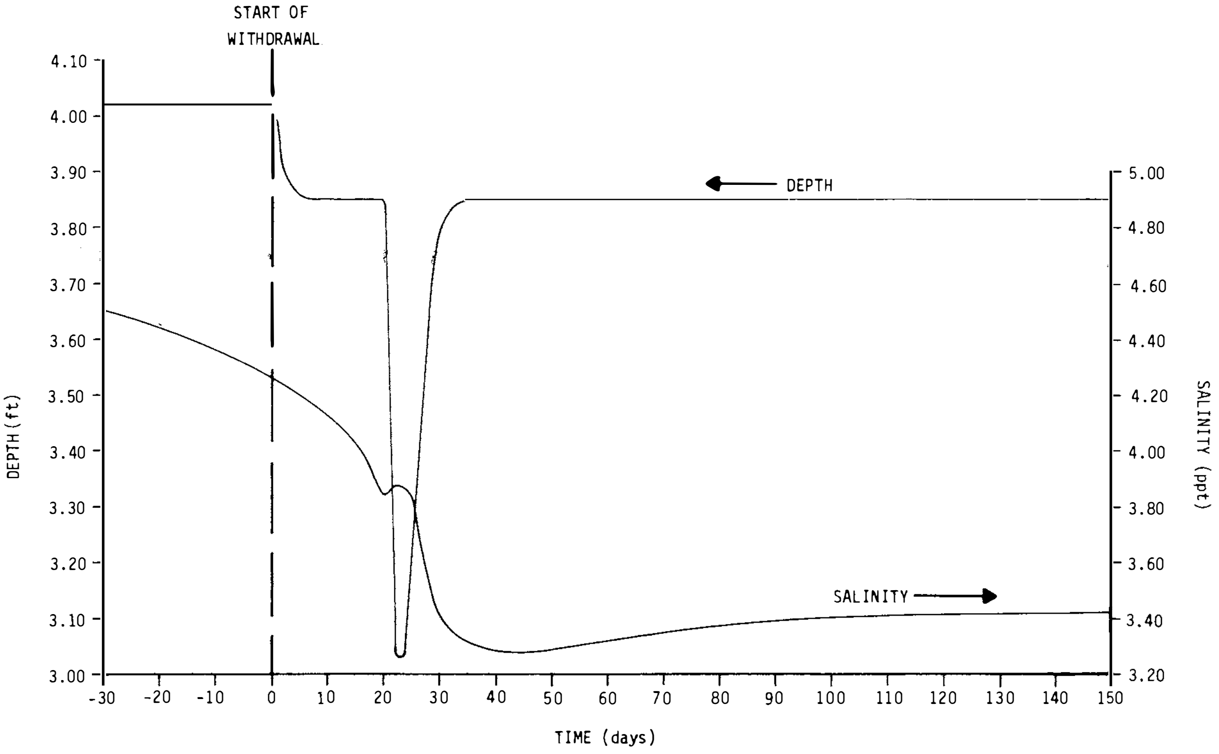


Figure D.12-6. Temporal Variation of Depth and Salinity of Black Lake (with Wind-Driven Tidal Effects)

Examination of Figure D.12-1 reveals that after 12 days of water withdrawal Black Lake reached hydraulic equilibrium while equilibrium with respect to salinity variation was achieved after 130 days.

For the second test case, the boundary conditions were the same as for the first except that 20 days after commencement of withdrawal the mean water level in both the Calcasieu Ship Channel and the Intracoastal Waterway was depressed 1.61 feet for a period of 3 days (simulating a wind-driven tidal effect). The resulting variation of water surface height and salinity in Black Lake is shown in Figure D.12-6. A comparison of Figure D.12-1 and D.12-6 indicates that the reduced water level at the boundary points caused a corresponding decrease in surface height in Black Lake. This decrease lagged behind that at the boundary point by 1 day. Subsequent to the return of the water levels at the boundary points to their original values, however, the surface height of the lake behaved essentially the same as during the corresponding time period in the first test case.

The effect on the salinity history was less noticable, with the salinity tending to increase slightly during the period of reduced water level. The salinity, subsequent to the return of the water levels at the boundary points, fell below the equilibrium value observed in the first test case, but it alternately returned to essentially the same equilibrium value (3.42 ppt).

The location of the point in Black Lake corresponding to Figure D.12-1 and D.12-6 is indicated in Figure D.12-7. In the same figure all locations of the spatial originas and the paths of the spatial coordinates are indicated for Figures D.12-2 through D.12-5.

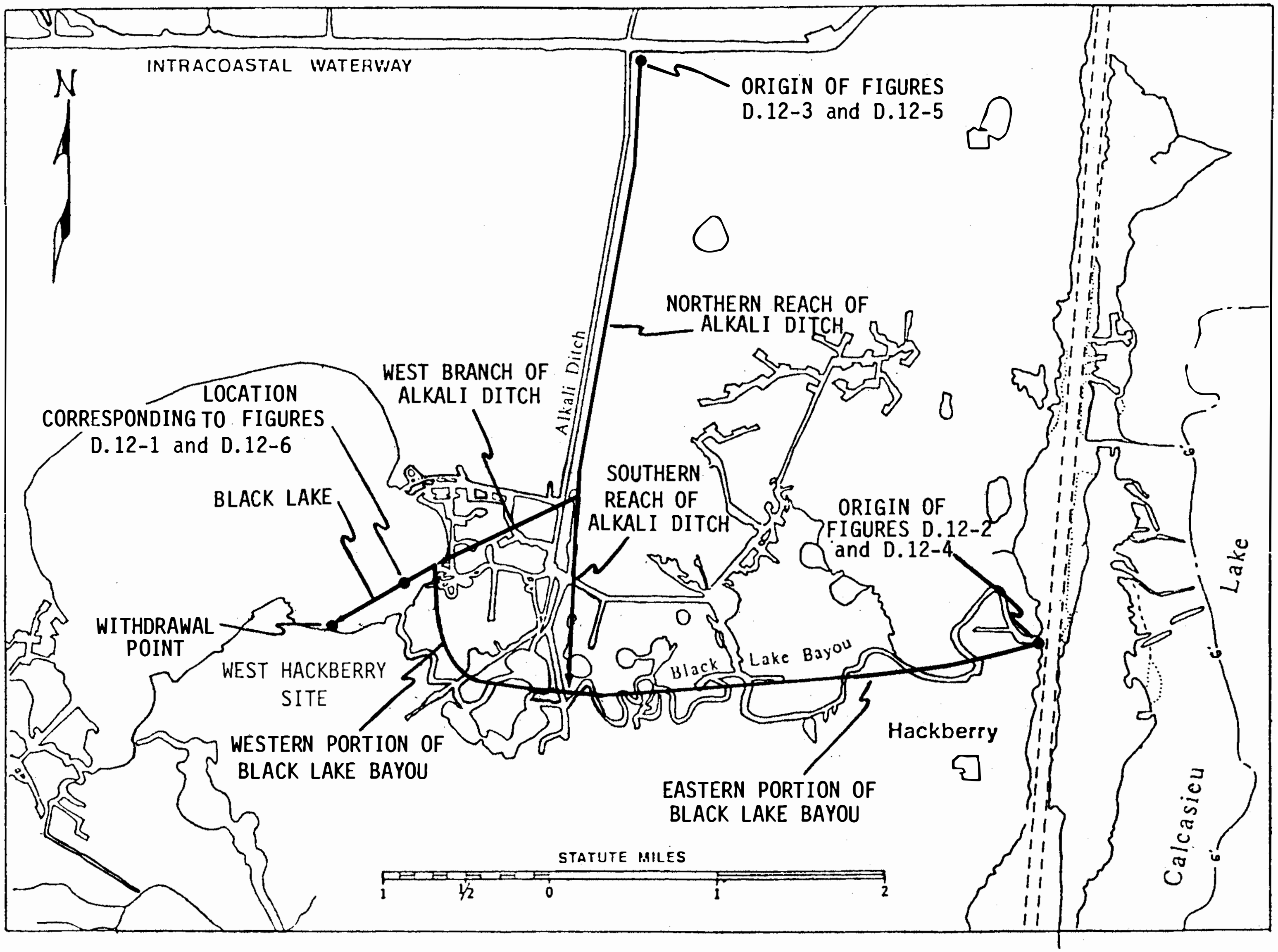


Figure D.12-7. Location of Reference Points and Reaches in the Black Lake Network Analysis

APPENDIX D.13

WITHDRAWAL OF WATER FROM CALCASIEU SHIP CHANNEL

The equations governing the behavior of water in Calcasieu Ship Channel can only be solved numerically. The MIT Water Quality Network Model which is described in Appendix D.14 has been used to provide such a solution. A network was developed consisting of Calcasieu Ship Channel, Calcasieu Lake, West Cove, and Calcasieu Pass. The dimensions of each water body were consistent with those given in Table B.3-2. Boundary conditions were established as follows:

Location	Hydraulic	Water Quality
Mile 21 of Calcasieu Ship Channel	Constant flow rate of 2440 ft^3/sec.	Constant salinity of 6.1 ppt.
Withdrawal point on the Calcasieu Ship Channel	Zero withdrawal for 90 days followed by withdrawal of 95.5 ft^3/sec for 150 days.	Zero dispersive flux
Junction of Calcasieu Pass with the Gulf of Mexico	Sinusoidal variation of surface height with a range of 2.0 feet and a period of 12 hours.	Ocean boundary with a salinity of 24.5 ppt.

During an initial 90-day period no withdrawal of water took place and the network of water bodies was allowed to approach equilibrium. The resulting variation of water depth and salinity in Calcasieu Ship Channel near the point of withdrawal during the final 30 days of the 90-day start-up period is presented in Figure D.13-1. The distribution of salinity in Calcasieu Ship Channel, Calcasieu Pass, Calcasieu Lake and West Cove is shown in Figures D.13-2 through D.13-4. The corresponding distribution of flow velocities is included in Figures D.13-5 through D.13-7.

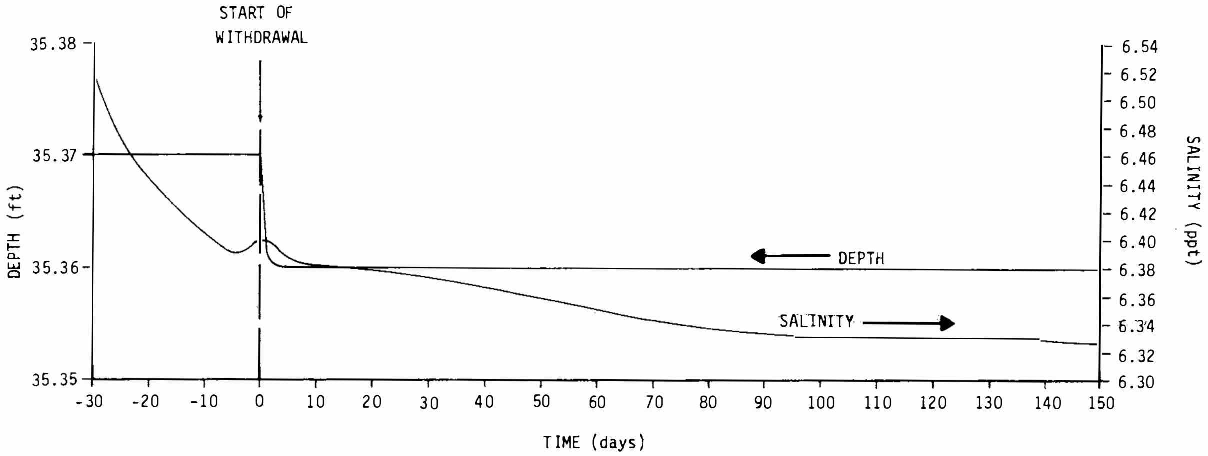


Figure D.13-1. Temporal Variations of Depth and Salinity of Calcasieu Ship Channel

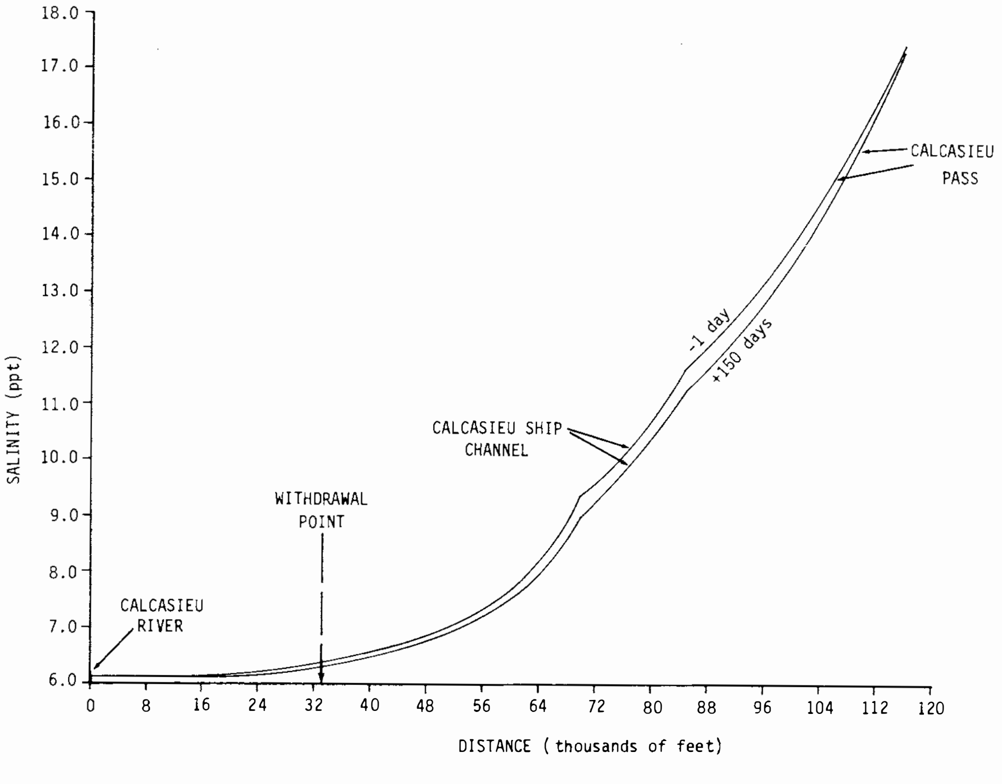


Figure D.13-2. Spatial Variation of Salinity in Calcasieu Ship Channel and Pass

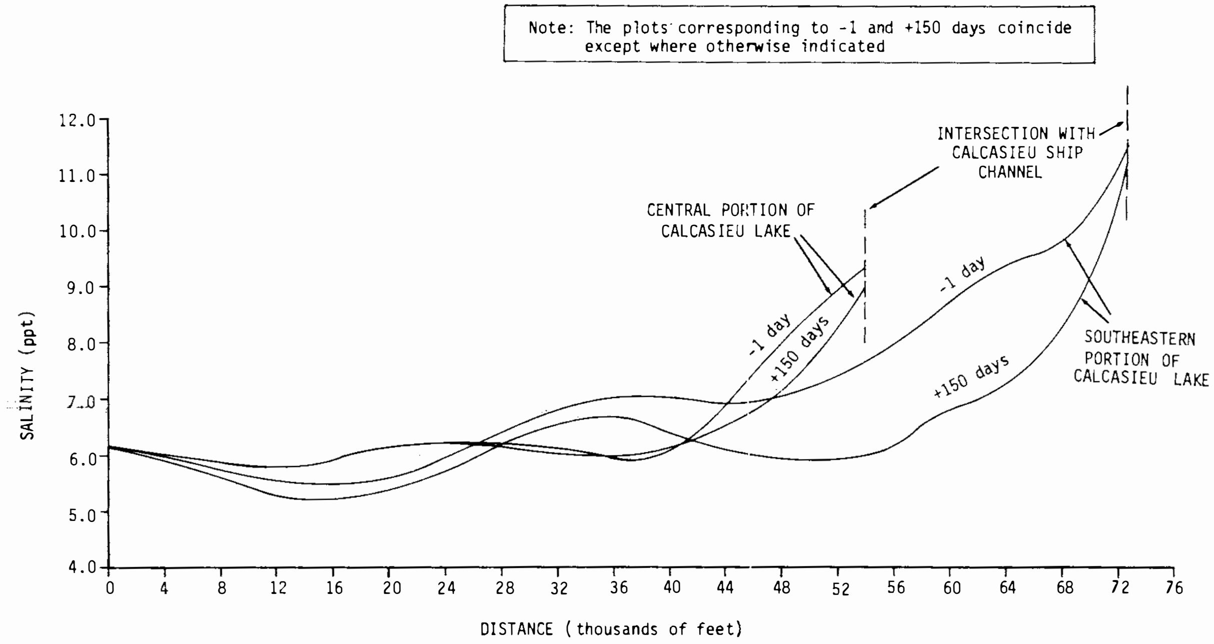


Figure D.13-3. Spatial Variation of Salinity in Calcasieu Lake

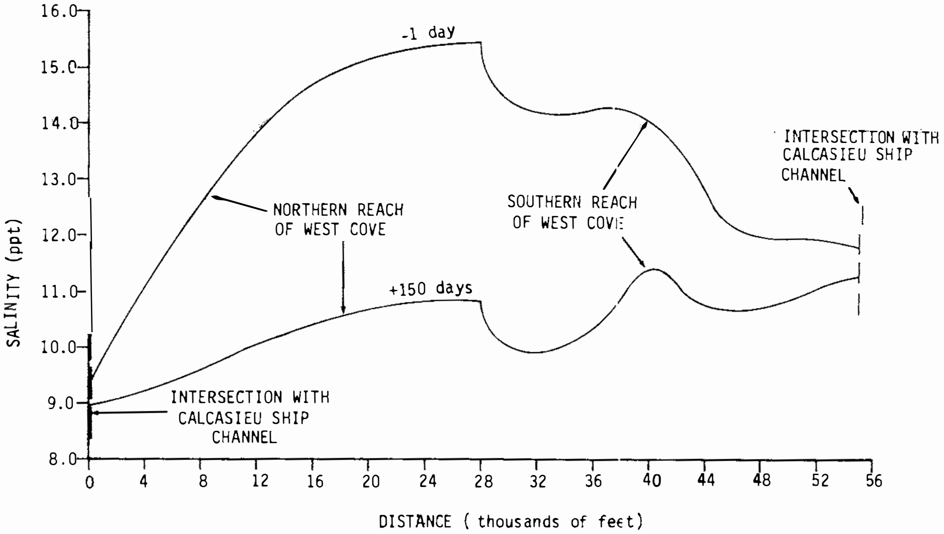


Figure D.13-4. Spatial Variation of Salinity in West Cove

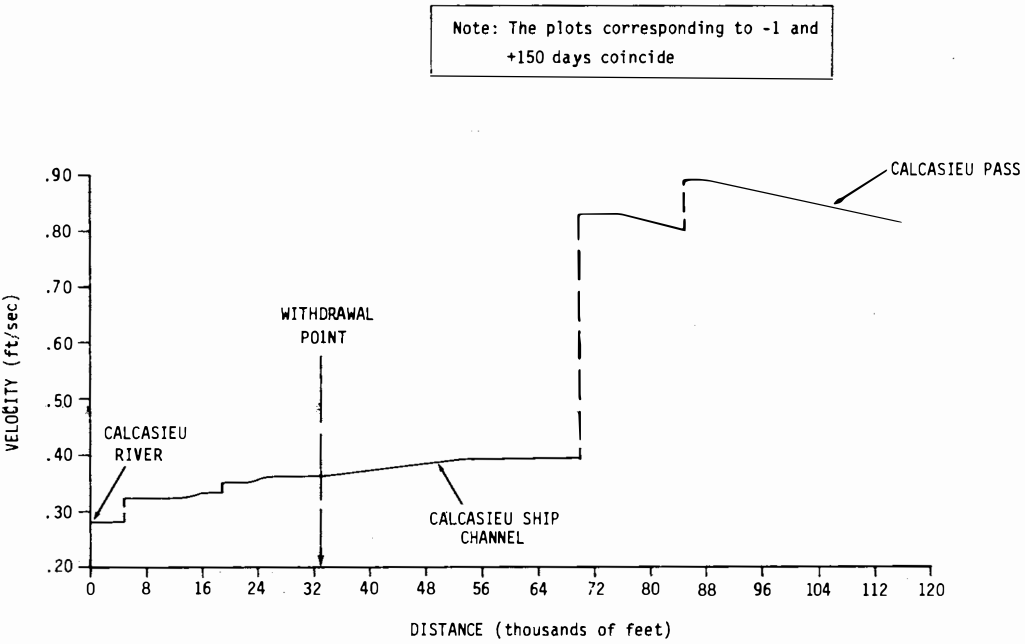


Figure D.13-5. Spatial Variation of Flow Velocity in Calcasieu Ship Channel and Pass

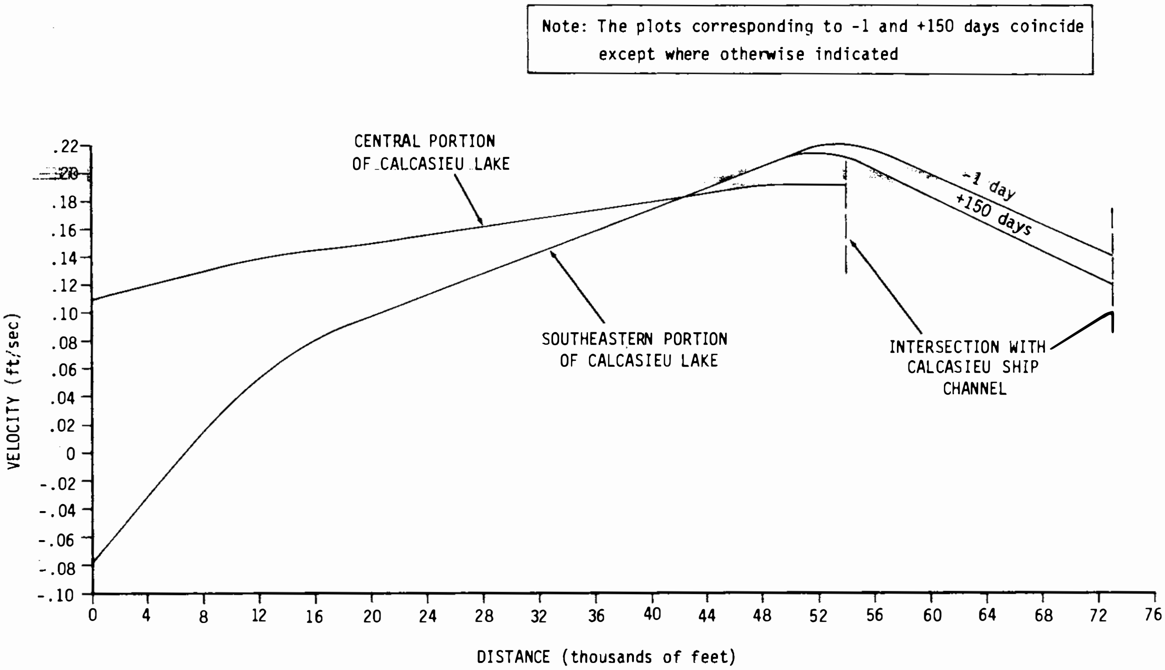


Figure D.13-6. Spatial Variation of Flow Velocity in Calcasieu Lake

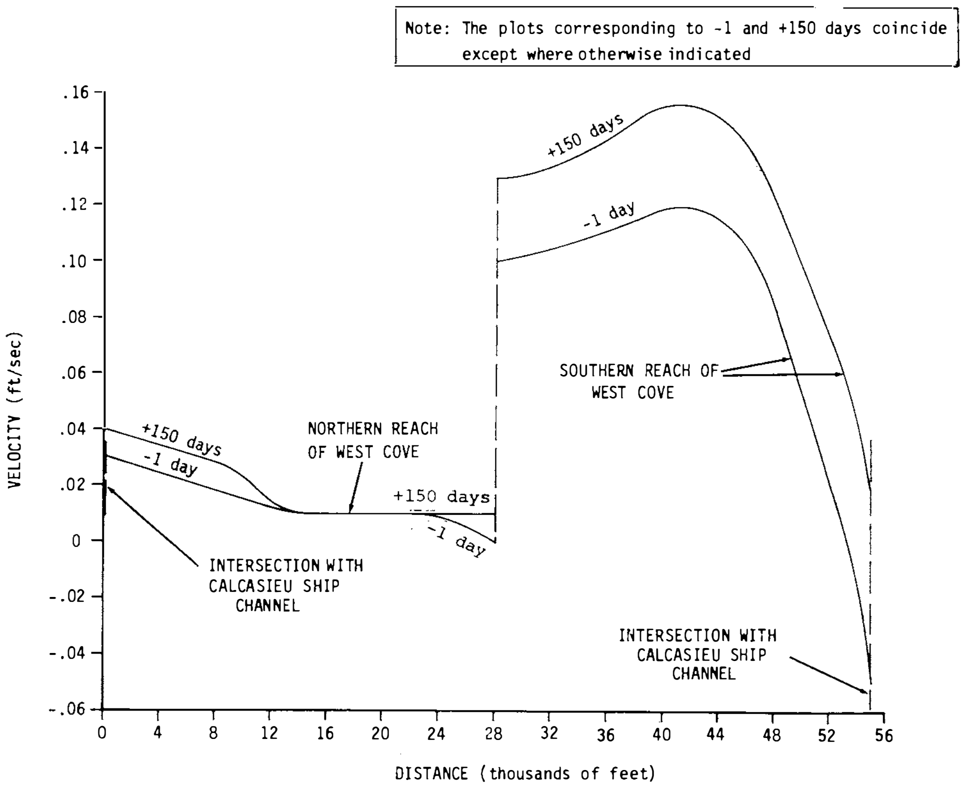

Note: The plots corresponding to -1 and +150 days coincide except where otherwise indicated

Figure D.13-7. Spatial Variation of Flow Velocity in West Cove

Following the start-up period water was withdrawn from the channel for 150 days at a rate of 95.5 ft^3/sec corresponding to a displacement operation. The resulting variation of water depth and salinity in Calcasieu Ship Channel near the point of withdrawal is also shown in Figure D.13-1. The distribution of salinity in Calcasieu Ship Channel, Calcasieu Pass, Calcasieu Lake and West Cove at the end of the 150-day withdrawal process is included in Figures D.13-2 through D.13-4. The corresponding distribution of flow velocities is included in Figures D.13-5 through D.13-7.

Examination of Figure D.13-1 reveals that after 5 days of water withdrawal Calcasieu Ship Channel reached hydraulic equilibrium while equilibrium with respect to salinity variation was achieved after 100 days.

The location of the point in Calcasieu Ship Channel corresponding to Figure D.13-1 is presented in Figure D.13-8. In the same figure the locations of the spatial origins and the paths of the spatial coordinates are indicated for Figures D.13-2 through D.13-7.

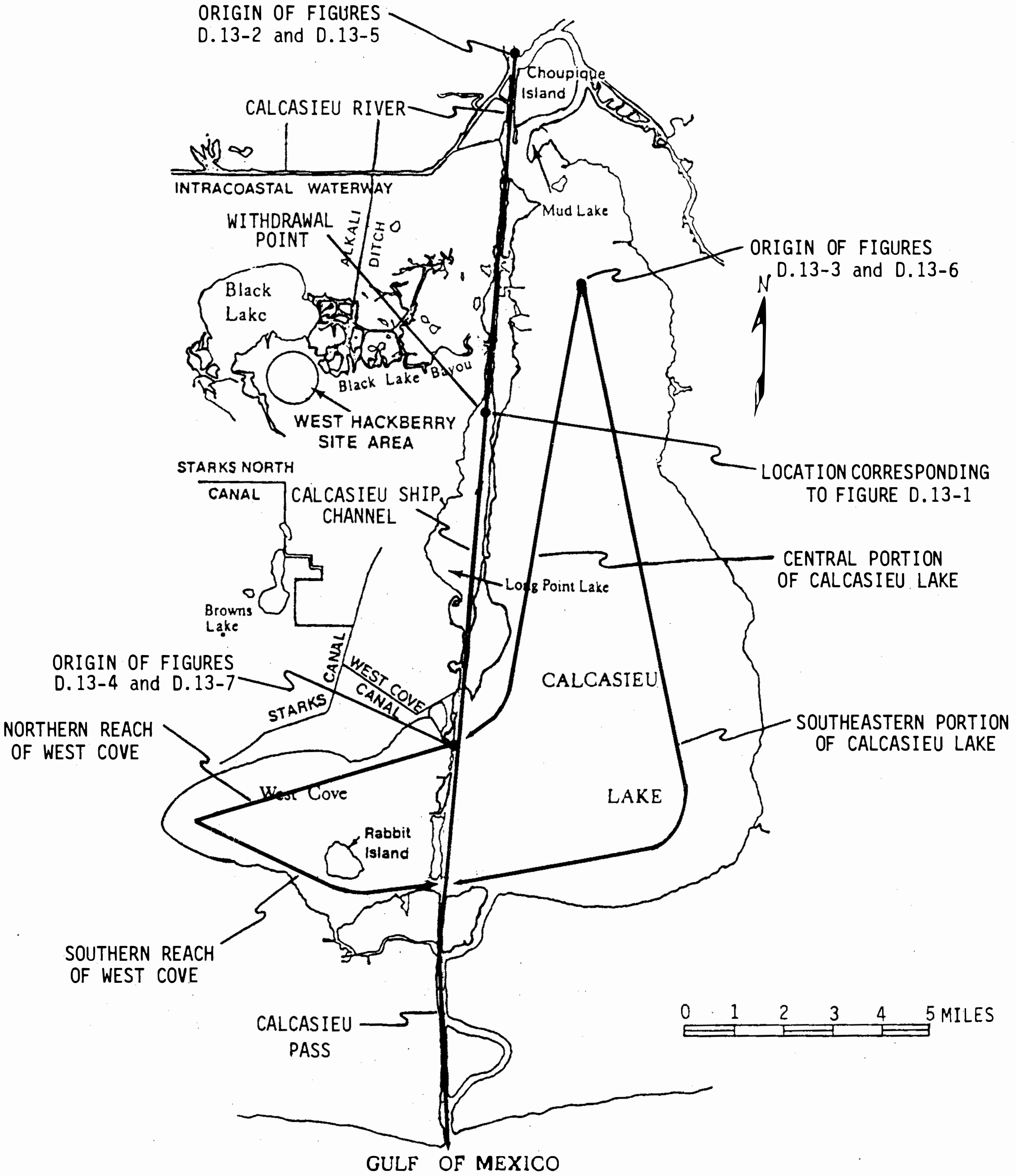


Figure D.13-8. Location of Reference Points and Reaches in the Calcasieu Ship Channel Network Analysis

APPENDIX D.14

MIT WATER QUALITY NETWORK MODEL

The model was developed by the Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, Massachusetts Institute of Technology (Harleman, 1976). In the model the one-dimensional continuity and momentus equations are solved to generate the temporal and spatial variations in the tidal discharges and elevations. The conservation of species equations for the water quality variables are solved using such hydrodynamic information. The solution involves an inplicit finite element scheme to compute the temporal and spatial variations of certain water quality variables as follows:

1) Salinity-coupled to hydrodynamics through a state equation,
2) Temperature-coupled to transformation rates,
3) Carbonaceous BOD-coupled to dissolved oxygen equation,
4) Nitrogen-cycle variables - intra-cycle and extra-cycle coupling

    N_1 - Ammonia-N

    N_2 - Nitrite-N

    N_3 - Nitrate-N

    N_4 - Phytoplankton-N

    N_5 - Zooplankton-N

    N_6 - Particulate Organic-N

    N_7 - Dissolved Organic-N

5) Dissolved oxygen-coupled to CBOD and nitrification

6) Fecal coliform

The structure of the model is a closed matter flow loop for the element nitrogen and it is developed under the assumption that the dominant activity in the estuarine ecosystem is aerobic and that nitrogen alone limits the growth of organisms. The predominant characteristics of the model include the following:

1) Strict adherence to the mass convervation principle as applied to the element nitrogen.

2) The ecosystem model is coupled with a real-time hydrodynamic transport system as opposed to a tidal-average or slack-tide approximation.

3) The structure of the model was formulated such that the level of complexity would not be too complex to the point of diminishing returns, nor too simplified to the point where rate-governing parameters must be determined by curve fitting the available field data.

REFERENCES CITED

Harleman, D.R.F., Dailey, J.E., Thatcher, M.L., Najarian, T.O. Brocard, D.N., and Ferrara, R.A., User's Manual for the M.I.T. Transient Water Quality Network Model Including Nitrogen-Cycle Dynamics for Rivers and Estuaries, Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, Massachusetts Institute of Technology, Report No. 216, August, 1976.

APPENDIX D.15

SEAWATER/BRINE CHEMICAL EQUILIBRIUM

1. General

Basic water quality concerns for the brine disposal operation includes:

- salinity increases
- temperature increases
- brine composition
- changes in calcium to magnesium ratios
- heavy metal concentration increases
- changes in chemical speciation

The first two of these have been covered earlier in assessment of brine holding facilities (Brine Pond Assessment) and in the NOAA reports (FEA, April 22, 1977), (NOAA, 1977), and presently require no additional discussion.

Consideration included in this appendix are concerned with prediction of a brine chemical equilibrium (saturated) using literature data on leachwater and salt composition. This data served as inputs to a computer model capable of prediciting aqueous chemical equilibrium. Likewise, the brine composition predicted in this manner was combined with literature information on seawater constituents to obtain inputs needed to predict the chemical equilibrium of seawater and seawater - brine mixtures. These mixtures can be related to the excess salninity contours in a brine plume similar in nature to that in Figure D.15-1.

In this manner, the free concentrations of components, the speciation and abundance of bound forms, and the nature and composition of precipitates was investigated. A flow scheme of the chemical equilibrium concentration study is shown in Figure D.15-2.

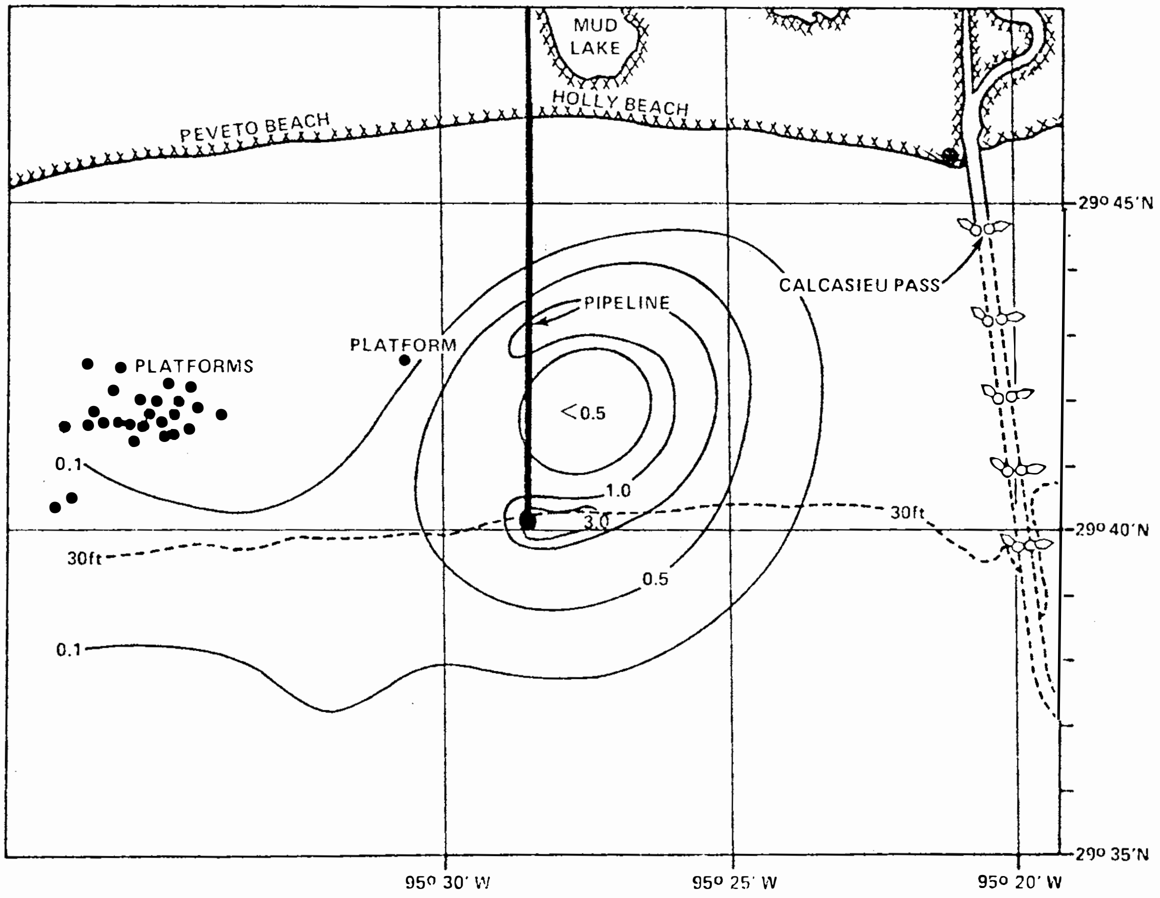
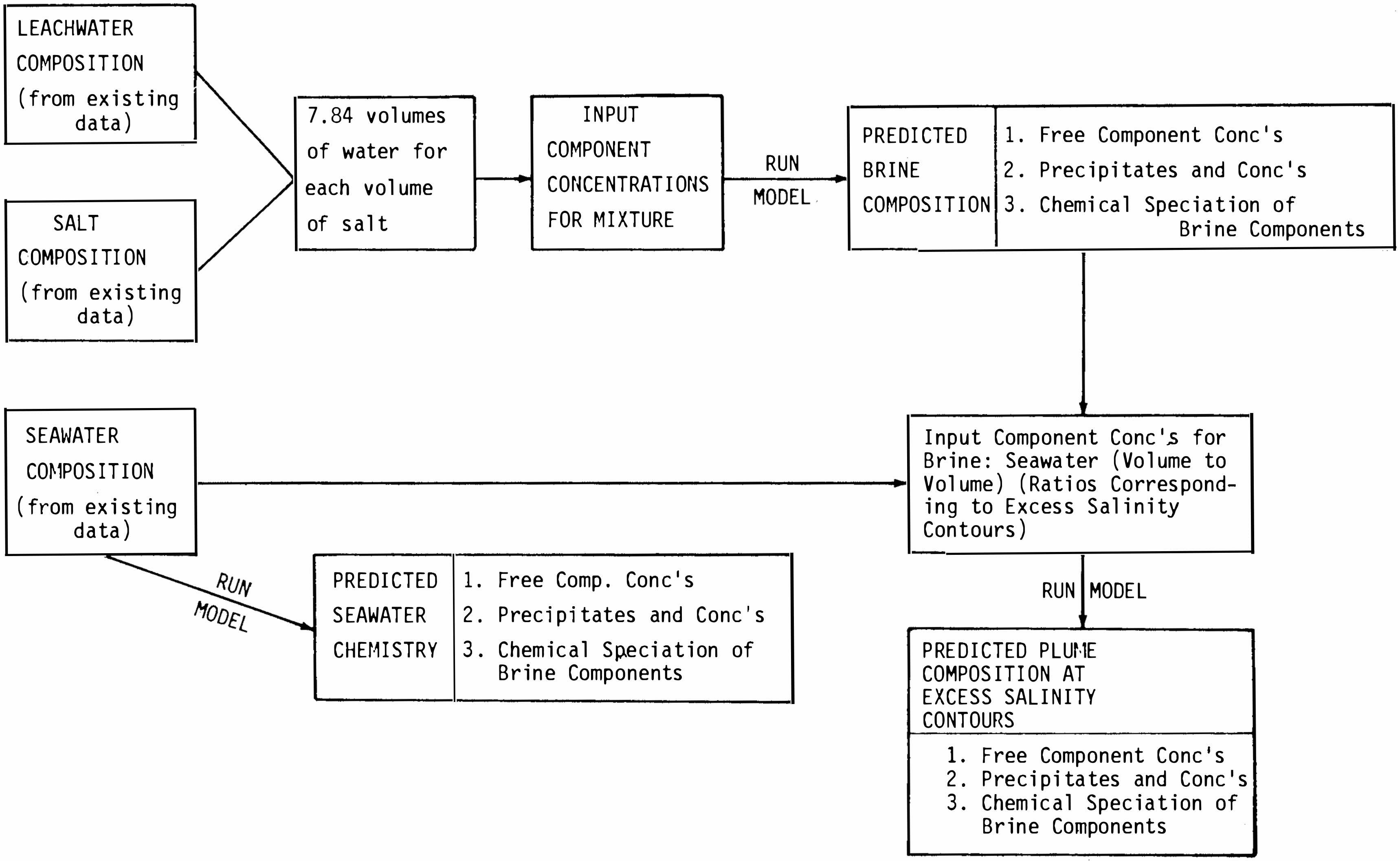


Figure D.15-1. Brine Plume Prediction for the MIT Model for Disposal for the West Hackberry Site (NOAA, 1977)

Figure D.15-2 SCHEMATIC DIAGRAM OF INTERACTION STUDY INPUTS AND RESULTS



2. Model Description

MINEQL*, a computer program for calculation of chemical equilibrium composition in aqueous systems was utilized to solve the chemical equilibrium (MIT, 1976). The model is based on the use of an equilibrium constant approach in which an initial guess for a set of components is used for calculation of the minimum Gibbs-Free energy composition from equilibrium constants. Then mass balance equations are solved by iteration to complete a solution to the problem.

The program consists of a main program (MAIN) which initializes program variables and calls the various subroutines. Subroutine INPUT combines user supplied inputs with thermodynamic data normally or disk storage. INION reads ionic charge data and IONCOR performs the ionic strength correction. With the problem defined, OUTPUT prints these data for verification, IONCMP, components, and IONSPC, species. SOLID modifies the problem for existence of solid phases then SOLVE solves the problem for soluble species. SOLIDX solves for the amounts of solid species, performs precipitation and dissolution tests. If no precipitation or dissolution occurs OUTPUTS prints the results. In case of precipitation or dissolution SOLIDX restores the matrices to the state they were in before SOLID was called and the solution sequence is started with a new set of solids.

3. Basic Assumptions

Several basic assumptions were made in order to run the model efficiently without loss of reliability. These assumptions were:

- that the pH of the brine should be fixed
- that the pH of seawater and seawater-brine mixtures should be fixed
- that the ultimate replenishment source for Black Lake is primarily Calcasieu Ship Channel ("worst case")

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*MINEQL is a model developed by Westall, Zachary and Morel of Ralph Parsons Laboratory, MIT under EPA Grant No. R-803738.

- that without an accurate oxidation-reduction potential for seawater in the vicinity of the disposal area, oxidation-reduction should not be considered.

The fixed pH values 8.27 for brine and 8.1 for seawater and seawater-brine mixtures were chosen because the buffering capacity of these solutions is high enough that the minor changes in $[H_3O^+]$ or $[OH^-]$ due to chemical equilibrium changes would be negligible for this disposal operation.

Calcasieu Ship Channel data was used (as a worst case) when data was lacking for Black Lake for two reasons: 1) it is a replenishment source for Black Lake via Black Lake Bayou and 2) data was not available for the ICW near Alkali Ditch. This is a "worst case" as levels of heavy metals are expected to be lower in the ICW which also feeds Black Lake via Alkali Ditch than in the ship channel.

No specific oxidation-reduction potentials were available in the literature, therefore oxidation-reduction reactions were not considered. The oxidation-reduction potential at the site could easily be significantly different from open-ocean values found in the literature due to organic materials from Calcasieu and Sabine estuaries. Thus, the lack of value in considering oxidation-reduction reactions based on questionable data was the reason for not considering that type of reactions.

4. Model Inputs

Model inputs consisted of components and species type specifications. In all cases a set of components was used with a single type specification to specify fixed pH or hydrogen ion concentration. Components and input concentrations for the leachwater, salt and seawater are given in Tables D.15-1, D.15-2 and D.15-3 respectively , with unit concentrations (actual model concentrations are in molar concentrations).

These input concentrations came from existing literature information, with (in the case of leachwater and salt) incomplete information

TABLE D.15-1

Concentrations of Leachwater Components Used as the Basis of Inputs for the Chemical Equilibrium Model (MINEQL)

Component	Concentration	Reference
Barium	10 μg/l	1
Calcium	58 mg/l	1
Carbonate	42 mg/l	1
Chloride	2600 mg/l	1
Copper (II)	4 μg/l	1
Hydronium Ion $(H_3O)^+$	pH = 7.4*	2
Iron (III)	60 μg/l	1
Lead	30 μg/l	2
Magnesium	170 mg/l	1
Mercury	.04 μg/l	1
Nickel	3 μg/l	2
Nitrate	100 mg/l	1
Potassium	56 mg/l	1
Sodium	1500 mg/l	1
Sulfate	370 mg/l	1

1 (USGS, Louisiana, 1976)

2 (Preliminary Draft Sampling Report for the Bayou Choctaw and West Hackberry Salt Dome Facilities) (FEA,1977)

*For reference only, in prediction of brine composition pH fixed at 8.27. Based on pH of brine from Olin Corp. (Olin, 1975)

TABLE D.15-2

Concentrations of Salt Components Used as the Basis of Inputs for the Chemical Equilibrium Model (MINEQL)

Component	Concentrations (ppm)*
Aluminum	150.1
Calcium	90.0
Chloride	63994.
Copper (II)	1.03
Hydromium Ion	pH = 8.27**
Iron (III)	90.2
Lead	2.0
Magnesium	1090.0
Manganese (II)	101.2
Nickel	.012
Potassium	9100.0
Silicon	200.0
Silver	0.29
Sodium	98685.
Strontium	1000.0
Titanium Oxide	3.0 as Titanium
Zinc	.05

*Source: (Bloomberg and Ladenburg, 1959)

**pH of brine fixed at 8.27 pH value from Olin Corp. (Olin, 1975)

TABLE D.15-3

Concentrations of Seawater Components Used as the Basis of Inputs for the Chemical Equilibrium Model (MINEQL)

Component	Concentration	Reference
Aluminum	1 mg/l	1
Barium	50 μg/l	1
Bromide	66 mg/l	1
Cadmium	0.3 μg/l	1
Calcium	402.7 mg.1	1,2,3
Cerium	0.4 μg/l	1
Cesium	2.0 μg/l	1
Chloride	10,640 mg/l	1,2
Chromium	1.0 μg/l	1
Cobalt (II)	10.0 μg/l	2
Copper (II)	3.0 μg/l	2
Fluoride	1.3 mg/l	1,2
Gold	0.006 μg/l	1
Hydronium Ion (H_3O^+)	pH = 8.1	4
Iodide	60.0 μg/l	2
Iron	10.0 μg/l	2
Lead	4.0 μg/l	2
Lithium	100 μg/l	1
Magnesium	1324 mg/l	1,2
Manganese (II)	10.0 μg/l	1
Mercury	0.03 μg/l	1,2
Nickel	2.0 μg/l	2
Nitrate	10.0 μg/l	4
Potassium	382.7 μg/l	1,2,3
Scandium	0.04 μg/l	2
Silicon (as SiO_3)	13.4 mg/l	1
Silver	0.3 μg/l	1
Strontium	9 mg/l	1,2
Sulfate	2100 mg/l	4
Thorium	0.5 μg/l	1
Tin (IV)	3.0 μg/l	1
Titanium (as TiO)	1.33 μg/l	1,2
Uranyl Ion (UO_2^{2+})	3.4 μg/l	2
Zinc	10.0 μg/l	

1 (McIlhenny and Ballard, 1968) 2 (Horne, 1969)

3 (Fairbridge, 1972) 4 (USGS, Louisiana, 1976)

presenting a significant difficulty. For seawater rather complete literature information was available but differences in ocean water composition and coastal water with thirty-foot depths was not determined.

5. Model Outputs

Model outputs consist of free concentrations of components, a listing of species in which components are bound and the percent bound in each species and a list of precipitated species and their concentrations. The free concentrations are presented in both tabular and graphic form. Table D.15-4 and Figures D.15-3 through D.15-7 contain this information. Tables D.15-5 and D.15-6 and Figures D.15-8 through D.15-10 contain data on precipitates and their concentrations. Finally Tables D.15-7 and D.15-8 give the predicted chemical speciation for brine and brine-seawater mixtures with the precentage of each component bound in the various forms.

TABLE D.15-4

Predicted Free Component Concentrations for the Various Excess Salinity Areas as Predicted by the MINEQL Model

	Excess Salinity in Parts Per Thousand				
Component	0.0	10.0	30.0	60.0	159.4
Aluminum	N*	N	N	N	N
Barium	1.4 μg/l	1.6 μg/l	2.2 μg/l	3.1 μg/l	6.6 μg/l
Bromide	66.0 mg/l	63.5 mg/l	58.6 mg/l	50.9 mg/l	33.0 mg/l
Cadmium	.009 μg/l	.005 μg/l	.002 μg/l	.0007 μg/l	.0001 μg/l
Calcium	359.5 mg/l	376.8 mg/l	404.8 mg/l	448.9 mg/l	400.8 mg/l
Carbonate	.15 mg/l	.18 mg/l	.23 mg/l	.31 mg/l	.54 mg/l
Cerium	.21 μg/l	.20 μg/l	.17 μg/l	.14 μg/l	.07 μg/l
Cesium	1.7 μg/l	1.5 μg/l	1.2 μg/l	0.9 μg/l	0.4 μg/l
Chloride	19.36 g/l	26.63 g/l	41.48 g/l	64.52 g/l	118.06 g/l
Chromium	N	N	N	N	N
Cobalt (II)	6.1 μg/l	5.4 μg/l	4.4 μg/l	3.1 μg/l	1.4 μg/l
Copper (II)	0.8 μg/l	0.8 μg/l	0.8 μg/l	0.8 μg/l	0.8 μg/l
Fluoride	0.97 mg/l	0.94 mg/l	0.86 mg/l	0.75 mg/l	0.50 mg/l
Gold	N	N	N	N	N
Hydronium Ion (H_2O^+)	Fixed**	Fixed	Fixed	Fixed	Fixed
Iodide	59.6 μg/l	57.9 μg/l	53.3 μg/l	46.3 μg/l	30.1 μg/l
Iron (III)	N	N	N	N	N
Lead	0.2 μg/l	0.3 μg/l	0.2 μg/l	0.1 μg/l	.004 μg/l
Lithium	99.3 μg/l	95.8 μg/l	88.2 μg/l	76.4 μg/l	49.8 μg/l
Magnesium	505.5 mg/l	508.0 mg/l	503.1 mg/l	488.5 mg/l	432.6 mg/l
Manganese (II)	3.1 μg/l	112.1 μg/l	201.6 μg/l	212.6 μg/l	148.9 μg/l
Mercury	N	N	N	N	N
Nickel	1.2 μg/l	1.7 μg/l	2.6 μg/l	3.5 μg/l	4.6 μg/l
Nitrate	10.0 μg/l	9.5 μg/l	8.9 μg/l	7.7 μg/l	5.0 μg/l
Potassium	371.8 mg/l	402.7 mg/l	465.3 mg/l	567.0 mg/l	797.6 mg/l
Scandium	N	N	N	N	N
Silicon as SiO_3	0.02 μg/l	0.01 μg/l	0.006 μg/l	0.006 μg/l	0.006 μg/l
Silver	N	N	N	N	N
Sodium	10.51 g/l	15.24 g/l	25.06 g/l	40.23 g/l	75.41 g/l

TABLE D.15-4
(Concluded)

Predicted Free Component Concentrations for the Various Excess Salinity Areas as Predicted by the MINEQL Model

	Excess Salinity in Parts Per Thousand				
Component	0.0	10.0	30.0	60.0	159.4
Strontium	7.1 mg/l	8.3 mg/l	11.0 mg/l	15.9 mg/l	33.6 mg/l
Sulfate	1095.1 mg/l	920.2 mg/l	697.4 mg/l	480.3 mg/l	226.7 mg/l
Thorium	N	N	N	N	N
Tin (IV)	N	N	N	N	N
Titanium Oxide (TiO)	N	N	N	N	N
Uranyl Ion (UO_2)	N	N	N	N	N
Zinc	1.4 μg/l	4.8 μg/l	4.8 μg/l	4.8 μg/l	3.2 μg/l

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[*] N specifies zero or essentially zero free concentration.

[**] Due to buffering capacity of seawater an assumption is made that the pH would remain essentially constant despite brine discharge, therefore the pH is fixed at a constant value.

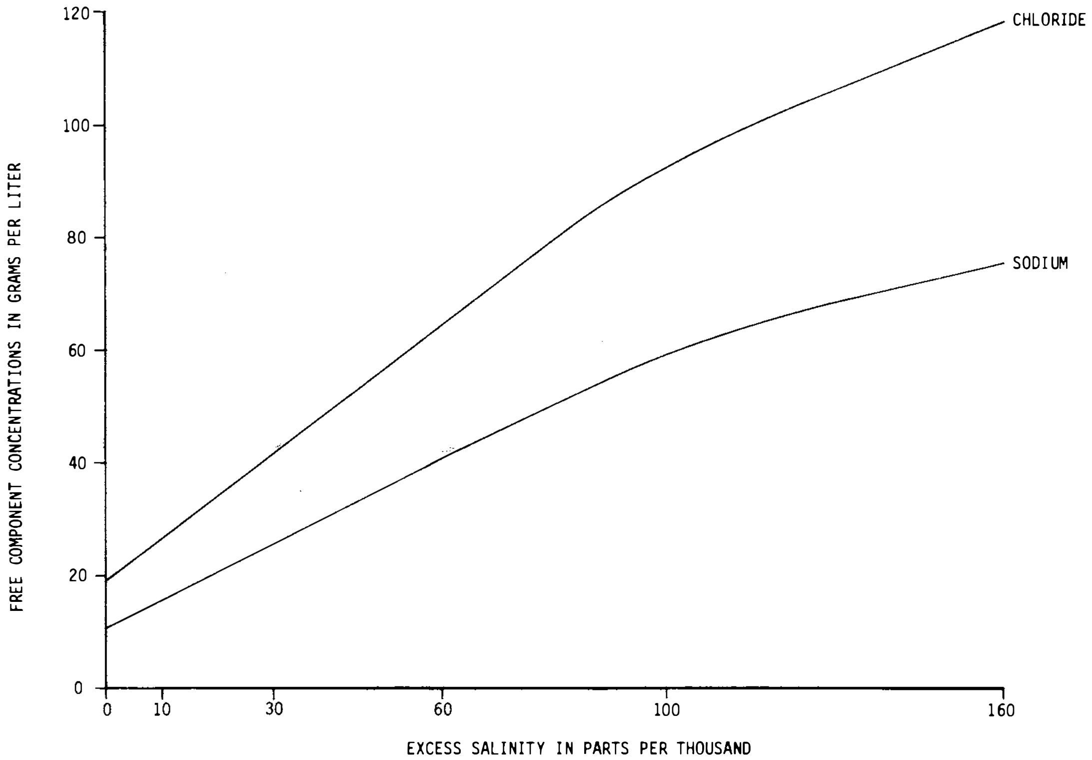

Figure D.15-3. Free (Unbound) Concentrations of Components at Various Salinity Contours

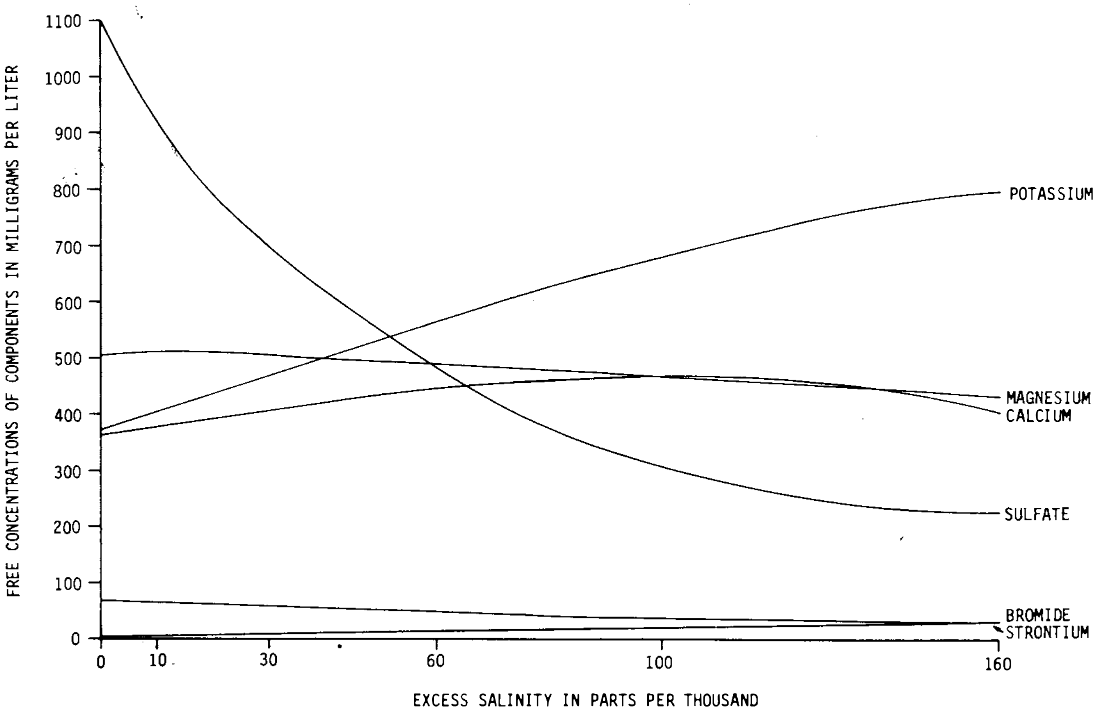

Figure D.15-4. Free (Unbound) Concentrations of Components at Various Salinity Contours

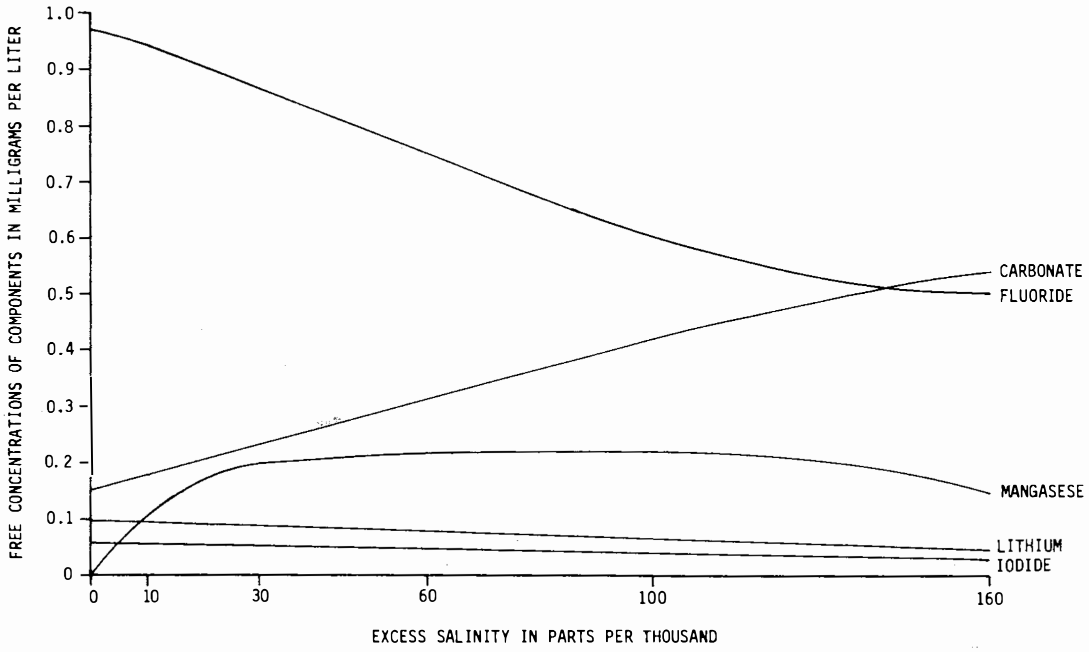

Figure D.15-5. Free (Unbound) Concentrations of Components at Various Salinity Contours

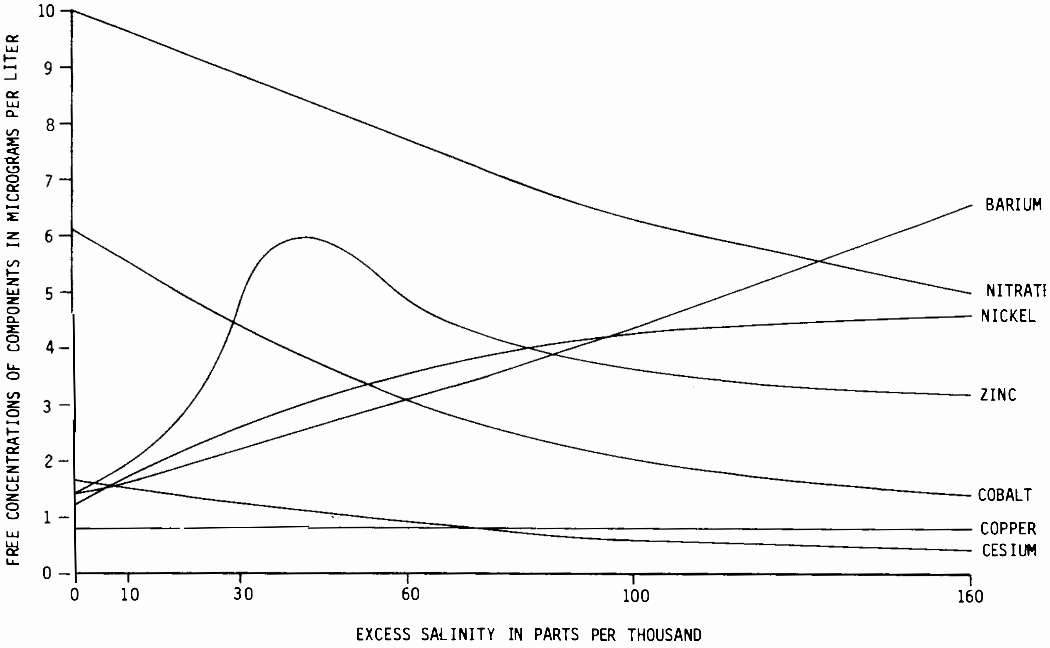

Figure D.15-6. Free (Unbound) Concentrations of Components at Various Salinity Contours

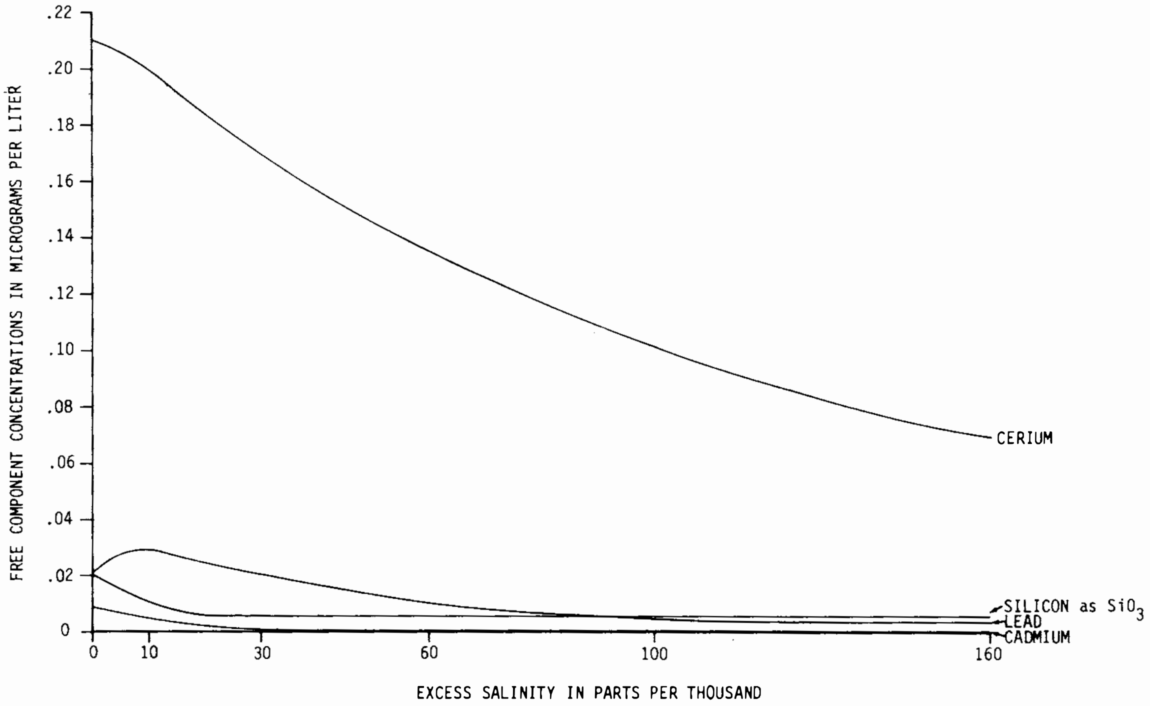

Figure D.15-7. Free (Unbound) Concentrations of Components at Various Salinity Contours

TABLE D.15-5

Precipitates Predicted to Exist in the Brine with Concentrations

Precipitate	Concentration
Aluminum Hydroxide $Al(OH)_3$	55.4 mg/l
Calcium Carbonate $CaCO_3$	42.4 mg/l
Copper (II) Hydroxide $Cu(OH)_3$	196.1 μg/l
Iron (III) Hydroxide $Fe(OH)_3$	22.1 mg/l
Titanium as $TiO(OH)_2$	0.24 μg/l

TABLE D.15-6

Precipitates Predicted to Exist at Various Excess Salinity Contours in the Brine Plume with Concentrations

Precipitate	Excess Salinity Contours				
	0.0	10.0	30.0	60.0	159.4
Aluminum Hydroxide $Al(OH)_3$	--	--	1.33 mg/l	8.74 mg/l	25.97 mg/l
Aluminum Hydroxy-Silicate $Al_2(SiO_3)_2(OH)_2$	4.44 mg/l	7.4 mg/l	11.53 mg/l	9.44 mg/l	4.92 mg/l
Barium Sulfate $BaSO_4$	82.39 μg/l	79.82 μg/l	73.75 μg/l	64.18 μg/l	39.68 μg/l
Calcium Carbonate $CaCO_3$	--	--	--	--	349.3 mg/l
Copper (II) Hydroxide $Cu(OH)_2$	0.52 μg/l	7.26 μg/l	21.76 μg/l	43.03 μg/l	92.88 μg/l
Gold Hydroxide $Au(OH)$	.0064 μg/l	.0062 μg/l	.0058 μg/l	.0049 μg/l	.70 μg/l
Iron (III) Hydroxide $Fe(OH)_3$	.02 mg/l	.84 mg/l	2.5 mg/l	19.77 mg/l	11.11 mg/l
Strontium Sulfate $SrSO_4$	7.15 mg/l	13.67 mg/l	26.82 mg/l	45.18 mg/l	74.76 mg/l
Tin (IV) Hydroxide $Sn(OH)_4$	3.86 μg/l	3.73 μg/l	3.44 μg/l	2.87 μg/l	2.26 μg/l
Titanium as $TiO(OH)_2$	2.04 μg/l	1.97 μg/l	1.82 μg/l	1.61 μg/l	0.09 μg/l
Zinc Silicate $ZnSiO_3$	18.5 μg/l	17.7 μg/l	11.3 μg/l	9.6 μg/l	--

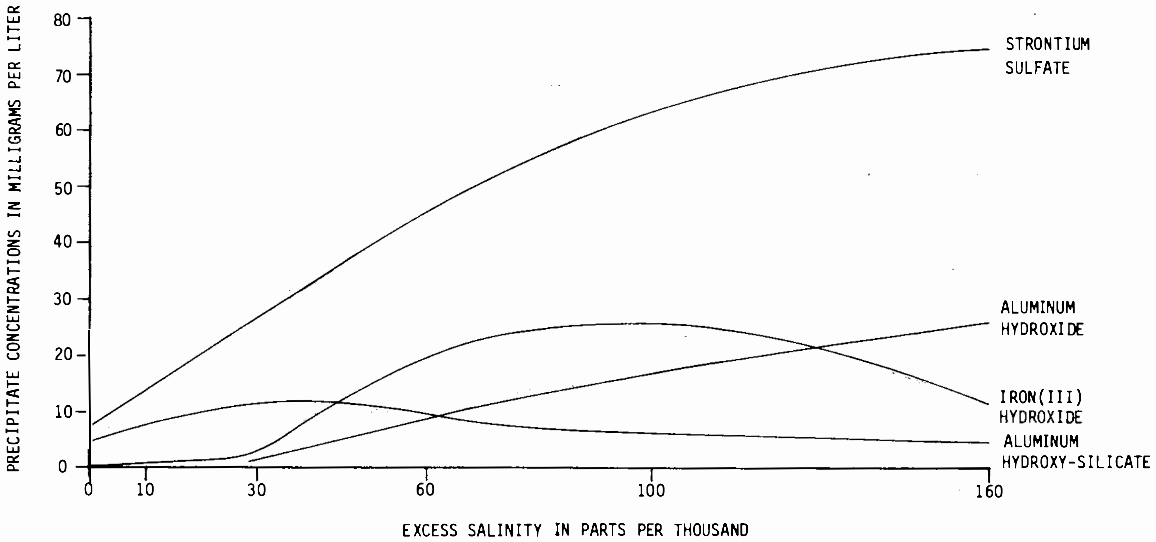

Figure D.15-8. Precipitate Concentrations at Various Salinities

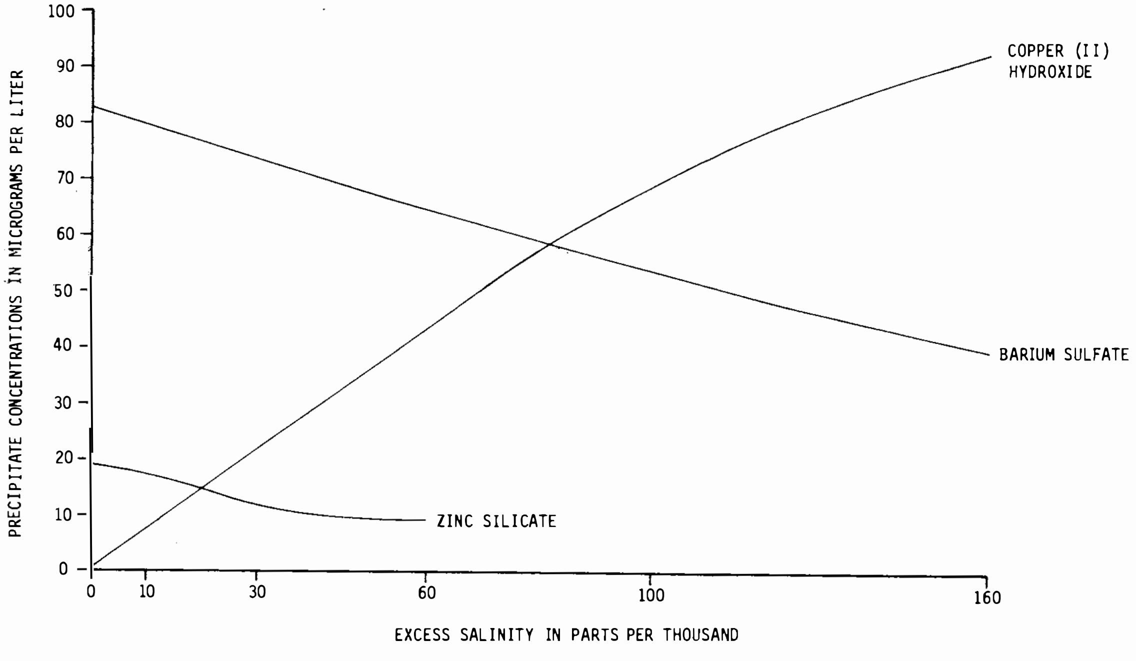

Figure D.15-9. Precipitate Concentrations at Various Salinities

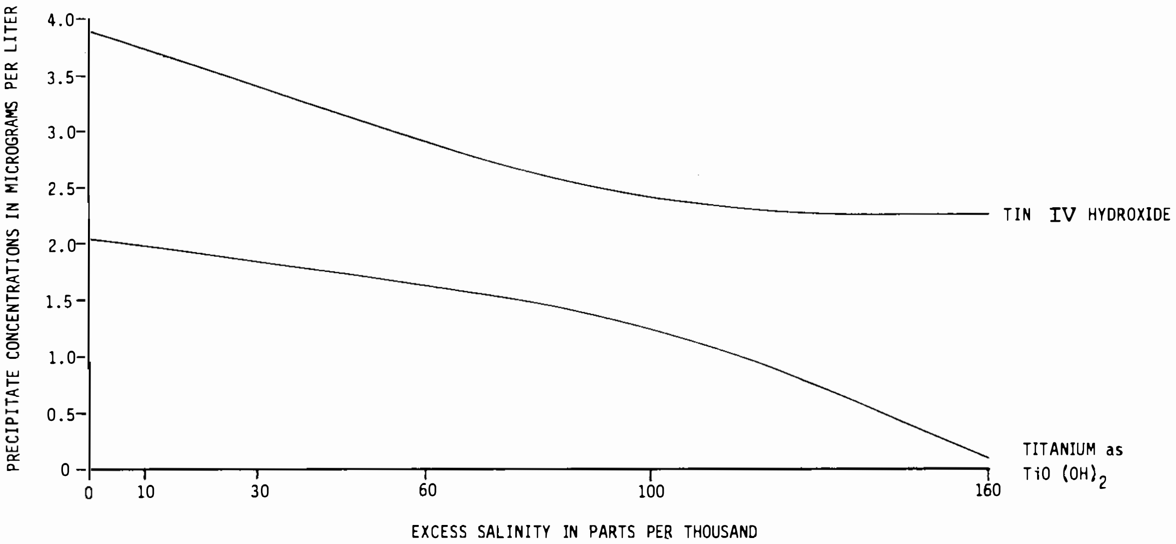

Figure D.15-10. Precipitate Concentrations at Various Salinities

TABLE D.15-7

Predicted Chemical Species Present in the Brine and the Percentages of Components Bound in Each Species

Component	Input Conc. in Leachwater-Salt Mixture	Species	% Bound
Aluminum	19.2 mg/l	$AL(OH)_3$	100.0
Barium	10.0 μg/l	Ba^{2+}	100.0
Calcium	709.9 mg/l	Ca^{2+}	97.0
		$CaCO_3$	2.4
Carbonate	41.35 mg/l	$CaCO_3$	61.5
		$NaCO_3-$	17.7
		NCO_3-	15.6
		N_2CO_3	1.6
		$MgHCO_3$	1.2
Chloride	216.2633 gm/l	Cl^-	100.0
Copper	135.4 μg/l	$Cu(OH)_2$	94.4
		$CuCl_2$	3.0
		$CuCl+$	1.6
Hydronium Ion	(pH fixed @ 8.27)	(H_3O+)	--
Iron (III)	11.6 mg/l	$Fe(OH)_3$	100.0
Lead	285.9 μg/l	$PbCl_3-$	99.1
Magnesium	208.7 mg/l	Mg^{2+}	99.2
Manganese (II)	12.9 mg/l	$MnCl_3-$	58.7
		$MnCl_2$	30.4
		$MnCl+$	10.3
Mercury	0.04 μg/l	$[HgCl_4]^-$	98.4
		$[HgCl_3]^-$	1.6
Nickel	31.5 μg/l	$NiCl+$	79.3
		Ni^{2+}	17.5
		$Ni(OH)+$	3.1
Potassium	1216.0 mg/l	$K+$	99.9
Silver	37.0 μg/l	$[AgCl_4]^-$	97.4
Sodium	140.2390 gm/l	$Na+$	99.9
Strontium	127.9 mg/l	Sr^{2+}	100.0

TABLE D.15-7

(Concluded)

Predicted Chemical Species Present in the Brine and the Percentages of Components Bound in Each Species

Component	Input Conc. in Leachwater-Salt Mixture	Species	% Bound
Sulfate	369.8 mg/l	$NaSO_4^-$	83.2
		SO_4^{2-}	11.6
		$CaSO_4$	2.2
		$MgSO_4$	2.0
		KSO_4^-	1.1
Titanium Oxide	0.10 μg/l	$TiO(OH)_2$	100.0

TABLE 15-8

Predicted Chemical Species Present in the Brine Plume at Various Excess Salinity Contours with Percentage Distribution of the Species

Percent Bound in Species For:

Component	Species	Seawater	10 ppt Excess Salinity	30 ppt Excess Salinity	60 ppt Excess Salinity	159.4 ppt Excess Salinity
Aluminum	$Al_2(SiO_3)_2(OH)_2$	100.0	100.0	84.9	41.4	11.0
	$Al\ (OH)_3$	--	--	15.0	58.6	89.0
Barium	Ba^{2+}	2.8	3.4	4.7	7.6	22.1
	$BaSO_4$	97.2	96.6	95.3	92.4	77.9
Bromide	Br-	100.0	100.0	100.0	100.0	100.0
Cadmium	Cd^{2+}	3.0	1.7	--	--	--
	$CdCl^+$	38.4	30.9	21.2	13.4	6.3
	$CdCl_2$	51.0	56.4	60.2	59.2	51.0
	$CdCl_3^-$	7.0	10.6	17.7	27.1	42.6
Calcium	Ca^{2+}	89.0	90.4	92.5	94.6	72.6
	$CaSO_4$	11.0	9.6	7.4	5.2	1.9
	$CaCO_3$	--	--	--	--	25.3
Carbonate	CO_3^{2-}	2.5	2.4	2.3	2.2	--
	$CaCO_3$	1.2	1.3	1.3	1.4	88.5
	$CaHCO_3^+$	3.9	4.0	4.1	4.3	--
	$MgCO_3$	4.5	4.5	4.2	3.9	--
	$MgHCO_3^+$	9.1	8.9	8.5	7.8	--
	$NaCO_3^-$	4.2	6.0	9.5	14.4	2.8
	HCO_3^-	73.9	72.3	69.4	65.5	6.8

TABLE D.15-8 (Continued)

Predicted Chemical Species Present in the Brine Plume at Various Excess Salinity Contours with Percentage Distribution of the Species

Percent Bound in Species For:

Component	Species	Seawater	10 ppt Excess Salinity	30 ppt Excess Salinity	60 ppt Excess Salinity	159.4 ppt Excess Salinity
Cerium	Ce^{3+}	38.7	38.3	36.3	32.6	25.2
	$CeSO_4^+$	28.7	23.9	17.2	10.6	4.1
	$CeCl^{2-}$	15.2	20.7	30.6	42.7	60.4
	CeF^{2-}	2.8	2.7	1.4	1.9	--
	Ce)OH)$^{2-}$	--	14.3	13.5	12.2	9.4
Cesium	Cs^+	82.5	77.6	68.9	58.8	43.8
	CsCl	17.4	22.4	31.1	41.1	56.2
Chloride	Cl^-	100.0	100.0	100.0	100.0	100.0
Chromium	$Cr(OH)_2$	3.0	3.0	3.0	3.0	3.0
	$Cr(OH)_4$	97.0	97.0	97.0	97.0	97.0
Cobalt (II)	Co^{2+}	60.8	56.5	49.0	40.2	28.1
	$CoSO_4$	11.9	9.5	6.2	3.5	1.2
	CoCl+	24.7	31.6	42.7	54.5	69.6
	Co(OH)+	2.3	2.2	1.9	1.6	1.1

TABLE d.15-8 (Continued)

Predicted Chemical Species Present in the Brine Plume at Various Excess Salinity Contours with Percentage Distribution of the Species

Percent Bound in Species For:

Component	Species	Seawater	10 ppt Excess Salinity	30 ppt Excess Salinity	60 ppt Excess Salinity	159.4 ppt Excess Salinity
Copper (II)	Cu^{2+}	27.6	10.5	4.6	2.5	1.2
	$CuCO_3$	19.1	8.7	5.0	3.6	3.0
	$CuSO_4$	3.4	1.1	--	--	--
	$CuCl+$	14.1	7.4	5.1	4.2	3.7
	$CuCl_2$	2.4	1.7	1.8	2.4	3.8
	$Cu(OH)^+$	21.2	8.1	3.6	1.9	--
	$Cu(OH)_2$	11.3	62.4	79.7	84.5	87.3
Fluoride	F^-	74.9	74.7	74.8	75.1	77.3
	CaF^+	2.0	2.1	2.2	2.5	2.3
	MgF^+	23.1	23.2	23.0	22.4	20.4
Gold	Au(OH)	100.0	100.0	100.0	100.0	100.0
Iodide	I^-	99.4	100.0	100.0	100.0	100.0
	AgI	--	--	--	--	9.5
Iron (III)	$Fe(OH)_3$	99.9	100.0	100.0	100.0	100.0

TABLE D.15-8 (Continued)

Predicted Chemical Species Present in the Brine Plume at Various Excess Salinity Contours with Percentage Distribution of the Species

Percent Bound in Species For:

Component	Species	Seawater	10 ppt Excess Salinity	30 ppt Excess Salinity	60 ppt Excess Salinity	159.4 ppt Excess Salinity
Lead	$PbCO_3$	2.0	--	--	--	--
	$PbCl^+$	3.6	2.1	--	--	--
	$PbCl_2$	7.6	6.0	4.0	2.7	1.5
	$PbCl_3^-$	83.2	89.5	94.3	96.7	98.3
	$Pb(OH)^+$	2.7	2.2	--	--	--
Lithium	Li^+	99.0	99.1	99.3	99.5	99.8
	$LiSO_4^-$	1.0	--	--	--	--
Magnesium	Mg^{2+}	86.3	88.1	90.7	93.3	96.5
	$MgSO_4$	13.5	11.7	9.2	6.5	3.2
Manganese (II)	Mn^{2+}	30.8	23.0	13.8	7.2	2.3
	$MnSO_4$	3.9	2.4	1.1	--	--
	$MnCl^+$	49.7	51.3	47.8	38.6	22.6
	$MnCl_2$	13.2	18.7	27.1	34.1	36.5
	$MnCl_3^-$	2.3	4.4	10.0	19.6	38.5
Mercury	$HgCl_2$	3.3	1.9	--	--	--
	$[HgCl_3]^-$	14.5	11.2	7.6	5.0	2.8
	$[HgCl_4]^-$	81.9	86.9	91.6	94.6	97.1

TABLE D.15-8 (Continued)

Predicted Chemical Species Present in the Brine Plume at Various Excess Salinity Contours with Percentage Distribution of the Species

Percent Bound in Species For:

Component	Species	Seawater	10 ppt Excess Salinity	30 ppt Excess Salinity	60 ppt Excess Salinity	159.4 ppt Excess Salinity
Nickel	Ni^{2+}	60.5	56.8	48.2	39.5	27.6
	$NiSO_4$	7.5	5.9	3.9	2.2	--
	$NiCl^+$	24.6	31.3	42.0	53.5	68.3
	$Ni(OH)^+$	7.4	6.8	5.9	4.8	3.4
Nitrate	NO_3^-	100.0	100.0	100.0	100.0	100.0
Potassium	K^+	96.8	97.2	97.9	98.5	99.3
	KSO_4^-	3.2	2.8	2.1	1.5	--
Scandium	$Sc(OH)_3$	100.0	100.0	100.0	100.0	100.0
	$HSiO_3^-$	4.5	3.4	1.5	1.7	2.6
Silicon as (SiO_3)	H_2SiO_3	69.3	51.4	22.4	25.9	39.7
	$Al_2(SiO_3)_2(OH)_2$	26.1	45.2	76.2	72.5	57.7
Silver	AgI	99.7	99.0	94.0	69.8	13.1
	$AgCl_4$	--	--	5.1	27.4	82.7
	$AgCl_3$	--	--	--	2.2	3.7
Strontium	Sr^{2+}	67.5	55.9	46.0	42.4	48.5
	$SrSo_4$	32.4	44.1	54.0	57.6	51.5

TABLE D.15-8 (Concluded)

Predicted Chemical Species Present in the Brine Plume at Various Excess Salinity Contours with Percentage Distribution of the Species

Percent Bound in Species For:

Component	Species	Seawater	10 ppt Excess Salinity	30 ppt Excess Salinity	60 ppt Excess Salinity	159.4 ppt Excess Salinity
Sulfate	SO_4^{2-}	51.0	45.2	36.5	28.1	19.1
	$CaSO_4$	5.1	4.7	4.1	3.5	2.1
	$MgSO_4$	14.8	13.1	10.5	7.8	4.7
	$NaSO_4^-$	27.5	35.3	46.9	58.0	74.0
	KSO_4^-	1.4	1.4	1.3	1.2	--
Thorium	ThF_2^{2-}	25.6	25.2	24.3	22.2	14.3
	ThF_3^-	38.8	36.8	32.7	26.1	11.2
	$Th(OH)^{3-}$	35.1	37.4	42.5	51.1	73.8
Tin (IV)	$Sn(OH)_4$	100.0	100.0	100.0	100.0	100.0
Titanium Oxide TiO	$TiO(OH_2)$	100.0	100.0	100.0	100.0	100.0
Uranyl Ion (UO_2^{2+})	$UO_2(CO_3)_2$	2.7	2.3	1.8	1.3	--
	$UO_2(CO_3)_3$	97.2	97.7	98.2	98.7	99.2
Zinc	Zn^{2+}	13.7	18.1	40.4	34.7	17.7
	$ZnSO_4$	1.7	1.9	3.2	1.9	--
	$ZnSiO_3$	84.3	77.2	43.9	32.3	--
	$ZnCl^+$	--	1.0	3.5	4.7	4.4
	$ZnCl_3^-$	--	--	7.4	23.9	2.2
	$ZnCl_2$	--	--	--	1.3	74.8

6. Summary and Conclusions

Predictions on the chemical equilibrium composition of brine, seawater and brine-seawater mixtures have been presented in the data. Limitations of these predictions consist mainly of gaps in existing data on leachwater, salt and seawater composition especially in the area of aquatic nutrients such as various forms of phosphorus and nitrogen. It is also significant that the seawater composition was not entirely representative of coastal waters.

Nevertheless, the chemical fate of heavy metals content of the brine has been predicted as well as the change in ratios of important metabolic catalysts such as magnesium and calcium. Also the formation of precipitates was covered.

Important changes in chemical composition observed include:

- Ratio of free concentrations of magnesium and calcium remained relative constant with changes in the excess salinity.
- Free concentrations of heavy metals generally declined with increasing excess salinity.
- Speciation of the heavy metals changed with increasing excess salinity to give greater amounts of chloro-complexes and other soluble species.
- The types of precipitates remained relatively constant across the excess salinity scale with concentrations of most precipitates increasing with salinity increases.

These observations dictate a number of assumptions and/or conclusions:

- Changes in calcium to magnesium ratios appear to be small if only ratios of free concentrations are considered.
- The availability of heavy metals to marine organisms may be increased or decreased by predicted formation of chloro-complexes at higher salinities.
- The number and types of precipitates predicted remained essentially constant as the excess salinity increased with increasing amounts of most precipitated compounds at higher salinities.

Impacts from the brine disposal would consist chiefly of the effects of the gross salinity increases within the brine plume, with the range of salinity increase being an important factor (see discussion of the ecological impacts). Only minimal impact should be felt from concentration or speciation changes of the heavy metals. Free component concentrations of magnesium and calcium are predicted to vary only slightly with increasing salinity suggesting that the calcium to magnesium ratio would not change appreciably (assuming free forms are the most important biologically). Formation of increased amounts of dissolved and precipitated solids would occur. Most of these solids would tend to have an affinity for the surface of existing particulants causing particulate growth of an undetermined amount. Formation and possible settling of these particulates could have an influence on the marine life in the disposal area (see ecological impacts).

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APPENDIX D.16

CALCULATION OF SEDIMENT TRANSPORT

1. General

The annual volumetric transport rate for sediment can be expressed by the universal soil-loss equation (Wischmeier and Smith, 1965). The universal soil-loss equation is a widely used calculation for estimating soil erosion on both farm land and construction sites. However, the equation has several limitations in the Texoma area:

1. The slope factor will tend to overestimate the net result in land with gentle slopes;
2. The equation does not predict soil-loss that is due solely to thaw, snowmelt, or wind;
3. No known value has been developed for saline soils;
4. This equation is still being perfected for the southeastern area of the United States.

The soil-loss equation is

$$A = R\ K\ L\ S\ C\ P$$

where A is the computed rate of soil loss per unit area - (tons per acre per year).

R, the rainfall factor, is the number of erosion-index units in a normal year's rain. The erosion index is a measure of the erosive force of specific rainfall.

K, the soil-erodibility factor, is the erosion rate per unit of erosion index for a specific soil in cultivated continuous fallow, on a 9-percent slope 72.6 feet long.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-foot length on the same soil type and gradient.*

S, the slope-gradient factor, is the ratio of soil loss from the field gradient to that from a 9-percent slope.*

C, the cropping-management factor, is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the factor K is evaluated. If there is no cropping management factor, then C = 1.

P, the erosion-control practice factor, is the ratio of soil loss with contouring, stripcropping, or terracing to that with straight-row farming, up-and-down slope. If there is no erosion control practice, then P = 1.

2. Calculations for the West Hackberry Site

The factors associated with the universal soil loss equation at West Hackberry site are:

Factors	Justification
R = 350	(USDA, 1975a)
K = 0.38	(USDA, 1975b) and silt loam classification (USDA, 1971)
LS = 0.29**	slope 0.6% length 3,000 feet (USDA, 1975a)
C = 1	no cropping management factor
P = 1	no erosion control factor

---

* The slope length factor, L, and the slope-gradient factor, S, are normally calculated together based on the relation

$$LS = \left(\frac{\lambda}{72.6}\right)^m \left(\frac{430x^2 + 30x + 0.43}{6.57415}\right)$$

where m = 0.5 if S = 5% or greater, 0.4 if S = 4%, and 0.3 if S = 3% or less; x = sin θ; and θ = angle of slope

** The percent slope and slope length are the same on the northern and eastern sides of the dome. On the western side, the values are slightly different (0.5% - 3375 feet), however, the LS value for the equation remains the same.

Then

$$A = 350 \times 0.38 \times 0.29 \times 1.0 \times 1.0$$

$$= 38.6 \text{ tons/acre/year}$$

The construction period, T, is 5 months or 5/12 year. The soil loss per acre, D, is

$$D = A \times T$$

$$= 38.6 \times 5/12$$

$$= 16.1 \text{ tons/acre}$$

As noted in Section 2.4, the area that would be disturbed due to construction at West Hackberry is 200 acres. To approximate the total amount of soil erosion, E, one must multiply the soil loss per unit area times the number of acres distrubed.

$$E = D \times \text{number of acres disturbed}$$

$$= 16.1 \text{ tons/acres} \times 200 \text{ acres}$$

$$= 3220 \text{ tons}$$

To better illustrate the loss of 3220 tons of soil from 200 acres of nearly flat surface, one could compute the depth of soil lost if the loss is evenly distributed across the entire construction site. Assume that the density of soil is 2025 lb/yd^3 (Power 1963). Given that the depth of soil lost equals the volume of soil lost divided by the site acreage, it is computed that 3220 tons is approximately equivalent to losing 0.12 inches of soil over the whole site.

A loss of 0.12 inches of soil over the site is not exactly realistic, because most of the lost soil would come from a relatively small area of higher elevation on the dome. Lower elevations may actually experience an increase in soil depth.

According to the facility design and the topography of the land on and around the dome, 171.3 acres would be disturbed in the area of Black Lake and 28.7 acres would be disturbed in the area of Black Lake Bayou.

Black Lake => 171.3 acres/200 acres x 3200 tons
= 2758 tons
Black Lake Bayou => 28.7 acres/200 x 3220 tons
= 462 tons

Therefore, due to construction at West Hackberry site, 2758 tons of soil would be transported into Black Lake and 462 tons of soil would be transported into Black Lake Bayou as shown in Figure 4.3-10.

3. Calculations for the Black Bayou Site

The factors associated with the universal soil loss equation at the Black Bayou Salt Dome site are:

Factors	Justification
R = 350	(USDA, 1975a)
K = 0.2	(USDA, 1975b) and silt loam classification
LS = 0.34	slope - 2.4% length 333 feet (USDA, 1975a)
C = 1	no cropping management factor
P = 1	no erosion control factor

Then

$A = 350 \times 0.2 \times 0.34 \times 1.0 \times 1.0$
23.8 tons/acre/year.

The construction period, T, is 5 months or 5/12 year. The soil loss per acre, D, is

$D = A \times T$
$= 23.8 \times 5/12$
$= 9.9$ tons/acre

Also according to section 2.5, the only dry land that will be disturbed at Black Bayou would be the central plant facilities which consists of 10 acres. To approximate the amount of soil erosion, E, due to construction of the Black Bayou SPR facility, multiply the soil loss per unit area, D, times the number of acres disturbed.

$$\begin{aligned} E &= D \times \text{number of acres disturbed} \\ &= 9.9 \text{ tons/acre} \times 10 \text{ acres} \\ &= 99 \text{ tons} \end{aligned}$$

To better illustrate the loss of 99 tons of soil from 10 acres of nearly flat surface, one could compute the depth of soil lost if the loss is evenly distributed across the entire construction site. Assume that the density of soil is 2025 lbs/yd^3 (Power, 1963). Given that the depth of soil lost equals the volume of soil lost divided by the site acreage, it is computed that 99 tons is approximately equivalent to losing 0.073 inches of soil over the whole site.

A loss of 0.073 inches of soil over the site is probably not exactly realistic, because most of the lost soil would mostly come from a relatively small area of higher elevation on the dome. Lower elevations may actually experience an increase in soil depth.

This 99 acres of soil would be redistributed in all directions back into Black Bayou as shown in Figure 4.4-03.

4. Calculations for the Vinton Site

The factors associated with the universal soil loss equation at the Vinton Salt Dome site are:

Factors	Justification
R = 350	(USDA, 1975a)

$K = 0.36$ (USDA, 1975b) and silt loam classification (USDA, 1969)

$LS = 0.4$* slope 1.7%, length 500 ft. (eastern) (USDA, 1975a)

$C = 1$ no cropping management factor

$P = 1$ no erosion control factor

Then

$$A = 350 \times 0.36 \times 0.4 \times 1.0 \times 1.0$$
$$A = 50.4 \text{ tons/acre/year}$$

The construction period, T, is 5 months or 5/12 year. The soil loss per acre, D. is

$$\begin{aligned} D &= A \times T \\ &= 50.4 \text{ tons/acre/year} \times 5/12 \\ &= 21 \text{ tons/acre} \end{aligned}$$

According to Section 2.6, the area disturbed for construction of the wellheads, central plant facilities and roads will be 30 acres. To approximate the amount of soil erosion, E, due to construction at Vinton, one must multiply the soil loss per unit area per construction period times the number of acres disturbed.

$$\begin{aligned} E &= D \times \text{number of acres} \\ &= 21.0 \times 30 \text{ acres} \\ &= 630 \text{ tons} \end{aligned}$$

To better illustrate the loss of 630 tons of soil from 30 acres of nearly flat surface, one could compute the depth of soil lost if the loss is evenly distributed across the entire construction site. Assume that the density of soil is 2025 lb/yd^3 (Power, 1963). Given that the depth of soil lost equal the volume of soil lost divided by the site acreage, it is computed that 630 tons is approximately equivalent to losing 0.15 inches of soil over the entire site.

---

*All construction is on the eastern side of the dome.

A loss of 0.15 inches of soil over the site is probably not exactly realistic, because most of the lost soil would come from a relatively small area of higher elevation on the dome. Lower elevations may actually experience an increase in soil depth.

According to the facility design and the topography of the land, all of the construction at Vinton would take place on the eastern slope of the dome adjacent to Ged Lake. It is therefore logical to expect that all of the 630 tons of soils would be transported into Ged Lake as shown in Figure 4.5-02.

5. Calculations for the Big Hill Site

The factors associated with the universal soil loss equation for construction at the Big Hill Salt Dome site are:

Factors	Justification	
R = 350	(USDA, 1975a)	
K = 0.24	(USDA, 1975b) and silt loam classification (USDA, 1965)	
LS = 0.28 - east	east - 0.4% - 3750 feet	(USDA, 1975a)
0.28 - south	south - 0.8% - 1875 feet	
0.33 - north	north - 1.5% - 1000 feet	
C = 1	no cropping management factor	
P = 1	no erosion control factor	

To the east and south,

$$A = 350 \times .24 \times .28 \times 1 \times 1$$
$$= 23.5 \text{ tons/acre/year}$$

And to the north,

$$A = 350 \times 0.24 \times 0.33 \times 1 \times 1$$
$$= 27.7 \text{ tons/acre/year}$$

The time of construction is 5 months or 5/12 year. The soil loss per acre to the east and south is

$$\begin{aligned} D &= A \times T \\ &= 23.5 \times 5/12 \\ &= 9.8 \text{ tons/acre} \end{aligned}$$

The soil loss per acre to the north is

$$\begin{aligned} D &= 27.7 \times 5/12 \\ &= 11.5 \text{ tons/acre} \end{aligned}$$

As noted in Section 2.7, the area that would be disturbed due to construction at Big Hill would be 140 acres. Of this 140 acres, 107.5 are located on the eastern and southern portions of the dome and the other 32.5 acres are on the northern portion of the dome. Therefore, to approximate the total amount of soil erosion, E, one must multiply the soil loss per unit area per construction period times the number of acres disturbed.

$$\begin{aligned} E &= D \times \text{number of acres disturbed} \\ &= 9.8 \text{ ton/acre} \times 107.5 \text{ acres} + 11.5 \text{ tons/acre} \times \\ &\quad 32.5 \text{ acre} \\ &= 1053.5 \text{ tons} + 373.8 \text{ tons} \\ &= 1427.3 \text{ tons} \end{aligned}$$

To better illustrate the loss of 1427.5 tons of soil from 140 acres of nearly flat surface, one could compute the depth of soil lost if the loss is evenly distributed across the entire construction site. Assume that the density of soil is 2025 lb/yd^3 (Power, 1963). Given that the depth of soil lost equals the volume of soil lost divided by the site acreage, it is computed that 1427.3 tons is approximately equivalent to losing 0.75 inches of soil over the whole site.

A loss of 0.75 inches of soil over the site is probably not exactly realistic, because most of the lost soil would come from a relatively small area of higher evevation on the dome. Lower elevations may actually experience an increase in soil depth.

According to the facility design and the topography of the land, the soil loss due to construction of the southern and eastern portions of the dome (1043.5 tons) would settle in the marsh south and east of the dome as shown in Figure 4.6-04. The soil loss on the northern portion of the dome (373.8 tons) would be transported into the gullies and sloughs to the north as shown in the same figure.

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APPENDIX D.17

INCREASES IN SUSPENDED SOLIDS

1. Development of Governing Equations

Let

Q = mass rate of sediment transport into water body (lbm/day)
A_L = surface area of water body (ft^2)
V_L = volume of water (ft^3)
v_p = settling velocity (ft/day)
ρ_p = mass density of suspended particles (lbm/ft^3)
t = time (days)

The governing equations for conservation of sediment with mass transport would be

$$\frac{d\rho_p}{dt} = \frac{Q}{V_L} - \frac{\rho_p A_L v_p}{V_L} \tag{1}$$

or

$$\frac{d\rho_p}{dt} = \frac{Q}{V_L} - \frac{\rho_p v_p}{D_L} \tag{2}$$

This equation can be integrated to yield the solution,

$$1 - \frac{\rho_p v_p A_L}{Q} = e^{-\frac{v_p t}{D}} \tag{3}$$

$$\rho_p = \frac{Q}{v_p A_L} \left[1 - \exp\left(-v_p t/D\right)\right] \tag{4}$$

The governing equation for the conservation of sediment without mass transport would be

$$\frac{d\rho_p}{dt} = \frac{\rho_p v_p}{D_L} \qquad (5)$$

This equation can be integrated to yield the solution

$$\ln\left[\rho_p/(\rho_p)_o\right] = -\frac{v_p}{D}(t-t_o) \qquad (6)$$

or

$$\rho_p = (\rho_p)_o \, e^{-\frac{v_p(t-t_o)}{D_L}} \qquad (7)$$

where

$(\rho_p)_o$ = initial mass density of suspended particles (lbm/ft^3)

2. Calculations for Suspended Solids for Black Lake

$$Q = \frac{2758 x 2000}{5 \text{ x } 30} = 36806 \text{ lbm/day}$$

$V_L = 382 \text{ x } 10^6 \text{ ft}^3$

$A_L = 95.5 \text{ x } 10^6 \text{ ft}^2$

v_p = .018 mm/sec = 5.1 ft/day

D_L = 4 ft

As previously developed, the mass density of suspended particles with mass transport can be calculated according to the relation

$$\rho_p = \frac{Q}{v_p A_L}\left[1-\exp(-v_p t/D_L)\right] \qquad (4)$$

$$= 7.56 \times 10^{-5}\left[(1-\exp(-1.275t)\right]$$

Calculations of ρ_p for various values of t (up to 150 days) yields the following results:

t(days)	ρ_p(lbm/ft^3)	C(ppm)
0	0	o
0.1	$0.91 \cdot 10^{-5}$	0.146
0.5	$3.56 \cdot 10^{-5}$	0.569
1.0	$5.44 \cdot 10^{-5}$	0.870
1.5	$6.44 \cdot 10^{-5}$	1.030
2.0	$6.96 \cdot 10^{-5}$	1.113
3.0	$7.39 \cdot 10^{-5}$	1.182
4.0	$7.51 \cdot 10^{-5}$	1.201
6.0	$7.56 \cdot 10^{-5}$	1.209
10.0	$7.56 \cdot 10^{-5}$	1.209

After 150 days (t_o = 150) the construction period ends and mass transport into the lake is assumed to cease. The mass density of suspended particles susbsequent to this time can be calculated according to the relation

$$\rho_p = (\rho_p)_o \, e^{\frac{-v_p(t-t_o)}{D_L}} \qquad (7)$$

The value of ρ_p calculated by Eq (4) after 150 days represents the value of $(\rho_p)_o$. Thus

$$\rho_p = 7.56 \times 10^{-5} \exp\left[(-1.275(t-t_o)\right] \qquad (8)$$

Calculation of ρ_p for various values of t(greater than 150 days) uields the following results

$t-t_o$(days)	ρ_p(lbm/ft^3)	C(ppm)
0	$7.56 \cdot 10^{-5}$	1.209
.01	$7.46 \cdot 10^{-5}$	1.193
.1	$6.65 \cdot 10^{-5}$	.1063
1.0	$2.11 \cdot 10^{-5}$	1.063
5.0	$0.01 \cdot 10^{-5}$	0.002

3. Calculations for Suspended Solids for Black Lake Bayou

$$Q = \frac{462x2000}{5x30} = 6152 \text{ lbm/day}$$

$V_L = 13.6 \times 10^6$ ft^3

$A_L = 3.4 \times 10^6$ ft^3

$v_p = 0.18$ mm/sec = 5.1 ft/day

$D_L = 4$ ft

As previously developed, the mass density of suspended particles with mass transport can be calculated according to the relation:

$$\rho_p = \frac{Q}{v_p A_L} \left(1-e^{-v_p t/D}\right) \qquad (4)$$

$$= 3.55 \times 10^{-4} \left[1-\exp(-1.275t)\right]$$

Calculation of ρ_p for various values of t (up to 150 days) yields the following results:

t(days)	ρ_p(lbm/ft^3)	C(ppm)
0	0	0
0.01	$0.05 \cdot 10^{-4}$	0.080
0.1	$0.43 \cdot 10^{-4}$	0.688
0.5	$1.67 \cdot 10^{-4}$	2.670
1.0	$2.56 \cdot 10^{-4}$	4.094
2.0	$3.27 \cdot 10^{-4}$	5.229
3.0	$3.47 \cdot 10^{-4}$	5.549
4.0	$3.52 \cdot 10^{-4}$	5.629
5.0	$3.54 \cdot 10^{-4}$	5.661
6.0	$3.55 \cdot 10^{-4}$	5.677
10.0	$3.55 \cdot 10^{-4}$	5.677
20.0	$3.55 \cdot 10^{-4}$	5.677

After 150 days (t_o=150) the construction period ends and mass transport into the bayou is assumed to cease. The mass density of suspended particles subsequent to this time can be calculated according to the relation:

$$\rho_p = (\rho_p)_o \, e^{-\frac{v_p(t-t_o)}{D_L}} \qquad (7)$$

The value of ρ_p calculated by Eq (4) after 150 days represents the value of $(\rho_p)_o$. Thus

$$(\rho_p)_o = 3.55 \times 10^{-4} \text{ lbm/ft}^3$$

Then

$$\rho_p = 3.55 \times 10^{-4} \; \exp\left[-1.275(t-t_o)\right] \qquad (8)$$

Calculation of ρ_p for various values of t (greater than 150 days) yields the following results:

$t-t_o$(days)	ρ_p(lbm/ft^3)	C(ppm)
0	$3.55 \cdot 10^{-4}$	5.677
.1	$3.17 \cdot 10^{-4}$	5.069
1.0	$0.99 \cdot 10^{-4}$	1.583
5.0	$0.01 \cdot 10^{-4}$	0.016

4. Calculations for Suspended Solids for Black Bayou

$$Q = \frac{99x200}{5x30} = 1322 \text{ lbm/day}$$

$$V_L = 12.7 \times 10^6 \text{ ft}^3$$

$$v_p = 0.18 \text{ mm/sec} = 5.10 \text{ ft/day}$$

$$A_L = 4.2 \times 10^6 \text{ ft}^2$$

$$D_L = 3 \text{ ft}$$

As previously developed the mass density of suspended particles with mass transport can be calculated according to the relation:

$$\rho_p = \frac{Q}{v_p A_L} \quad 1 - e^{\left(-v_p t/D_L\right)}$$

$$6.17 \times 10^{-5} \left[1-\exp(-1.7t)\right]$$

Calculation of ρ_p for various values of t (up to 150 days) yields the following results:

t(days)	ρ_p(lbm/ft^3)	C(ppm)
0	0	0
.01	$0.14 \cdot 10^{-5}$	0.022
.1	$0.97 \cdot 10^{-5}$	0.155
0.5	$3.53 \cdot 10^{-5}$	0.564
1.0	$5.04 \cdot 10^{-5}$	0.806
2.0	$5.96 \cdot 10^{-5}$	0.953

t(days)	ρ_p(lbm/ft^3)	C(ppm)
3.0	$6.13 \cdot 10^{-5}$	0.980
4.0	$6.16 \cdot 10^{-5}$	0.985
5.0	$6.17 \cdot 10^{-5}$	0.987
10.0	$6.17 \cdot 10^{-5}$	0.987

After 150 days (t_o=150) the construction period ends and mass transport into the bayou is assumed to cease. The mass density of suspended particles subsequent to this time can be calculated according to the relation:

$$\rho_p = (\rho_p)_o \, e^{\frac{-v_p(t-t_o)}{D_L}}$$

The value of ρ_p calculated by Eq (14) after 150 days represents the value of $(\rho_p)_o$. Thus

$$(\rho_p)_o = 6.17 \times 10^{-5} \text{ lbm/ft}^3$$

Then

$$(\rho_p)_o = 6.17 \times 10^{-5} \left[\exp\ (-117t-t_o)\right]$$

Calculation of ρ_p for various values of t (up to 150 days) yields the following results:

$t-t_o$(days)	ρ_p(lbm/ft^3)	C(ppm)
0	$6.17 \cdot 10^{-5}$	0.987
.1	$5.21 \cdot 10^{-5}$	0.833
1.0	$1.13 \cdot 10^{-5}$	0.181
2.0	$2.06 \cdot 10^{-6}$	0.033
5.0	$1.26 \cdot 10^{-8}$	----

5. Calculations for Suspended Solids for Ged Lake

$$Q = \frac{630 x 2000}{5 x 30} = 8400 \text{ lbm/day}$$

$$V_L = 52.2 \text{ x } 10^6 \text{ft}^3$$

$$v_p = 0.18 \text{ mm/sec} = 5.10 \text{ ft/day}$$

$$A_L = 3.48 \text{ x } 10^6 \text{ft}^2$$

$$D_L = 15 \text{ feet}$$

As previously developed the mass density of suspended particles with mass transport can be calculated according to the relation:

$$\rho_p = \frac{Q}{v_p A_L} \left(1-e^{-v_p t/D_L}\right)$$

$$= 4.73 \text{ x } 10^{-4} \left[1- \exp(-.345)\right]$$

Calculation of ρ_p for various values of t (up to 150 days) yields the following results:

t(days)	ρ_p(lbm/ft^3)	C(ppm)
0	0	0
.5	$.739\cdot10^{-4}$	1.18
1.0	$1.36\cdot10^{-4}$	2.18
1.5	$1.89\cdot10^{-4}$	3.03
2.0	$2.33\cdot10^{-4}$	3.73
3.0	$3.02\cdot10^{-4}$	4.84
4.0	$3.52\cdot10^{-4}$	5.64
6.0	$4.11\cdot10^{-4}$	6.59
8.0	$4.42\cdot10^{-4}$	7.08
10.0	$4.57\cdot10^{-4}$	7.32
20.0	$4.72\cdot10^{-4}$	7.56

After 150 days (t_o=150) the construction period ends and mass transport into the lake is assumed to cease. The mass density of suspended particles subsequent to this time can be calculated according to the relation:

$$(\rho_p)_o = 4.73 \times 10^{-4} \text{ lbm/ft}^3$$

Then

$$\rho_p = 4.73 \times 10^{-4} \left[\exp\ (-.34t)\right]$$

Calculation of ρ_p for various values of t (up to 150 days) yields the following results:

t-t_0(days)	ρ_p(lbm/ft^3)	C(ppm)
0	$4.73\cdot10^{-4}$	7.56
0.1	$4.71\cdot10^{-4}$	7.53
.1	$4.57\cdot10^{-4}$	7.31
.5	$3.99\cdot10^{-4}$	6.38
1	$3.37\cdot10^{-4}$	5.39
5	$0.86\cdot10^{-4}$	1.38
10	$0.16\cdot10^{-4}$	0.26
20	$0.01\cdot10^{-4}$	0.02

APPENDIX D.18

WITHDRAWAL OF WATER FROM BLACK BAYOU*

1. Water Level in Black Bayou During Leaching Operations in the Absence of Replenishment Water

The area of the entire bayou is (Barrett, 1970)

$$\begin{aligned} A &= 386 \text{ acres} \\ &= 16.8 \times 10^6 \text{ ft}^2 \end{aligned}$$

The withdrawal rate during leaching is

$$Q_o = 5.78 \times 10^6 \text{ ft}^3/\text{day}$$

If the bayou is isolated from other water bodies

$$\begin{aligned} \frac{dh}{dt} &= \frac{-Q_o}{A} \\ &= \frac{-1.03\text{x}10^6 . 5.615}{16.8\text{x}10^6} \\ &= -0.344 \text{ ft/day} \end{aligned} \tag{1}$$

2. Water Level in Black Bayou During Displacement Operations in the Absence of Replenishment Water

The area of the bayou as given earlier is

$$A = 16.8 \times 10^6 \text{ ft}^2$$

The withdrawal rate during displacement is

$$Q_o = 5.90 \times 10^6 \text{ ft}^3/\text{day}$$

---

*The notation used in this appendix is consistent with that used in Appendix D.12.

If the bayou is isolated from other water bodies

$$\frac{dh}{dt} = \frac{-Q_o}{A}$$

$$= \frac{-1.05x10^6x5.615}{16.8x10^6}$$

$$= -0.351 \text{ ft/day} \qquad (2)$$

3. Application of MIT Water Quality Network Model

The equations governing the behavior of water in Black Bayou can only be solved numerically. The MIT Water Quality Network Model which is described in Appendix D.14 has been used to provide such a solution. A network was developed consisting of Black Bayou, Black Bayou Cutoff, and Right Prong. The dimensions of each water body were consistent with those given in Table B.3-12. Boundary conditions were established as follows:

Location	Hydraulic	Water Quality
Junction of Black Bayou with ICW	Sinusoidal variation of surface height with a range of .5 feet and a period of 12 hours.	Constant salinity of 0.4 ppt
Junction of Black Bayou Cutoff with ICW	Sinusoidal variation of surface height with a range of .5 feet and a period of 12 hours.	Constant salinity of 0.4 ppt
Withdrawal point on Black Bayou	Constant withdrawal rate of 66.9 ft^3/sec	Zero dispersive flux
Junction of Black Bayou and Sabine	Sinusoidal variation of surface height with a range of 1.0 feet and a period of 12 hours.	Constant salinity of 6.65 ppt

During an initial 90-day period no withdrawal of water took place and the network of water bodies was allowed to approach equilibrium.

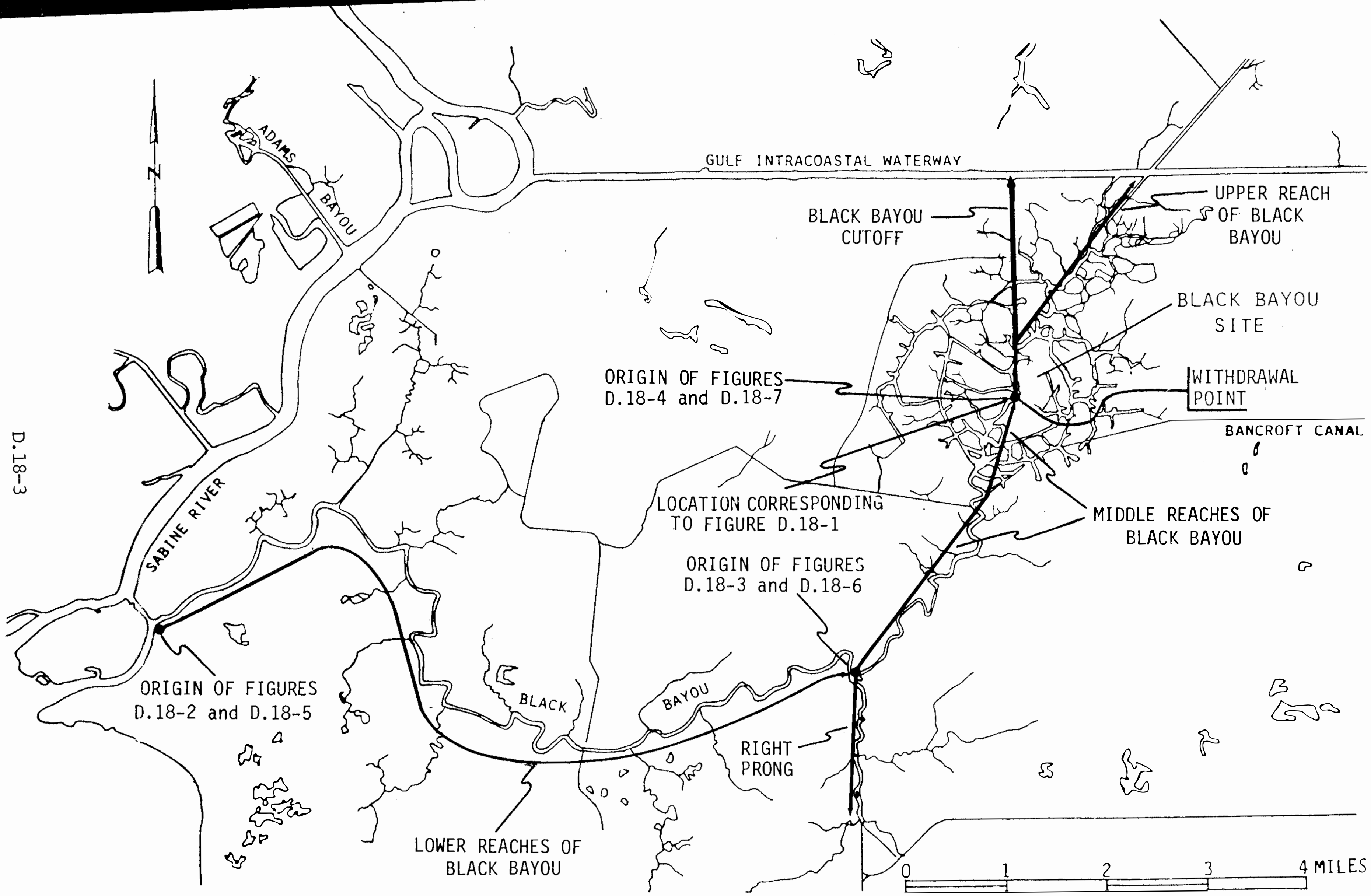

Figure D.18-8. Location of Reference Points and Reaches in the Black Bayou Network Analysis

The resulting variation of water depth and salinity in Black Bayou near the point of withdrawal during the final 30 days of the 90-day start-up period is presented in Figure D.18-1. The distribution of salinity in Black Bayou, Right Prong and Black Bayou Cutoff is shown in Figures D.18-2 through D.18-4. The corresponding distribution of flow velocities is included in Figures D.18-5 through D.18-7.

Following the start-up period water was withdrawn from the bayou for 150 days at a rate of 66.9 ft^3/sec corresponding to a displacement operation. The resulting variation of water depth and salinity in Black Bayou near the point of withdrawal is also shown in Figure D.18-1. The distribution of salinity in Black Bayou, Right Prong and Black Bayou Cutoff at the end of the 150-day withdrawal process is included in Figures D.18-2 through D.18-4. The corresponding distribution of flow velocities is included in Figures D.18-5 through D.18-7.

Examination of Figure D.18-1 reveals that after 4 days of water withdrawal Black Bayou reached hydraulic equilibrium while equilibrium with respect to salinity variation was achieved after 55 days.

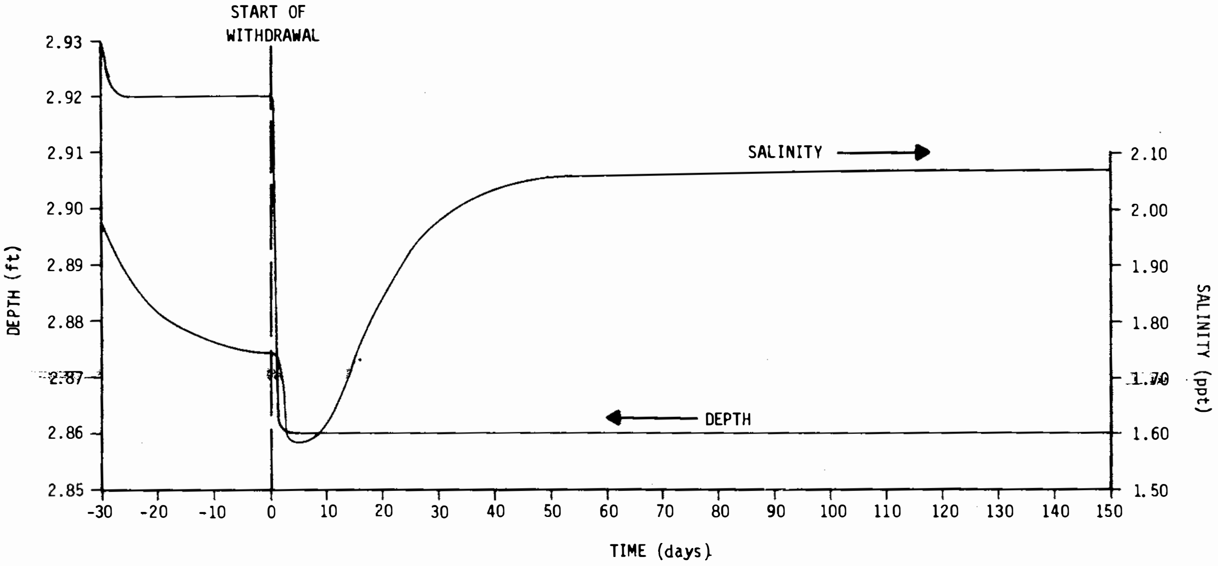

Figure D.18-1. Temporal Variation of Depth and Salinity of Black Bayou

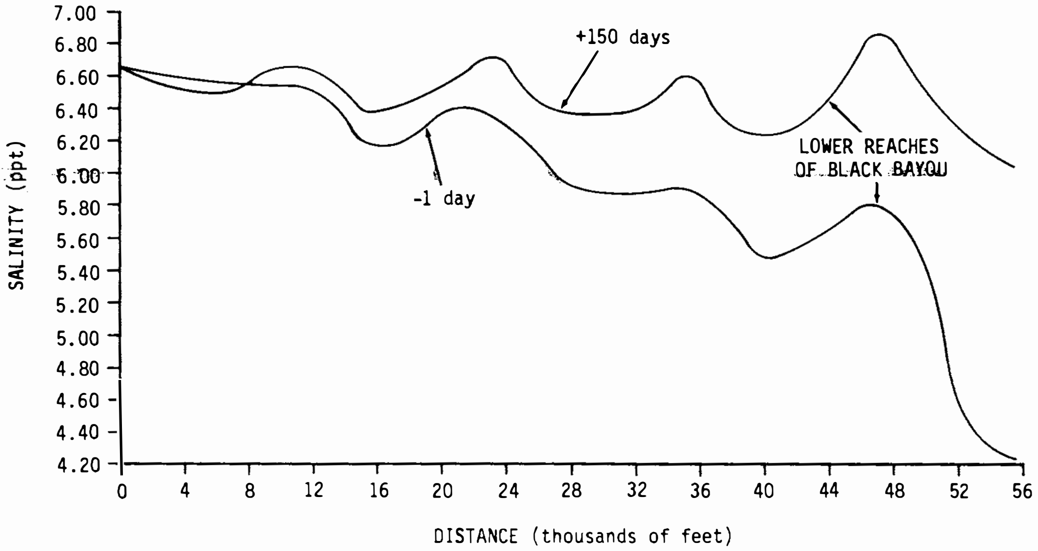

Figure D.18-2. Spatial Distribution of Salinity in the Lower Reaches of Black Bayou

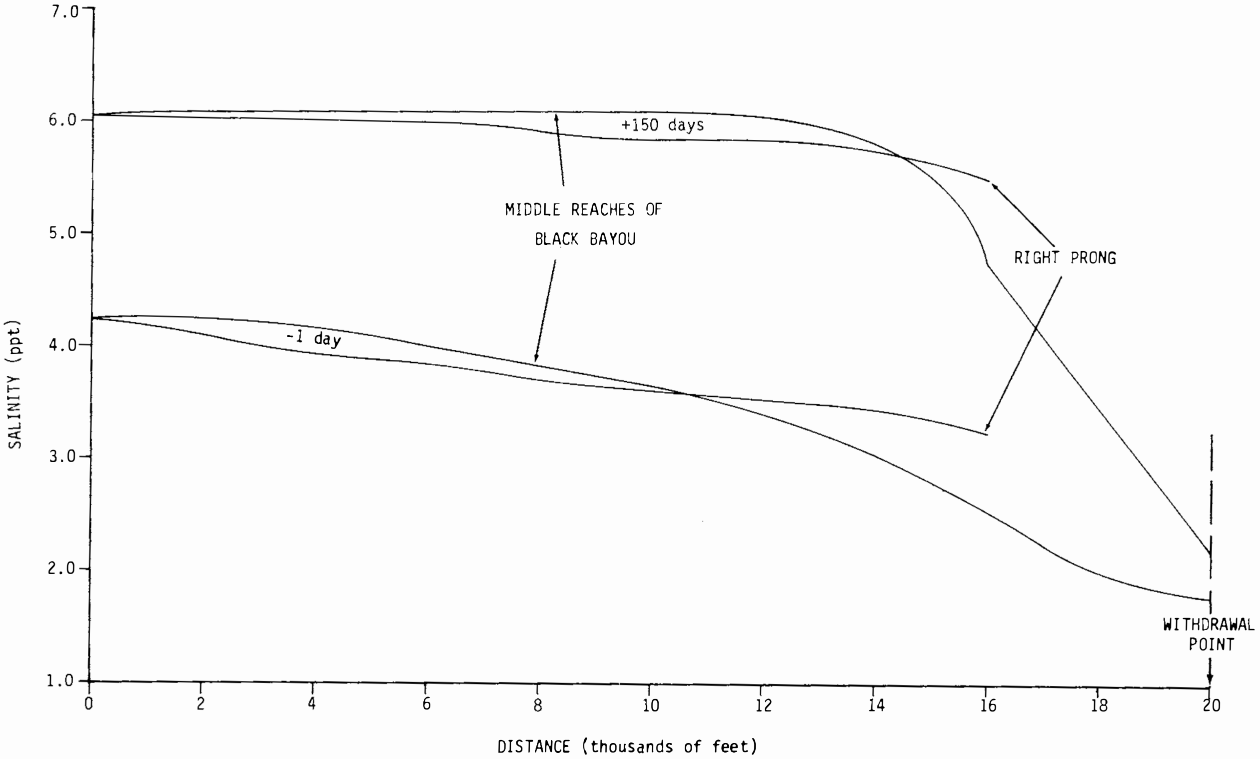

Figure D.18-3. Spatial Distribution of Salinity in the Middle Reaches of Black Bayou and Right Prong

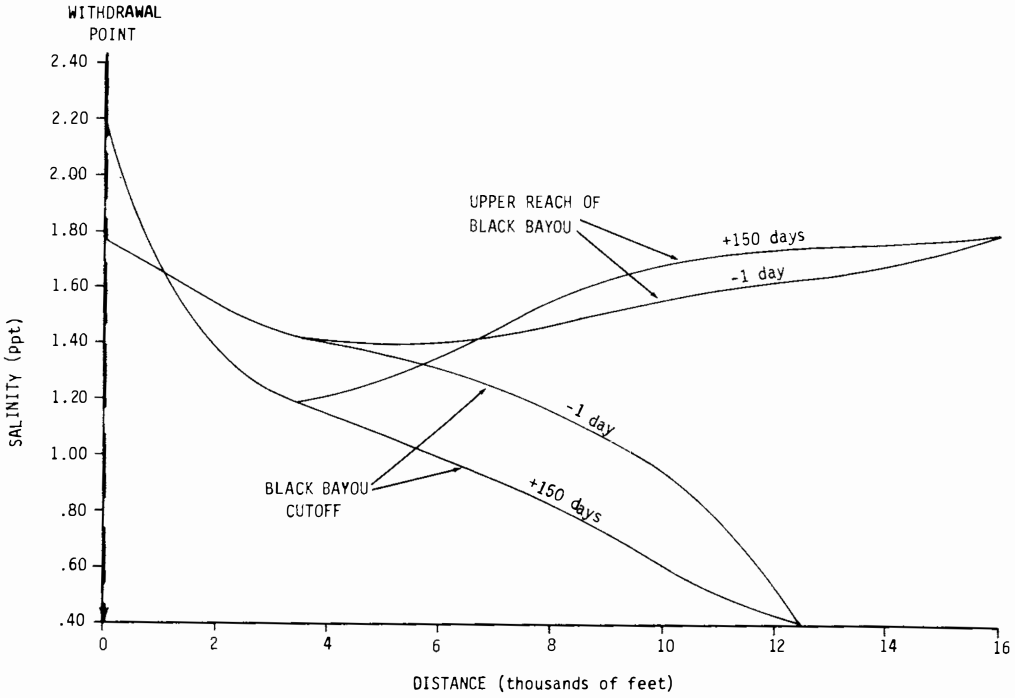

Figure D.18-4. Spatial Distribution of Salinity in the Upper Reaches of Black Bayou and Black Bayou Cutoff

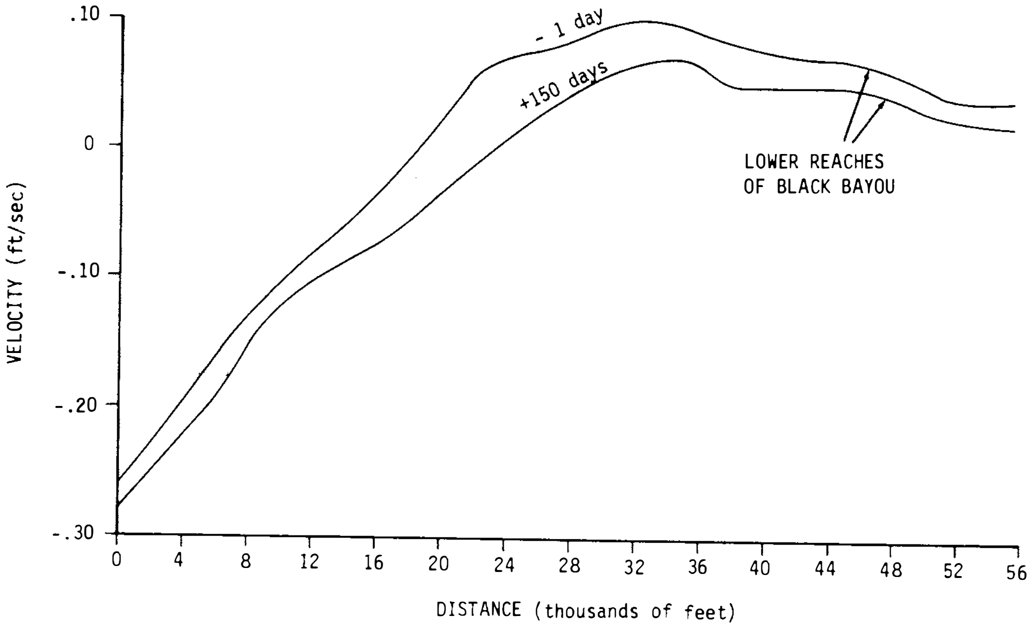

Figure D.18.5. Spatial Distribution of Flow Velocity in the Lower Reaches of Black Bayou

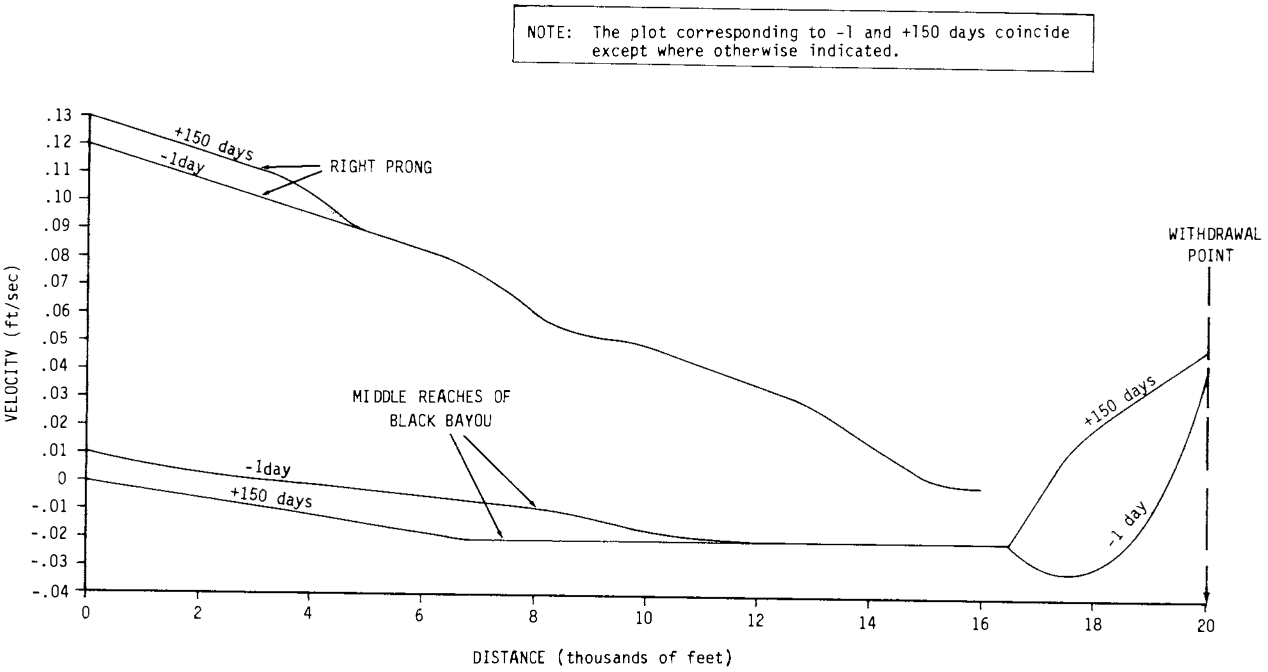

Figure D.18-6. Spatial Distribution of Flow Velocity in the Middle Reaches of Black Bayou and Right Prong

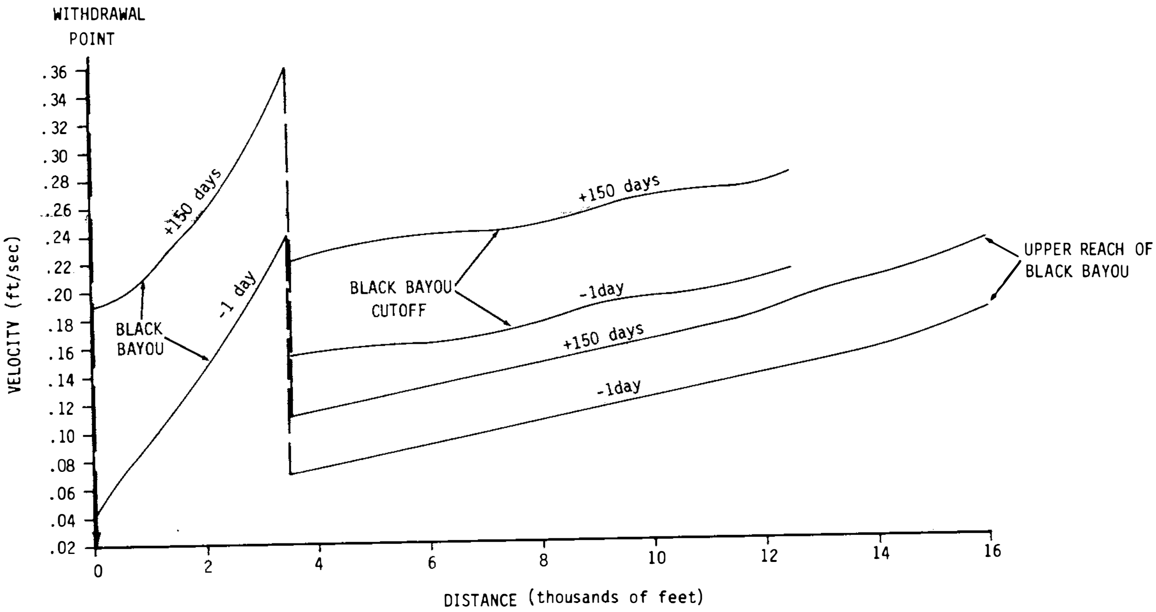

Figure D.18-7. Spatial Distribution of Flow Velocity in the Upper Reaches of Black Bayou and Black Bayou Cutoff

APPENDIX D.19

WITHDRAWAL OF WATER FROM SABINE LAKE

The equations governing the behavior of water in Sabine Lake can only be solved numerically. The MIT Water Quality Network Model which is described in Appendix D.14 has been used to provide such a solution. A network was developed consisting of Sabine Lake, Sabine Pass, and the Sabine-Neches Canal. The dimensions of each water body were consistent with those given in Table B.3-12. Boundary conditions were established as follows:

Location	Hydraulic	Water Quality
Junction of Neches River with Sabine Lake	Constant flow rate of 5184 ft^3/sec	Constant salinity of 7.0 ppt
Junction of Sabine River with Sabine Lake	Constant flow rate of 7969 ft^3/sec	Constant salinity of 7.0 ppt
Withdrawal point on Sabine Lake	Constant withdrawal rate of 66.9 ft^3/sec	Zero dispersive flux
Junction of Sabine Pass with Gulf of Mexico	Sinusoidal variation of surface height with a range of 1.9 feet and a period of 12 hours	Ocean boundary with a salinity of 22.7 ppt

During an initial 30-day period no withdrawal of water took place and the network of water bodies was allowed to approach equilibrium. The resulting variation of water depth and salinity in Sabine Lake near the point of withdrawal during this 30-day start-up period is presented in Figure D.19-1. The distribution of salinity in Sabine Lake, Sabine Pass and the Sabine-Neches Canal is shown in Figures D.19-2 and D.19-3. The corresponding distribution of flow velocities is included in Figures D.19-4 and D.19-5.

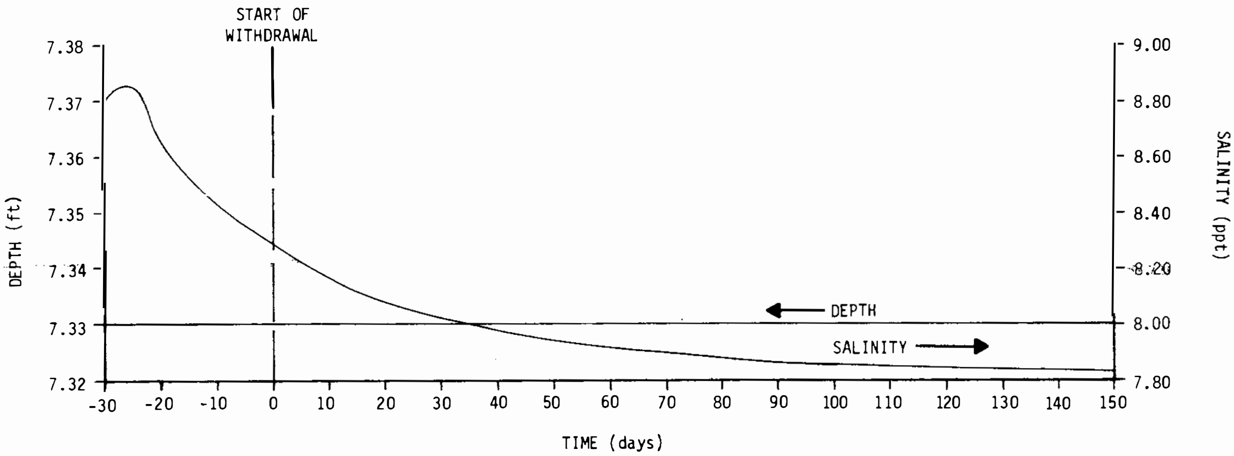

Figure D.19-1. Temporal Variation of Depth and Salinity of Sabine Lake

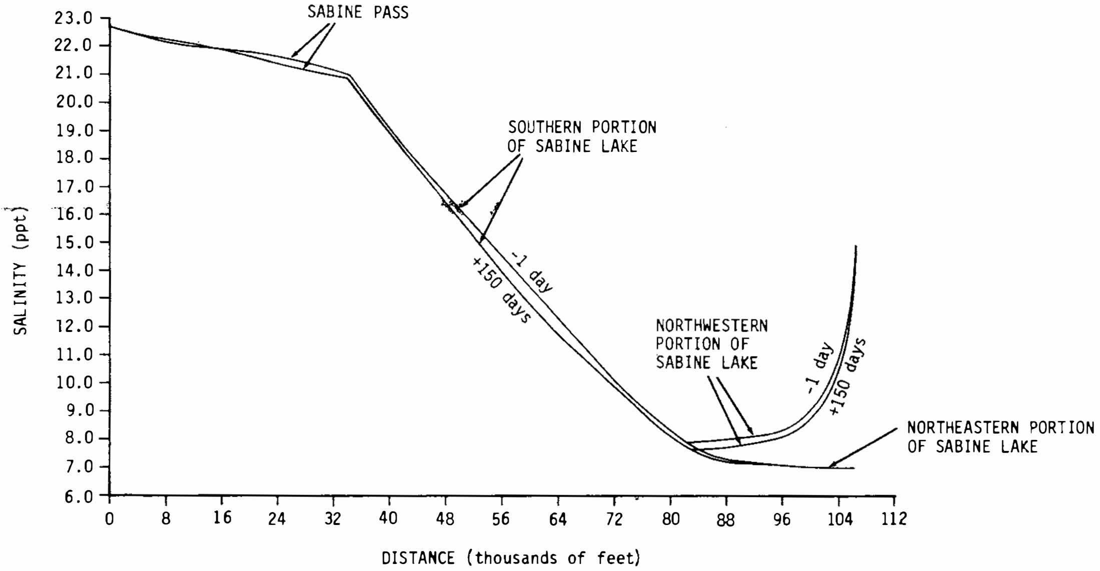

Figure D.19-2. Spatial Variation of Salinity in Sabine Lake and Pass

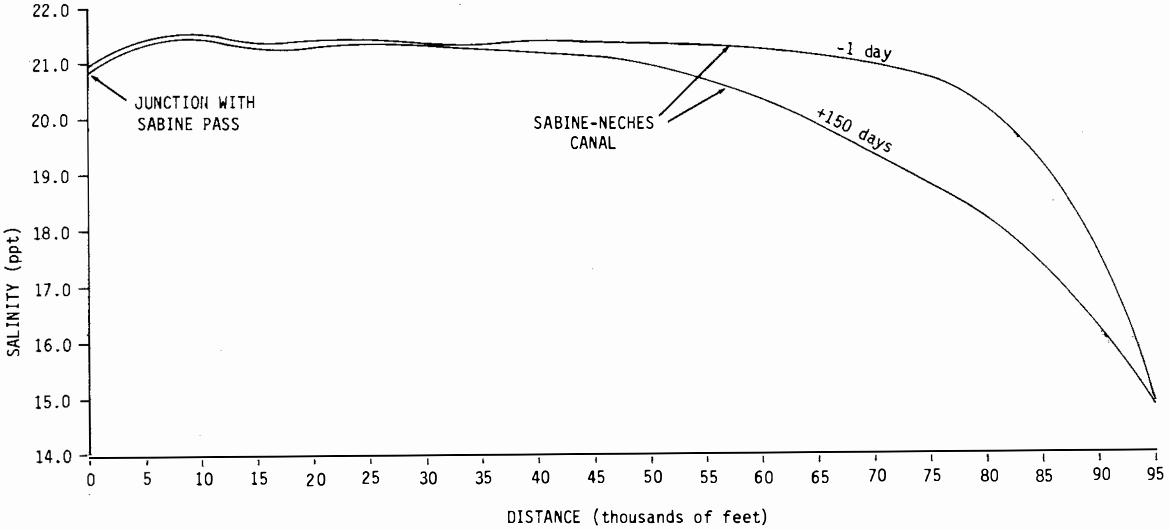

Figure D.19-3. Spatial Variation of Salinity in the Sabine-Neches Canal

NOTE: The plot corresponding to -1 and +150 days coincide except where otherwise indicated.

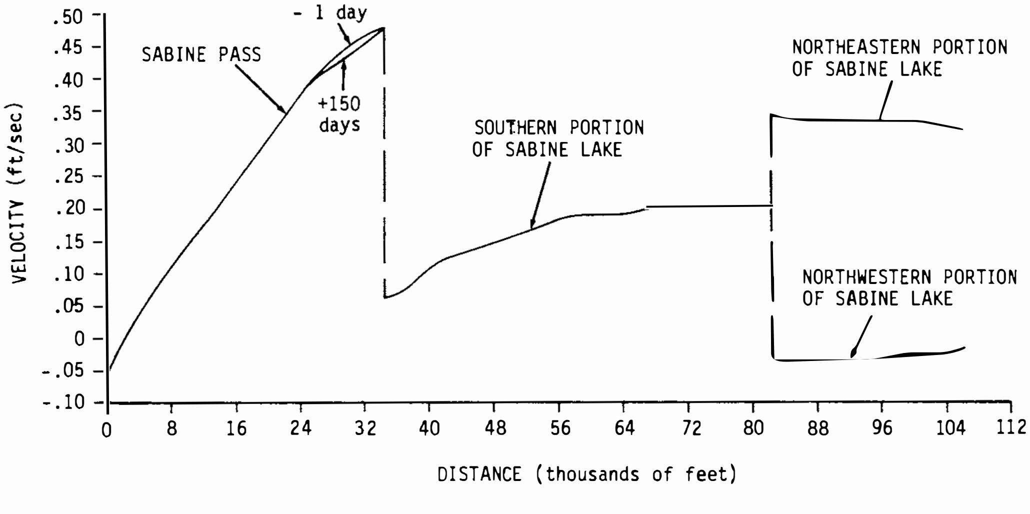

Figure D.19-4. Spatial Variation of Flow Velocity in Sabine Lake and Pass

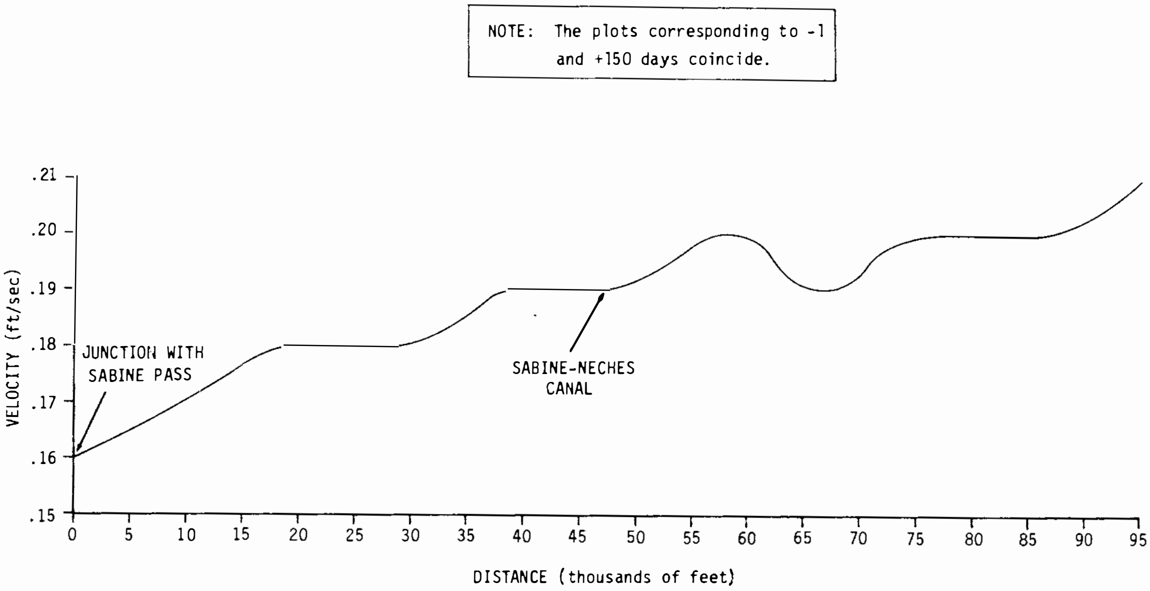

Figure D.19-5. Spatial Variation of Flow Velocity in Sabine-Neches Canal

Following the start-up period water was withdrawn from the lake for 150 days at a rate of 66.9 ft^3/sec, corresponding to a displacement operation. The resulting variation of water depth and salinity in Sabine Lake near the point of withdrawal is also shown in Figure D.19-1. The spatial distribution of salinity in Sabine Lake, Sabine Pass and the Sabine-Neches Canal at the end of the 150-day withdrawal process is included in Figures D.19-2 and D.19-3. The corresponding distribution of flow velocities is included in Figures D.19-4 and D.19-5.

Examination of Figure D.19-1 reveals that the withdrawal of water from Sabine Lake had no appreciable effect on the surface height of the lake in the vicinity of the withdrawal point. Thus hydraulic equilibrium was maintained throughout the withdrawal process. The salinity of the lake decreased during the withdrawal process, reaching equilibrium approximately 130 days after withdrawal commenced. Part of the decrease in salinity was due to the fact that the lake apparently had not reached true equilibrium with respect to salinity during the 30-day start-up period.

The location of the point in Sabine Lake corresponding to Figure D.19-1 is presented in Figure D.19-6. In the same figure the locations of the spatial origins and the paths of the spatial coordinates are indicated in Figures D.19-2 through D.19-5.

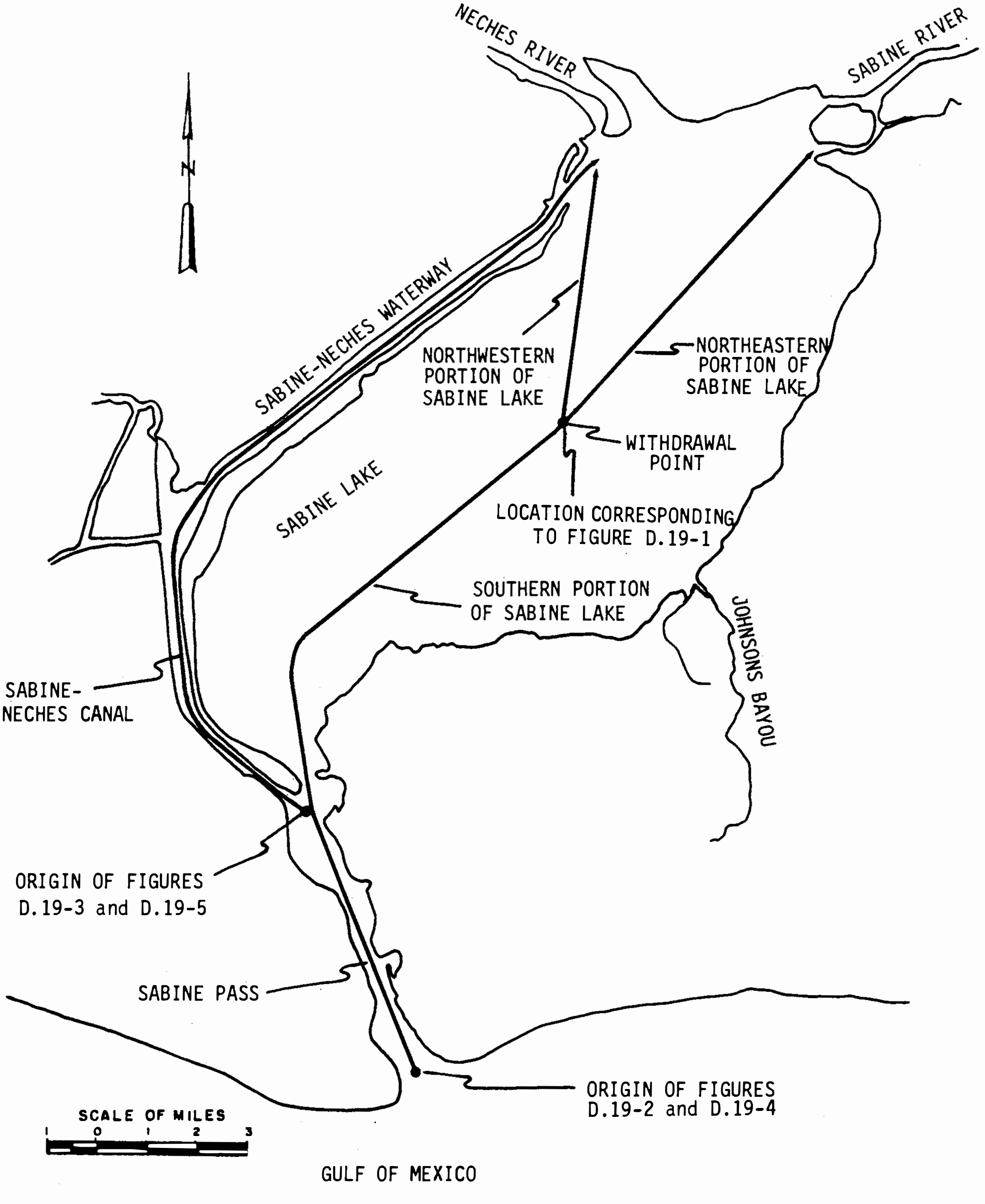

Figure D.19-6. Location of Reference Points and Reaches in the Sabine River Network Analysis

APPENDIX D.20

WITHDRAWAL OF WATER FROM VINTON CANAL*

1. Water Level in Vinton Canal During Leaching Operations

The area of the canal is

$$A = (5.23 \times 10^4 \text{ ft})(60 \text{ ft})$$
$$= 3.14 \times 10^6 \text{ ft}^2$$

The withdrawal rate during leaching is

$$Q_o = 1.93 \times 10^6 \text{ ft}^3/\text{day}$$

If the canal is isolated from other water bodies

$$\frac{dh}{dt} = \frac{Q_o}{A} = \frac{1.93 \times 10^6}{3.14 \times 10^6} = 0.615 \text{ ft/day} \qquad (1)$$

2. Induced Currents in Vinton Canal and the ICW During Leaching Operations

The width of Vinton Canal is

$$W = 60 \text{ ft}$$

And the depth is

$$D = 4 \text{ ft}$$

---

[*] The notation used in this appendix is consistent with that used in Appendix D.12

Thus the cross-sectional area is

$$A_c = 4 \times 60$$
$$= 240 \text{ ft}^2$$

The withdrawal rate is

$$Q_o = 0.93 \times 10^6 \text{ ft}^3/\text{day}$$
$$= 22.3 \text{ ft}^3/\text{sec}$$

If all of the replenishment water flows through Vinton Canal, under steady-state conditions, the induced velocity would be:

$$U_i = Q_o/A_c$$
$$= 22.3/240$$
$$= 0.0929 \text{ ft/sec} \qquad (2)$$

The width of the ICW is

$$W = 300 \text{ ft}$$

The depth of the ICW is

$$D = 12 \text{ ft}$$

Thus the cross-sectional area is

$$A_c = 3600 \text{ ft}^2$$

If all the replenishment water flows through the ICW, under steady-state conditions, the induced velocity would be

$$U_i = Q_o/A_c$$
$$= 22.3/3600$$
$$= 0.0062 \text{ ft/sec}$$

3. Surface Height Differential in Vinton Canal During Leaching Operations

The relation between the slope, S, and the induced flow rate, U_i, is (Streeter, 1961)

$$U_i = \frac{1.49}{n} R^{2/3} \quad S^{1/2} \tag{3}$$

where $n = 0.025 \text{ sec/ft}^{1/3}$

For the Vinton Canal the hydraulic radius is

$$R = \frac{4 \times 60}{2 \times 4 + 60}$$

$$= 3.53 \text{ ft} \tag{4}$$

If the induced current is assumed to occur in the portion of Vinton Canal between the withdrawal point and the ICW the distance is

$$L = 6.25 \text{ miles}$$

$$= 31,152 \text{ ft}$$

The slope is defined as

$$S \equiv \Delta h/L$$

where Δh = height differential (5)

The induced velocity under equilibrium conditons is given by Eq (2). A combination of Eqs (2) through (5) yields:

$$\Delta h = L \left(\frac{nU_i}{1.49 \; R^{2/3}} \right)^2$$

$$= 31,152 \left(\frac{0.025 \times 0.0929}{1.49 \times 3.53^{2/3}} \right)^2$$

$$= 0.0141 \text{ ft} \tag{6}$$

This would be the difference in the water level in the ICW in the vicinity of the Vinton Canal and the withdrawal point on Vinton Canal.

4. Water Level in Vinton Canal During the Displacement Operations

The area of the canal as given earlier is

$$A = 3.14 \times 10^6 \text{ ft}^2$$

The withdrawal rate during displacement is

$$Q_o = 1.95 \times 10^6 \text{ ft}^3/\text{day}$$

If the canal is isolated from other water bodies

$$\frac{dh}{dt} = \frac{Q_o}{A}$$

$$= \frac{1.95\text{x}10^6 \text{ ft}^3/\text{day}}{3.14\text{x}10^6 \text{ ft}^2}$$

$$= 0.626 \text{ ft/day} \qquad (7)$$

5. Induced Currents in Vinton Canal and the ICW During Displacement Operations

The cross-sectional area of Vinton Canal as calculated earlier is

$$A_c = 240 \text{ ft}^2$$

The withdrawal rate is

$$Q_o = 1.95 \times 10^6 \text{ ft}^3/\text{day}$$
$$= 22.7 \text{ ft}^3/\text{sec}$$

the surface height differential can be calculated according to the relation

$$\Delta h = L \left(\frac{nU_i}{1.49\ R^{2/3}} \right)^2$$

$$= 31{,}152 \left(\frac{0.025 \text{x} 0.0946}{1.49 \text{x} 3.53^{2/3}} \right)^2$$

$$= 0.0146 \text{ ft} \qquad (9)$$

If the replenishment water flows through Vinton Canal, under steady-state conditons, the induced velocity would be

$$\begin{aligned} U_i &= Q_o/A_c \\ &= 22.7/240 \\ &= 0.0946 \text{ ft/sec} \end{aligned} \tag{8}$$

The cross-sectional area of the ICW calculated earlier is

$$A_c = 3600 \text{ ft}^2$$

The withdrawal rate above is

$$Q_o = 22.7 \text{ ft}^3/\text{sec}$$

If all the replenishment water flows through the ICW, under steady-state conditons the induced velocity would be:

$$\begin{aligned} U_i &= Q_o/A_c \\ &= 22.7/3600 \\ &= 0.0063 \text{ ft/sec} \end{aligned}$$

6. Surface Height Differential in Vinton Canal During Displacement Operations

Based on Equations (3) through (6) given earlier, combined with the values,

$U_i = 0.0946$ ft/sec

$A_c = 240$ ft^2

$R = 3.53$ ft

$L = 31,152$ ft

$n = 0.025$ sec/ft$^{1/3}$

APPENDIX D.21

PRESSURE BUILD-UP IN DISPOSAL AQUIFERS AT THE VINTON SITE

The analysis of subsurface brine disposal operations generally focuses on the prediction of subsurface pressures in the aquifer during the injection operation. These pressures are of prime interest because if the subsurface pressure in any part of the aquifer exceeds the fracture pressure, the brine may escape the disposal aquifer and perhaps contaminate nearby fresh water aquifers. The subsurface pressure will be a function of the overall rise in aquifer pressure because of the additional volume of the injected material (material balance type consideration) and the rise in pressure in the immediate vicinity of the well bore while actually injecting (frictional loss in the rock pore channels).

The variables influencing the subsurface pressure are the amount of fluid already existing in the aquifer (defined by areal extent, thickness, porosity, compressibility) and the ease with which the brine will flow through the rock (defined by permeability, thickness, viscosity, etc). The equations that predict the effects of these variables on subsurface pressure are well defined in the literature and will be discussed only briefly herein. The analysis presented in this report is based primarily on the following equation:

$$p_w = p_i + \frac{q\mu}{7.08kh} \ln\left[\frac{14.22kt}{\mu c \phi r_w^2}\right]$$

where:

p_w = well bore pressure, psig

p_i = initial aquifer pressure, psig

q = injection rate, barrels per day

μ = brine viscosity, cp

k = permeability of rock, darcy
h = sand thickness, feet
t = time, days
c = aquifer-brine system compressibility, vol/vol/psi
ϕ = porosity, fraction
r_w = well bore radius, feet

This equation is valid only for a single injection well injecting at a constant rate in an aquifer of infinite extent. By the proper use of "image wells" and the mathematical theory of superposition, the equation can be utilized for multi-well injection at varying rates in aquifers of varying sizes.

In the proposed Vinton Dome project, the following brine disposal plan has been set forth:

Cycle 1: Brine will be disposed at a rate of 395,000 bbl/day (11,500 gpm) for 1144 days. This occurs during leaching operations.

Cycles 2-5: Brine will be disposed at a rate of 59,500 bbl/day (1735 gpm) for 840 days. This represents re-filling the cavity after having had to use the stored oil. The aquifer will have been "dormant" prior to the start of each of these cycles.

Geologic information on potential disposal aquifers indicated that there exists eleven sands of 50 feet in thickness, seven sands of 100 feet, and three sands of 150 feet. The areal extent of the sands in unknown but thought to be at least 3 square miles. Since it is proposed that then injection wells be used, the seven 100 foot sands and the three 150-foot sands were the ones considered in this analysis. The calculations were actually performed only on 100-foot sand to establish the limiting conditions.

Since areal extent of the aquifers is unknown and is so directly involved in prediction of disposal operations, the analysis presented herein was intended to indicate just what size aquifer would be necessary to provide the required capacity without exceeding fracture pressure. Data used in the analysis are shown in Table C.5-1.

As indicated in the table, test cases involving areas from 3 to 40 square miles were analyzed. The results are depicted in Figure C.5-4. As indicated in that figure an aquifer must be at least 32 square miles in extent to hold the volume of injected brine.

Of those test cases analyzed, the case involving an area of 36 square miles was considered to represent the smallest aquifer with an adequate margin of safety. The pressure history in such an aquifer, during the disposal process associated with the leaching operation, is presented in Figure C.5-5. It is important to note that in the analysis performed the aquifer was assumed to be totally confined, with no leakage occurring during disposal operations or during dormant periods.

APPENDIX D.22

POTENTIAL BRINE INJECTION CONCERNS RESULTING FROM CHEMICAL AND BIOLOGICAL CHARACTERISTICS

As noted in Section C.5.1.2.2, associated with brine injection, there are three potential problem areas resulting from the chemical and biological characteristics of the waters involved. These problem areas are:

(1) Incompatability of waters
(2) Water-sensitive formations
(3) Water quality considerations

With respect to incompatibility of waters, "Waters that are compatible can be mixed without producing any undesirable chemical reactions between components dissolved in the individual waters. Undesirable reactions are those that produce insoluble products such as calcium and carbonate ions, forming calcium carbonate or barium, and sulfate ions, forming barium sulfate. Insoluble products produced from these reactions can decrease flow in lines, injection wells, or reduce permeability." (Ostroff, 1965)

Potential problems with water compatibility exist at several different points in the brine disposal problem (Hower et. al. 1972; Barnes, 1972). Of primary concern in the current case is the compatibility of the brine to be injected with the waters of the aquifer where injection is to occur. When brine is injected into a reservoir containing waters incompatible with the brine, deposits will form only where the brine and reservoir water make contact and mix. Deposits will form only in a small volume of water if there is a small degree of mixing, but deposits will form in a large volume of water if a large degree of mixing occurs.

The problem of water-sensitive formations has been considered by a number of investigators (Ostroff, 1965; Hower, et. al. 1972; and Donaldson, 1972). Certain types of rocks are susceptible to permeability damage when infiltrated by fresh or slightly saline water. Damage of this type is related to rock properties and is caused by swelling of indigenous clays and the dispersion of indigenous nonswelling particles during fluid flow.

The swelling (hydration) of clays is a function of the salinity of the water being injected. Clays which are prone to swell are more sensitive to fresh water than saline water with a minimum salinity of 2- to 50 ppt. Because the brine salinity will be considerably above this level, clay swelling appears unlikely.

The third problem concerning water quality in general is clearly related to the two already discussed. As noted by Ostroff, "Water quality includes the amount of suspended solids in the water, number of bacteria present, and the corrosivity of the water. All of these solids could plug the pore spaces in the formation or build up an impermeable filter cake on the face of the reservoir rock that would impede water injection. Bacteria may contribute to corrosion and corrosion products, resulting in plugging of the injection well. Bacterial growths themselves can sometimes result in plugging. Corrosive water not only damages the system but may produce corrosion products which can plug the well. A common example of this is iron sulfide formed from corrosion by hydrogen sulfide."

"The character of the reservoir rock largely influences the quality of water that can be injected. A reservoir rock with small pore sizes and low porosity requires water of very low suspended solids or high-quality water. Conversely, a high-porosity reservoir having large pores and voids would take water containing a considerable amount of suspended solids."

For evaluating water quality for injection purposes a rating system has been devised (Wright, 1965) as shown in Table D.22-1. At the present time, no results from these types of tests are available for water samples from the Vinton site.

Table D.22-1. Water Quality Rating Chart (Wright, 1963)

	Rating					
	1	2	3	5	10	20
Membrane filter test (0.45 μ filter) slope	0-0.09 excellent	0.10-0.29 very good	0.30-0.49 good	0.50-0.99 acceptable	1.00-1.79 fair	1.80+ excessive
Filtered solids mg liter	0. -0.04 negligible	0.5-0.9 very low	1.0-2.4 low	2.5-4.9 moderate	5.0-9.9 large	10.0+ excessive
Tot. sulfide increases lb day/1,000 sq ft	0 none	0.001 very low	0.002-4 low	0.005-9 moderate	0.01-0.019 large	0.02+ excessive
Iron count increases lb day/1,000 sq ft	0 none	0.001-0.011 very low	0.012-0.11 low	0.12-0.59 moderate	0.60-1.1 large	1.2+ excessive
Sulfate-reducing bacteria colonies/ml	0 none	1-5 very low	6-9 low	10-20 moderate	30-90 large	100+ excessive
Total Bacterai count colonies/ml	0 none	1-99 very low	100-999 low	1,000-9,999 moderate	10,000-99,999 large	100,000+ excessive
Corrosion rate (30 days) (insulated coupon) mils/year	0 none	0.01-0.09 very low	0.10-0.99 low	1.00-4.9 moderate	5.0-9.9 high	10.0+ excessive
Pit depth (30 days (insulated coupon) mils	0 none	1 shallow	2-3 minor	4-5 moderate	6-10 deep	10+ excessive
Pit frequency (30days) (insulated coupon) pits/sq in	0 none	1 very low	2 low	3 moderate	4 high	5+ excessive

A major water quality problem involves suspended solids. "Suspended solids carried by water may be sand grains from the water-sand, corrosion products such as iron sulfide or iron oxide, free sulfer, or bacterial growths. If allowed to enter the injection wells, these materials will either plug the wells completely or cause increases in injection pressures. These materials are often present in water in a finely divided state and in amounts small enough so that their presence is not easily detected by looking at the water. Yet, when large volumes of water are injected, even small amounts of suspended solids can form an appreciable filter cake or deposit in an injection well bore." (Ostroff, 1965)

A second water quality problem arises from the corrosive qualities of the water. The brine to be injected should not be corrosive to the metals used in the disposal system. Such corrosion would not only be destructive to the disposal equipment but might also produce corrosion products that would plug the injection well.

A third major water quality problem results from the presence of bacteria (Ostroff, 1965; Ehrlich, 1972). "The number and type of bacteria present in injection water affect the quality of the water. Bacteria can contribute to corrosion or produce plugging. Desulfovibrio or sulfate-reducing bacteria utilize oxygen in sulfate ion to oxidize organic compounds. Corrosive hydrogen sulfide is produced in the process. Increases in sulfide content of water within the water-handing system are caused by sulfate reducers. Desulfovibrio are nearly always present, but, when conditions are not right for their growth, they are not a serious problem."

"The total bacterial count is indicative of the number of all varieties of bacteria in the water. Large growths of bacteria can result in colonies of the microorganisms plugging the injection well or otherwise fouling equipment." (Ostroff, 1965)

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APPENDIX D.23

LEAKAGE FROM IMPROPERLY PLUGGED ABANDONED WELLS

If communication exists between the disposal aquifer and shallower fresh-water-bearing aquifers through an abandoned well, then brine* can be expected to escape. Normally, such communication would not be expected because the State of Louisiana has certain prescribed and proven procedures for abandoning wells.

This discussion centers on the hypothesis that a fracture of some type develops along the length of the abondoned well from the disposal zone to the fresh-water zone. Furthermore it is hypothesized that the fracture is 0.01 inch wide and extends along one-fourth of the perimeter of the abondoned well.

Before the start of brine disposal, there is virtually no potential for water to flow through the fracture because the disposal aquifer and the fresh-water aquifer are essentially in hydrostatic equilibrium. As brine injection begins, the pressure in the disposal aquifer increases and water begins to flow along the fracture. The rate of escape will steadily increase as the disposal aquifer pressure increases with continued disposal. At the end of the disposal cycle, water will continue to escape as long as the pressure in the disposal aquifer remains above its original level.

There are three resistances in series that impede the escape of the water and were considered in the calculations:

1) The frictional loss in the disposal aquifer
2) The frictional loss in the fracture
3) The frictional loss in the fresh-water aquifer.

The data used in this analysis is shown in Table D.23-1 and the

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*The water escaping will most likely be the native aquifer water rather than the injected brine. This water, however, will generally have a salinity greater than 35 ppt and thus would be classified as brine.

results are shown in Figure D.23-1. The results show that the maximum rate of escape will be 0.56 barrels per day. At the end of the first disposal cycle (39,500 bbl/day/well in ten injectors for 1144 days), about 300 barrels of brine will have escaped. Brine continues to escape at the conclusion of the first injection cycle, and five years later is still escaping at a rate of about one half barrel per day. At this time, about 1300 barrels will have escaped.

Table D.23-1

DATA USED IN THE LEAKAGE CALCULATIONS

DISPOSAL AQUIFER

Areal extend = 36 square miles
Thickness = 100 feet
Porosity = 0.33
Depth = 5000 feet
Abandoned well bore radius = 1 foot
Permeability = 1 darcy

FRESH WATER AQUIFER

Areal extent = infinite
Thickness = 400 feet
Porosity = 0.33
Depth = 400 feet
Abandoned well bore radius = 1 foot
Permeability = 30 darcies

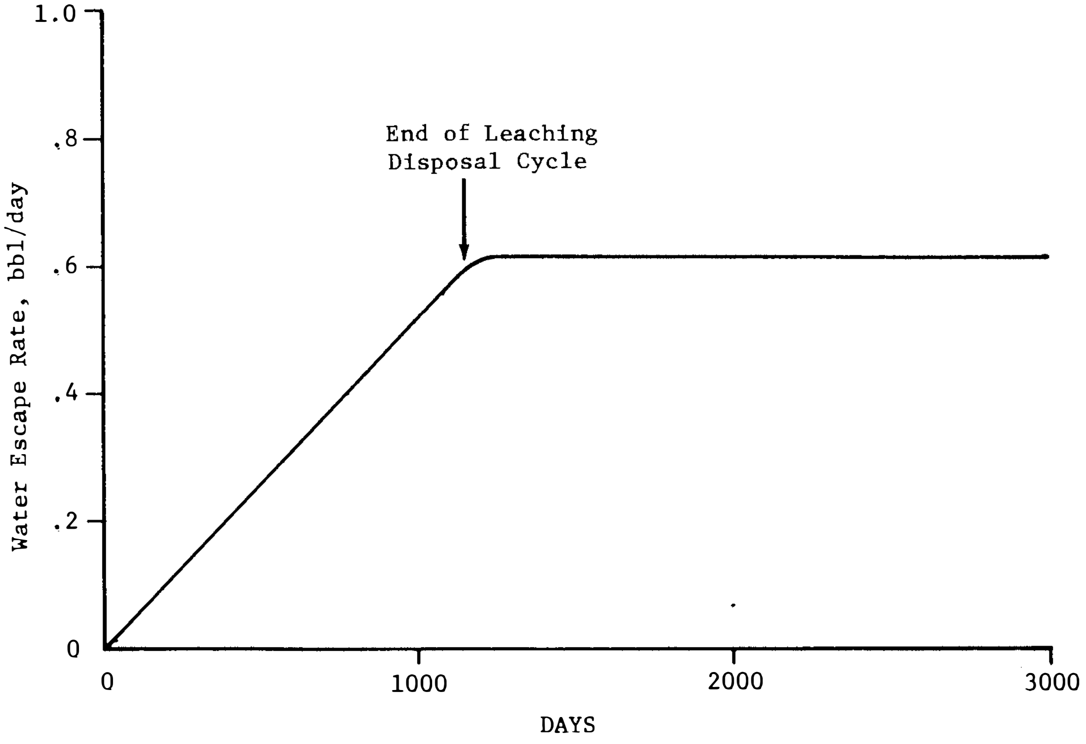

Figure D.23-1 Water Loss Through an Improperly Plugged Abandoned Well

APPENDIX D.24

WITHDRAWAL OF WATER FROM THE ICW*

1. Water Level in the ICW During Leaching Operations

The area of the waterway is

$$\begin{aligned} A &= 36.5 \text{ miles}^{**} \times 300 \text{ ft} \\ &= 1.93 \times 10^5 \times 300 \text{ ft} \\ &= 5.78 \times 10^7 \text{ ft}^2 \end{aligned}$$

The withdrawal rate during leaching is

$$Q_o = 3.85 \times 10^6 \text{ ft}^3/\text{day}$$

If the waterway is isolated from other water bodies

$$\begin{aligned} \frac{dh}{dt} &= \frac{Q_o}{A} \\ &= \frac{3.85\text{x}10^6}{5.78\text{x}10^7} \\ &= 0.067 \text{ ft/day} \end{aligned} \qquad (1)$$

2. Induced Currents in the ICW During Leaching Operations

The width of the ICW is

$$W = 300 \text{ feet}$$

And the depth is

$$D = 12 \text{ ft}$$

---

*The notation used in this appendix is consistent with that used in Appendix D.12.

**From Galveston Bay to the Port Arthur Canal.

Thus the cross-sectional area is

$$A_c = 12 \times 300$$
$$= 3600 \text{ ft}^2$$

The withdrawal rate is

$$Q_o = 3.85 \times 10^6 \text{ ft}^3/\text{day}$$
$$= 44.6 \text{ ft}^3/\text{sec}$$

If all of the replenishment water flows through the ICW, under steady-state conditons, the induced velocity would be:

$$U_i = Q_o/A_c$$
$$= 44.6/3600$$
$$U_i = 0.0124 \text{ ft/sec} \qquad (2)$$

3. Induced Currents in the ICW During Displacement Operations

The cross-sectional area of the ICW as calculated earlier is:

$$A_c = 3600 \text{ ft}^2$$

The withdrawal rate is

$$Q_o = 3.93 \times 10^6 \text{ ft}^3/\text{day}$$
$$= 45.5 \text{ ft}^3/\text{sec}$$

If the replenishment water flows through the ICW, under steady-state conditions, the induced velocity would be

$$U_i = Q_o/A_c$$
$$= 45.5/3600$$
$$= 0.0126 \text{ ft/sec} \qquad (3)$$

APPENDIX D.25

THE MIT TRANSIENT PLUME ANALYSIS*

7.1 General Approach

The analysis of the salinity distribution induced by the West Hackberry brine discharge is divided into three regions in accordance with the physical processes which are responsible for transporting the brine effluent. These regions are shown in Figure 39 and are discussed briefly below. Following a review of diffuser design in Section 7.2, model details and inputs for each region are discussed in Section 7.3, and model results and calculations are presented in Section 7.4.

In the near field region dilution is affected by turbulent jet mixing and is a function of diffuser design, ambient current velocity, and possibly water depth. The trajectory of each plume and the lateral spreading of each plume after it falls to the bottom are strongly affected by the negative buoyancy of the discharge. The near field region is assumed to extend downstream until the plumes from adjacent nozzles merge to form a continuous plume at a distance on the order of 100 feet. This definition is changed somewhat in the analysis of a longer diffuser.

The intermediate field is characterized primarily by buoyant lateral spreading and vertical collapse of the plume. Ambient diffusion acts to further dilute the plume but its importance, initially, is secondary in comparison with buoyant spreading. The intermediate field is assumed to end (and the far field to begin) at a distance of about 1000 feet corresponding to the point at

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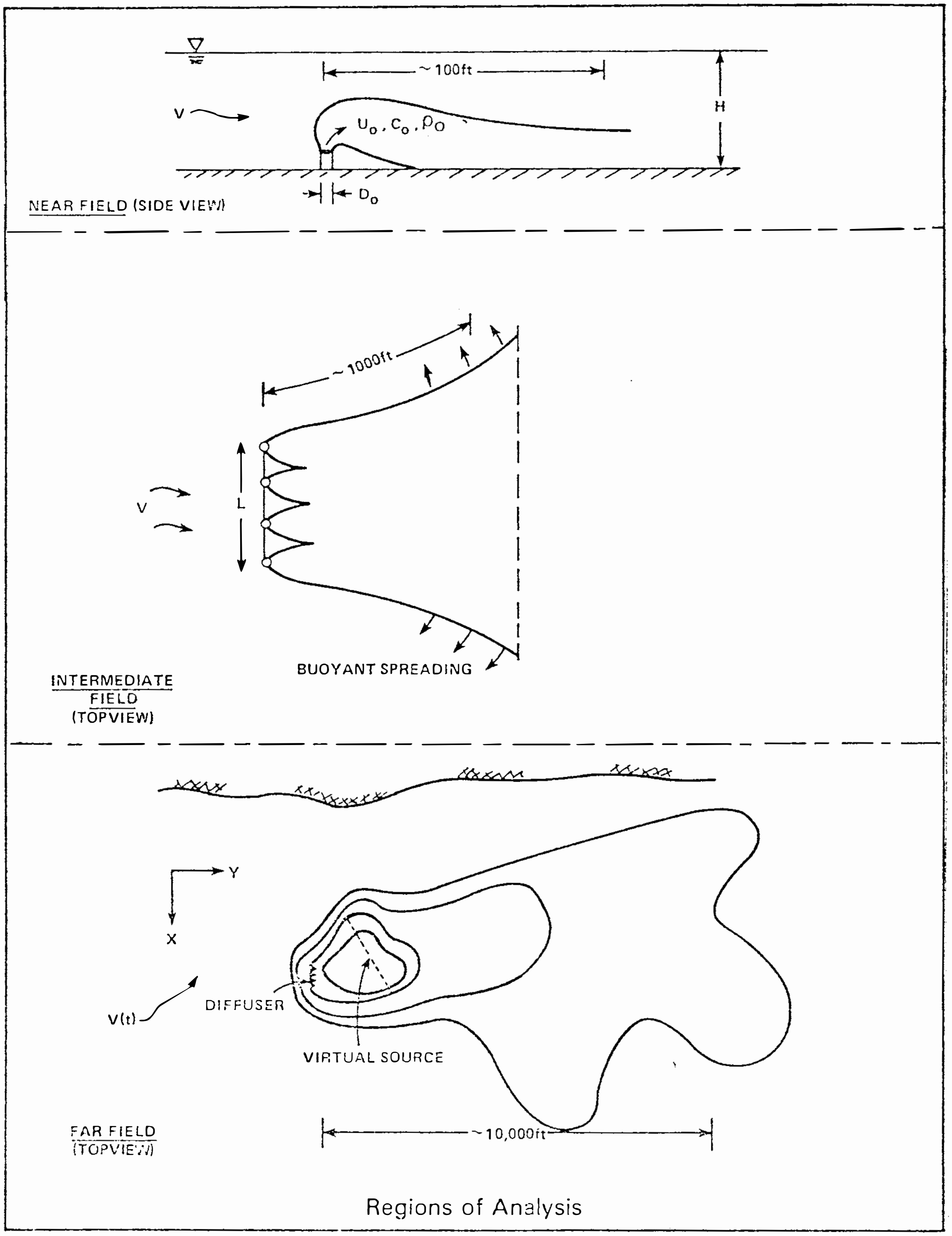
*Reprinted from Report to Federal Energy Administration Strategic Petroleum Reserve Program Salt Dome Storage Analysis of Brine Disposal in the Gulf of Mexico, (2) West Hackberry U.S. Department of Commerce, National Oceanic and Atmospheric Administration, March 1977.



Regions of Analysis

Fig. 39. Regions of Brine Discharge Analysis

which vertical collapse of the plume due to buoyancy is comparable with vertical growth due to diffusion.

The far field is the largest of the three regions and is characterized by the ambient processes of advection and diffusion. These processes are essentially independent of diffuser design and are the ones which ultimately control any accumulation of effluents.

7.2 Choice of Diffuser Design

In this and the following two sections reference is made to a "base case" diffuser design and ambient conditions (the calculations which describe this diffuser are referred to in Table 4 as Run 7) as well as to several pertubations on this situation (Runs 8-12). Runs 1-6 were reported earlier (EDS,77).

A diffuser is characterized by a number of parameters. Fixed parameters for the West Hackberry site include the flow rate Q_o (assumed equal to 1,000,000 barrels per day or 65 ft^3/s), the discharge concentration c_o and the discharge density ρ_o. The latter two parameters can be combined with respect to the ambient parameters c_a and ρ_a to define the discharge excess concentration $\Delta c_o = c_o - c_a$ (assumed equal to 230 ppt) and the discharge relative density difference $\Delta\rho_o/\rho_a = (\rho_o-\rho_a)/\rho_a$, (assumed equal to .25). The sensitivity of the analysis to these parameters was examined by also making calculations (Run 10) using discharge parameters which were characteristic of the Bryan Mound site (Q_o = 650,000 barrels per day or about 42 ft^3/sec).

In order to maximize the amount of ambient water intercepted by the diffuser, only diffusers extending perpendicular to the shore were considered. In addition, it was assumed that the discharge ports were located at the water bottom and were in a vertical plane perpendicular to the diffuser (see Figure 39). For this type of design, the engineering variables include the diffuser length L, port diameter D_o, vertical angle of the port with the ground Θ_o,

TABLE 4

Summary of Parameters Used in West Hackberry Brine Discharge Calculations

Run	Condition Tested	Discharge Parameters		Diffuser Parameters					Current Parameters			Calculation Times, T_n
		Q_o (cfs)	ΔC_o (ppt)	H (ft)	L (ft)	N	D_o (in)	U_o (fps)	T (hr)	A (fps)	B (fps)	(hr)
7	Base Case	65	230	30	3070	52	3	25	96	0.5	-1.0	309 333 357 381
8	Stagnant Flow	65	230	30	3070	52	3	25	384	0.25	-0.75	477 573 669 765
9	Shallow Water	65	230	20	3070	52	2	25	96	0.5	-1.0	309 333 357 381
10	Bryan Mound Discharge	42	230	30	3070	34	3	25	96	0.5	-1.0	309 333 357 381
11	Long Diffuser	65	230	30	8680	52	3	25	96	0.5	-1.0	309 333 357 381
12	Pre-dilution	130	115	30	8680	147	3	18	96	0.5	-1.0	309 333 357 381

the exit velocity u_0, and the water depth H. These variables can be used to define the number of ports, $N = Q_0/(\pi/4\ D_0{}^2 u_0)$, and the port spacing, $\ell = L/N$. A large number of parameter combinations is clearly possible. However, there is presently insufficient experimental or theoretical basis to define an optimum combination. Therefore, a base case diffuser design was selected based on three criteria: 1) the physical impact could be analyzed, 2) the anticipated impact would be acceptable, and 3) the design would be conventional and present no engineering difficulties. Application of these criteria led to the following design.

The diffuser length, L, was chosen such that the intermediate field plume would be spread over a large enough area so that a wedge of saline water would not form under normal conditions. A criterion for the prevention of wedge formation is

$$F_1{}^2 = \frac{V^2 \rho_a}{\Delta\rho_1 g h_1} > F_{1c}{}^2$$

where F_1 is a Froude number defined at the end of the near field, V is the ambient current speed ($V^2 = u^2 + v^2$, $\tan^{-1}\theta = u/v$), g is gravity, $\Delta\rho_1 = \rho_1 - \rho_a$, ρ_1 and h_1 are the density and characteristic height of the plume at the end of the near field and F_{1c} is a critical value of F_1 (and is of order 1). Defining the volumetric dilution, S_1, obtained in the near field by

$$S_1 = \frac{V\cos\theta\ L\ h_1}{Q_o} = \frac{\Delta\rho_o}{\Delta\rho_1}$$

implies that

$$L > \frac{Q_o \Delta\rho_o g F_{1c}{}^2}{\rho_a V^3 \cos\theta} .$$

This criterion suggests that wedge formation is independent of near field performance and that the diffuser should be as long as possible. Assuming a value of $F_{1c} = 1$, it is clear that some brine buildup will be unavoidable under conditions of low V but that a length of about 3000 feet will be satisfactory for an alongshore current of about 0.5 ft/sec. A value of L = 3070 feet was chosen as a base case because it yielded the same port spacing as was used for the Bryan Mound analysis (EDS, 77). An analysis was also performed for a diffuser length, L = 8680 feet (Run 11).

The port riser angle, Θ_o, was chosen as 90^o. While experiments show that dilution for jets directed with a current may exceed the dilution for jets pointed vertically upward, the performance of jets directed into a crossflow has not been documented and is probably worse. Because ambient currents at the site occur in all directions, the diffuser with anticipated "neutral" performance was selected.

Diffuser performance as a function of u_o and D_o is often expressed in terms of the dimensionless parameters of discharge Froude number, discharge velocity ratio, and relative submergence:

$$F_o = \frac{u_o}{\sqrt{\frac{\Delta\rho_o}{\rho_a} g\ D_o}} \quad \text{(discharge Froude number)}$$

$$k = \frac{u_o}{V} \quad \text{(discharge velocity ratio)}$$

$$\frac{H}{D_o} \quad \text{(relative submergence).}$$

Experiments do not exist over the full range of F_o and k which is appropriate for the present situation. However, it is clear that dilution improves with increasing u_0 and decreasing D_0. Values of u_0 = 25 ft/sec and D_0 = 3 inches were chosen because it was felt that the corresponding diffuser (with N = 52 and ℓ = 59 feet) could be easily built. In addition, for these values of u_0 and D_0, F_0 was about 18 which corresponded closely to some of the experimental parameters used in the near field analysis (see Section 7.3). It is expected that if u_0 were increased and/or D_0 were decreased, near field dilution could be improved somewhat.

Two values of H (30 feet for the base case and 20 feet for Run 9) were chosen corresponding to offshore distances of about 6 miles and 3 miles respectively. As long as the discharge plumes do not reach the surface the effect of H will only be felt in the far field. Experiments suggest that the dimensionless plume rise $z_m/D_0 \approx 2\ F_0$, indicating that the plume will not reach the surface to any significant degree for either water depth.

In a previous analysis done for the Bryan Mound area (EDS, 77) it was pointed out that one way to decrease near field concentrations was to pre-dilute the brine flow by pumping additional sea water through the diffuser and thereby increasing Q_0 and decreasing Δc_0 proportionally. The present analysis for West Hackberry includes an example calculation (Run 12) in which the discharge flow rate Q_0, the diffuser length L, and the number of ports N, have been increased by factors of $2, 2^{3/2}$, and $2^{3/2}$ respectively, while the discharge excess concentration Δc_0, and velocity u_0 have been reduced by factors of 2 and $2^{1/2}$ respectively. This leaves the port diameter D_0, spacing ℓ, and discharge Froude number F_0 the same as for the base case.

7.3 Model Details and Inputs

Near Field

Diffuser performance in the near field was analyzed using existing experimental data (U. S. Army Engineer Waterways Experiment Station, 1971), which was applied to the chosen diffuser design. Graphs of jet centerline dilution and width as a function of distance $\tilde{x}$, $S_c(\tilde{x}) = \Delta C_0(\tilde{x})/\Delta C_c(\tilde{x})$ and $W(\tilde{x})$ respectively were derived from tabulated data for experiments involving $F_0 \approx 18$ and a range of ambient velocities. When scaled to the prototype base care diffuser design these velocities correspond to $0.4 < V < 4.0$ ft/sec. For each ambient velocity V, $S_1(V)$ was determined by evaluating $S_c(\tilde{x})$ at the value of $\tilde{x}$ corresponding to the point of jet merging ($W=\ell$). It should be noted that for all of the calculations except Run 11, ℓ was constant (59 feet) and hence S_1 was independent of diffuser design. Run 11 involved a long diffuser in which $\ell = 147$ feet. The data could not be extrapolated reliably to this distance, so for this run too, S_1 was (conservatively) evaluated based on a width of 59 feet. Using this procedure the relationship

$$S_1 = 45 + \frac{1375}{k}$$

was determined. For the cases in which $u_0 = 25$ ft/sec (all but Run 12) this yields

$$S_1 = 45 + 55\ V.$$

where

where V is expressed in ft/sec. Dilution for Run 12 (in which $u_0 = 18$ ft/sec was somewhat higher.

Intermediate Field

Lateral spreading and vertical collapse in the intermediate field were calculated to provide appropriate initial conditions for the far field analysis. A steady longshore current and a constant water depth were assumed. Because of the latter assumption, any downhill movement of the brine field due to gravity was ignored. A balance between lateral buoyancy force and bottom friction resulted in the following equation for lateral spreading about the plume centerline

$$\frac{\Delta\rho_o g h^2}{\rho_a S_1} = \frac{fW}{8}\left(\frac{dW}{d\tilde{x}}\right)^2 v^2$$

Where W and h are the intermediate field plume width and depth, respectively, (W = L and h = h_1 at the end of the near field), and f is a friction factor (assumed equal to .001). Although dilution caused by ambient diffusion was omitted from this analysis (a conservative assumption from the standpoint of mixing), the end of the intermediate field was chosen as the distance at which the rate of vertical collapse of the plume due to buoyancy was equal to the rate of vertical growth of the plume which would have occurred due to diffusion in the absence of buoyancy. Thus, calculations were terminated when

$$\frac{h}{W}\frac{dW}{d\tilde{x}} = \frac{E_z}{h\ V}.$$

where E_z is a vertical diffusion coefficient (assumed equal to .001 ft^2/s).

The above analysis was applied to all cases except Run 11, the long diffuser. For that run the analysis was applied to the individual plumes from each nozzle starting at the same point as for the base case and continuing until the plumes merged. At this point the above criterion indicated that vertical diffusion would exceed buoyant collapse and hence the intermediate field calculations were terminated.

Far Field

Concentrations in the far field region were analyzed using the MIT Transient Plume Model (Adams, et al, 1975). This model approximates continuous three-dimensional excess concentrations at times T by superimposing Gaussian excess concentration distributions for a number of instantaneously released "patches" of mass which enter the far field at a virtual source (transition between intermediate and far fields) at times ranging from $\tau = 0$ to T. The excess concentration for each patch is approximated by the distribution:

$$c_i(x,y,z,\tau,T) = \frac{m(z,\tau,T)}{2\pi\rho_a\sigma_x(\tau,T)\sigma_y(\tau,T)} \exp -\left[\frac{[x-x_c(\tau,T)]^2}{2\sigma_x^2(\tau,T)} + \frac{[y-y_c(\tau,T)]^2}{2\sigma_y^2(\tau,T)}\right]$$

where z is the vertical coordinate (z = 0 at the bottom and z = H at the water surface) and m, x_c, y_c, σ_x, and σ_y are the distribution moments which describe the quantity of excess mass per unit depth, the horizontal coordinates of the center of mass, and the horizontal standard deviations of each patch, respectively. These moments are related to the processes of advection and diffusion through the governing equation

$$\frac{\partial\Delta c}{\partial t} = -u\frac{\partial\Delta c}{\partial x} - v\frac{\partial\Delta c}{\partial y} + E_x\frac{\partial\Delta c}{\partial x} + E_z\frac{\partial\Delta c}{\partial y} + \frac{\partial}{\partial z}\left(E_z\frac{\partial\Delta c}{\partial z}\right)$$

$$\Delta c = 0 \text{ at } x \text{ or } y = \pm\infty; \quad E_z\frac{\partial\Delta c}{\partial z} = 0 \text{ at } z = 0 \text{ or } H$$

where u and v are the x and y components of velocity, E_x and E_y are horizontal relative diffusion coefficients, and E_z is a vertical diffusion coefficient. Using the method of moments, it can be shown that

$$\frac{\partial m}{\partial t} = E_z\frac{\partial^2 m}{\partial z^2} \qquad \frac{\partial y_c}{\partial t} = v$$

$$E_z\frac{\partial m}{\partial z} = 0 \text{ at } z = 0,H \qquad \frac{\partial\sigma_x^2/2}{\partial t} = E_x$$

$$\frac{\partial x_c}{\partial t} = u \qquad \frac{\partial\sigma_y^2/2}{\partial t} = E_y$$

These equations are integrated in time from $t = \tau$ to T starting with initial conditions provided by the near and intermediate field calculations:

$$m_o = \frac{\rho_a Q_o \Delta c_o \Delta\tau}{h_2}$$

$$x_{co} = \tilde{x}_2 \sin\theta$$

$$y_{co} = \tilde{x}_2 \cos\theta$$

$$\sigma_{xo} = \sigma_{yo} = W_2/12$$

where $\Delta\tau$ is the period of time represented by the patch injection and W_2 and h_2 are the plume width and heigth at the end of the intermediate field ($\tilde{x} = \tilde{x}_2$). Because there is little information available regarding far field model parameters for this site, reasonable estimates had to be made. The value of E_z was chosen as .001 ft^2/sec to reflect the stabilizing influence of the vertical density gradient. Isotropic horizontal diffusion coefficients ($E_x = E_y = E_h$) were related to the patch size ($\sigma_x = \sigma_y = \sigma_h$) in the form

$$E_h = \text{minimum } (.003\sigma_h^{1.15}, 322) \; (ft^2/sec).$$

The variable form represents the growth of diffusion rate with the scale of the diffusion at a rate comparable with but somewhat smaller than that found in field dye experiments (Okubo, 1971). The constant value is the coefficient used in the steady-state model analysis for Bryan Mound (Radian, 1976) and corresponds approximately to a diffusion scale based on the distance from shore.

Idealized current sequences were assumed in the transient plume model. These consisted of tidal currents and, for the longshore component only, non-tidal currents in the form of

$$u = u_T$$

$$v = v_T + v_{NT}$$

Diurnal, rotary tidal currents were specified such that

$$u_T = .3 \cos\left(\frac{2\pi}{24} t\right) \qquad v_T = .6 \cos\left(\frac{2\pi}{24} (t+6)\right)$$

where t is in hours and u_T and v_T are in ft/sec. The non-tidal longshore current represents the contribution from a number of factors including wind-driven motion, baroclinic motion, large-scale circulation, etc., and was assumed to fit the schematic cycle described in Figure 40. Although idealized, this sequence reproduces the observed phenomena of a small mean current (where $A \neq B$), wind reversals, and thus current reversals, following the passage of a weather system, and periods of calm (except for the tide). For the base case calculations (all but Run 8) A = 0.5 ft/sec, B = -1.0 ft/sec and T = 96 hours; the effect of a relatively long period of stagnation was tested in Run 8 using A = 0.25 ft/sec, B = -0.75 ft/sec and T = 384 hours. To test the sensitivity of the analysis to the phase of the cycle, concentrations were calculated at four times within the cycle. These times are shown in Figure 40 , and defined by

$$T_n = n^*T + \frac{n}{4} T - 3 \qquad n = 1,2,3,4$$

where T_n and T are in hours. The term n*T (n* = 3 for T = 96 h and n* = 1 for T = 384 h) represents a "spin-up" time and was included to allow the calculations to reach "quasi-steady state". Also, note that the cycle period, T, was always chosen as a multiple of 24 hours, and thus the four times displayed are at the same phase within the assumed tidal cycle.

7.4 Results and Conclusions

Computations (Runs) were made for the six conditions described in Table 4. For each run excess concentrations were output at

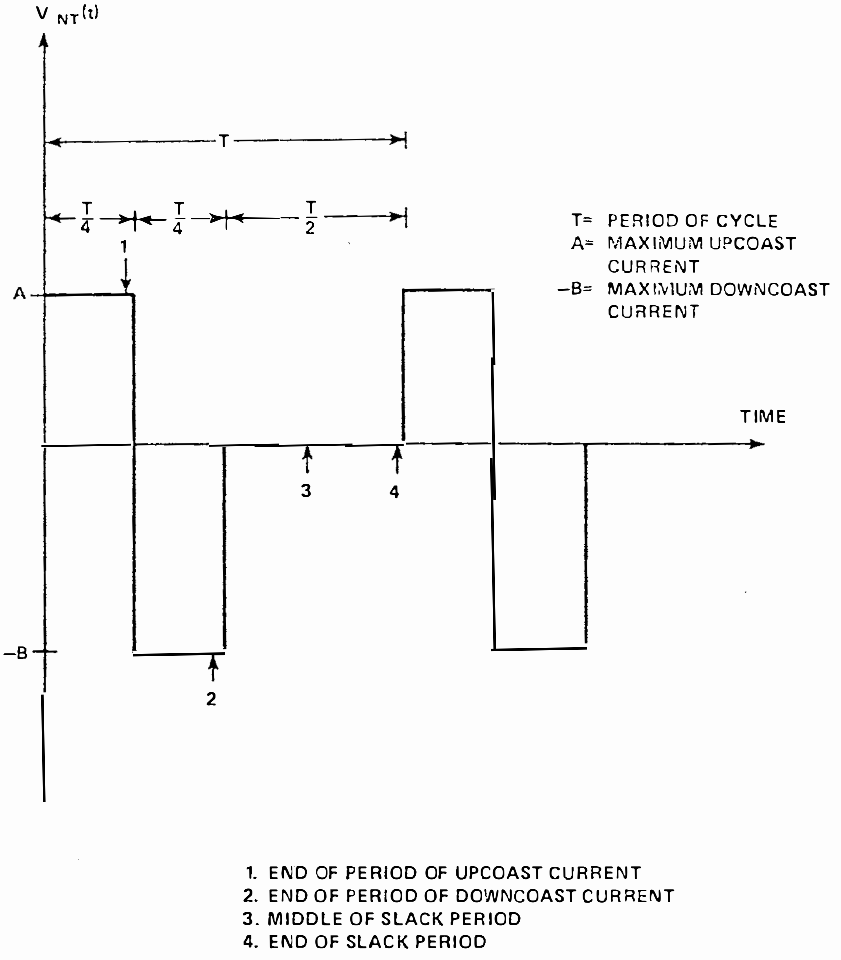


Fig. 40. Idealized Non-Tidal Current Cycle

the four times within the current sequence described above and at three depths (bottom, mid-depth and surface). For the base case diffuser (Run 7), bottom, mid-depth, and surface excess salinity contours are presented for the first time (T_1 = 309h) in Figs. 41 a, b, c and bottom concentrations are presented for the remaining times in Figs. 42-44. For Runs 9-12, which show sensitivity to water depth, discharge flow rate, diffuser length and pre-dilution, respectively, bottom concentrations for the first time only (T_1 = 309h) are shown in Figs. 46-49. Run is intended to show the effect of prolonged stagnation and hence bottom contours for this run are presented for the fourth time (T_4 = 765h) which corresponds to the end of a slack period lasting 8 days. Note that in some plots, the horizontal scales are distorted and are not the same for all of the runs. The location of the diffuser is indicated on the plots by a solid line, the virtual source is indicated by a dashed line, and the concentration contours within the near and intermediate fields have been visually interpolated.

In Figs. 50-55, plots of excess concentration versus bottom area are presented for each run and each time. Note that only concentrations within the far field (areas greater than about 10^6 ft^2) are included. The value of dilution ($S = \Delta c_o/\Delta c$) is also included to allow for easy calculation of the concentration of pollutants other than excess salinity.

A number of conclusions can be drawn from these calculations. Run 7, the base case, shows that while the current sequence has only a moderate effect on the maximum predicted concentration in the far field (∿2 to 5 ppt) it has a substantial influence on the shape of the calculated concentration distribution. Periods of strong ambient current (e.g., T_2 for each run) produce long, narrow plumes. Concentrations near the diffuser are relatively low due to the positive dependence of near field dilution on current speed. During periods of little net drift (e.g., T_3 and T_4 for each run), the plumes remain close to the diffuser. Concentrations near the diffuser are generally

Fig. 41a. Predicted Far Field Excess Salinity (ppt) Calculation at Bottom H=30 ft
Base Case

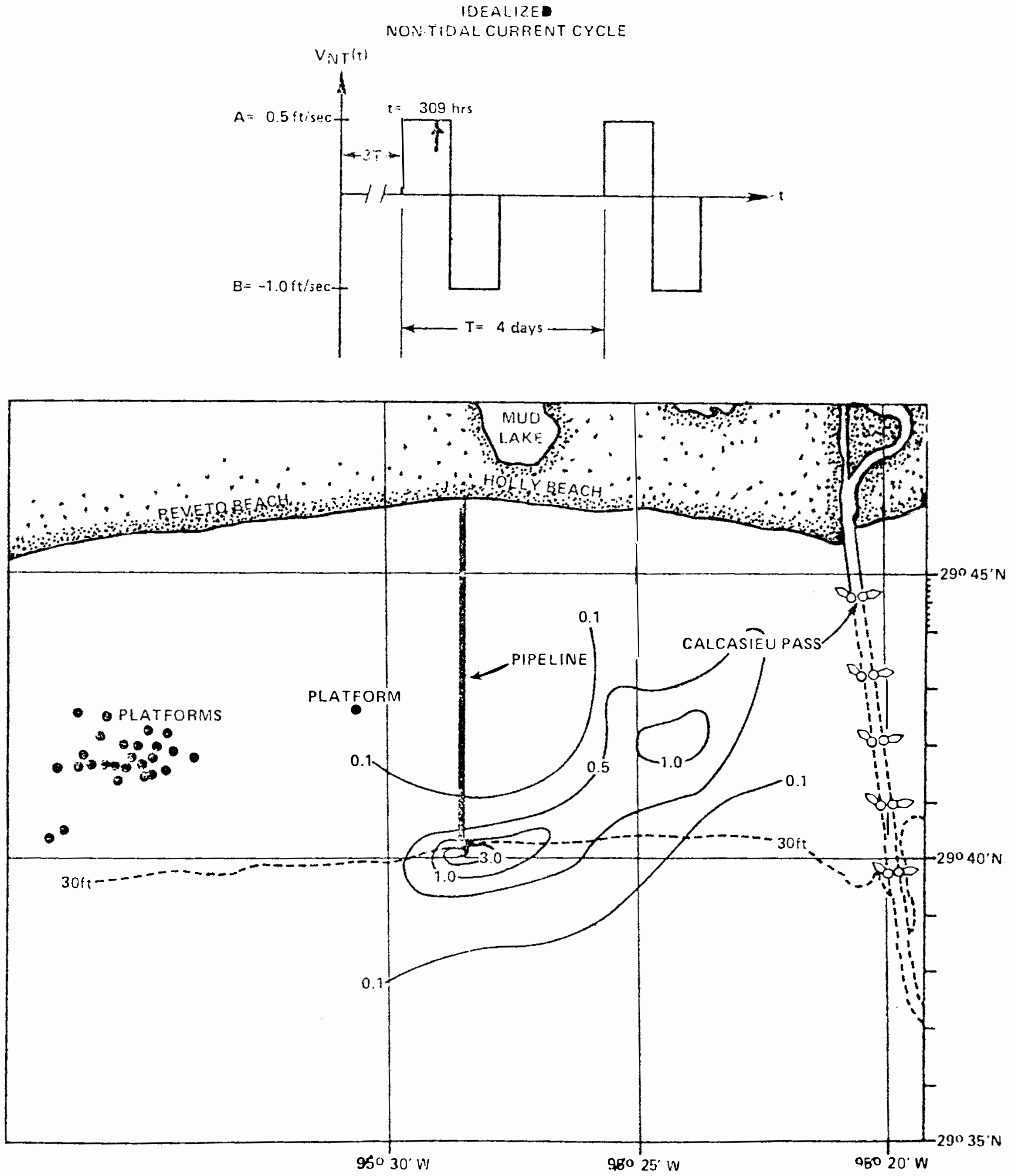
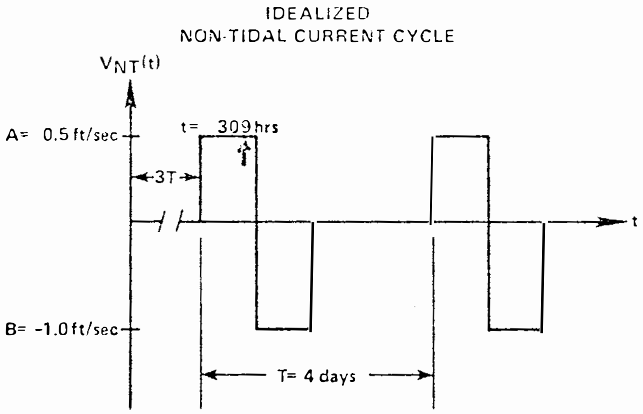


Fig. 41b. Predicted Far Field Excess Salinity (ppt) Calculation at Mid-depth H=30ft Base Case



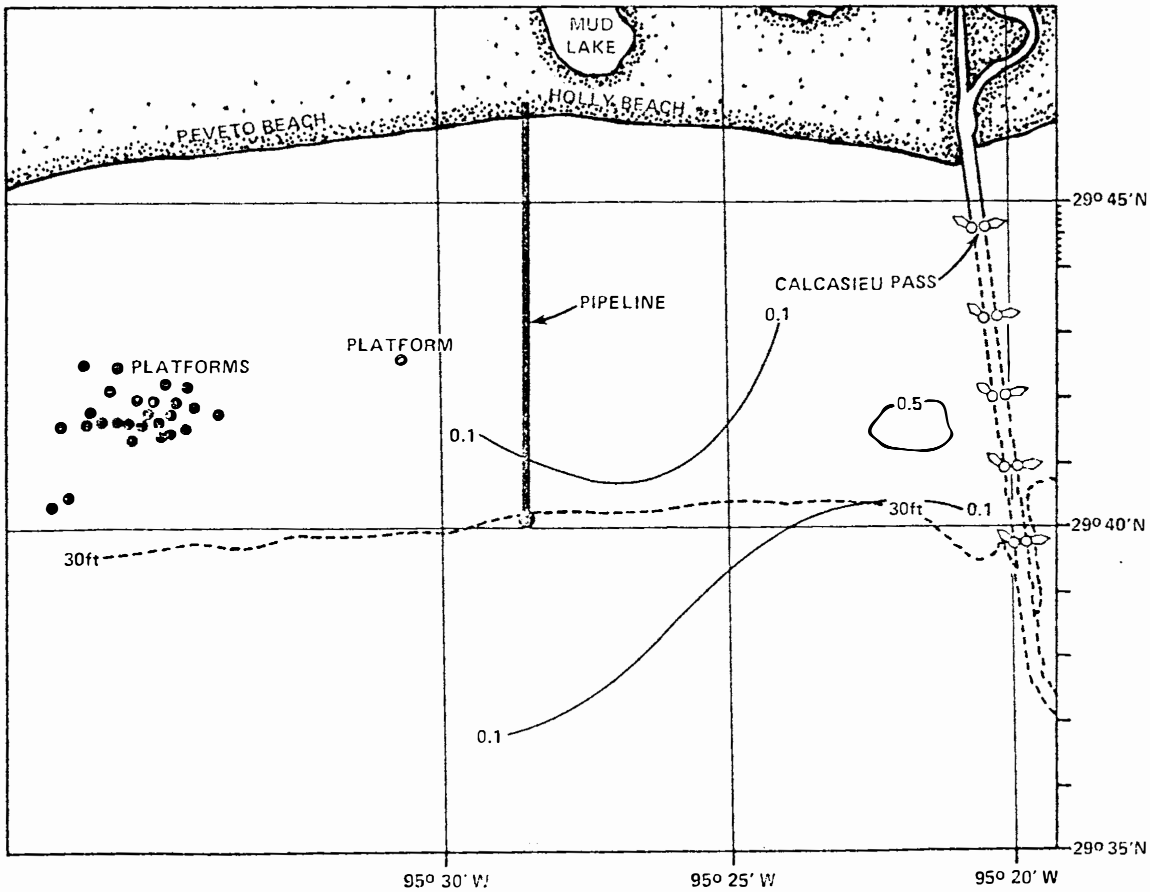


Fig. 41c. Predicted Far Field Excess Salinity (ppt) Calculation
at the Surface H=30ft
Base Case

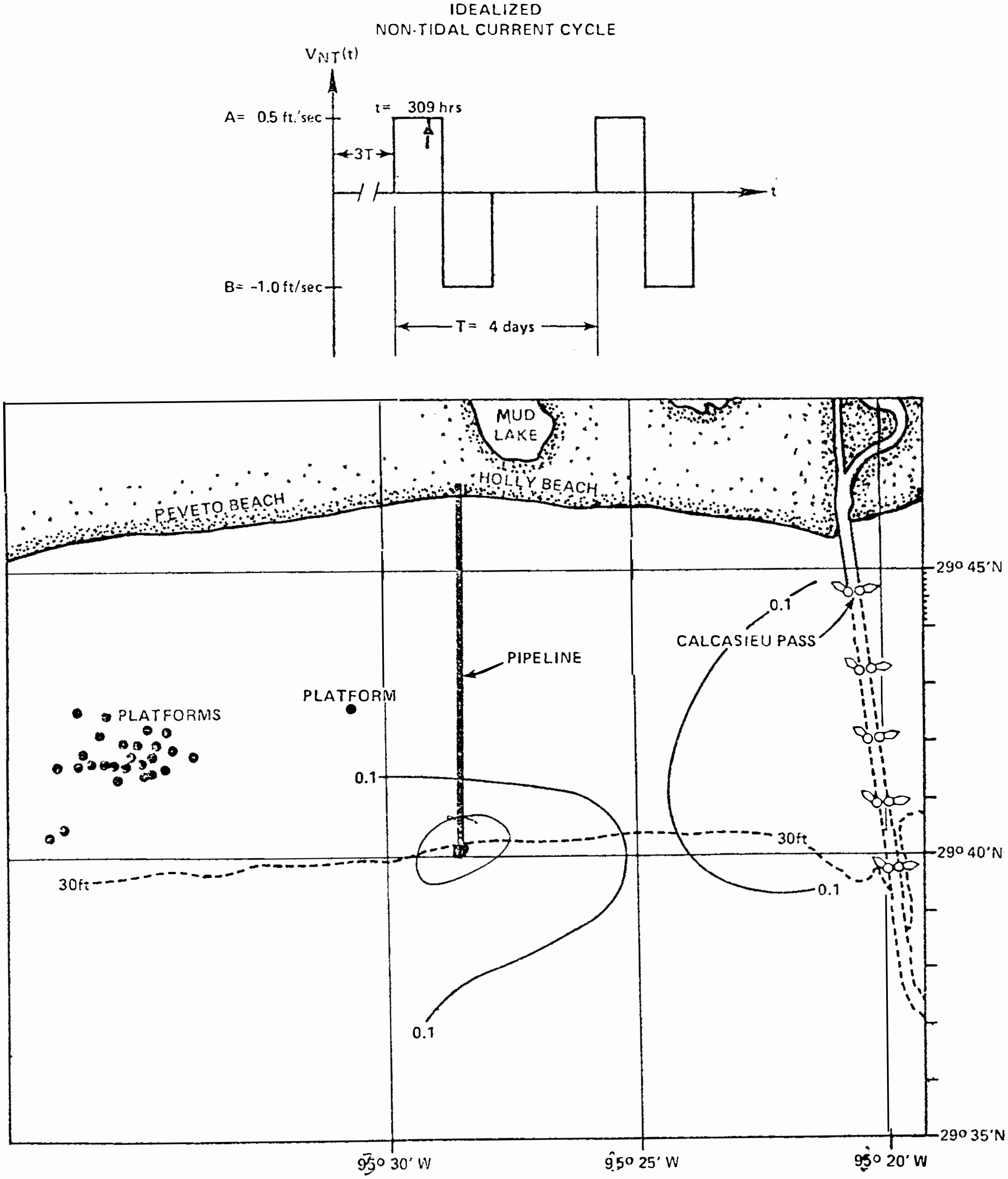


Fig. 42. Predicted Far Field Excess Salinity (ppt) Calculation at Bottom H=30 ft Base Case

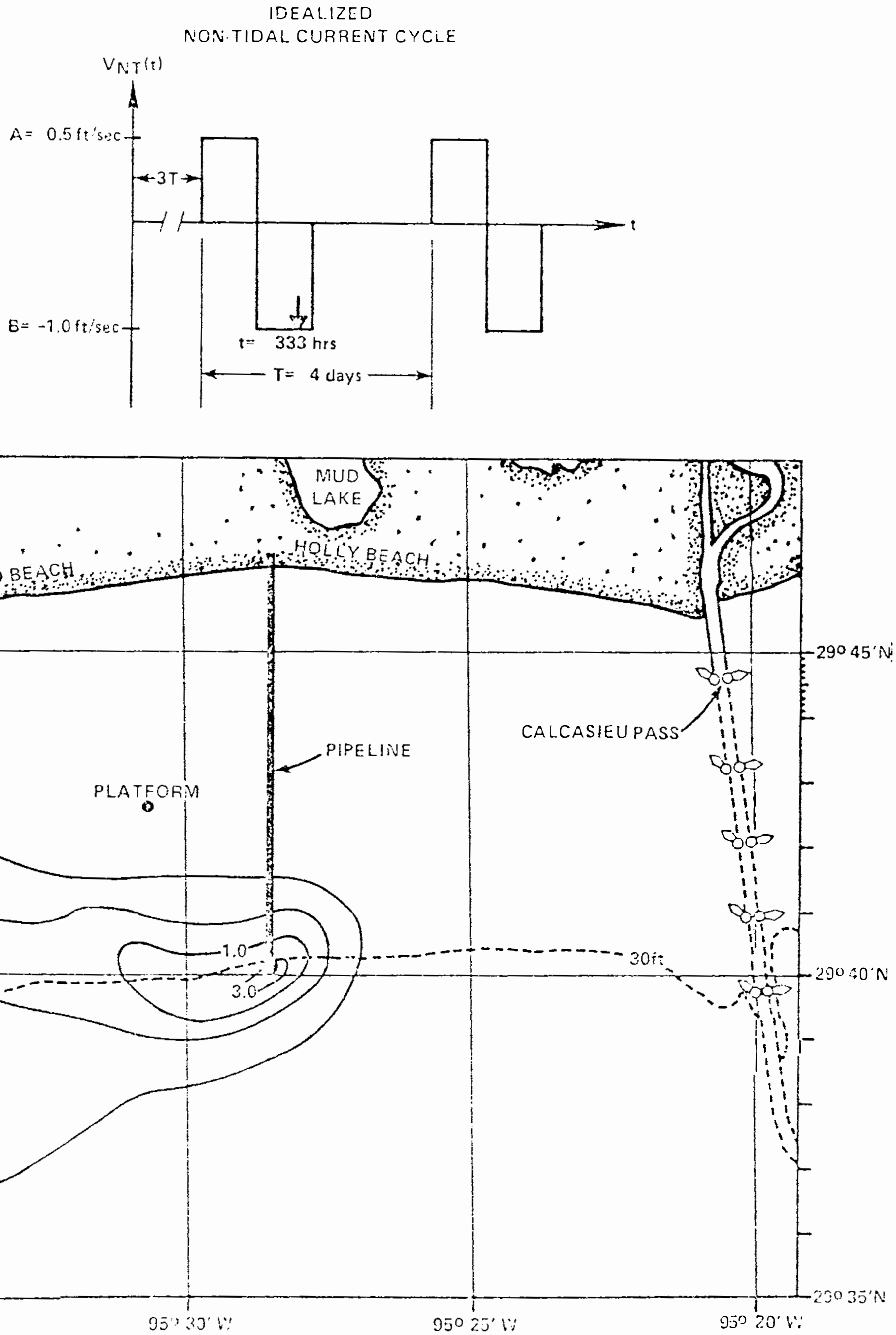


Fig. 43. Predicted Far Field Excess Salinity (ppt) Calculation
at Bottom H=30 ft
Base Case

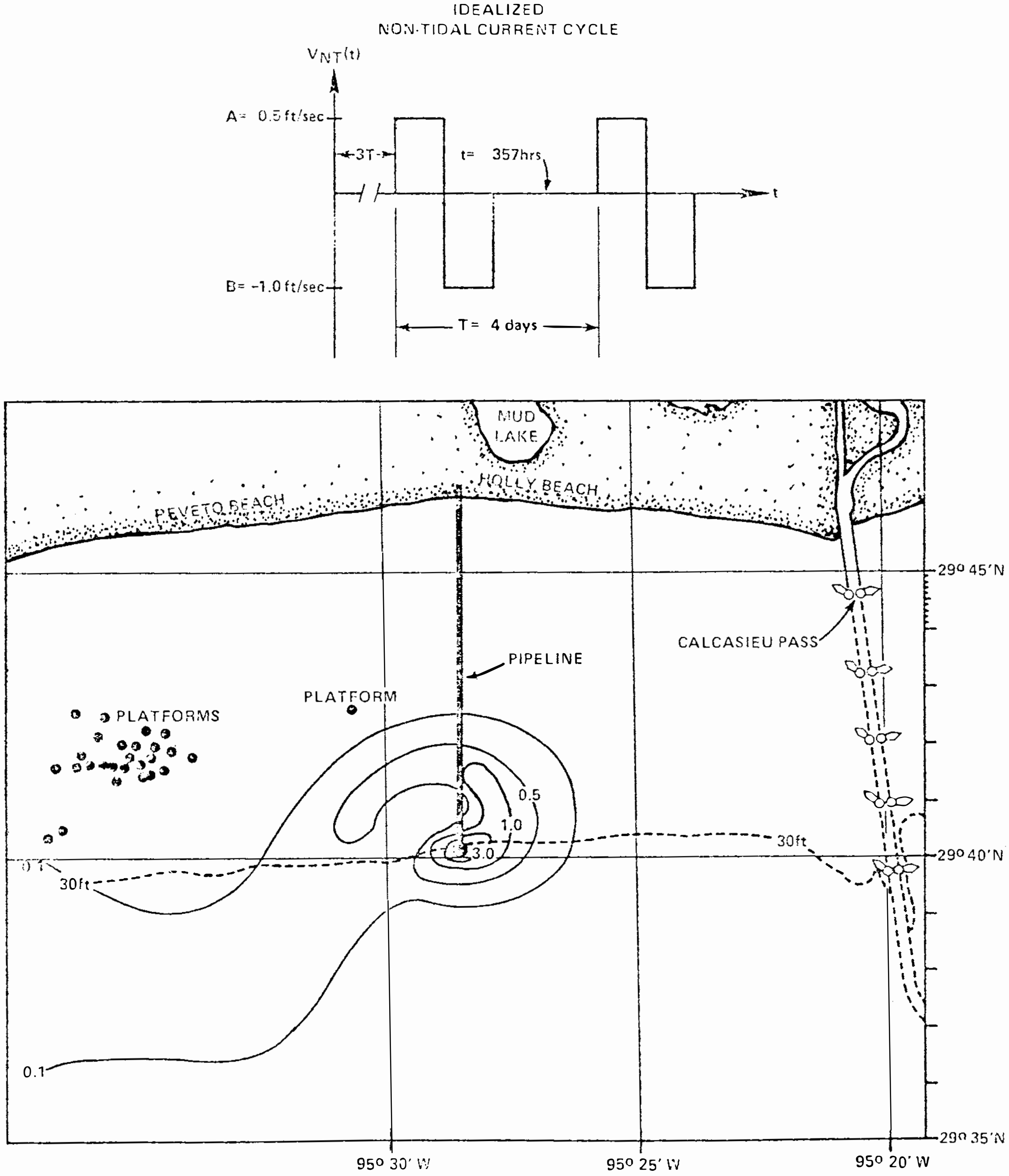


Fig. 44. Predicted Far Field Excess Salinity (ppt) Calculation
at Bottom H=30 ft
Base Case

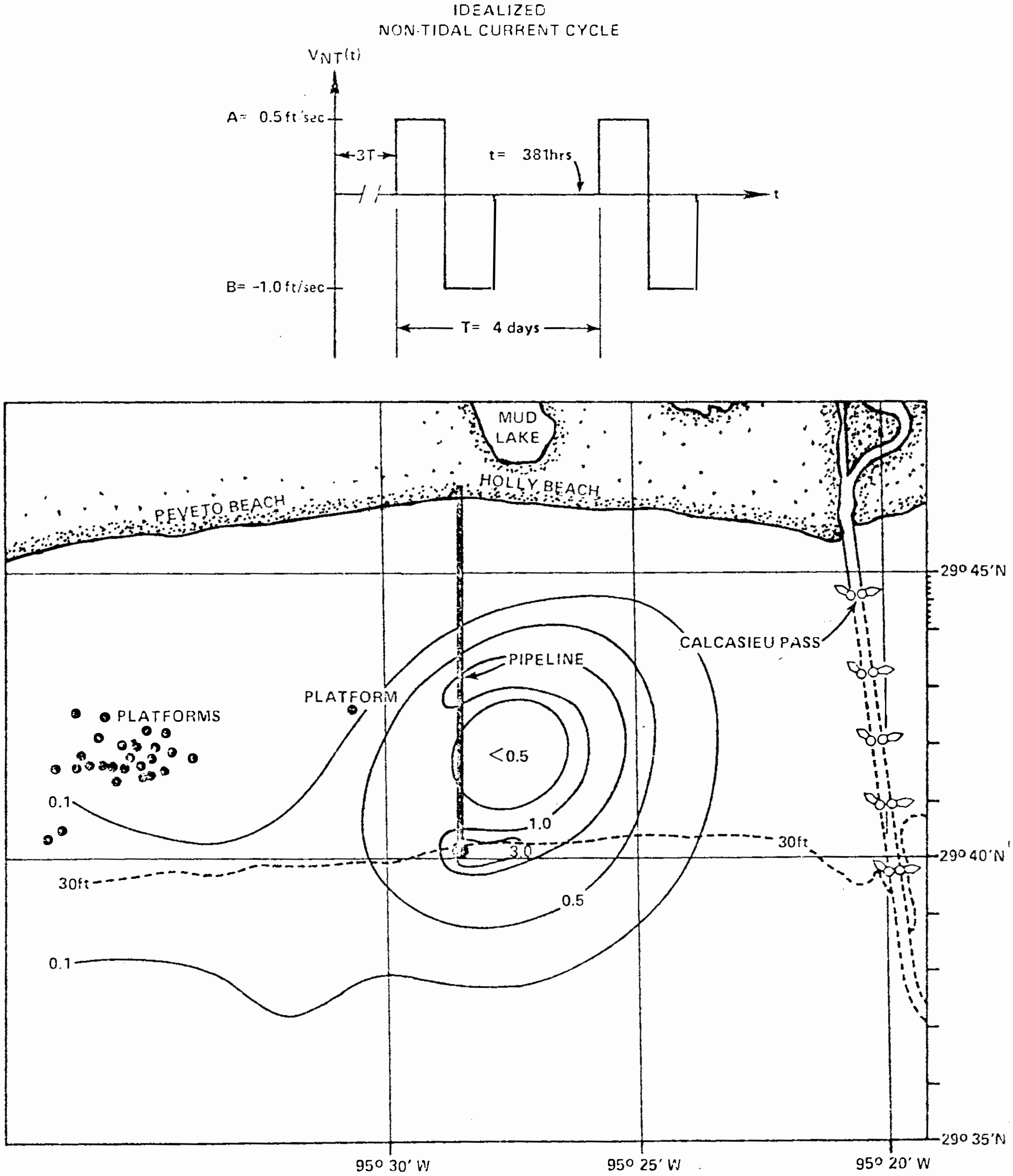


Fig. 45. Predicted Far Field Excess Salinity (ppt) Calculation at Bottom H=30 ft

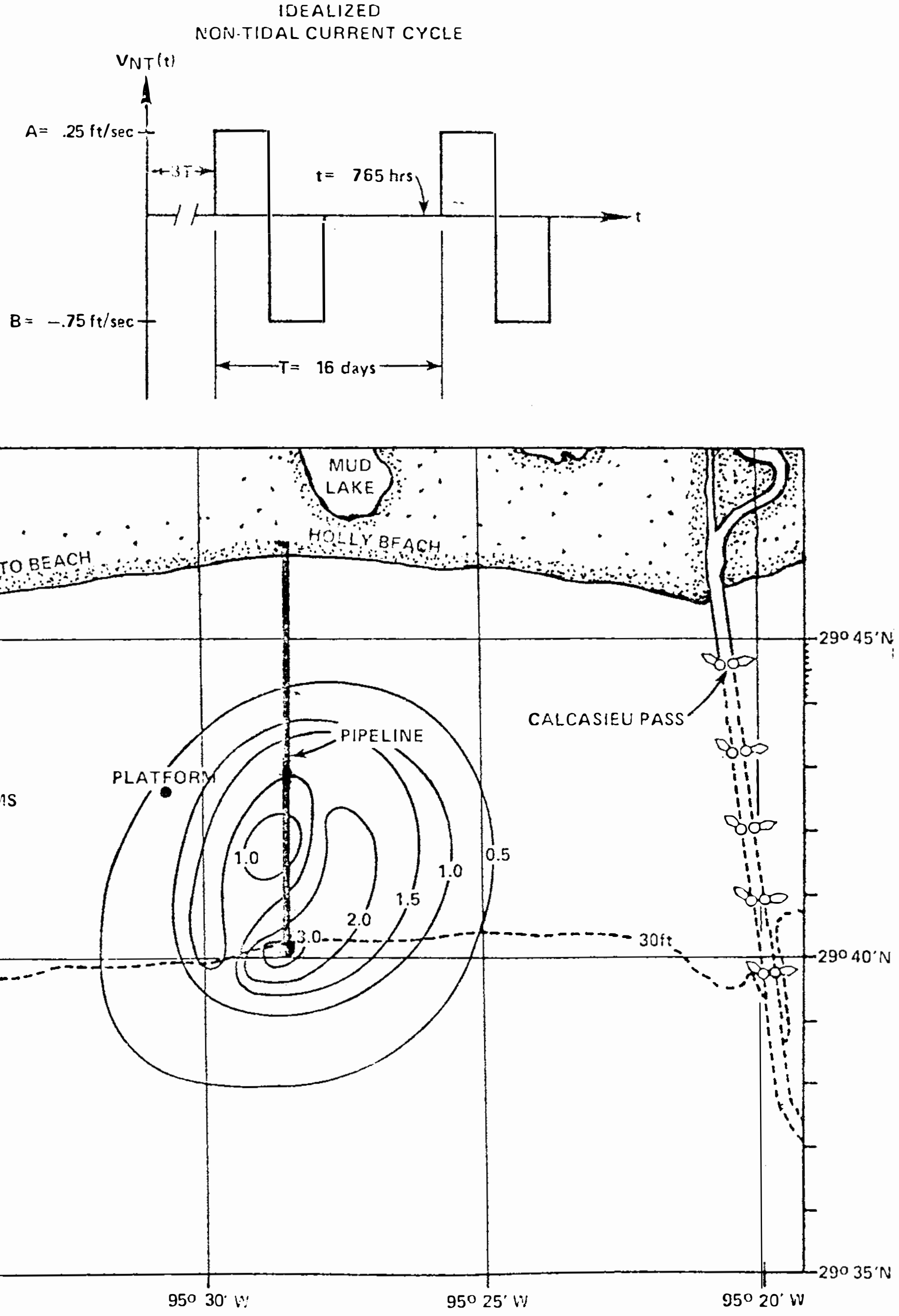
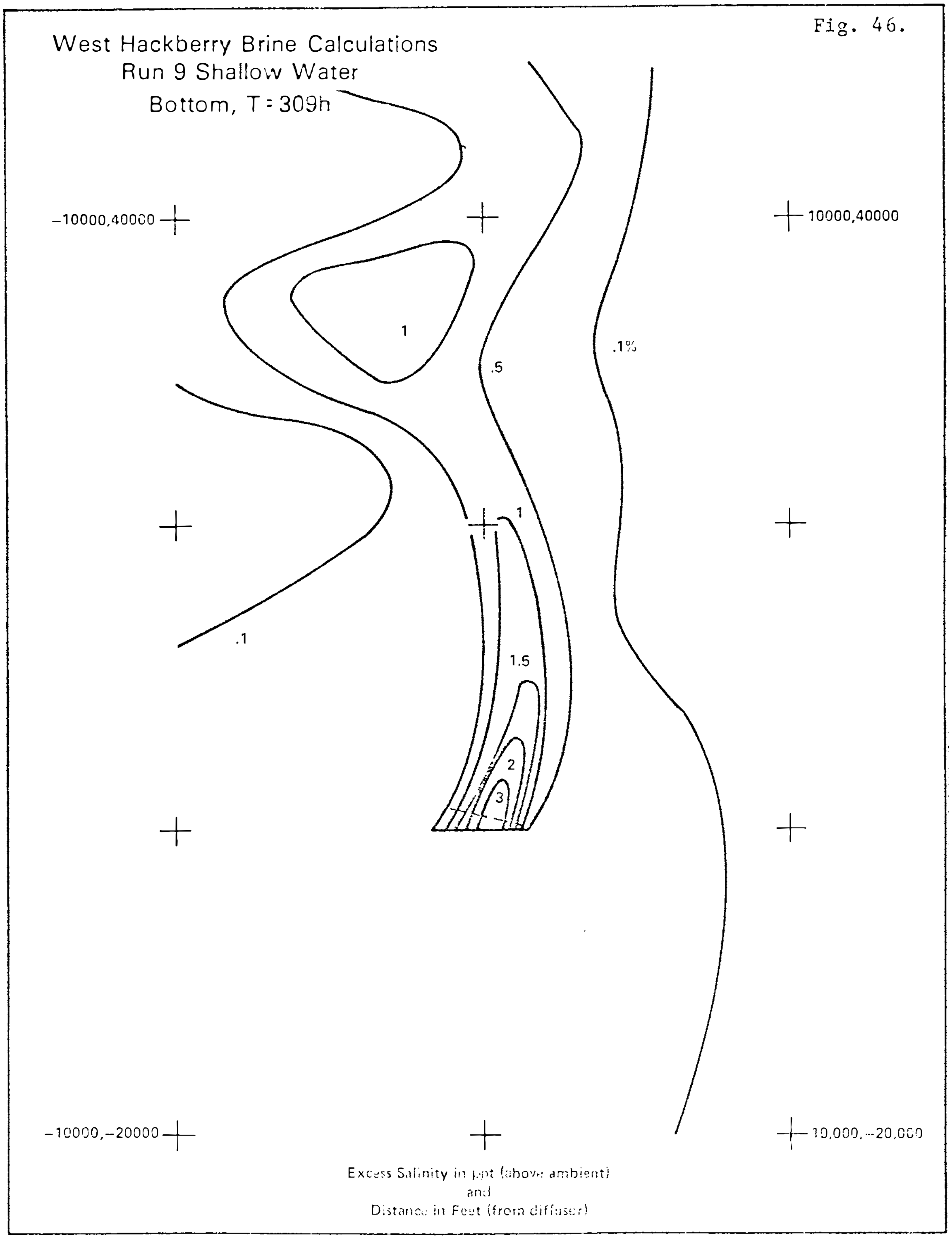


Fig. 46.

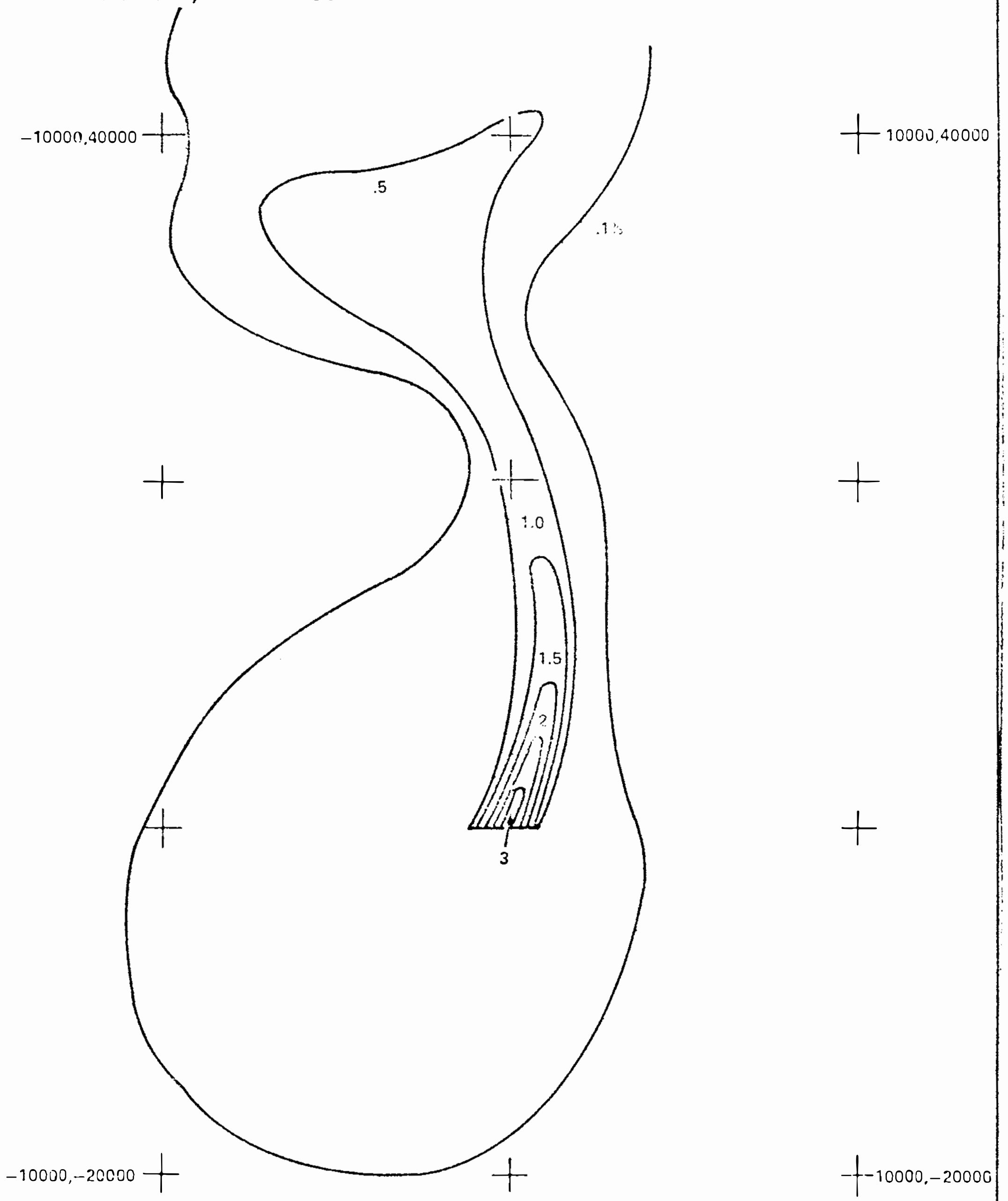


West Hackberry Brine Calculations
Run 9 Shallow Water
Bottom, T = 309h

Excess Salinity in ppt (above ambient)
and
Distance in Feet (from diffuser)

Fig. 47.

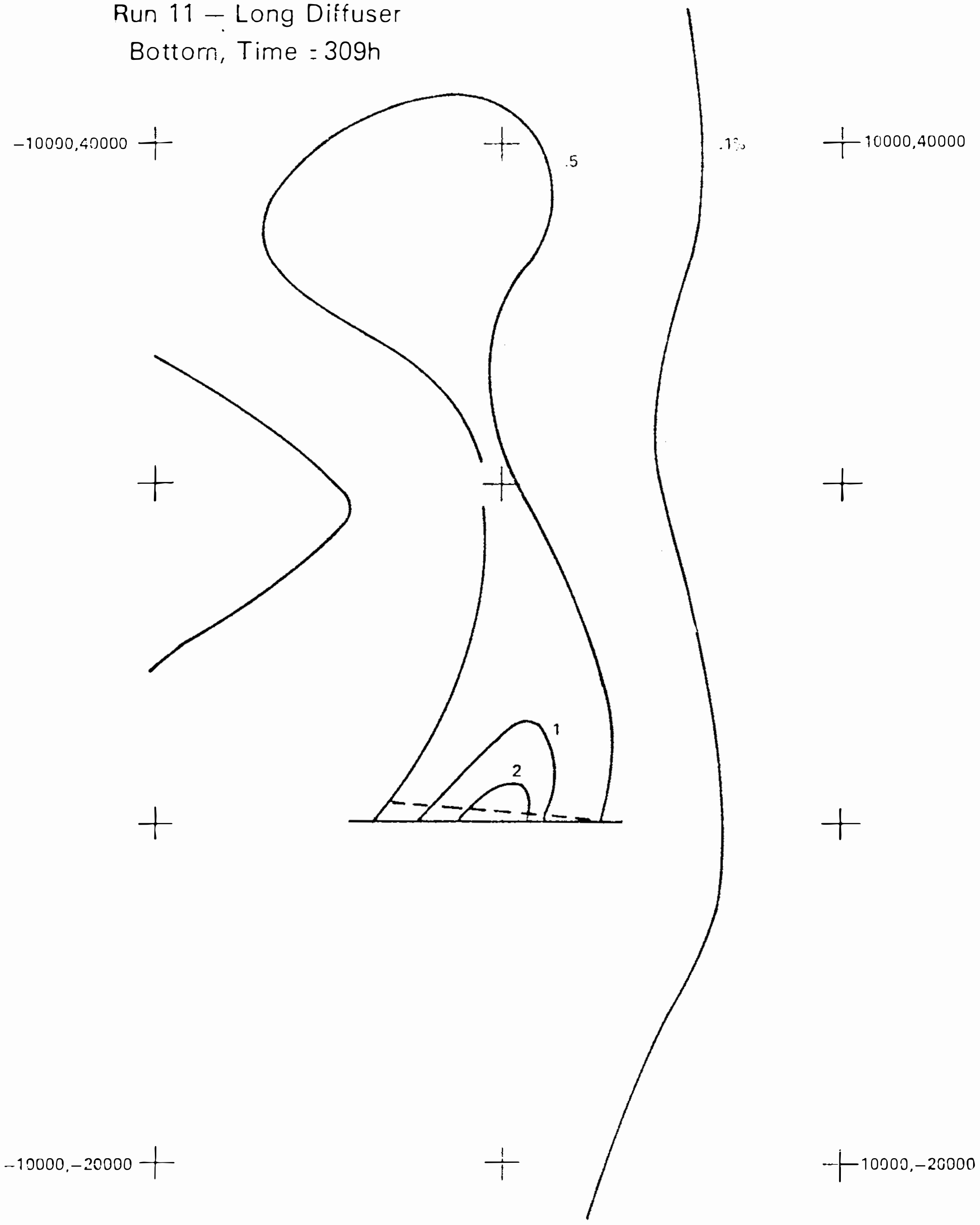
West Hackberry Brine Calculations
Run 10 Bryan Mound Discharge Conditions
Bottom, Time = 309h



Excess Salinity in ppt (above ambient)
and
Distance in Feet (from diffuser)

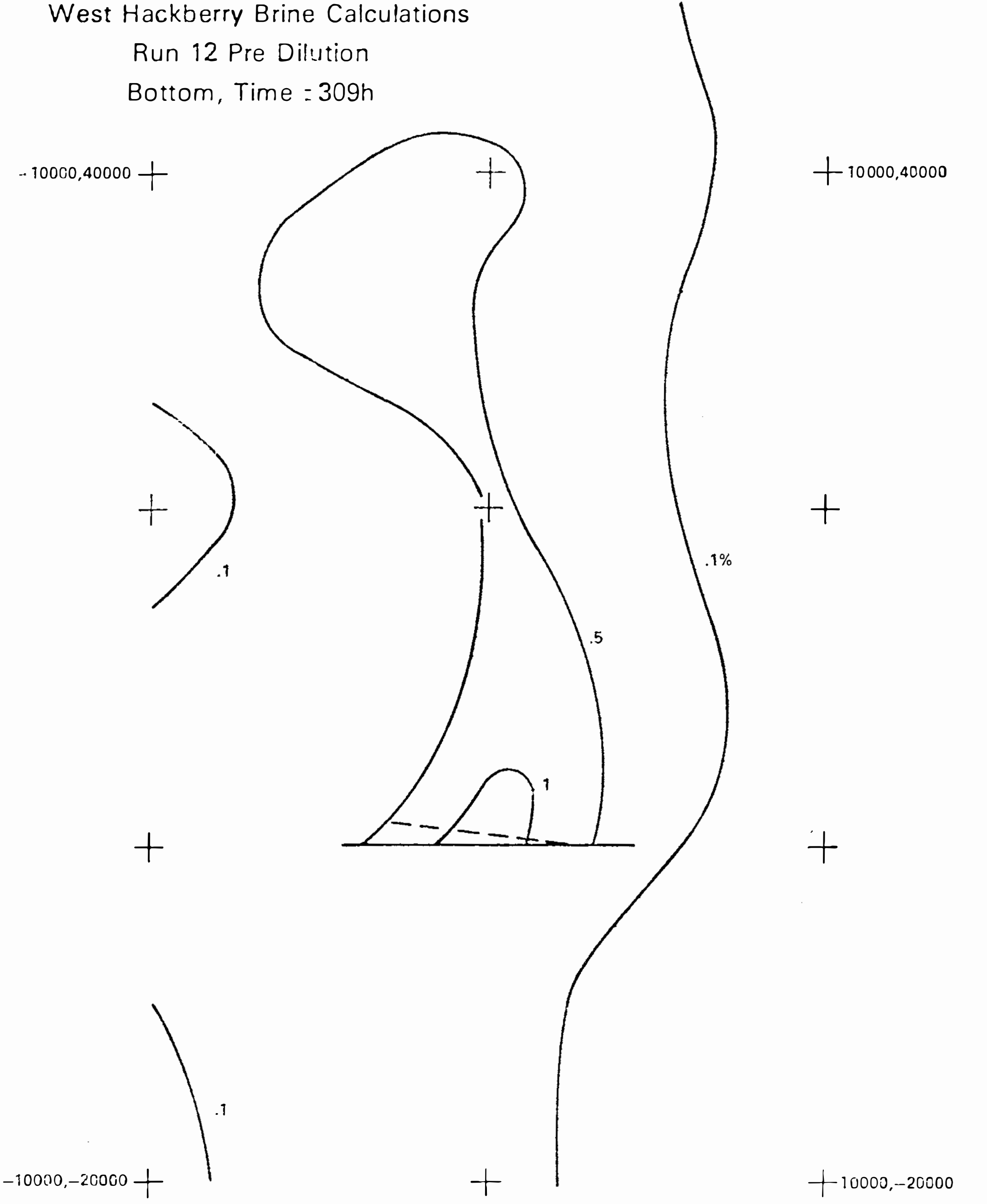
Fig. 48.

West Hackberry Brine Calculations
Run 11 — Long Diffuser
Bottom, Time = 309h



Excess Salinity in ppt (above ambient)
and
Distance in Feet (from diffuser)

Fig. 49.



Excess Salinity in ppt (above ambient)
and
Distance in Feet (from diffuser)

Fig. 50. Bottom Impact Areas (ft^2) vs Excess Salinity (ppt) at Various Times for Run 7.
Base Case

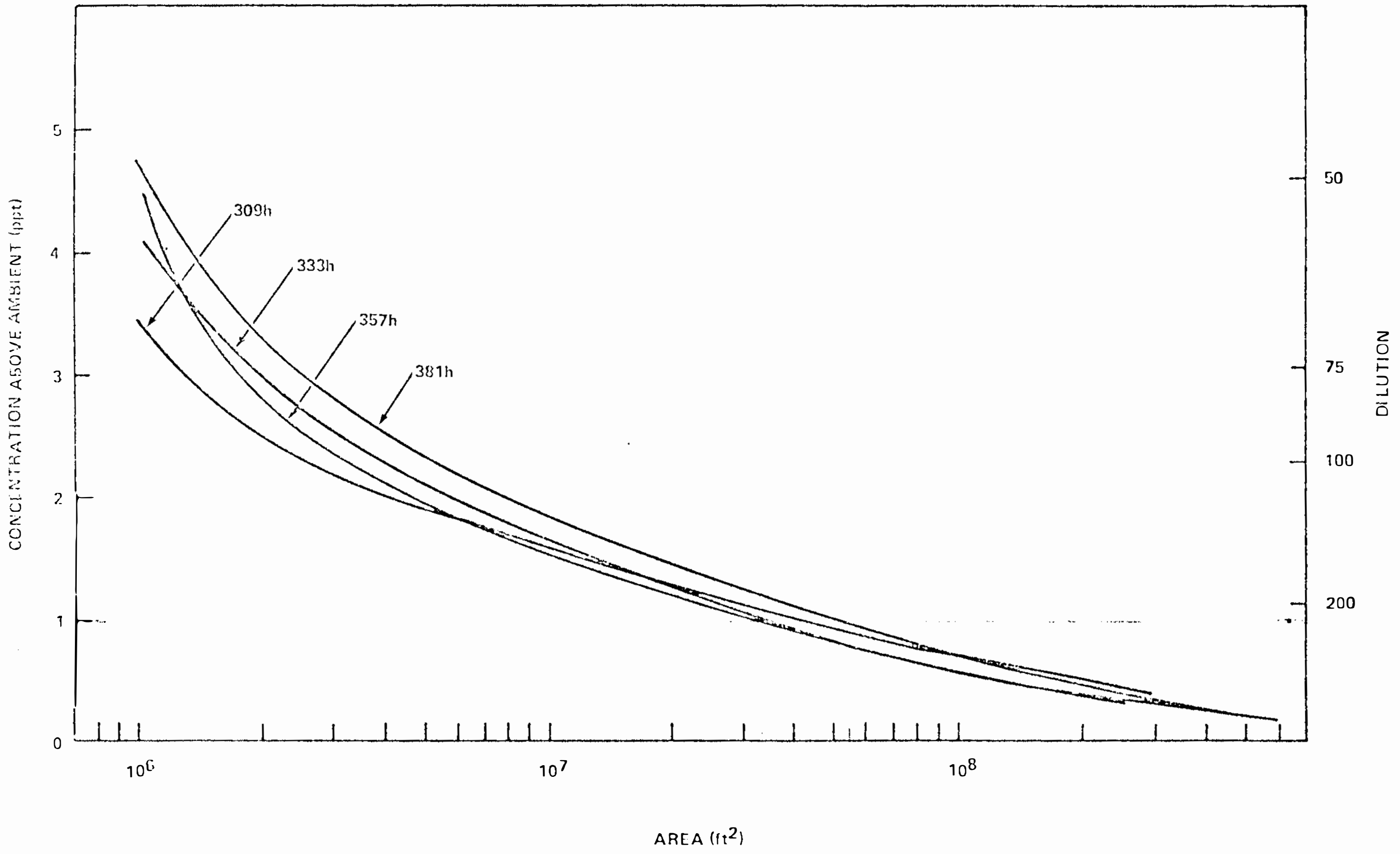


Fig. 51. Bottom Impact Areas (ft^2) vs Excess Salinity (ppt) at Various Times for Run 8. 16 Day Current Cycle

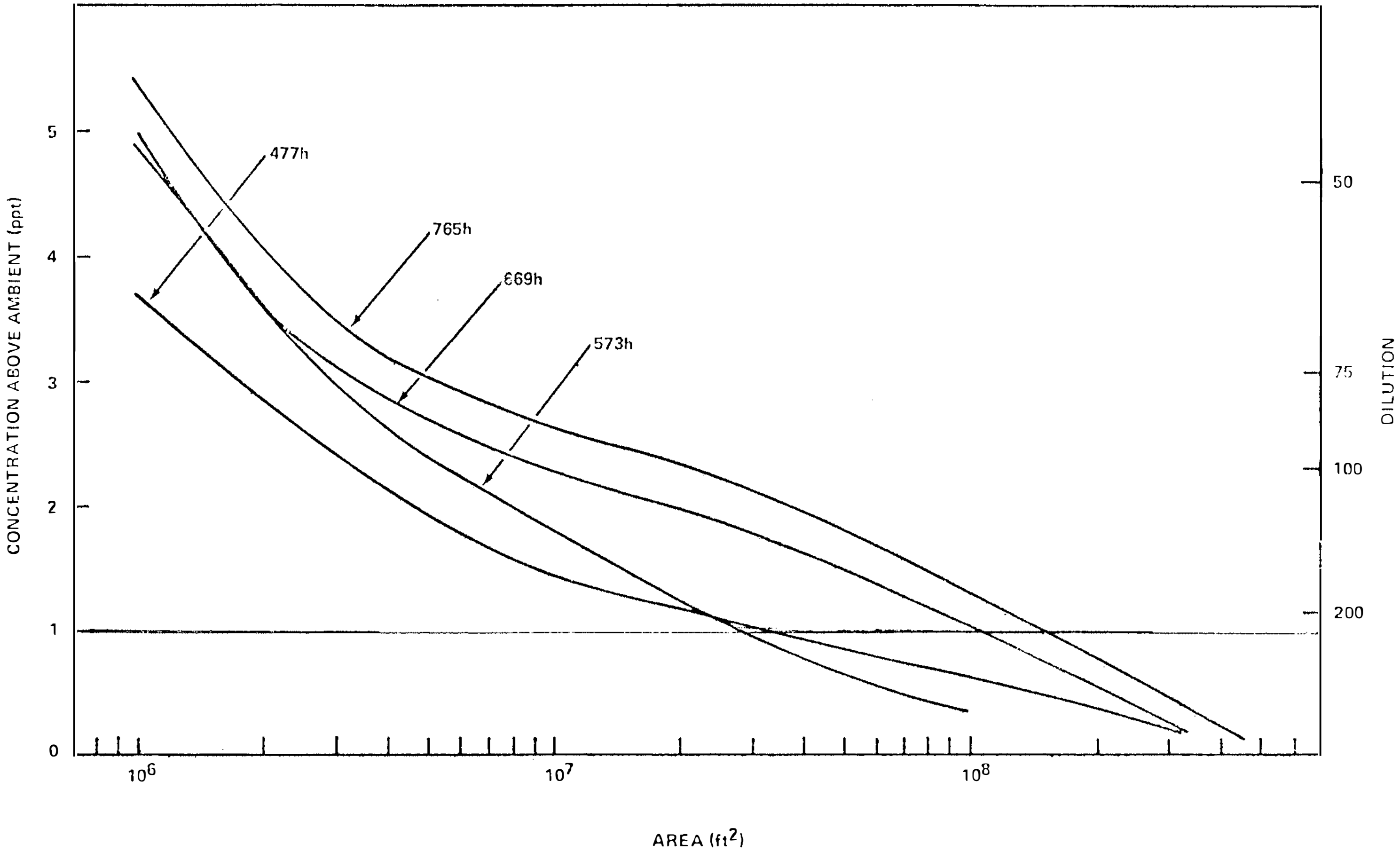


Fig. 52. Bottom Impact Areas (ft²) vs Excess Salinity (ppt) at Various Times for Run 9. Shallow Water Depth

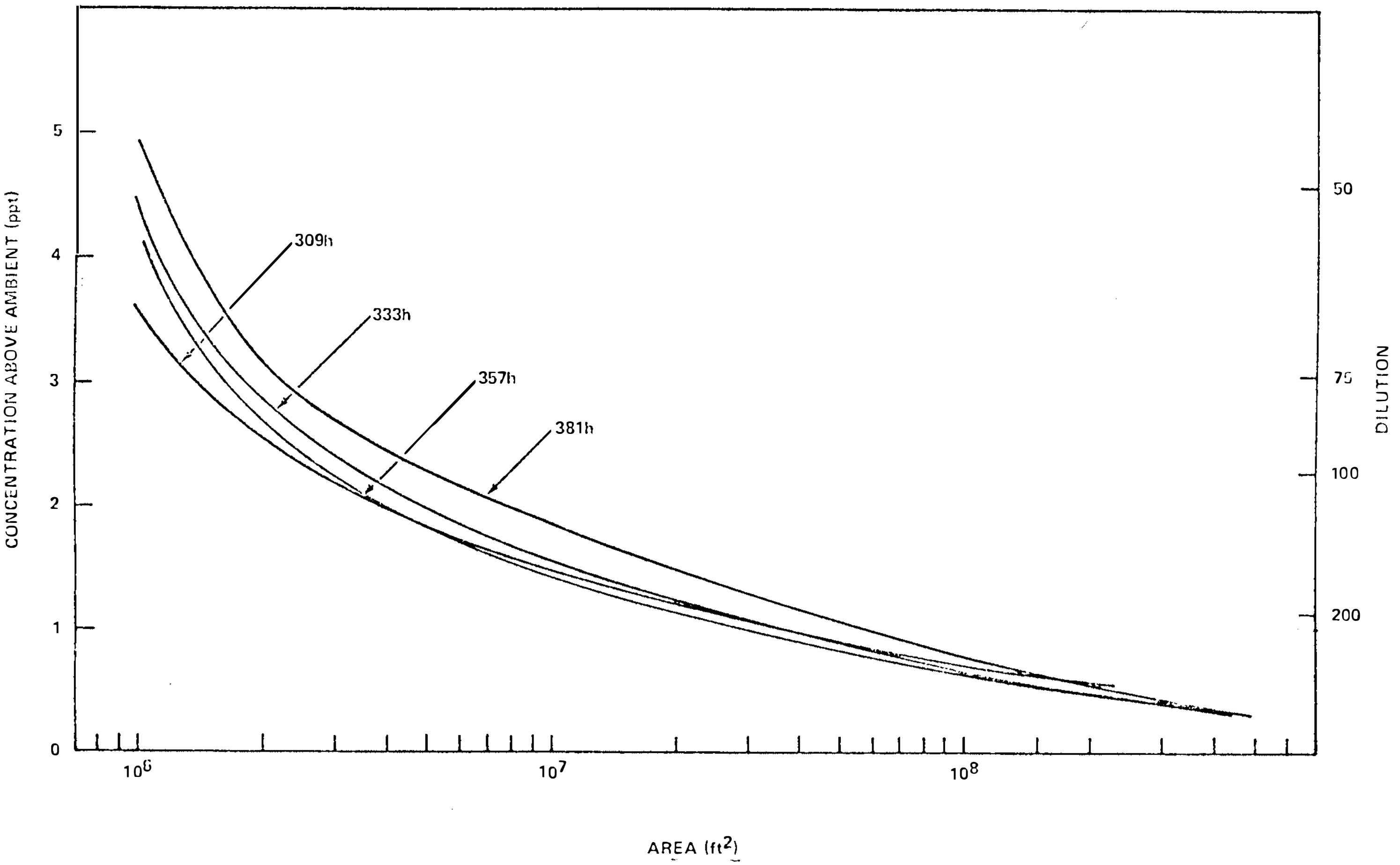


Fig. 53. Bottom Impact Areas (ft²) vs Excess Salinity (ppt) at Various Times for Run 10. Bryan Mound Discharge Conditions

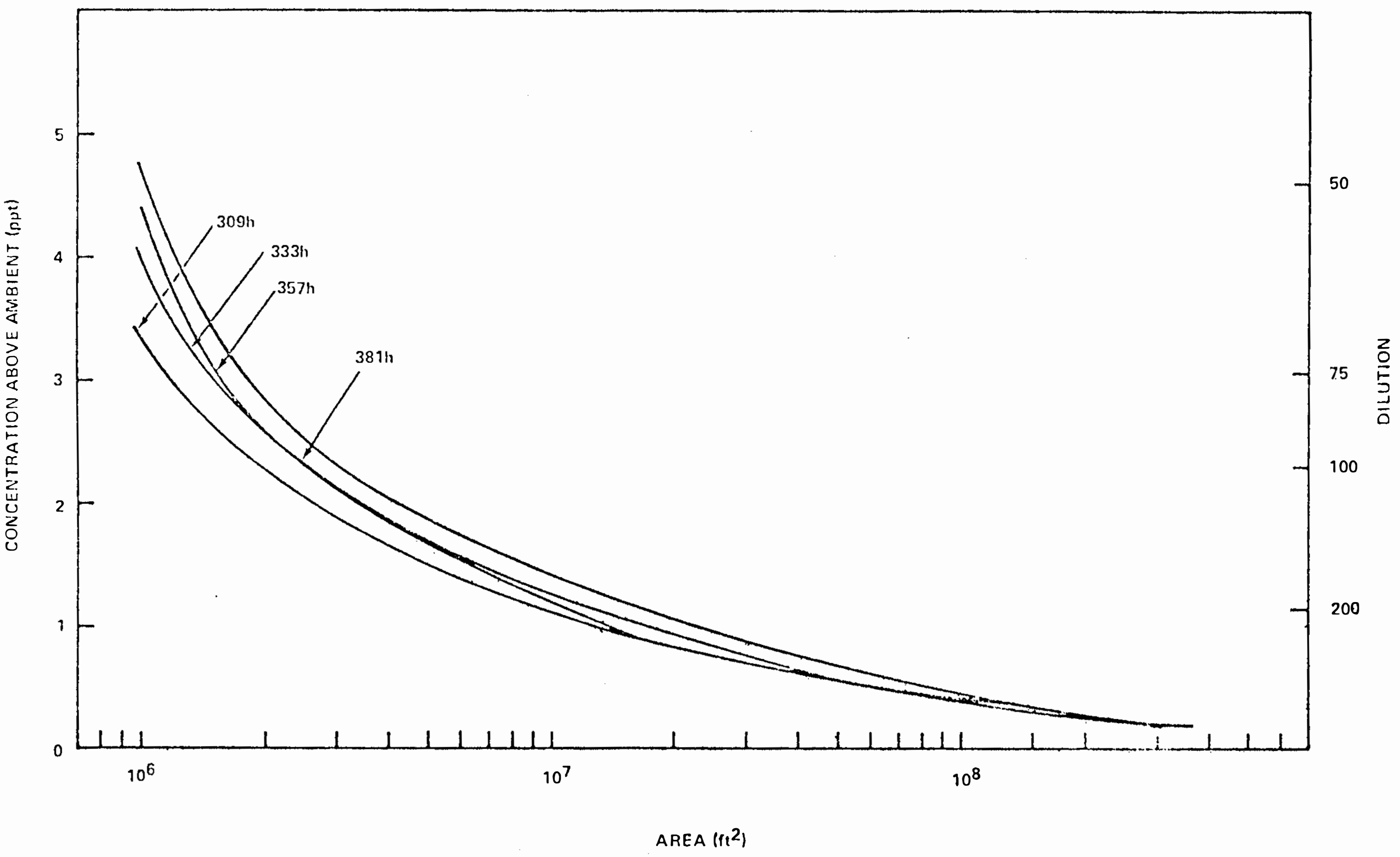


Fig. 54. Bottom Impact Area (ft²) vs Excess Salinity (ppt) at Various Times for Run 11. Long Diffuser

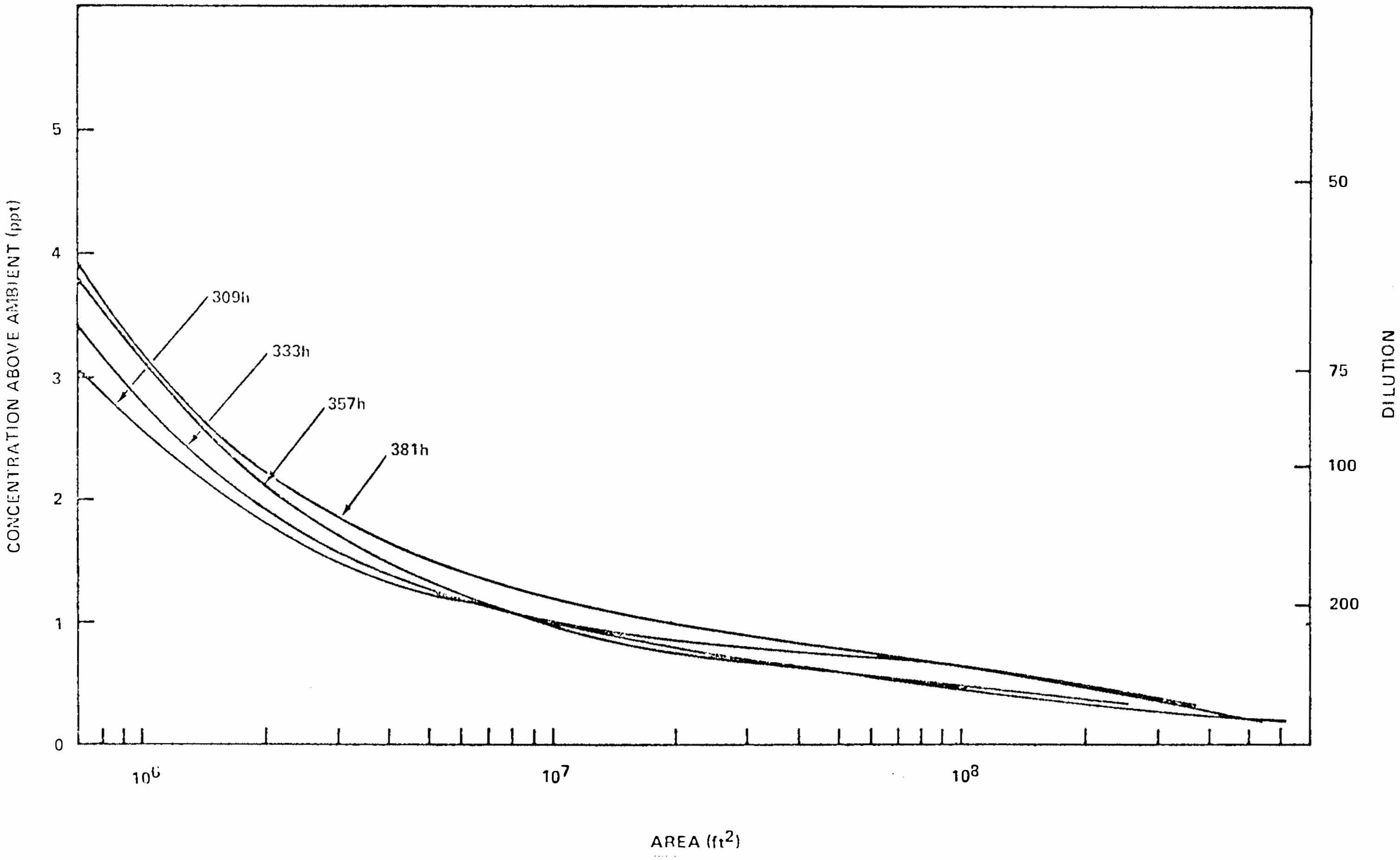
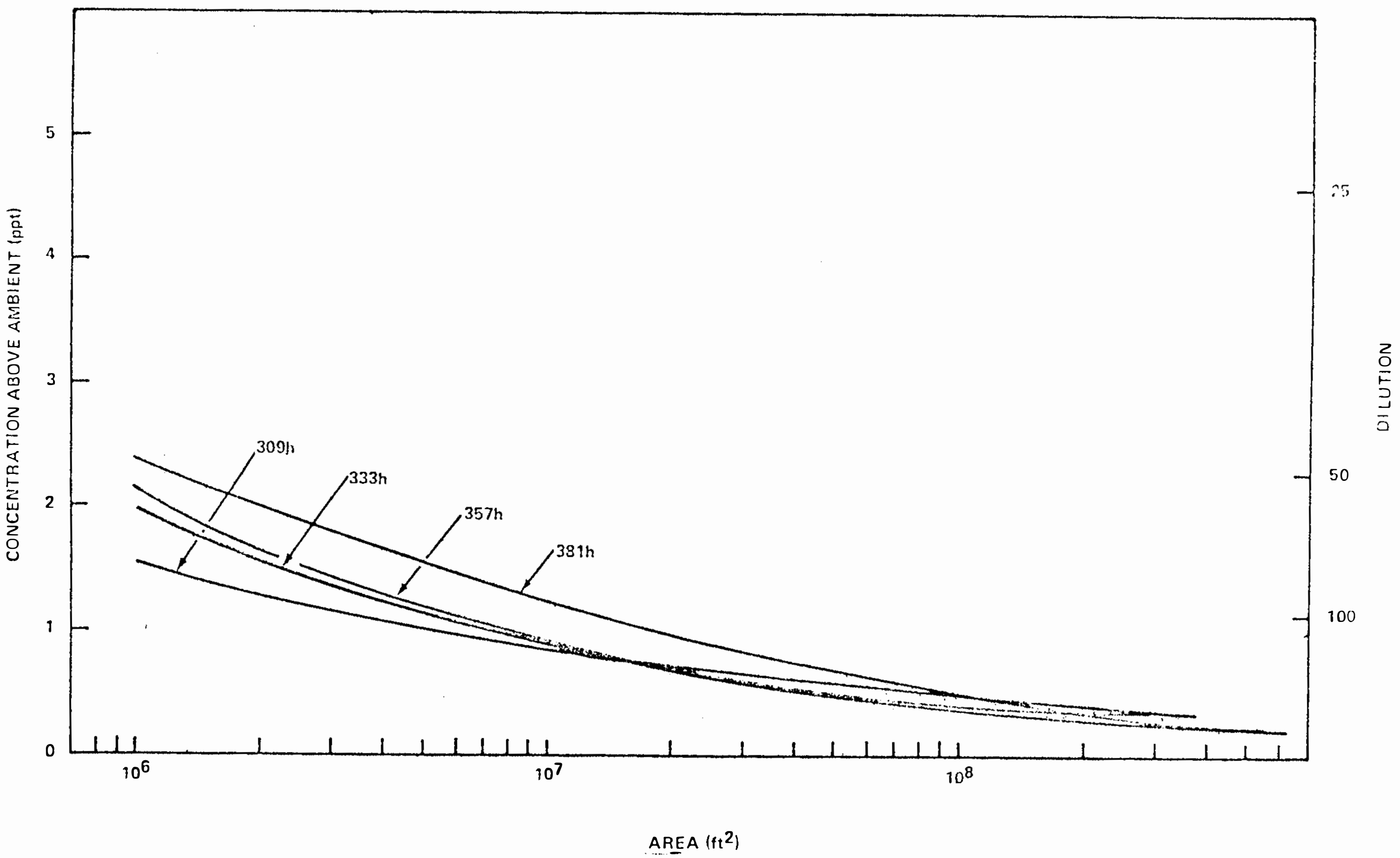


Fig. 55. Bottom Impact Areas (ft^2) vs Excess Salinity (ppt) at Various Times for Run 12.
Predilution



higher than for the strong net current cases due to concentration build-up and the poorer near field performance at lower ambient velocities. The time, T_1, for each run represents an intermediate situation where the current is instantaneously strong, but the effects of prior stagnation and/or a current in the reverse direction can be seen.

The buildup of concentration with time during periods of stagnation can be seen by comparing Figs. 43, 44, and 45 which involve Runs 7 and 8 and show bottom excess concentrations after periods of stagnation lasting 1, 2, and 8 days respectively. After 8 days it appears that concentrations near the diffuser have been increased by a background concentration of about 1 ppt.

Comparison of Runs 7 and 9 show that, for the cases considered, the depth of water has little influence on bottom concentrations. The reason is that the individual plumes do not reach the surface, and by the time that vertical diffusion produces mixing over the entire water depth, the resulting concentrations are relatively low and hence not very sensitive to the water depth. For the same reason mid-depth and surface excess concentrations are considerably lower than these on the bottom. (See Figures 41 a, b, c.)

The influence of the rate of brine loading is studied in Run 10 by performing calculations using a discharge flow rate which is characteristic of the Bryan Mound site. Comparison of Runs 7 and 10 (Figs. 41a and 47) indicate that the factor of .35 decrease in Q_O has a small effect on the induced concentration distribution. Because the discharge ports assumed for Run 10 were similar to those assumed for Run 7--the only difference was the number of ports and hence the length of the diffuser--concentrations near the diffusers are similar while at large distances from the diffuser, concentrations are somwehat lower for Run 10.

Run 11 tests a longer diffuser. The intent of this design would be to decrease the interaction among the plumes from the individual plumes (thus minimizing the possibility of salinity build-ups) and generally to spread the salt over a larger area in order to promote greater mixing. Examination of the area plots (Figs. 48 and 41 for Runs 11 and 7 respectively) suggest that while the concentrations near the longer diffuser are comparable with those for the base case--again the individual ports are identical with the exception of spacing--concentrations for Run 11 die off more rapidly at short distances from the diffuser than those for Run 7. The latter observation can be explained in terms of the shorter virtual source height h_2 which characterizes the longer diffuser. Because the same quantity of salt is being added, however, concentrations at large distances from the diffuser approach those for the base case.

Run 12 illustrates the effect of a two-fold decrease in discharge excess concentration caused by mixing the brine flow with an equal flow of ambient sea water. As expected, excess concentrations near the diffuser are lower than those for the other runs by a factor of about two. Again, however, because the total amount of salt which is injected is not being changed, concentrations at large distances from the diffuser approach those for the other runs.

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APPENDIX D.26

PRELIMINARY BASELINE WATER QUALITY SAMPLING IN WEST HACKBERRY VICINITY

Environmental baseline data were collected on April 8 and 9, 1977, taken for the purpose of documenting existing water quality characteristics for the West Hackberry area. Water samples were collected at 6 stations in the area of the oil distribution and raw water pipeline rights-of-way and at a point halfway between Black Lake and the Calcasieu Lake on Black Lake Bayou (Figures 1 and 2). The stations were numbered as follows:

Location	Sampling Station Number
Sabine River	7
Burton Shell Slip	8
Black Bayou Cutoff	9
Black Bayou	10
Intracoastal Waterway	11
Black Lake (southwest)	12
Black Lake (southeast)	13
Black Lake Bayou	14

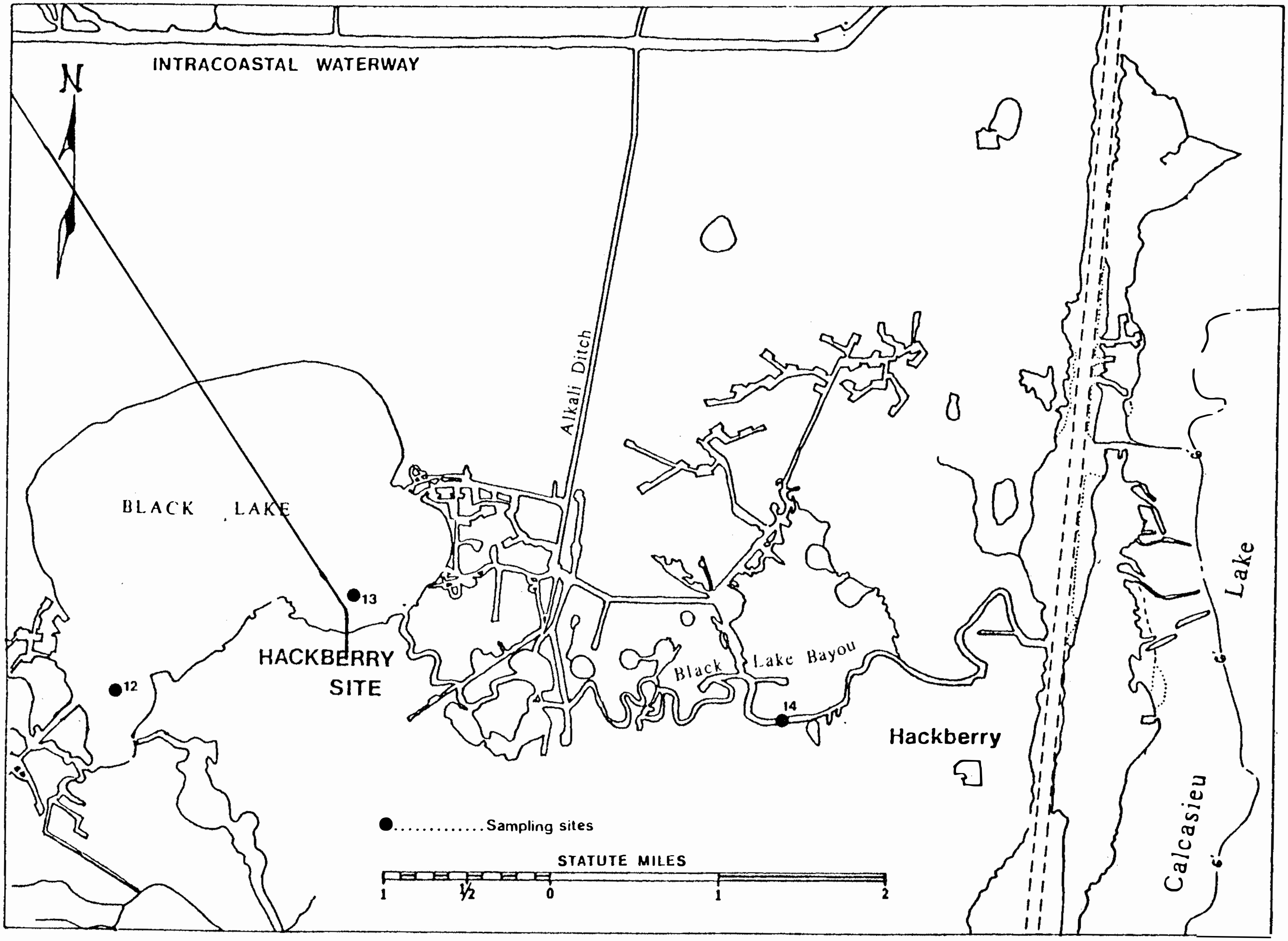

Figure 1 Sampling Locations Onsite at the West Hackberry Salt Dome Facility

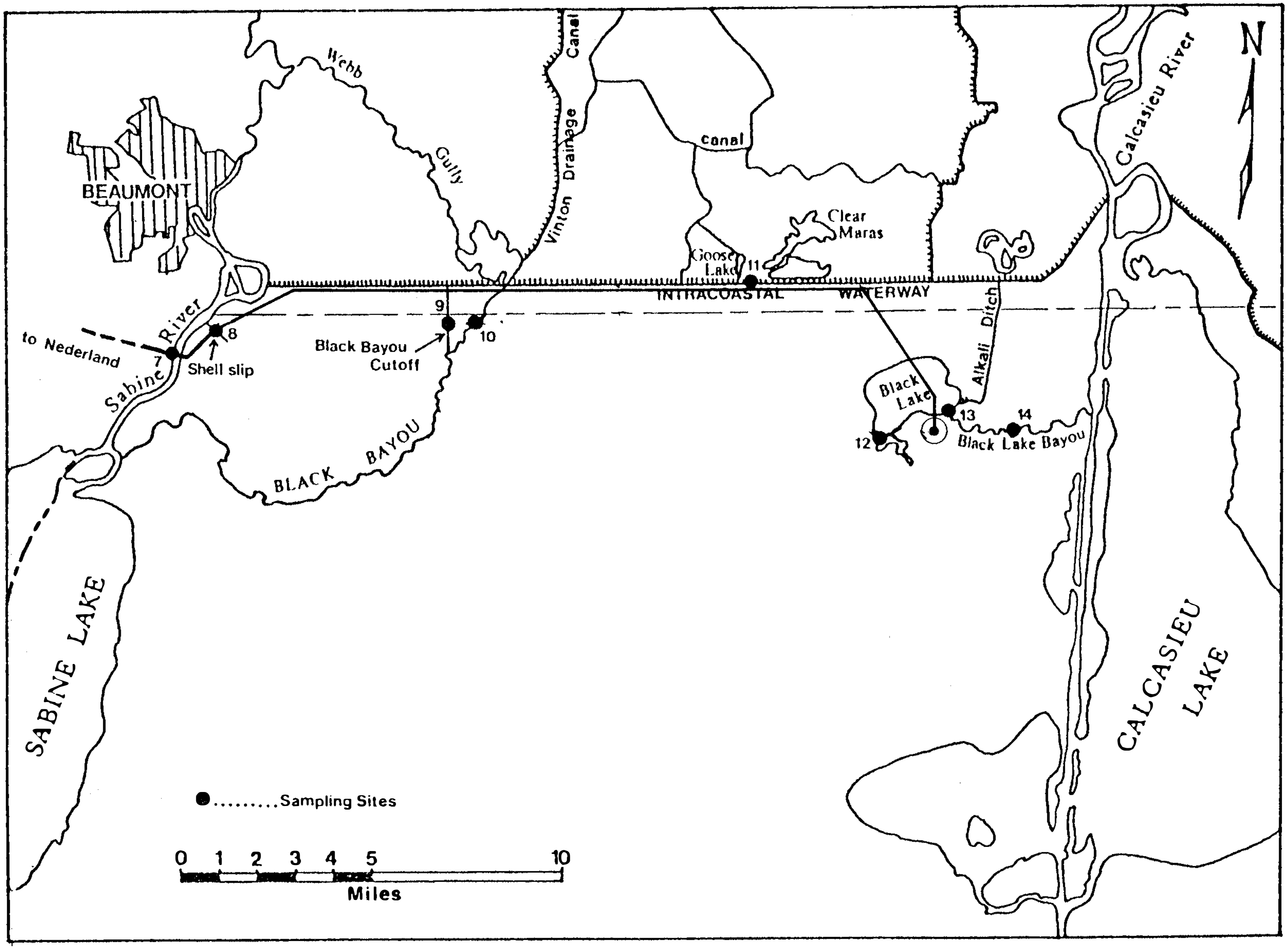

Figure 2 Sampling Stations on the Oil Distribution Pipeline Corridor for the West Hackberry Salt Dome Facility

Table 7 Comparative Presentation of Water Chemistry Data Collected at West Hackberry Salt Dome Facility

Parameters	EPA Proposed Criteria	Sabine River	Burton Shell Slip	Black Bayou Cutoff	Black Bayou	Intracoastal Waterway	Black Lake (southwest)	Black Lake (southeast)	Black Lake Bayou
total Kjeldahl Nitrogen, mg/l	-	4.9	4.1	4.7	2.1	5.1	1.1	1.3	1.2
Solids, susp., mg/l	-	28	24	28	32	112	16	24	60
Solids, suspended volatile, mg/l	-	12	16	16	24	28	12	12	32
Oil and Grease, mg/l	-	1	1	1	4	1	3	1	1
Mercury, mg/l	0.0001(m)[2]	<0.0001	0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
Lead, mg/l	0.1x96 hr LC_{50}	0.02	0.05	0.05	0.01	0.03	0.01	0.05	0.09
Nickel, mg/l	0.01x96 hr LC_{50}	0.01	<0.01	<0.01	<0.01	0.03	0.02	0.04	0.05
COD, mg/l	-	21	46	454	289	113	81	173	909
Salinity, 0/00	-	0.1	1.2	0.4	1.8	0.08	5.2	4.8	6.5
Conductivity, umhos	-	290	2,000	700	2,800	1,090	8,000	7,100	9,900
Water Temperature °C	32-35	17	18.5	21.5	22.5	21.5	25	32	23.8
Dissolved Oxygen, mg/l	5.0	8.2	10.6	6.2	9.2	7.8	7.2	5.8	5.8
pH	6.5-9.0	7.3	7.5	7.3	7.5	7.5	7.3	7.5	7.7

Table 8 Comparative Presentation of Sediment Chemistry Collected at West Hackberry Salt Dome Facility

Parameters		Unofficial Criteria	Sabine River	Burton Shell Slip	Black Bayou Cutoff	Black Bayou	Intracoastal Waterway	Black Lake (southwest)	Black Lake (southeast)	Black Lake Bayou
total Kjeldahl Nitrogen, mg/kg		2,640 1,000	543	920	609	482	218	598	2,050*	660
Solids, volatile, mg/kg		-	7,980	40,100	51,400	26,500	6,620	45,900	78,500	368,000
Oil and Grease, mg/kg		1,500 7,150	132	228	135	108	113	173	74	638
Mercury, mg/kg		1.0	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Lead, mg/kg		50	8.1	11.8	14.8	7.7	8.6	13.3	11.6	7.6
Zinc, mg/kg		50	16.5	26.4	41.0	31.5	11.4	11.1	12.9	20.3
Nickel, mg/kg		-	3.0	10.0	21.8	12.1	10.2	6.5	9.2	7.6
COD, mg/kg		177,000 50,000	2,530	25,600	31,700	8,990	397	62,600*	51,300*	162,000*
Particle Size			57%/0.2	65%/0.2	53%/0.2	60%/0.2	13%/0.6	56%/0.2	55%/0.2	80%/0.2
			30%/0.4	20%/0.4	40%/0.4	20%/0.4	27%/1	24%/0.4	35%/0.4	7%/1
			10%/0.6	15%/1	7%/1.2	15%/1	60%/≥10	20%/1.2	5%/1.2	10%/1.8
			3%/1.4			5%/1.2			5%/1.2	3%/7
	% Clay		100%	100%	100%	100%	40%	100%	95%	97%
	% Silt								5%	3%
	% Sand						60%			

* Exceeds one of the proposed unofficial numerical criteria.

Table 9 Comparative Presentation of Elutriate Data Collected at Sampling Stations in the Vicinity of West Hackberry Salt Dome Facility

Parameters	EPA Proposed Criteria	Sabine River	Burton Shell Slip	Black Bayou Cutoff	Black Bayou	Intracoastal Waterway	Black Lake (southwest)	Black Lake (southeast)	Black Lake Bayou
total Kjeldahl Nitrogen, mg/l	-	16.6	8.7	9.7	8.8	8.1	9.3	10.4	9.9
Oil and Grease, mg/l	-	10	6	25	6	3	5	4	2
Mercury, mg/l	0.0001(n)[2]	<0.0001	0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
Lead, mg/l	0.1x96 hr LC_{50}	0.06	0.04	0.04	0.03	<0.01	0.05	0.05	0.08
Nickel, mg/l	0.01x96 hr LC_{50}	0.04	0.02	0.02	0.01	0.01	0.02	0.03	0.03
COD, mg/l	-	108	79	171	108	57	101	108	332
Salinity, 0/00	-	0	0	0.1	0.9	0.5	2.4	2.5	5
Conductivity, umhos	-	210	90	420	1,350	810	3,900	4,100	8,100

APPENDIX D.27

WITHDRAWAL OF WATER FROM THE ICW FOR WEST HACKBERRY LEACHING/DISPLACEMENT OPERATIONS

Application of MIT Water Quality Network Model

If the ICW is used as a source of displacement water, replenishment water would be simultaneously supplied from both the Sabine River and the Calcasieu River. The flow may also be influenced by the Alkali Ditch and the associated network of water bodies connecting it with Black Lake and the Calcasieu Ship Channel. The governing equations for this complex flow process are most conveniently solved using standard numerical models. The MIT Water Quality Network Model which is described in Appendix D.14 has been used to provide such a solution. A network was developed consisting of the segment of the ICW from Sabine River to the Calcasieu Ship Channel, Old Canal, the Alkali Ditch and a withdrawal point as shown schematically in Figure D.27-1. The dimensions assumed for these water bodies were as follows:

	Top Width	Bottom Width	Depth
ICW	440 feet	200 feet	16 feet
Old Canal	315 feet	75 feet	16 feet
Alkali Ditch	185 feet	85 feet	7 feet

All other water bodies are taken into account implicitly by way of boundary conditions or by assumed distributed lateral inflows into the ICW. For the first case the boundary conditions and lateral inflows were established as follows:

Location	Hydraulic	Water Quality
Junction of the ICW with the Sabine River	Sinusoidal variation of surface height with a range of 1.0 feet, a period of 12 hours and a lag time of 113.0 minutes	Constant salinity of 14 ppt.
Junction of the ICW with the Calcasieu Ship Channel	Sinusoidal variation of surface height with a range of 1.25 feet, a period of 12 hours and a lag time of 4.0 minutes.	Constant salinity of 15 ppt.

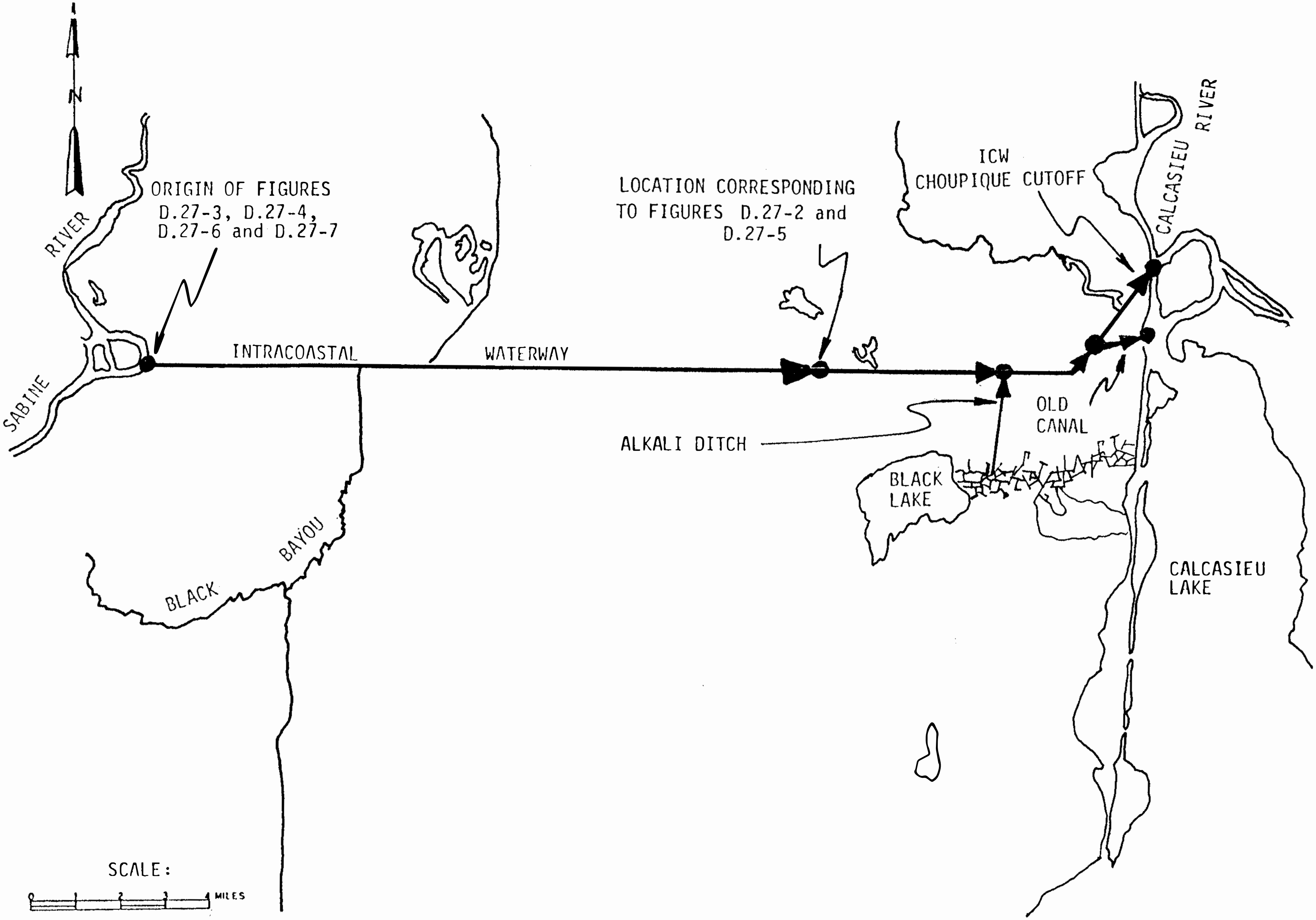

Figure D.27-1. Location of Reference Points and Reaches in the Intracoastal Waterway Network Analysis

Junction of Old Canal with the Calcasieu Ship Channel	Sinusoidal variation of surface height with a range of 1.25 feet, a period of 12 hours and a lag time of zero.	Constant salinity of 15 ppt.
Entire Length of ICW	Constant lateral inflow of 0.004 ft^3/sec/ft	Constant salinity of 0.1 ppt for lateral inflow
Junction of Alkali Ditch with Channel Network Connection to Black Lake and Calcasieu Ship Channel	Sinusoidal variation of surface height with range of 0.30 feet, period of 12 hours and lag time of zero.	Constant salinity of 14 ppt.
Withdrawal Point in the ICW	Zero withdrawal for 60 days followed by withdrawal of 95.5 ft^3/sec for 150 days.	Zero diffusive flux.

During an initial 60-day period no withdrawal of water took place and the network of water bodies was allowed to approach equilibrium. The resulting variation of water surface height and salinity near the withdrawal point during the last 30 days of this start-up period is included in Figure D.27-2. The spatial distribution of salinity in the ICW, Old Canal, and Alkali Ditch at the end of the 60-day start-up period is included in Figure D.27-3. The corresponding distribution of flow velocities is included in Figure D.27-4.

The variation of water surface height and salinity at the withdrawal point for a 150-day withdrawal operation is also shown in Figure D.27-2. The spatial distribution of salinity in the ICW, Old Canal, and Alkali Ditch at the end of the 150-day withdrawal process is included in Figure D.27-3. The corresponding spatial distribution of flow velocities is included in Figure D.27-4.

Examination of Figure D.27-2 reveals that after the start of water withdrawal no change in the ICW surface height occurred near the withdrawal point, while equilibrium with respect to salinity variation was achieved after about 35 days.

For a second case the hydraulic boundary conditions were altered to determine the sensitivity to the conditions assumed for the Alkali Ditch. In this case the hydraulic boundary condition at the end of the Alkali Ditch near Black Lake was lifted and the water level was allowed to vary as determined by the model calculation. A constant salinity of 14 ppt was

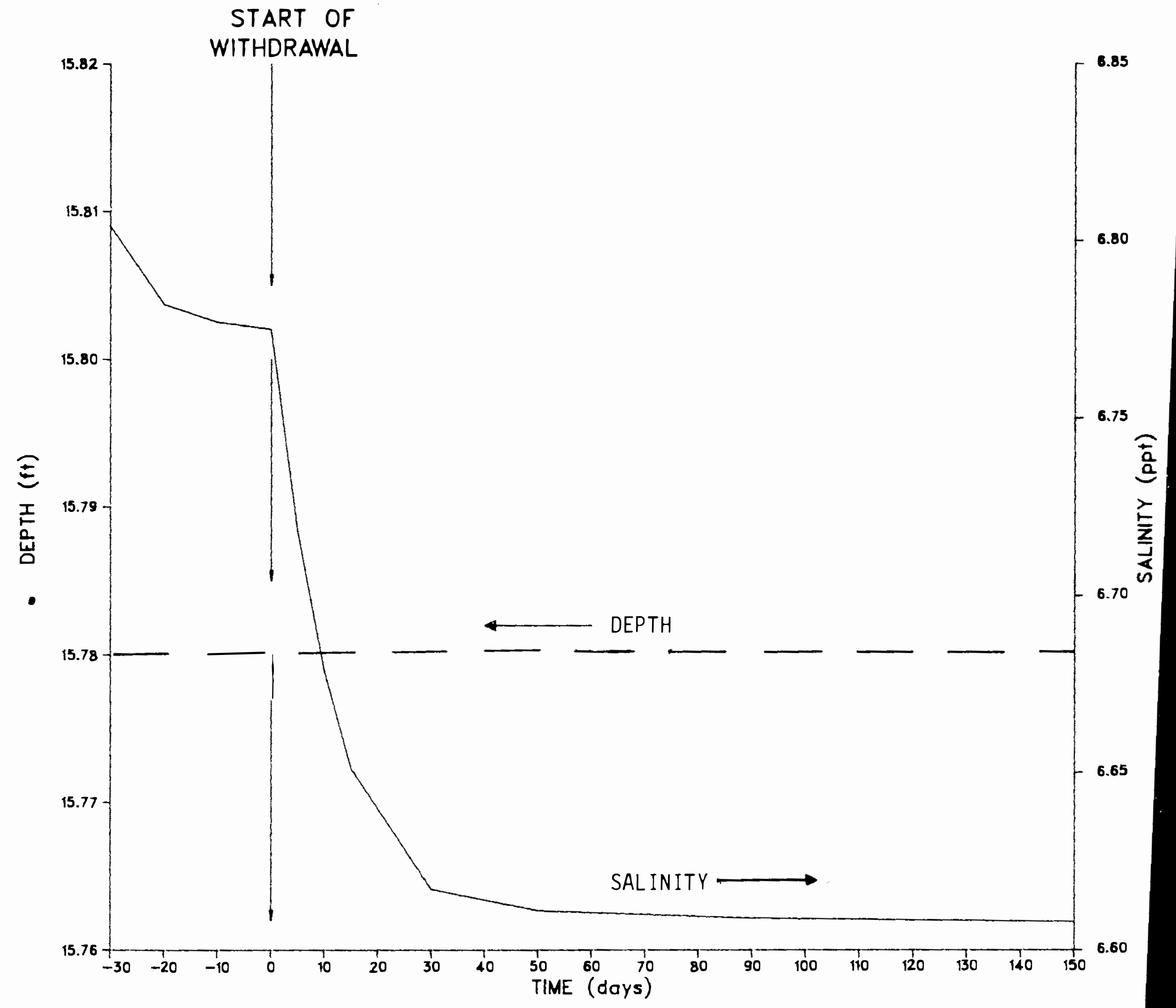

FIGURE D.27-2 TEMPORAL VARIATION OF DEPTH AND SALINITY IN THE ICW NEAR THE WITHDRAWAL POINT (TEST CASE 2- NO HYDRAULIC BOUNDARY CONDITIONS IN ALKALI DITCH.)

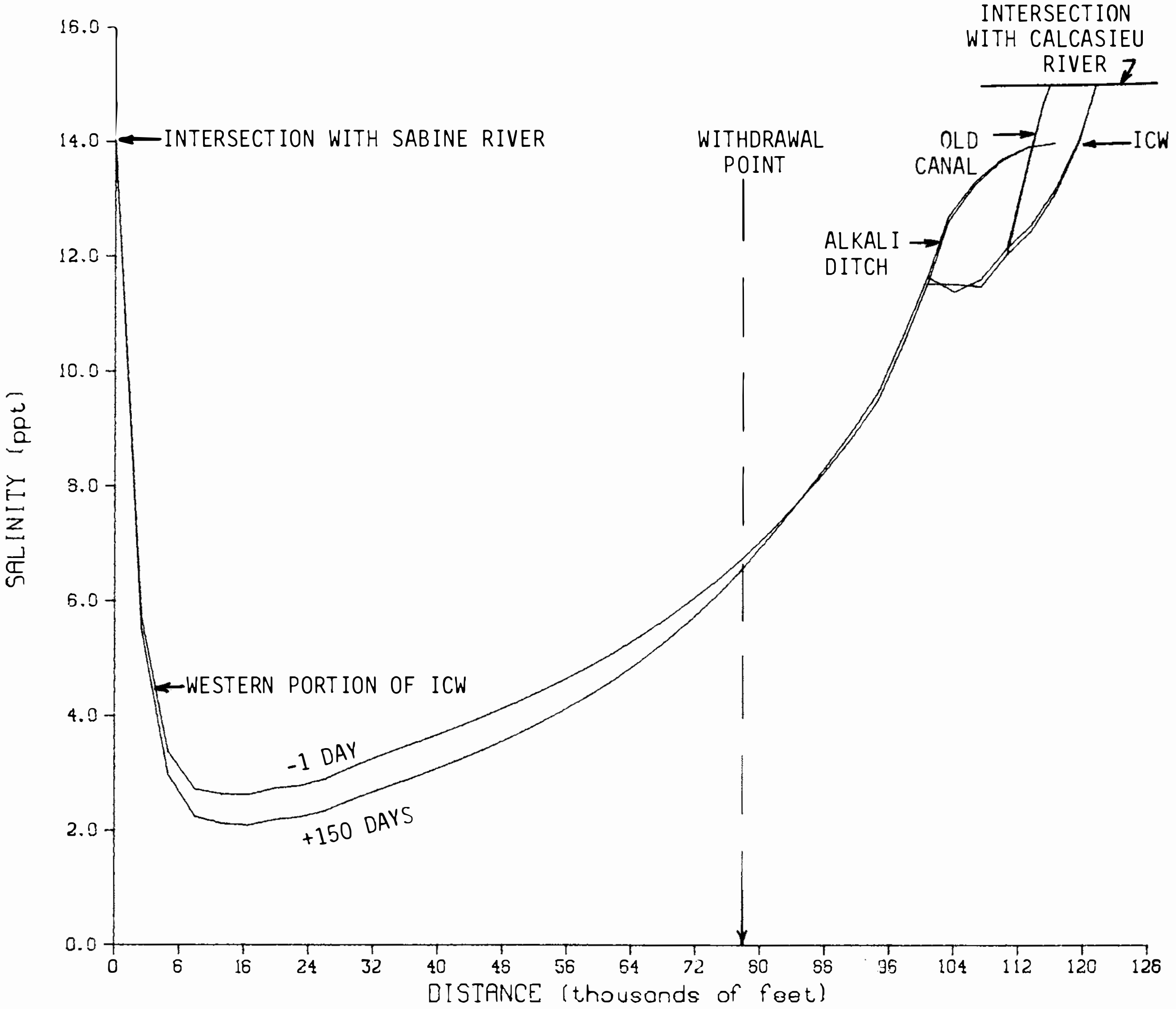

FIGURE D.27-3 SPATIAL VARIATION OF SALINITY IN THE ICW, OLD CANAL AND ALKALI DITCH. (TEST CASE 1- HYDRAULIC BOUNDARY CONDITIONS IN ALKALI DITCH.)

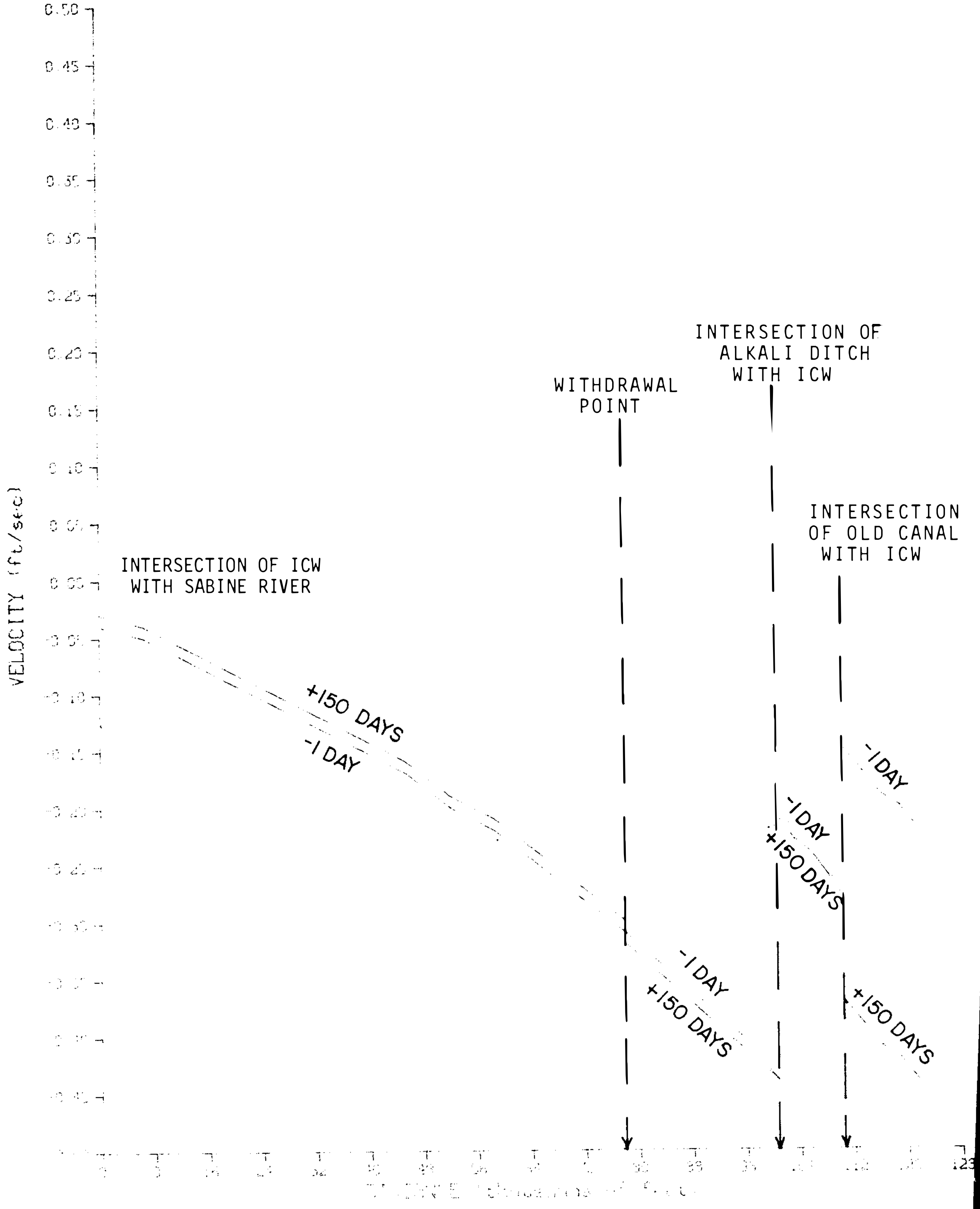

FIGURE D.27-4 SPATIAL VARIATION OF FLOW VELOCITY IN ICW. (TEST CASE 1- HYDRAULIC BOUNDARY CONDITIONS IN ALKALI DITCH.)

fixed at this point throughout the problem, however. All other boundary conditions were established as for the first case.

The results of the second case are presented in a format identical to that shown for the first case. Figure D.27-5 includes the variation of water surface height at the withdrawal point for the 30 days prior to withdrawal. The spatial distribution of salinity in the ICW, Old Canal, and Alkali Ditch at the end of the 60-day start-up period is shown in Figure D.27-6. The corresponding distribution of flow velocities is shown in Figure D.27-7.

The variation of water surface height and salinity at the withdrawal point for a 150-day displacement operation is also shown in Figure D.27-5. The distribution of salinity at the end of the 150-day withdrawal process, is included in Figure D.27-6. The corresponding distribution of flow velocities is shown in Figure D.27-7.

Examination of Figure D.27-5 reveals that after the start of water withdrawal the ICW reached hydraulic equilibrium almost immediately, while equilibrium with respect to salinity variation was achieved after about 35 days.

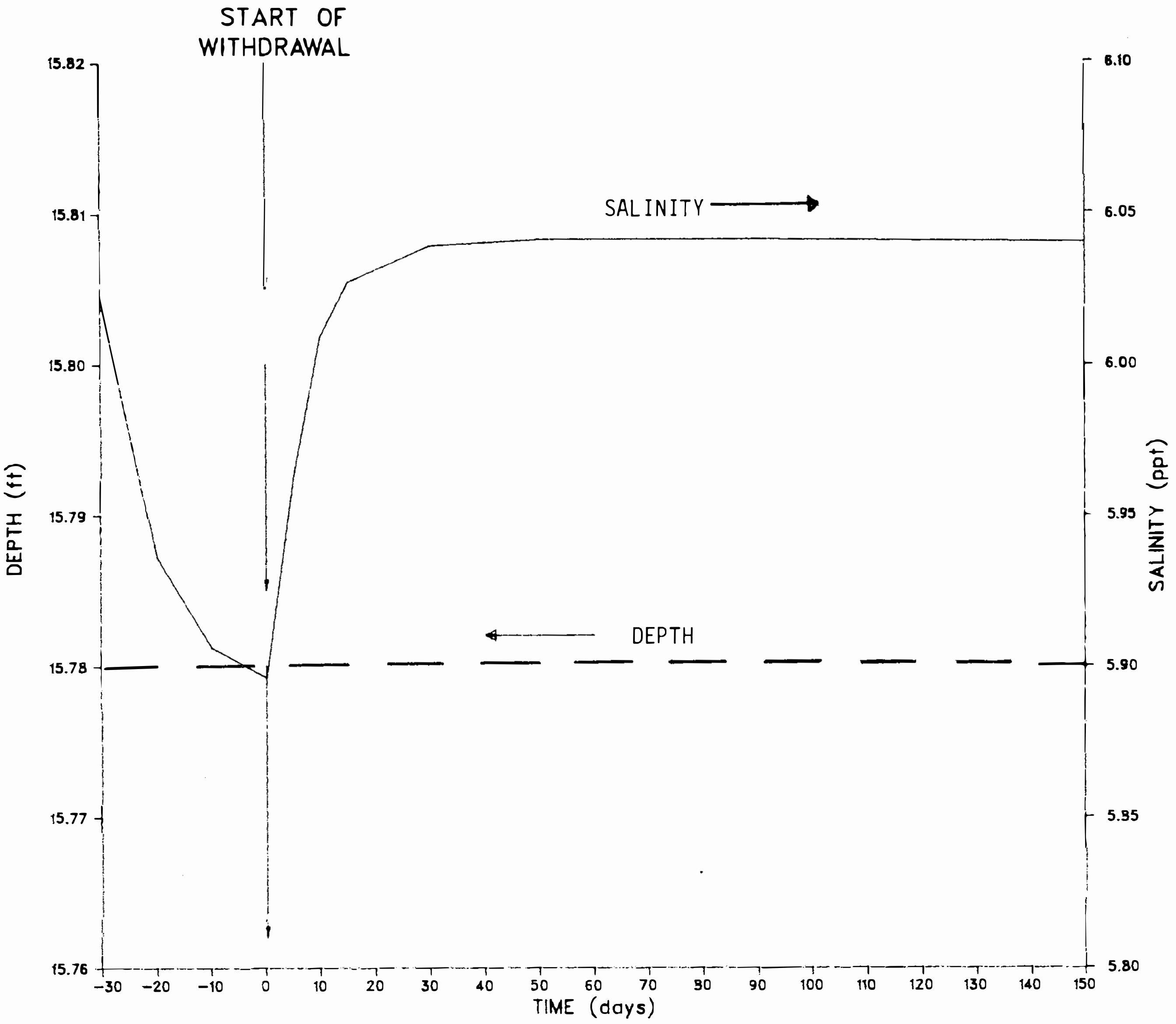

FIGURE D.27-5 TEMPORAL VARIATION OF DEPTH AND SALINITY IN THE ICW NEAR THE WITHDRAWAL POINT (TEST CASE 1- HYDRAULIC BOUNDARY CONDITIONS IN ALKALI DITCH.)

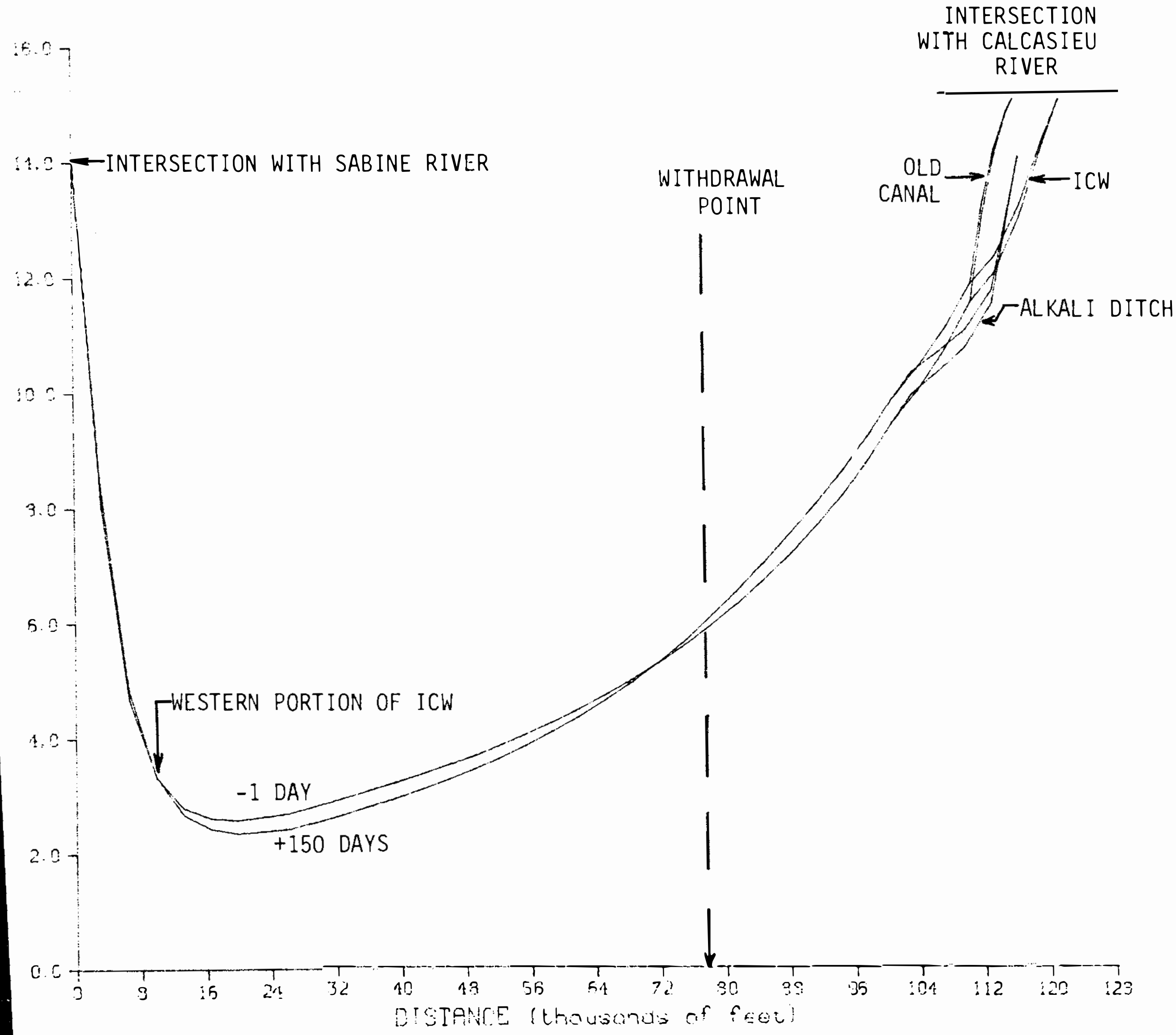

FIGURE D.27-6 SAME AS D.27-3 EXCEPT (TEST CASE 2- NO HYDRAULIC BOUNDARY CONDITION IN ALKALI DITCH.)

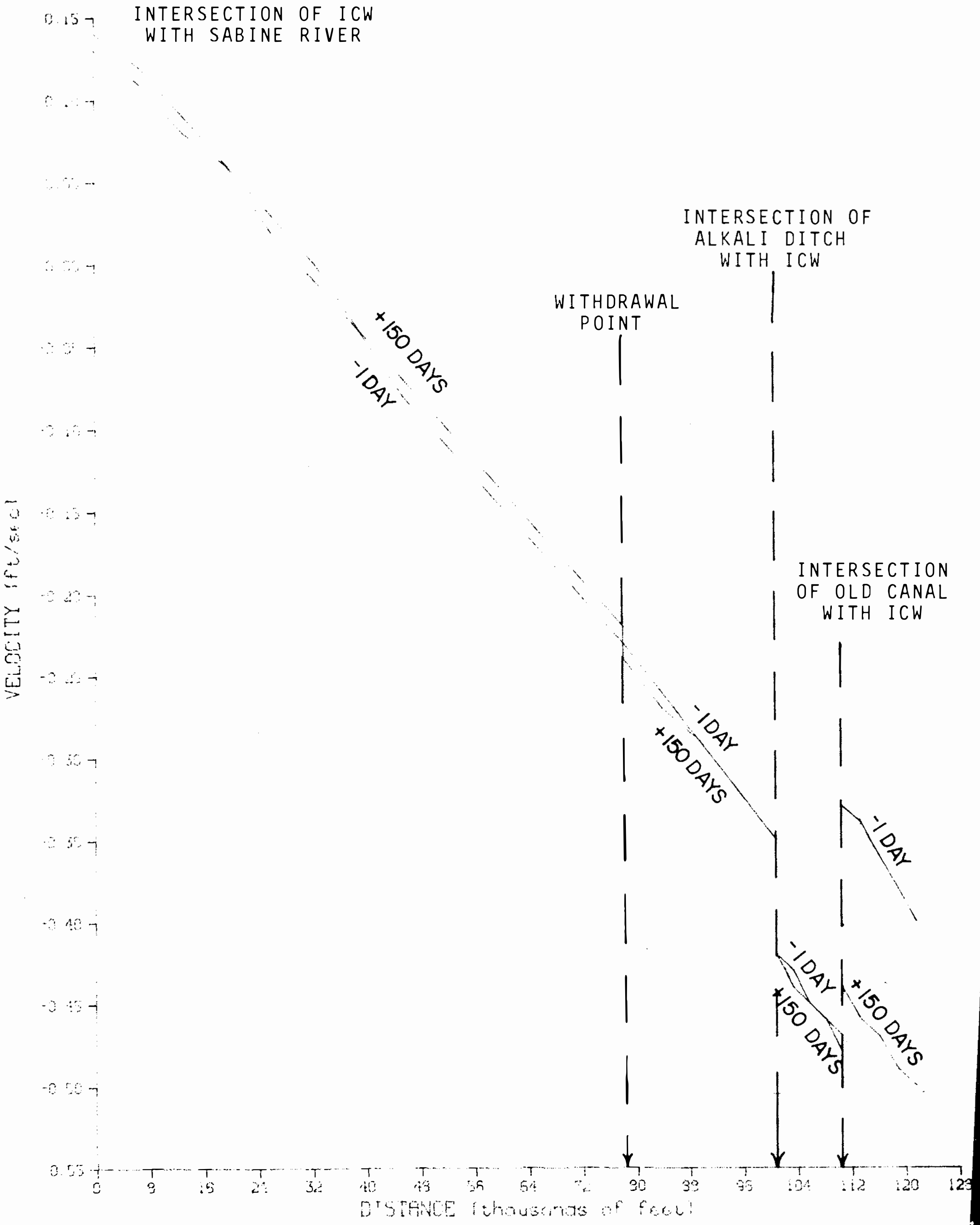

FIGURE D.27-7 SPATIAL VARIATION OF FLOW VELOCITY IN ICW. (TEST CASE 2- NO HYDRAULIC BOUNDARY CONDITIONS IN ALKALI DITCH.)

APPENDIX E

SITE SPECIFIC SHORT-TERM AND LONG-TERM EMISSION RATES AND EMISSIONS FROM MARINE VESSEL TRANSFERRING OF CRUDE OIL

APPENDIX E.1

Site-Specific Short-Term and Long-Term Emission Rates

TABLE E-1

Site Specific Short-Term Emission Rates And Source Locations For West Hackberry

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO$_2$	NO$_2$	CO
Construction						
1. Drill Rig(1)	Dome Site	0.3	0.3	0.2	3.8	0.8
2. Tank Preparation						
a. Surface Grinding(2)	Dome Site	--	0.8	--	--	--
	Sun Terminal	--	0.8	--	--	--
b. Paint Application(3)	Dome Site	2.1	--	--	--	--
	Sun Terminal	2.1	--	--	--	--
Operation						
1. Tanker Loading(4)	Sun Terminal	109.2	--	--	--	--
2. Tanker Ballasting(5)	Sun Terminal	4.9	--	--	--	--
3. Tank Emissions*(6)						
a. Surge Storage(7)	Sun Terminal	0.3	--	--	--	--
b. Ballast Treatment(8)	Sun Terminal	0.1	--	--	--	--

Notes:

1. Q = (Emission Factor [g/hp·hr]) x 1500 hp x .75 of capacity x 20/24 hours = g/s
2. Q = (1000# abrasive/hr)(1% of material lost)(454 g/#)(hr/3600 sec)(0.6 [fraction of particles < 30 μm]) = g/s
3. Q = (1120# HC/ton applied)(400 ft^2/hr)(1 gal pt/200 ft^2)(15#/gal)(ton/2000#)(454g/#)(hr/3600 sec) = g/s
4. Q = (0.55#/1000 gal)(42 gal/bbl)(1.0 x 10^6 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(.6 by tanker) (1.5 [weathering factor]) = g/s
5. Q = (0.42#/1000 gal)(42 gal/bbl)(175,000 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(0.2 of capacity ballasted) = (1.5 [weathering factor]) g/s
6. TVP = 5 psia
7. 3 - 200,000 bbl tanks
8. 2 - 55,000 bbl tanks

* Standing storage loss only

TABLE E-1

Site Specific Short-Term Emission Rates And Source Locations For West Hackberry

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
(continued)						
c. Surge Storage(1)	Dome Site	0.01	--	--	--	--
d. Blanket Tank(2)	Dome Site	0.003	--	--	--	--
4. Pipeline						
a. Pump Seals(3)	Sun Terminal	0.07	--	--	--	--
b. Valves(4)	Sun Terminal	0.02	--	--	--	--
c. Pump Seals(5)	Dome Site	0.17	--	--	--	--
d. Valves(5)	Dome Site	0.05	--	--	--	--

1. 1 - 20,000 bbl tank
2. 1 - 3,000 bbl tank
3. Q = 1.13#/day-seal)(6 pumps)(2 seals/pump)(454 g/#)(day/24 hours)(hr/3600 sec) = g/s
4. Q = 0.108#/day-valve)(6 pumps)(6.25 valve/pump) 454 g/#)(day/24 hours)(hr/3600 sec) = g/s
5. See formulae as used in footnotes 3 and 4 based upon 14 pumps at the dome site.

TABLE E-2

Site Specific Short-Term Emission Rates And Source Locations For Black Bayou

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Construction						
1. Drill Rig(1)	Dome Site	0.3	0.3	0.2	3.8	0.8
2. Tank Preparation						
a. Surface Grinding(2)	Dome Site	--	0.8	--	--	--
	Sun Terminal	--	0.8	--	--	--
b. Paint Application(3)	Dome Site	2.1	--	--	--	--
	Sun Terminal	2.1	--	--	--	--
Operation						
1. Tanker Loading(4)	Sun Terminal	109.2	--	--	--	--
2. Tanker Ballasting(5)	Sun Terminal	4.9	--	--	--	--
3. Tank Emissions*(6)						
a. Surge Storage(7)	Sun Terminal	0.3	--	--	--	--
b. Ballast Treatment(8)	Sun Terminal	0.1	--	--	--	--

Notes:

1. Q = (Emission Factor [g/hp·hr]) x 1500 hp x .75 of capacity x 20/24 hours = g/s
2. Q = (1000# abrasive/hr)(1% of material lost)(454 g/#)(hr/3600 sec)(0.6 [fraction of particles < 30 μm]) = g/s
3. Q = (1120# HC/ton applied)(400 ft^2/hr)(1 gal pt/200 ft^2)(15#/gal)(ton/2000#)(454g/#)(hr/3600 sec) = g/s
4. Q = (0.55#/1000 gal)(42 gal/bbl)(1.4 x 10^6 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(.6 by tanker) (1.5 [weathering factor]) = g/s
5. Q = (0.42#/1000 gal)(42 gal/bbl)(175,000 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(0.2 of capacity ballasted) = (1.5 [weathering factor]) g/s
6. TVP = 5 psia
7. 3 - 200,000 bbl tanks
8. 2 - 55,000 bbl tanks

* Standing storage loss only

TABLE E-2

Site Specific Short-Term Emission Rates And Source Locations For Black Bayou

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
(continued)						
c. Surge Storage(1)	Dome Site	0.01	--	--	--	--
d. Blanket Tank(2)	Dome Site	0.003	--	--	--	--
4. Pipeline						
a. Pump Seals(3)	Sun Terminal	0.07	--	--	--	--
b. Valves(4)	Sun Terminal	0.02	--	--	--	--
c. Pump Seals(5)	Dome Site	0.13	--	--	--	--
d. Valves(5)	Dome Site	0.04	--	--	--	--

Notes:

1. 1 - 20,000 bbl tank
2. 1 - 3,000 bbl tank
3. Q = 1.13#/day-seal)(6 pumps)(2 seals/pump)(454 g/#)(day/24 hours)(hr/3600 sec) = g/s
4. Q = (0.108#/day-valve)(6 pumps)(6.25 valves/pump)(454 g/#)(day/24 hours)(hr/3600 sec) = g/s
5. See formulae as used in footnotes 3 and 4 based upon 11 pumps at the dome site.

TABLE E-3

Site Specific Short-Term Emission Rates And Source Locations For Vinton

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Construction						
1. Drill Rig(1)	Dome Site	0.3	0.3	0.2	3.8	0.8
2. Tank Preparation						
a. Surface Grinding(2)	Dome Site	--	0.8	--	--	--
	Sun Terminal	--	0.8	--	--	--
b. Paint Application(3)	Dome Site	2.1	--	--	--	--
	Sun Terminal	2.1	--	--	--	--
Operation						
1. Tanker Loading(4)	Sun Terminal	36.4	--	--	--	--
2. Tanker Ballasting(5)	Sun Terminal	1.6	--	--	--	--
3. Tank Emissions*(6)						
a. Surge Storage(7)	Sun Terminal	0.3	--	--	--	--
b. Ballast Treatment(8)	Sun Terminal	0.1	--	--	--	--

Notes:

1. Q = (Emission Factor [g/hp·hr]) x 1500 hp x .75 of capacity x 20/24 hours = g/s
2. Q = (1000# abrasive/hr)(1% of material lost)(454 g/#)(hr/3600 sec)(0.6 [fraction of particles < 30 μm]) = g/s
3. Q = (1120# HC/ton applied)(400 ft^2/hr)(1 gal pt/200 ft^2)(15#/gal)(ton/2000#)(454g/#)(hr/3600 sec) = g/s
4. Q = (0.55#/1000 gal)(42 gal/bbl)(333,330 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(0.6 by tanker) (1.5 [weathering factor]) = g/s
5. Q = (0.42#/1000 gal)(42 gal/bbl)(58,300 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(0.2 of capacity ballasted) (1.5 [weathering factor]) = g/s
6. TVP = 5 psia
7. 3 - 200,000 bbl tanks
8. 2 - 55,000 bbl tanks

* Standing storage loss only

TABLE E-3

Site Specific Short-Term Emission Rates And Source Locations For Vinton

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
(continued)						
c. Surge Storage(1)	Dome Site	0.01	--	--	--	--
d. Blanket Tank(2)	Dome Site	0.003	--	--	--	--
4. Pipeline						
a. Pump Seals(3)	Sun Terminal	0.05	--	--	--	--
b. Valves(4)	Sun Terminal	0.01	--	--	--	--
c. Pump Seals(5)	Dome Site	0.11	--	--	--	--
d. Valves(5)	Dome Site	0.03	--	--	--	--

Notes:

1. 1 - 20,000 bbl tank
2. 1 - 3,000 bbl tank
3. Q = 1.13 #/day-seal)(4 pumps)(2 seals/pump)(454 g/#)(day/24 hours)(hr/3600 sec) = g/s
4. Q = (0.018 #/day-valve)(4 pumps)(6.25 valves/pump)(454 g/#)(day/24 hours)(hr/3600 sec) = g/s
5. See formulae as used in footnotes 3 and 4 based upon 9 pumps at the dome site.

TABLE E-4

Site Specific Short-Term Emission Rates And Source Locations For Big Hill

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Construction						
1. Drill Rig(1)	Dome Site	0.2	0.3	0.2	3.8	0.8
2. Tank Preparation						
a. Surface Grinding(2)	Dome Site	--	0.8	--	--	--
	Sun·Terminal	--	0.8	--	--	--
b. Paint Application(3)	Dome Site	2.1	--	--	--	--
	Sun Terminal	2.1	--	--	--	--
Operation						
1. Tanker Loading(4)	Sun Terminal	72.8	--	--	--	--
2. Tanker Ballasting(5)	Sun Terminal	3.2	--	--	--	--
3. Tank Emissions*(6)						
a. Surge Storage(7)	Sun Terminal	0.3	--	--	--	--
b. Ballast Treatment(8)	Sun Terminal	0.1	--	--	--	--

Notes:

1. Q = (Emission Factor [g/hp·hr]) x 1500 hp x .75 of capacity x 20/24 hours = g/s
2. Q = (1000# abrasive/hr)(1% of material lost)(454 g/#)(hr/3600 sec)(0.6 [fraction of particles < 30 μm]) = g/s
3. Q = (1120# HC/ton applied)(400 ft^2/hr)(1 gal pt/200 ft^2)(15#/gal)(ton/2000#)(454g/#)(hr/3600 sec) = g/s
4. Q = (0.55#/1000 gal)(42 gal/bbl)(666,666 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(0.6 by tanker) (1.5 [weathering factor]) = g/s
5. Q = (0.42#/1000 gal)(42 gal/bbl)(117,300 bbl/day)(454 g/#)(day/24 hrs)(hr/3600 sec)(0.2 of capacity ballasted) (1.5 [weathering factor]) = g/s
6. TVP = 5 psia
7. 3 - 200,000 bbl tanks
8. 2 - 55,000 bbl tanks

* Standing storage loss only

TABLE E-4

Site Specific Short-Term Emission Rates And Source Locations For Big Hill

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
(continued)						
c. Surge Storage(1)	Dome Site	0.01	--	--	--	--
d. Blanket Tank(2)	Dome Site	0.003	--	--	--	--
4. Pipeline						
a. Pump Seals(3)	Sun Terminal	0.05	--	--	--	--
b. Valves(4)	Sun Terminal	0.01	--	--	--	--
c. Pump Seals(5)	Dome Site	0.12	--	--	--	--
d. Valves(5)	Dome Site	0.04	--	--	--	--

Notes:

1. 1 - 20,000 bbl tank
2. 1 - 3,000 bbl tank
3. Q = 1.13 #/day-seal)(4 pumps)(2 seals/pump)(454 g/#)(day/24 hours)(hr/3600 sec) = g/s
4. Q = (0.018 #/day-valve)(4 pumps)(6.25 valves/pump)(454 g/#)(day/24 hours)(hr/3600 sec) = g/s
5. See formulae as used in footnotes 3 and 4 based upon 10 pumps at the dome site.

TABLE E-5

Site Specific Long-Term Emission Rates And Source Locations For West Hackberry

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Construction 1. Site Preparation	Sun Terminal(1) Dome Site(2)	-- --	54 66.5			

Notes:

1. Q = (1.2 tons/acre-month)(130 acres)(12 months of construction/year)(2000 #/ton) (454 g/#)(yr/3.15 x 10^7 sec) = gs
2. Q = (1.2 tons/acre-month)(160 acres)(12 months of construction/year)(2000 #/ton) (454 g/#)(yr/3.15 x 107 sec) = g/s

TABLE E-5

Site Specific Long-Term Emission Rates And Source Locations For West Hackberry

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Operation						
1. Tanker Loading(1)	Sun Terminal	29.9	--	--	--	--
2. Tanker Ballasting(2)	Sun Terminal	3.25	--	--	--	--
3. Tank Emissions*(3)						
a. Surge Storage(4)	Sun Terminal	0.23	--	--	--	--
b. Ballast Treatment(5)	Sun Terminal	0.08	--	--	--	--
c. Surge Storage(6)	Dome Site	0.008	--	--	--	--
d. Blanket Tank(7)	Dome Site	0.002	--	--	--	--
4. Pipeline						
a. Pump Seals(8)	Sun Terminal	0.07				
b. Valves(8)	Sun Terminal	0.02				
c. Pump Seals(9)	Dome Site	0.17				
d. Valves(9)	Dome Site	0.05				

Notes:

1. Q = (0.55#/10^3 gal)(42 gal/bbl)(1.0 x 10^6 bbl/day(150 days/yr(454 g/#)(yr/3.15 x 10^7 sec) (.6 by tanker) = g/s
2. Q = (0.42#/10^3 gal)(42 gal/bbl)(175,000 bbl/day)(365 days/yr)(yr/3.15 x 10^7 sec)(454 g/#) (.2 [ballast capacity]) = g/s
3. TVP = 4 psia
4. 3 - 200,000 bbl tanks
5. 2 - 55,000 bbl tanks
6. 1 - 20,000 bbl tank
7. 1 - 3,000 bbl tank
8. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 6 pumps
9. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 14 pumps

* Standing storage loss only

TABLE E-6

Site Specific Long-Term Emission Rates And Source Locations For Black Bayou

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Construction						
1. Site Preparation	Sun Terminal(1)	--	54			
	Dome Site(2)	--	95.5			

Notes:

1. Q = (1.2 tons/acre-month)(130 acres)(12 months of construction/year)(2000 #/ton) (454 g#)(yr/3.15 x 10^7 sec) = g/s
2. Q = (1.2 tons/acre-month)(230 acres)(12 months of construction/year)(2000 #/ton) (454 g/#)(yr/3.15 x 10^7 sec) = g/s

TABLE E-6

Site Specific Long-Term Emission Rates And Source Locations for Black Bayou

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Operation						
1. Tanker Loading(1)	Sun Terminal	29.9	--	--	--	--
2. Tanker Ballasting(2)	Sun Terminal	3.25	--	--	--	--
3. Tank Emissions*(3)						
a. Surge Storage(4)	Sun Terminal	0.23	--	--	--	--
b. Ballast Treatment(5)	Sun Terminal	0.08	--	--	--	--
c. Surge Storage(6)	Dome Site	0.008	--	--	--	--
d. Blanket Tank(7)	Dome Site	0.002	--	--	--	--
4. Pipeline						
a. Pump Seals(8)	Sun Terminal	0.07				
b. Valves(8)	Sun Terminal	0.02				
c. Pump Seals(9)	Dome Site	0.13				
d. Valves(9)	Dome Site	0.04				

Notes:

1. Q = (0.55#/10^3 gal)(42 gal/bbl)(1.4 x 10^6 bbl/day(150 days/yr(454 g/#)(yr/3.15 x 10^7 sec) (.6 by tanker) = g/s
2. Q = (0.42#/10^3 gal)(42 gal/bbl)(175,000 bbl/day)(365 days/yr)(yr/3.15 x 10^7 sec)(454 g/#) (.2 [ballast capacity]) = g/s
3. TVP = 4 psia
4. 3 - 200,000 bbl tanks
5. 2 - 55,000 bbl tanks
6. 1 - 20,000 bbl tank
7. 1 - 3,000 bbl tank
8. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 6 pumps
9. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 11 pumps

* Standing storage loss only

TABLE E-7

Site Specific Long-Term Emission Rates And Source Locations For Vinton

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Construction						
1. Site Preparation	Sun Terminal(1)	--	54			
	Dome Site(2)	--	12.5			

Notes:

1. Q = (1.2 tons/acre-month)(130 acres)(12 months of construction/year)(2000 #/ton) (454 g/#)(yr/3.15 x 10^7 sec) = gs
2. Q = (1.2 tons/acre-month)(160 acres)(12 months of construction/year)(2000 #/ton) (454 g/#)(yr/3.15 x 10^7 sec) = g/s

TABLE E-7

Site Specific Long-Term Emission Rates And Source Locations For Vinton

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Operation						
1. Tanker Loading(1)	Sun Terminal	10	--	--	--	--
2. Tanker Ballasting(2)	Sun Terminal	1.1	--	--	--	--
3. Tank Emissions*(3)						
a. Surge Storage(4)	Sun Terminal	0.23	--	--	--	--
b. Ballast Treatment(5)	Sun Terminal	0.08	--	--	--	--
c. Surge Storage(6)	Dome Site	0.008	--	--	--	--
d. Blanket Tank(7)	Dome Site	0.002	--	--	--	--
4. Pipeline						
a. Pump Seals(8)	Sun Terminal	0.05	--	--	--	--
b. Valves(8)	Sun Terminal	0.01	--	--	--	--
c. Pump Seals(9)	Dome Site	0.11	--	--	--	--
d. Valves(9)	Dome Site	0.03	--	--	--	--

Notes:

1. Q = (0.55#/10^3 gal)(42 gal/bbl)(1.4 x 10^6 bbl/day(150 days/yr(454 g/#)(yr/3.15 x 10^7 sec) (.6 by tanker) = g/s
2. Q = (0.42#/10^3 gal)(42 gal/bbl)(175,000 bbl/day)(365 days/yr)(yr/3.15 x 10^7 sec)(454 g/#) (.2 [ballast capacity]) = g/s
3. TVP = 4 psia
4. 3 - 200,000 bbl tanks
5. 2 - 55,000 bbl tanks
6. 1 - 20,000 bbl tank
7. 1 - 3,000 bbl tank
8. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 4 pumps
9. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 9 pumps

* Standing storage loss only

TABLE E-8

Site Specific Long-Term Emission Rates And Source Locations for Big Hill

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Construction 1. Site Preparation	Sun Terminal(1)	--	54			
	Dome Site(2)	--	95.5			

454 g/#)(yr/3.15 x 10^7 sec) = g/s
g/#)(yr/3.15 x 10^7 sec) = g/s

Notes:

1. Q = (1.2 tons/acre-month)(130 acres)(12 months of construction/year)(2000 #/ton) (454 g#)(yr/3.15 x 10^7 sec) = g/s
2. Q = (1.2 tons/acre-month)(230 acres)(12 months of construction/year)(2000 #/ton) (454 g/#)(yr/3.15 x 10^7 sec) = g/s

TABLE E-8

Site Specific Long-Term Emission Rates And Source Locations for Big Hill

SOURCE DESCRIPTION	LOCATION	POLLUTANT EMISSION RATE (g/s)				
		HC	PARTICULATE	SO_2	NO_2	CO
Operation						
1. Tanker Loading(1)	Sun Terminal	19.9	--	--	--	--
2. Tanker Ballasting(2)	Sun Terminal	2.15	--	--	--	--
3. Tank Emissions*(3)						
a. Surge Storage(4)	Sun Terminal	0.23	--	--	--	--
b. Ballast Treatment(5)	Sun Terminal	0.08	--	--	--	--
c. Surge Storage(6)	Dome Site	0.008	--	--	--	--
d. Blanket Tank(7)	Dome Site	0.002	--	--	--	--
4. Pipelines						
a. Pump Seals(8)	Sun Terminal	0.05	--	--	--	--
b. Valves(8)	Sun Terminal	0.01	--	--	--	--
c. Pump Seals(9)	Dome Site	0.12	--	--	--	--
d. Valves(9)	Dome Site	0.04	--	--	--	--

Notes:

1. Q = (0.55#/10^3 gal)(42 gal/bbl)(1.4 x 10^6 bbl/day(150 days/yr(454 g/#)(yr/3.15 x 10^7 sec) (.6 by tanker) = g/s
2. Q = (0.42#/10^3 gal)(42 gal/bbl)(175,000 bbl/day)(365 days/yr)(yr/3.15 x 10^7 sec)(454 g/#) (.2 [ballast capacity]) = g/s
3. TVP = 4 psia
4. 3 - 200,000 bbl tanks
5. 2 - 55,000 bbl tanks
6. 1 - 20,000 bbl tank
7. 1 - 3,000 bbl tank
8. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 4 pumps
9. See formulae as used in footnotes 3 and 4 on page 2 of Table A-1; based upon 10 pumps

* Standing storage loss only

APPENDIX E.2

EMISSIONS FROM MARINE VESSEL TRANSFERRING OF CRUDE OIL

1. Introduction

Ships and barges will be used to deliver crude oil to and from the marine terminals for the Strategic Petroleum Reserve (SPR) facility. Hydrocarbon emissions are generated at marine terminals when volatile hydrocarbon liquids are either loaded onto or unloaded from ships and barges.

The magnitude of crude oil transfer emissions are dependent on many factors. Industry testing programs have been conducted recently to evaluate the interrelationship of these and other important factors in developing up-to-date emission factors for ship and barge loading and ballasting emissions. Most of those studies completed have developed emission factors for gasoline. Crude oil transferring operations are under study by the Western Oil and Gas Association (WOGA) (Ref 1).

This appendix evaluates the existing emission data and proposes an analytical procedure for estimating the probable crude oil emission factors for the SPR facility.*

Section 2 presents the general nature and characteristics of marine transfer emissions. Sources testing data compiled by many industry sources concerning marine transfer emissions are presented in Section 3. Description of a proposed procedure and assumption required to estimate emission factors for crude oil are presented in Section 4. The final section concludes the emission factor analysis and presents a summary of emission factors proposed to be used for the SPR facility.

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*This appendix derives emission factors for crude handling operations which represent a reduction in emission factors presented in earlier FEA environmental reports. The results reported here represent the best approximations possible with currently existing data.

2. Emission Sources and Characteristics

2.1 Loading Emissions

Loading emissions are attributable to the displacement to the atmosphere of hydrocarbon vapors residing in empty vessel tanks by volatile hydrocarbon liquids being loaded into the vessel tanks. Loading emissions can be separated into (1) the arrival component and (2) the generated component. The arrival component of loading emissions consists of hydrocarbon vapors left in the empty vessel tanks from previous cargos. The generated component of loading emissions consists of hydrocarbon vapors evaporated in the vessel tanks as hydrocarbon liquids are being loaded.

The arrival component of loading emissions is directly dependent on the true vapor pressure of the previous cargo, the unloading rate of the previous cargo, and the cruise history of the cargo tank on the return voyage. The cruise history of a cargo tank may include heel washing, ballasting, butterworthing, vapor freeing, or no action at all.

The generated component of loading emissions is produced by the evaporation of hydrocarbon liquid being loaded into the vessel tank. The quantity of hydrocarbons evaporated is dependent on both the true vapor pressure of the hydrocarbons and the loading and unloading practices. The loading practice which has the greatest impact on the generated component is the loading and unloading rate.

A typical profile of gasoline concentration in a ship tank during loading is presented in Figure 1 (Ref 2). As indicated in the figure, the hydrocarbons present throughout most of the vessel tank vapor space are contributed to by

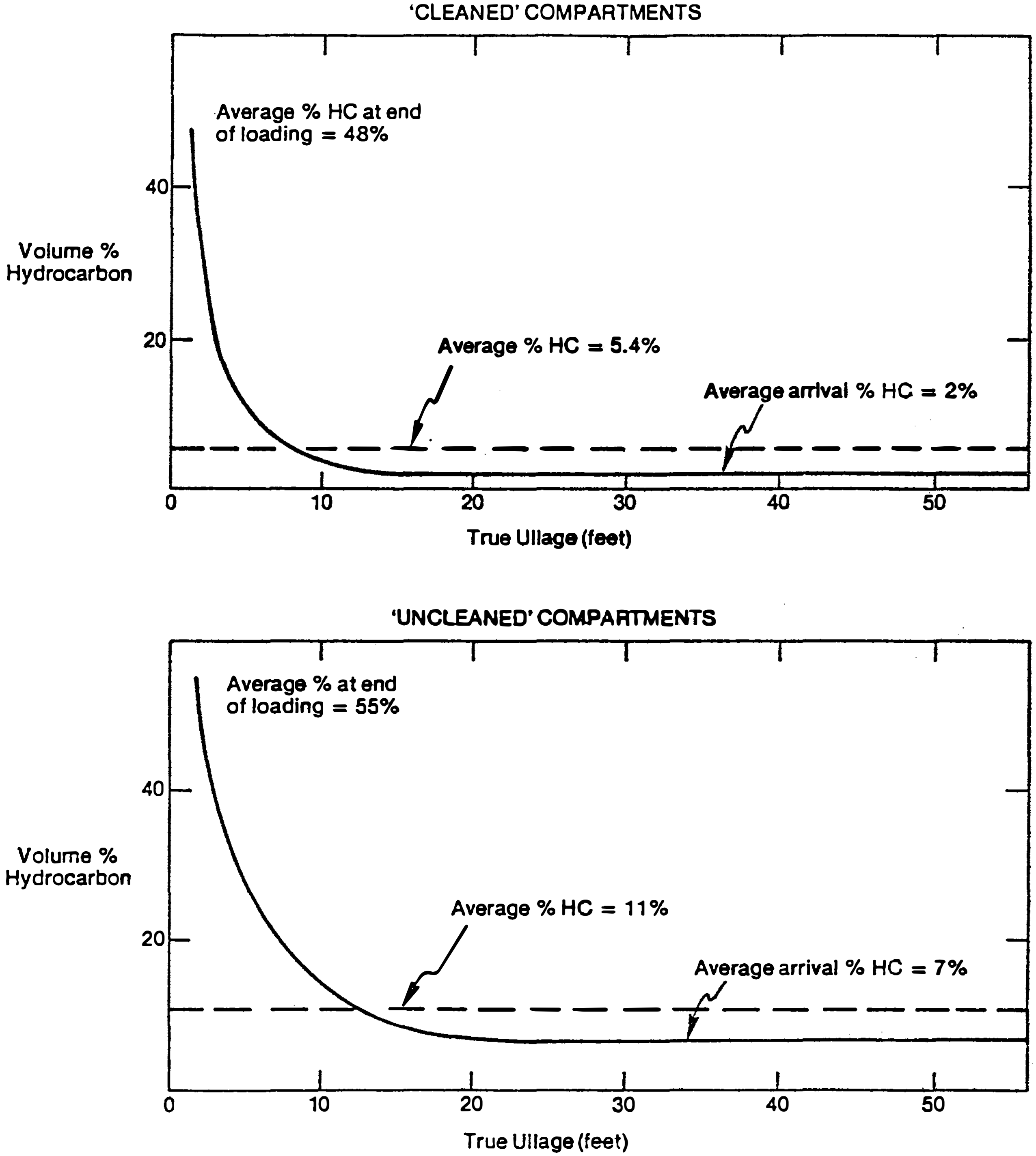

Figure 1. Typical Ship Emission Profiles

the arrival vapor component and the concentration is almost uniform. There is a sharp rise in hydrocarbon vapor concentration just above the liquid surface. This is the generated component. The generated component, also called a "vapor blanket," is attributable to evaporation of the hydrocarbon liquid.

From Figure 1 it is apparent that for large vessels with 55 foot ullages,* the average hydrocarbon concentration of vapors vented during loading operations is primarily dependent on the arrival component. For smaller vessels such as barges with 12 foot ullages, the average hydrocarbon concentration in the vented loading vapors is dependent on both the generated component and the arrival component.

2.2 Unloading Emissions

Unloading emissions are hydrocarbon emissions displaced during ballasting operations at the unloading dock subsequent to unloading a volatile hydrocarbon liquid such as gasoline or crude oil. During the unloading of a volatile hydrocarbon liquid, air drawn into the emptying tank absorbs hydrocarbons evaporating from the liquid surface. The greater part of the hydrocarbon vapors normally lies along the liquid surface in a vapor blanket. However, throughout the unloading operation, hydrocarbon liquid clinging to the vessel walls will continue to evaporate and to contribute to the hydrocarbon concentration in the upper levels of the emptying vessel tank.

Before sailing, an empty marine vessel must take on ballast water to maintain trim and stability. Normally, on vessels that are not fitted with segregated ballast tanks, this

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* The term "ullage" refers to the distance between the cargo liquid level and the rim of the ullage cap.

water is pumped into the empty vessel tanks. As ballast water enters tanks, it displaces the residual hydrocarbon vapors to the atmosphere generating the so termed "unloading emissions."

2.3 Parameters Affecting Emissions

Emission testing results indicate that many factors affect the magnitude of crude oil loading and unloading emissions. Due to the interrelated nature of these parameters, it is difficult to quantify the emission impacts. This section qualitatively presents the effects of the following parameters on marine loading and unloading emissions:

- loading and unloading rate
- true vapor pressure
- cruise history
- previous cargo
- chemical and physical properties

2.3.1 Loading and Unloading Rate

During the loading operation, the initial loading and unloading rate has a significant effect on hydrocarbon emissions due to the splashing and turbulence caused by higher initial loading or withdrawing rates. This splashing and turbulence results in rapid hydrocarbon evaporation and the formation of a vapor blanket. By reducing the initial velocity of entering or withdrawing rates, it is possible to reduce the turbulence and consequently, to reduce the size and concentration of the vapor blanket. Slow final loading rate can also lower the quantity of emissions. This is because when the hydrocarbon level in a marine vessel tank approaches the tank roof, the action of vapors flowing towards the ullage cap vent begins to disrupt the quiescent vapor blanket. Disruption of the vapor blanket results in noticeably higher hydrocarbon concentrations in the vented vapor (Ref 3).

2.3.2 True Vapor Pressure

The true vapor pressure (TVP) of a hydrocarbon liquid has a marked impact on the hydrocarbon content of its loading and unloading emissions. TVP is an indicator of a liquid's volatility and is a function of the liquid's Reid Vapor Pressure (RVP) and temperature. Compounds with high TVP exhibit high evaporation rates and consequently, contain high hydrocarbon concentrations in their loading and ballasting vapors. The monographs presented in Figures 2 and 3 correlate the TVP for crude oil and gasoline. The RVP of gasoline loaded in the Houston-Galveston area range from 9.5 to 13.6 psia in the winter season, while the RVP of crude oils unloaded normally range from 2 to 7 psia. For the purpose of assessing a SPR facility, the crude oil is assumed to have a maximum RVP of 5 psia and an average RVP of 4 psia at a temperature of 70° F.

2.3.3 Cruise History

The cruise history of a marine vessel includes all of the activities which a cargo tank experiences during the voyage prior to a loading or unloading operation. Examples of significant cruise history activities are ballasting, heel washing, butterworthing, and gas freeing. Cruise history impacts marine transfer emissions by directly affecting the arrival vapor component. Barges normally do not have significant cruise histories because they rarely take on ballast and do not usually have the manpower to clean cargo tanks.

Ballasting is the act of partially filling empty cargo tanks with water to maintain a ship's stability and trim. Recent testing results indicate that prior to ballasting,

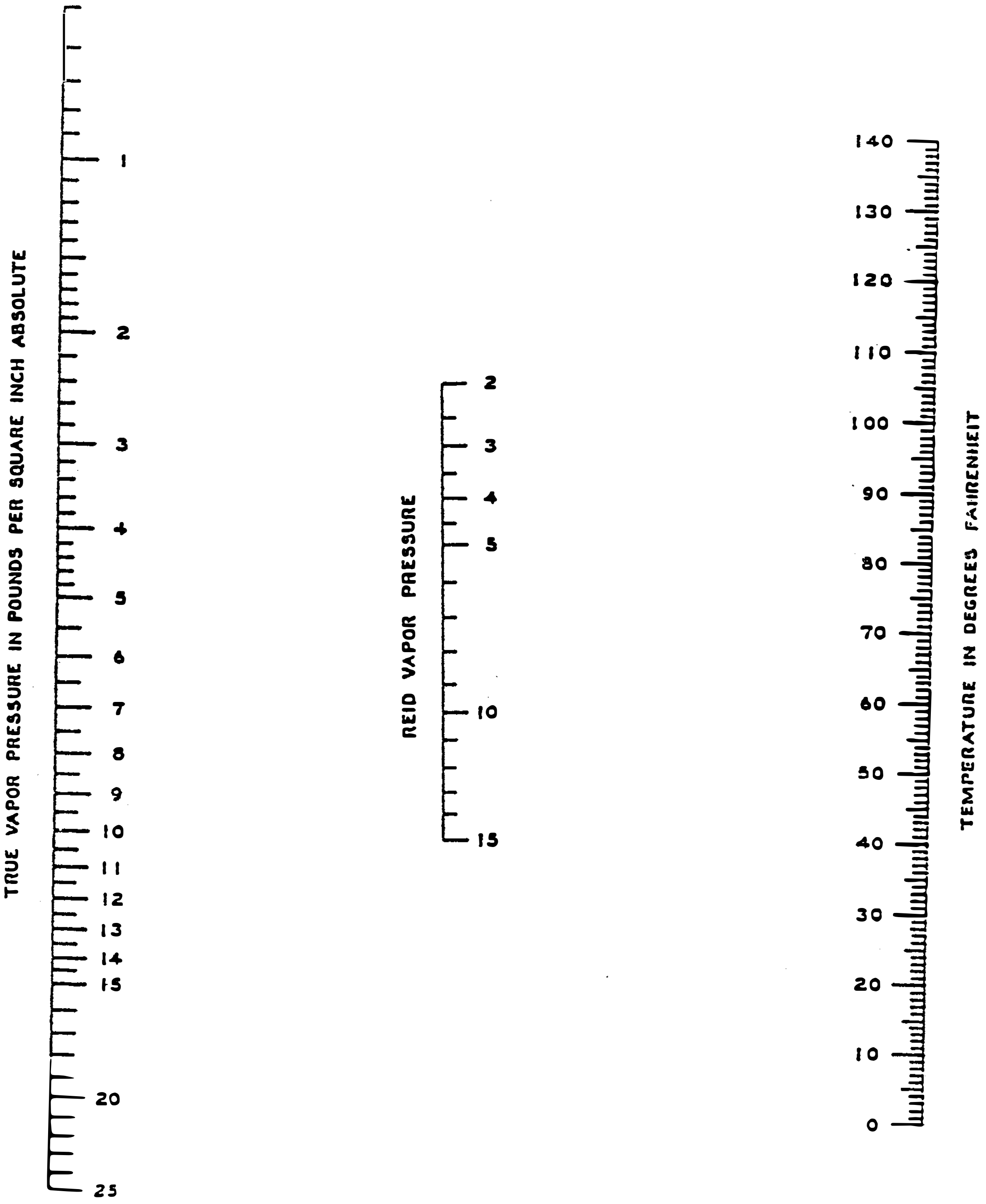
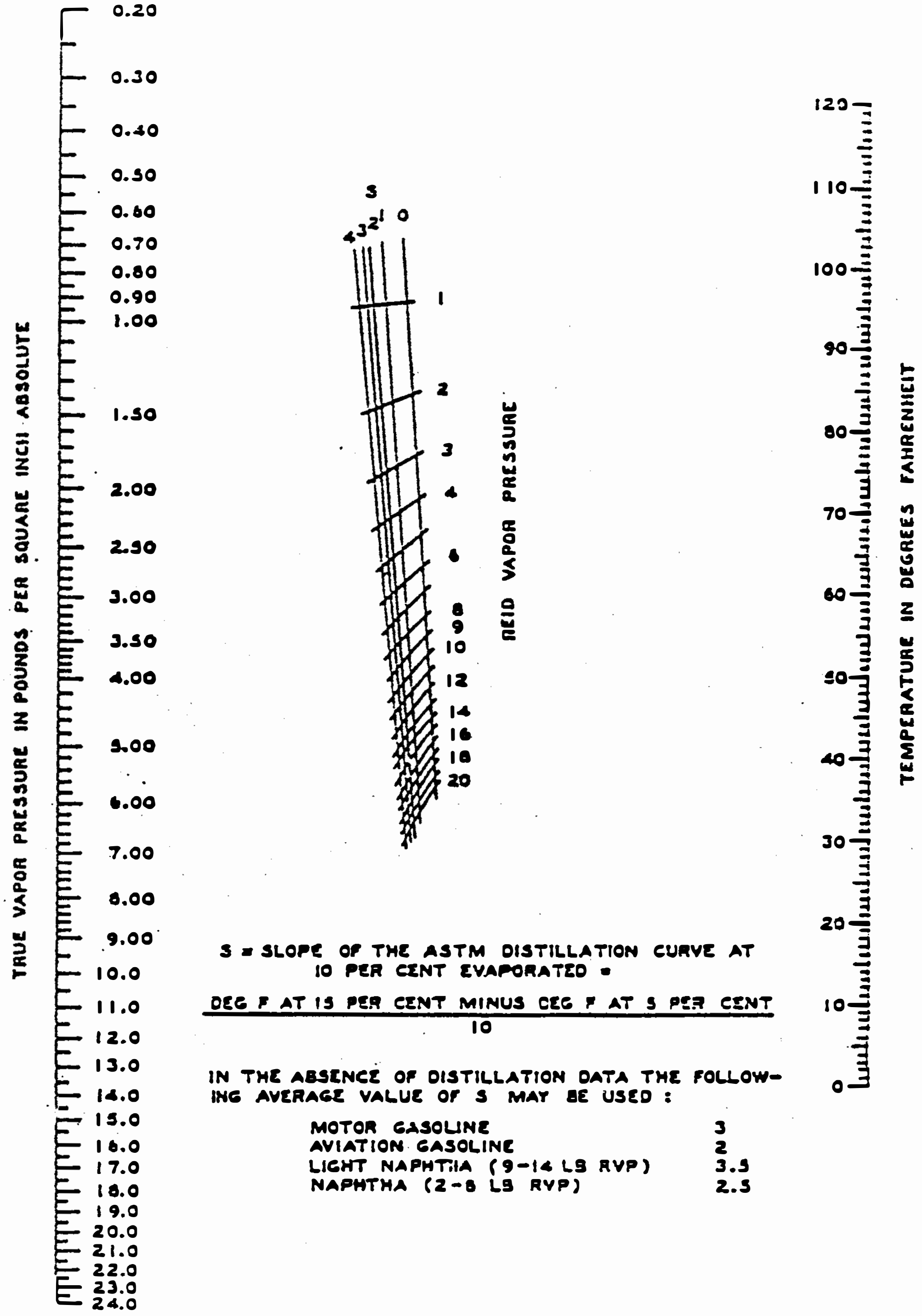


Figure 2. Vapor Pressures of Crude Oil



S = SLOPE OF THE ASTM DISTILLATION CURVE AT 10 PER CENT EVAPORATED =

$$\frac{\text{DEG F AT 15 PER CENT MINUS DEG F AT 5 PER CENT}}{10}$$

IN THE ABSENCE OF DISTILLATION DATA THE FOLLOWING AVERAGE VALUE OF S MAY BE USED :

MOTOR GASOLINE	3
AVIATION GASOLINE	2
LIGHT NAPHTHA (9-14 LB RVP)	3.5
NAPHTHA (2-8 LB RVP)	2.5

Figure 3. Vapor Pressures of Gasolines and Finished Petroleum Products

empty cargo tanks normally contain an almost homogeneous concentration of residual hydrocarbon vapors. When ballast water is taken into the empty tank, hydrocarbon vapors are vented, but the remaining vapors not displaced retain their original hydrocarbon concentration. Upon arrival at a loading dock, a ship discharges its ballast water and draws fresh air into the tank. The fresh air dilutes the arrival vapor concentration and lowers the effective arrival vapor concentration by an amount proportional to the volume of ballast used. Although ballasting practices vary from vessel to vessel, the average vessel is ballasted approximately 40%.

The heel of a tank is the residual puddles of hydrocarbon liquids remaining in tanks after emptying. These residual liquids will eventually evaporate and contribute to the arrival component of subsequent vessel-filling vapors. By washing out this heel with water, AMOCO Oil Company found that they were able to reduce the hydrocarbon emissions from subsequent filling operations from 5.7 volume percent to 2.7 volume percent hydrocarbons (Ref 3). Butterworthing is the washing down of tank walls in addition to washing out tank heels. Butterworthing also reduces loading emissions by reducing the arrival component concentration. The hydrocarbon liquids washed from the tanks are stored in a slops tank for disposal onshore (Ref 3).

In addition to heel washing and butterworthing, marine vessels can purge the hydrocarbon vapors from empty and ballasted tanks during the voyage by several gas freeing techniques which include air blowing and removal of ullage dome covers. A combination of tank washing and gas freeing will effectively remove the arrival component of loading emissions (Ref 3).

2.3.4 Previous Cargo

The previous cargo conveyed by a tanker also has a direct impact on the arrival component of loading emissions. Cargo ships which carried nonvolatile liquids on the previous voyage normally return with low arrival vapor concentration. EXXON Oil Company tests conducted in Baytown, Texas indicated that the arrival component of empty uncleaned cargo tanks which had previously conveyed fuel oil ranged from 0 volume percent to 1 volume percent hydrocarbons. Cargo tanks with the same cruise history which had previously conveyed gasoline, exhibited hydrocarbon concentrations in the arrival vapors which ranged from 4 percent (by volume basis) to 30 percent and averaged 7 percent (Ref 3).

2.3.5 Chemical and Physical Properties

The chemical compositions and molecular weight of crude oil vapors will vary over a wide range. The typical vapor consists predominantly of C_4 and C_5 compounds. The molecular weight ranges from 45 to 100 pound per pound mole with an average of approximately 70.

3. Industry Emission Testing Results

The petroleum industry has been involved in test programs to quantify the hydrocarbon emissions from gasoline and crude oil transfer operations at marine terminals. Table 1 summarizes the test programs which have been conducted by the petroleum industry. The industry programs have included motor gasoline, aviation gasoline, and crude oil loading onto tankers, barges, and ocean barges. Well over 200 vessel tanks were sampled in these programs. The petroleum industry tests were primarily conducted between 1974 and 1975 in the Houston-Galveston area. Tests have also been conducted on the California Coast and in the Great Lakes area (Ref 3).

Industry Testing Programs on Marine Loading Emissions

Company	Types of Marine Testing	Location	Date	Extent of Testing	Emission Factors
WOGA	tanker loading and ballasting emissions for crude oil and natural gasoline	Ventura County Union Oil Terminal Getty Oil Terminal California	May 1976 (tests are ongoing)	6 tests to date	preliminary data indicates that emissions from loading a nonvolatile crude into ballasted tanks which previously carried more volatile crude and not gasoline are 0.9 to 1.0 lb/1000 gallons
EXXON	primarily gasoline loading, but also averages and crude loading	Exxon Terminal Baytown Texas Karg Island, Iran	winter 1974-1975 summer 1975	100 ship tests 30 barge tests	**Gasoline Loading** tanker - gas free 3.24 vol % tanker - ballasted 6.96 vol % tanker - uncleaned 10.26 vol % average Exxon tanker 6.41 vol % (1.47 lb/mgal) ocean barge -gas free 5.69 vol % ocean barge -ballasted 9.08 vol % ocean barge -uncleaned 14.40 vol % avg. EXXON ocean barge 11.71 vol % (2.66 lb/mgal) barge 18.35 vol % (4.14 lb/mgal) **Aviation Gasoline Loading** tanker - gas free 1.63 vol % tanker - unclean (av. gas prev.) 6. 65 vol % tanker - unclean (no gas prev.) 10.64 vol % average EXXON tanker 5.35 vol % (1.47 lb/mgal) average military tanker 4.13 vol % (1.13 lb/mgal) barge 18.35 vol % (4.25 lb/mgal) **Weighted Average Dock** 1.8 lb/mgal Also have a TVP dependent correlation (see text)
American Petroleum Institute	motor gasoline loading	predominantly in Houston-Galveston area	1974-1976		clean tankers 1.3 lb/mgal clean barges 1.2 lb/mgal uncleaned tankers 2.5 lb/mgal uncleaned barges 3.8 lb/mgal
Arco	motor gasoline loading of tankers	Houston Refinery	Nov. 1974, Feb. and April 1975	11 tests	**Gasoline Loading on Tanker** fast load, low TVP, clean 2.1 vol % (0.4 lb/mgal) fast load, med TVP, clean 2.6 vol % (0.5 lb/mgal) slow load, high TVP, clean 4.2 vol % (0.9 lb/mgal) slow load, high TVP, part clean part lcean 6.9 vol % (1.5 lb/mgal) avg. ARCO tanker 3.9 vol % (0.84 lb/mgal)
AMOCO	primarily motor gasoline loading	Whiting, III	2/26/74-7/22/75	40-50 tests	none developed
	crude barge unloading	Texas City, Texas	5/29/74-8/5/75	9 tests	none developed AMOCO did state that average emissions for AMOCO ship less than 10.2 vol %
Shell	gasoline loading on tanker	Dear Park, Texas	Oct. 1974	5-10 tests	none developed
British Petroleum	crude oil loading on tanker	Middle East	1973	Unknown	none developed

4. Proposed Emission Factor Calculating Procedures

The emission factor calculation procedure, suggested in API publication 2514A for loading operations are used. In this method, the total mass emission factor (lb/1000 gal) is derived from the average HC volume concentration. The hydrocarbon volume concentration is then converted into a total hydrocarbon mass by multiplying an average vapor molecular weight and a correction factor accounting for vapor generation factor. These are:

$$H_f = \left(\frac{Xv}{100}\right) \left(\frac{K.W_m}{V_k}\right) \left(\frac{100+F}{100}\right) \qquad (1)$$

and

$$F = \left[\frac{(1-X_T)\left(\dfrac{U_i}{U_i-U_f}\right) - (1-X_r)\left(\dfrac{U_f}{U_i-U_f}\right)}{(1 - X_v)} \right] -1 \qquad (2)$$

where:

H_f = hydrocarbon emission factors, lb/1,000 gal

X_v = volumetric average of HC concentration of vented vapor, percent

K = constant, 133.7 ft^3/1,000 gal

W_m = molecular weight of HC vapor, lb/lb-mole

V_k = molar volume of perfect gas, 379.44 ft^3/lb mole at STP conditions

F = vapor generation factor, See Equation (3)

X_T = volumetric average HC concentration of arrival vapor, percent

X_v = volumetric average HC concentration of remaining vapor, percent

U_i = total tank depth, ft

U_f = final ullage, ft

According to API calculation, a maximum volume increase (vapor generation factor F) of 6 percent for both ships and barge was determined. Thus, if we combine the constants K and V_K with a conservative value of F equivalent to 6 percent, equation (1) can be simplified to:

$$H_f = 0.3735 \cdot (X_v) \cdot (W_m) \tag{3}$$

The total volume of HC concentration vented at loading conditions (X_v) is equal to the sum of arrival HC concentration (X_a) and the generation HC vapor concentration (X_g). Thus

$$X_v = X_a + X_g \tag{4}$$

Based on the above relation, EXXON has further derived the following loading emission correlation:

$$X_v = \left(\frac{E}{V}\right) = \left[\frac{C}{100}\right] + \left[\frac{P \cdot (G - U) \cdot A}{V}\right] \tag{5}$$

where:

E = total volume of HC emitted at the loading condition, CF
C = arrival HC concentration, percent
V = HC liquid loaded, ft^3
P = true vapor pressure of the HC liquid, psia
A = surface area of the HC liquid, ft^2
G = HC generation coefficient value of 0.36 $ft^3/ft^2 \cdot$ psia)
U = final true ullage correction in $ft^3/(ft^2 \cdot$ psia) from Figure 4

Assuming $V = A\ (U_i - U_f)$, Equation (5) becomes

$$X_v = \left[\frac{C}{100}\right] + \left[\frac{P \cdot (G - U)}{\left(U_i - U_f\right)}\right] \tag{6}$$

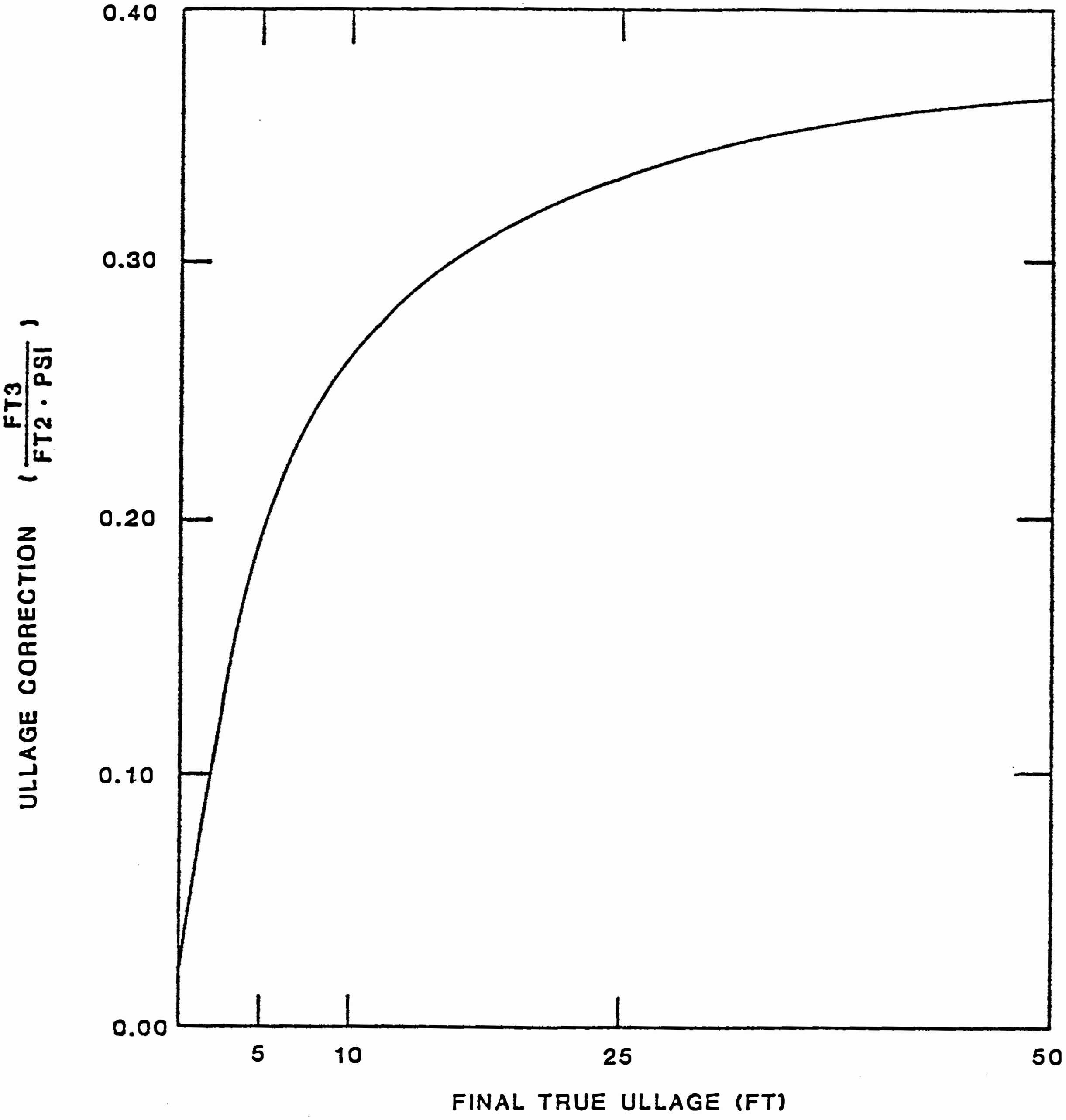


Figure 4. Hydrocarbon Generation Coefficient, Final Ullage Correction to the EXXON Corporation

The EXXON correlation of equation (6) is based principally upon gasoline loading data (Ref 3). For the loading of crude oil, SAI has proposed to adjust the first and second terms by multiplying correction factors α_1 and α_2, respectively. Thus, for crude oil loading operation:

$$X_v = \alpha_1 \left[\frac{C}{100}\right] + \left[\alpha_2 \frac{P \cdot (G - U)}{(U_i - U_f)}\right] \qquad (7)$$

In the above correlation, α_1 is principally affected by the characteristics of the previous cargo, whereas the value of α_2 is independent to the conditions of previous cargo.

For the purpose of SPR facility analysis, it is further assumed that no correction factor on C is necessary when previous cargo is a volatile hydrocarbon such as gasoline. Thus,

- o $\alpha_1 = 1$, when previous cargo is gasoline
- o $\alpha_2 = \alpha_2$, when previous cargo is crude oil.

The correction factor α_2 can be interpretated as the ratios of evaporation mass transfer coefficients between crude oil and gasoline. Mackay and Matsuger (Ref 6) have correlated the mass transfer coefficient (K) based on wind tunnel studies of evaporative hydrocarbon liquids. They found that the mass transfer coefficient is inversely proportional to the vapor phase Schmidt number (S_c) as follows:

$$K = f(U.A) \cdot (S_c)^{-0.67}$$

where U is wind speed, and A is the oil surface area.

The α_2 thus can be determined by

$$\alpha_2 = \frac{K_c}{K_g} = \frac{\left(S_c^{-0.67}\right)_{\text{crude oil}}}{\left(S_c^{-0.67}\right)_{\text{gasoline}}}$$

Since the Schmidt number (S_c) is defined by the mass transport properties $\mu/\rho D_{AB}$ (Ref 7)

α_2 can then be calculated by the following equations:

$$\alpha_2 = \frac{(\mu/\rho D_{AB})^{-0.67} \text{ crude oil}}{(\mu/\rho D_{AB})^{-0.67} \text{ gasoline}} \tag{8}$$

and

$$D_{AB} = 0.0018583 \frac{\sqrt{T^3 \frac{1}{M_A} + \frac{1}{M_B}}}{P\sigma_{AB}^2 \, \Omega_{D,AB}} \tag{9}$$

$$\mu = 2.6693\text{x}10^{-5} \frac{\sqrt{MT}}{\sigma^2 \Omega_{\mu_{AB}}} \tag{10}$$

μ = viscosity of vapor

ρ = density of vapor

D_{AB} = binary diffusivity for system A (air) and B (hydrocarbon)

M_A, M_B = molecular weight of A, B, respectively

P = fluid pressure, atmosphere

σ_{AB} = collision diameter, A

$\Omega_{D,AB}$ = collision integral for mass diffusivity

$\Omega_{\mu,AB}$ = collision integral for viscosity

The pertinent intermolecular properties and functions for prediction of transport properties of hydrocarbon gases at low densities are presented in Table 2 and Table 3, respectively.

Table 2. Intermolecular Parameters of Hydrocarbons

Substance	Molecular Weight M	Lennard-Jones Parameters[a]	
		σ (Å)	ϵ/κ (° K)
CH_4	16.04	3.822	137.
C_2H_2	26.04	4.221	185.
C_2H_4	28.05	4.232	205.
C_2H_6	30.07	4.418	230.
C_3H_6	42.08	—	—
C_3H_8	44.09	5.061	254.
n-C_4H_{10}	58.12	—	—
i-C_4H_{10}	58.12	5.341	313.
n-C_5H_{12}	72.15	5.769	345.
n-C_6H_{14}	86.17	5.909	413.
n-C_7H_{16}	100.20	—	—
n-C_8H_{18}	114.22	7.451	320.
n-C_9H_{20}	128.25	—	—
Cyclohexane	84.16	6.093	324.
C_6H_6	78.11	5.270	440.
Other organic compounds:			
CH_4	16.04	3.822	137.
CH_3Cl	50.49	3.375	855.
CH_2Cl_2	84.94	4.759	406.
$CHCl_3$	119.39	5.430	327.
CCl_4	153.84	5.881	327.
C_2N_2	52.04	4.38	339.
COS	60.08	4.13	335.
CS_2	76.14	4.438	488.

Source: (Ref 7)

Table 3. Functions for Prediction of Transport Properties of Gasses at Low Densities[a]

$\kappa T/\epsilon$ or $\kappa T/\epsilon_{AB}$	$\Omega_\mu = \Omega_k$ (For viscosity and thermal conductivity)	$\Omega_{\mathcal{D},AB}$ (For mass diffusivity)	$\kappa T/\epsilon$ or $\kappa T/\epsilon_{AB}$	$\Omega_\mu = \Omega_k$ (For viscosity and thermal conductivity)	$\Omega_{\mathcal{D},AB}$ (For mass diffusivity)
			2.50	1.093	0.9996
0.30	2.785	2.662	2.60	1.081	0.9878
0.35	2.628	2.476	2.70	1.069	0.9770
0.40	2.492	2.318	2.80	1.058	0.9672
0.45	2.368	2.184	2.90	1.048	0.9576
0.50	2.257	2.066	3.00	1.039	0.9490
0.55	2.156	1.966	3.10	1.030	0.9406
0.60	2.065	1.877	3.20	1.022	0.9328
0.65	1.982	1.798	3.30	1.014	0.9256
0.70	1.908	1.729	3.40	1.007	0.9186
0.75	1.841	1.667	3.50	0.9999	0.9120
0.80	1.780	1.612	3.60	0.9932	0.9058
0.85	1.725	1.562	3.70	0.9870	0.8998
0.90	1.675	1.517	3.80	0.9811	0.8942
0.95	1.629	1.476	3.90	0.9755	0.8888
1.00	1.587	1.439	4.00	0.9700	0.8836
1.05	1.549	1.406	4.10	0.9649	0.8788
1.10	1.514	1.375	4.20	0.9600	0.8740
1.15	1.482	1.346	4.30	0.9553	0.8694
1.20	1.452	1.320	4.40	0.9507	0.8652
1.25	1.424	1.296	4.50	0.9464	0.8610
1.30	1.399	1.273	4.60	0.9422	0.8568
1.35	1.375	1.253	4.70	0.9382	0.8530
1.40	1.353	1.233	4.80	0.9343	0.8492
1.45	1.333	1.215	4.90	0.9305	0.8456
1.50	1.314	1.198	5.0	0.9269	0.8422
1.55	1.296	1.182	6.0	0.8963	0.8124
1.60	1.279	1.167	7.0	0.8727	0.7896
1.65	1.264	1.153	8.0	0.8538	0.7712
1.70	1.248	1.140	9.0	0.8379	0.7556
1.75	1.234	1.128	10.0	0.8242	0.7424
1.80	1.221	1.116	20.0	0.7432	0.6640
1.85	1.209	1.105	30.0	0.7005	0.6232
1.90	1.197	1.094	40.0	0.6718	0.5960
1.95	1.186	1.084	50.0	0.6504	0.5756
2.00	1.175	1.075	60.0	0.6335	0.5596
2.10	1.156	1.057	70.0	0.6194	0.5464
2.20	1.138	1.041	80.0	0.6076	0.5352
2.30	1.122	1.026	90.0	0.5973	0.5256
2.40	1.107	1.012	100.0	0.5882	0.5170

[a] Taken from J. O. Hirschfelder, R. B. Bird, and E. L. Spotz, *Chem. Revs.*, 44, 205 (1949).

Table 4 presents the comparative analysis of hydrocarbon vapor emitted by loading gasoline and crude oil. As can be seen, due to the difference in chemical compositions between gasoline and crude oil, the gasoline generally exhibits higher transport properties and thus results in a higher evaporation mass diffusivity coefficient (i.e., 1.345 for gasoline versus 0.513 for crude oil). Based on this analysis, the value of α_2 can be determined as 0.381.

The appropriate arrival HC hydrocarbon concentration, (C), can be calculated based on API gasoline emission factors as follows:

Vessels	Arrival Conditions	Emission Factors (lb/1000 gal)	Generation Vapor $\frac{P\ .\ (G - U)}{(U_i - U_f)}$, %	Calculated Arrival Vapor (C), %
Ships	Cleaned	1.3	$\frac{7.5\ (0.36-0.010)}{(55-1.5)} = 3.64$	1.71 (2.50)
	Uncleaned	2.5	3.64	6.65 (8.00)
Barges	Cleaned	1.2	$\frac{7.5\ (0.36-0.27)}{(55-12)} = 1.57$	3.37
	Uncleaned	3.8	1.57	14.1

The calculated arrival HC vapor concentration for ships using API emission factor seems to be in close agreement with the EXXON reported value (value in parenthesis).

By substituting the appropriate values of C, α_2, and P, Equation (7) also compares well with the latest available WOGA test data. The WOGA test on September 5, 1976 estimated the overall crude oil emission factor to be 0.62 lb/1000 gallons which falls in the middle of the calculated emission factors. The calculated emission factors using Equation (7) are 0.35 lb/1000 gallons and 0.85 lb/1000 gallons for cleaned and uncleaned ships, respectively.

Table 4. Comparison of Chemical Compositions and Mass Transport Properties Between Gasoline and Crude Oil

Chemical Composition, Volume % of Loading Vapors	Gasoline[a]	Crude Oil[b]
$C_1 + C_2$	0.02	0.12
C_3	0.02	0.15
C_4	2.36	1.33
C_5	1.07	2.05
C_6	0.19	0.63
C_7	0.19	0.32
C_8	0.15	0.03
C_9	---	0.02
C_{10}	---	0.01
C_{11}	---	0.01
Air	96.0	95.35
$\Sigma\, \epsilon/K$	302.1	331.6
$\Sigma\, KT/\epsilon$	1.039	1.055
$\Omega_{\mathcal{D},AB}$	1.42	1.40
$\Omega_{\mu,AB}$	1.56	1.54
σA (Air)	3.681	3.681
σB	5.28	5.21
σAB	4.48	4.45
M_B	67	77
μ	6.919×10^{-4}	7.516×10^{-4}
$\mathcal{D}_{AB}$	0.36	0.081
ρ	2.99×10^{-3}	3.43×10^{-3}
$(\mu/\rho\, \mathcal{D}_{AB})^{-0.67}$	1.345	0.513

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[a] Shell Oil Company, Ship Valley Forge, test date 10/19/74

[b] Avila Terminal, Lion of California, test data 5/8/76

Source: (Ref 3)

Simarily, the emission from ship ballasting operation can be correlated based on arrival vapor concentrations during loading operations. Since the ballasting potentially dilutes tank arrival concentration by approximately the same percentage as that of ballasting volume, for a ship with 40 percent ballasting volume the emission factor can be calculated by dividing the arrival HC concentration (C) by 0.4.

5. Conclusion

A modified analytical procedure based on API and EXXON gasoline data enables quantitative estimation of hydrocarbon emission factors from crude oil transferring operations under various arrival conditions. The procedure employs correction factors to both arrival and generation components of the hydrocarbon vapors concentration previously derived from gasoline data. An emission reduction factor of 0.38 is derived for crude oil when comparing the evaporation mass diffusivity of crude oil with gasoline. The final hydrocarbon emission factors for crude oil loading operations are summarized in Table 5. As can be seen, the average emission factors from ship loading operations range from 0.55 to 0.58 lb/1000 gallons. Similar hydrocarbon emission factors range from 1.01 to 1.06 lb/1000 gallons for barge crude oil loading operations. The ballasting emission factors are calculated to range from 0.17 to 0.66 lb/1000 gallons.

Table 5. Summary of Maximum and Average Hydrocarbon Emission Factors (lb/1000 gallon) for Crude Oil Transport Operation

Vessels	Arrival Conditions[a]	Maximum Emission Factor[b]		Average Emission Factor[c]	
		Previous Cargo		Previous Cargo	
		Gasoline	Crude Oil	Gasoline	Crude Oil
Ship Loading					
	Cleaned	--	0.33	--	0.30
	Uncleaned	1.90	0.83	1.86	0.79
	Average	--	0.58	--	0.55
Barge Loading					
	Cleaned	--	0.52	--	0.48
	Uncleaned	3.87	1.59	3.83	1.54
	Average	--	1.06	--	1.01
Ship Ballasting					
	Cleaned	--	0.17	--	0.17
	Uncleaned	--	0.66	--	0.66

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[a] Average condition lies between cleaned and uncleaned conditions. The cleaned is defined as the arrival conditions where vessels had been subjected to any cleaning process prior to loading, as well as compartments which had previously contained a nonvolatile hydrocarbon.

[b] Based on RVP = 5.0 and temperature of 70° F.

[c] Based on RVP = 4.0 and temperature of 70° F.

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APPENDIX F

NOISE IMPACT CRITERIA AND ANALYSIS

The following is a discussion of the noise measures, techniques and assumptions used in assessing the environmental impact of construction site noise. Some ambient noise measurement data for areas typical of the sites being assessed are included for comparative purposes. A brief synopsis of the definitions, terminology and Federal guidelines regarding allowable noise exposures are included at the end of this appendix.

Noise Measures

The descriptors L_{eq} and L_{dn} quantify those aspects of sound which have been found to best correlate cumulative community exposure to noise with community annoyance. Accordingly, the Environmental Protection Agency has selected Equivalent Sound Level (L_{eq}) for the purpose of identifying levels of environmental noise.

The equivalent sound level is formulated in terms of the equivalent <u>steady</u> noise level which in a stated period of time would contain the same noise energy as the time-varying noise.

The mathematical definition of L_{eq} for an interval defined as occupying the period between two points in time t_1 and t_2 is:

$$L_{eq} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p(t)^2}{p_o^2} \, dt \right]$$

where p(t) is the time varying sound pressure and p_o is a reference pressure taken as 20 micropascals.

Analysis of Noise Impact from Construction Activity and Facility Operations

The exact determination of L_{eq} and L_{dn} requires a precise knowledge of the types of equipment used, the machine work cycles, scheduling, machine operating environment, and other factors which interact in a complex manner. In estimating noise impacts several simplifying assumptions have been made. It is assumed that a site can be characterized by construction equipment configured to result in isotropic acoustic sources which have duty cycles and emission levels characteristics of a construction site type.

The construction site is viewed as a noise source consisting of equipment which is used for various intervals of time throughout the period of construction. The equipment is considered to be used in work cycles similar to those of similar past projects. The models for construction site configuration, sound propagation loss and equipment usage have been developed in detail by the Environmental Protection Agency.[1,2] For this project, the most appropriate model is that of construction for public works. The construction phases are:

- clearing
- excavation
- foundation
- erection
- finishing.

The usage factors for the equipment used during each phase of general construction activity are given in Table F.1. Tables F.2, F.3 and F.4 show the equipment associated with pipeline and dock construction.

The models for construction site types locates all equipment in a circle 50 feet from a calculation point of reference (see Figure F-1). A simple propagation model in which noise is attenuated at a rate of 6 dB per doubling of distance has been assumed. Thus, around each construction site there exists a series of annuli which represent areas of greater attentuation. Because of the extraordinary low population density in the construction site areas fractional impact calculations are not appropriate. Instead, impact zones about the sites have been constructed, using the noise measures of L_{eq} and L_{dn}.

Pipeline construction is assumed to consist of discrete sites containing 1/8 mile lengths of pipeline construction. The equipment assumed for pipeline sites is shown in Table F.2.

Conventional pipeline equipment is shown for reference purposes. Pipeline construction is over varied land conditions, however, primarily swamp lands. Because of the inherently quieter swamp land pipeline construction techniques, a 10 dB reduction has been used referenced to conventional equipment for pipeline construction noise.

The L_{eq} obtained using the model was converted to an L_{dn} for a 24 hour day and then converted to an annual L_{dn} by adding 10 log (N/365) where N is the duration

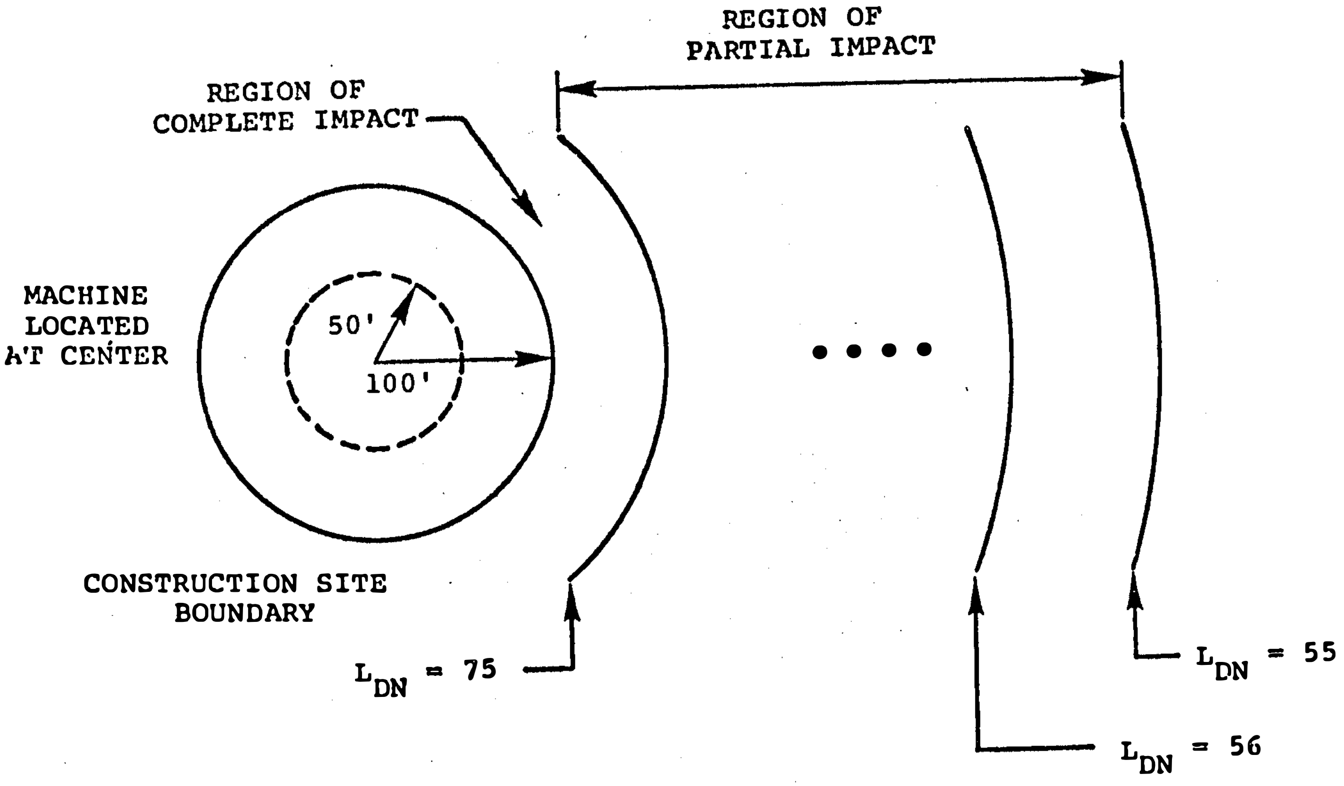

Figure F-1 Schematic of Construction Site Model

Table F-1 Usage Factors of Equipment in Public Works Construction*

Equipment **		Construction Phase					
		Clearing	Excavation	Foundation	Erection	Finishing	$L_{eq}(50')$ during work periods for each item, over one project
Air Compressor	[81]	1.0	1.0	.4	.4	.4(2)	79.0
Backhoe	[85]	.04	.4	-	-	.16	74.4
Concrete Mixer	[85]	-	-	.16(2)	.4(2)	.16(2)	80.7
Concrete Pump	[82]	-	-	-	-	-	-
Concrete Vibrator	[76]	-	-	-	-	-	-
Crane, Derrick	[88]	-	.1	.04	.04	-	73.8
Crane, Mobile	[83]	-	-	-	.16	-	69.7
Dozer	[87]	.3	.4	.2	-	.16	79.6
Generator	[78]	1.0	.4	.4	.4	.4	74.9
Grader	[85]	.08	-	-	.2	.08	74.1
Jack Hammer	[88]	.5	.5	-	.04	.1(2)	80.7
Loader	[79]	.3	.4	.2	-	.16	71.6
Paver	[89]	-	-	0.1	.5	-	81.4
Pile Driver	[101]	-	-	-	-	-	-
Pneumatic Tool	[85]	-	-	.04(2)	.1	.04	72.6
Pump	[76]	-	.4(2)	1.0(2)	.4(2)	-	75.7
Rock Drill	[98]	-	.02	-	-	-	82.6
Roller	[74]	-	-	.01	.5	.5	67.4
Saw	[78]	-	-	.04(2)	.04	-	63.4
Scraper	[88]	.08	-	.2	.08	.08	78.2
Shovel	[82]	.04	.4	.04	-	.04	71.1
Truck	[88]	.16(2)	.16	.4(2)	.2(2)	.16(2)	84.6
Fraction Hrs. at site		.14	.14	.29	.29	.14	

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* Numbers in parentheses represent average number of items in use, if that number is greater than one. Blanks indicate zero or very rare usage.

** Numbers in brackets [ ] represent average noise levels [dBA] at 50 ft.

Table F-2
Equipment Used in Conventional Pipeline Construction

Equipment	Number
Truck	(1)
Backhoe	(1)
Concrete Mixer	(1)
Crane	(1)

Table F-3
Equipment Used in Swamp Pipeline Construction

Equipment	Number
Swamp Buggy	(2)
Lay Barge	(1)

Table F-4
Equipment Used in Loading Dock Construction

Equipment	Number
Pile Driver	(2)
Truck	(2)

of construction in days. The sites are therefore viewed as complex noise sources with a determined annual value of L_{dn}.

Impact zones have been constructed and the land area has been examined for type of land use, i.e., residential, limited outdoor use, schools, playgrounds, etc. Where people are exposed to levels in excess of EPA guidelines, i.e., L_{dn} greater than 55 dB and/or $L_{eq}(24)$ greater than 55 dB, a noise impact is indicated.

The analysis of site operations indicate that noise from equipment used during the operation of facilities is dominated by pump noise.

Table F-5 shows typical pump tasks and requirements associated with salt dome and dock operations.
Figure F-2 shows the noise levels of pumps and motors for a range of horsepowers. Although pump requirements indicated in Table F-5 can generate considerable noise, the affect of pump noise will be minimal because of the case of pump houses.

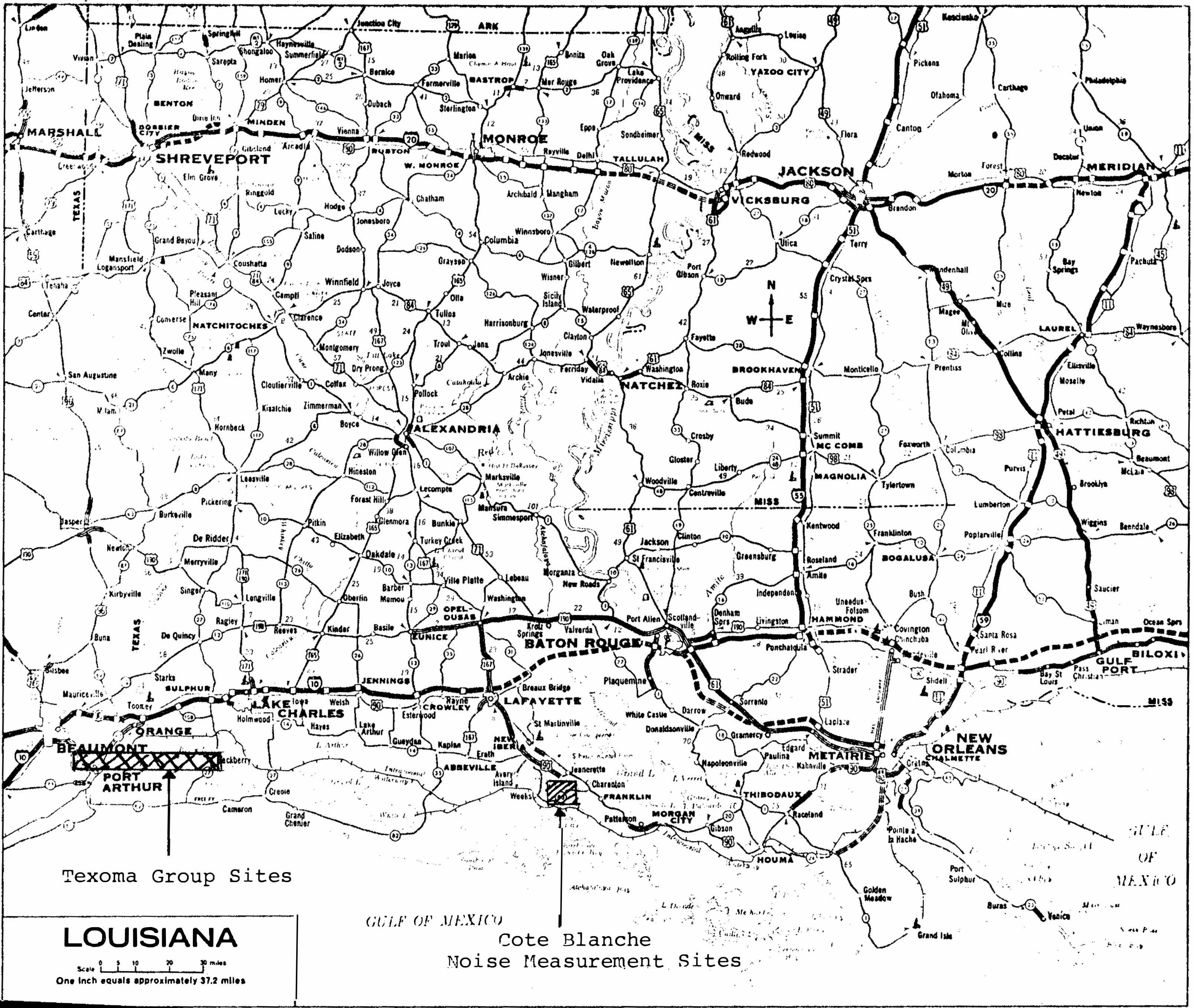
Pumps at the site are to be located in a pump house which is assumed to have a concrete slab foundation and metal wall construction. A transmission loss of 33 dB is reasonable for metal wall construction. However, ventilation requirements will necessitate air ports which will reduce the transmission loss to approximately 23 dB.

Additional noise at and near the storage facilities would be caused by the increased vehicle traffic due from maintenance and operating personnel. Personnel requiremnts are estimated at 40 during fill/discharge operations and 15 during standby operation.

Ambient Noise Level Data

Ambient noise levels have not been measured at the proposed or alternative storage sites; however, background ambient sound levels were measured for an FEA SPR Environmental Impact Statement for Cote Blanche Mine.

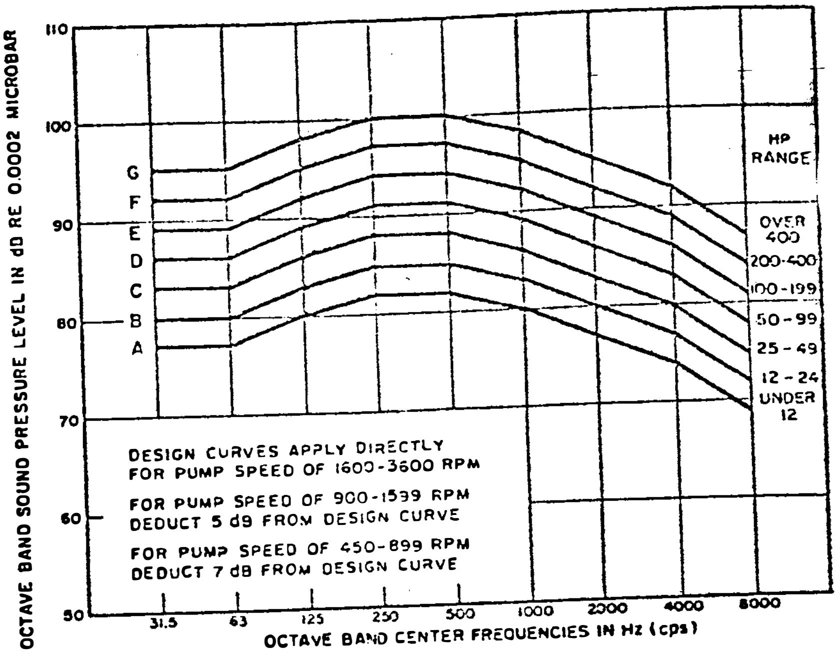
These measurements were taken at sites which are similar in geography and land use to the sites being assessed for the Texoma Group in this report (see Figure F-3). The results of the Cote Blanche measurements are included in this report to provide background noise level reference.



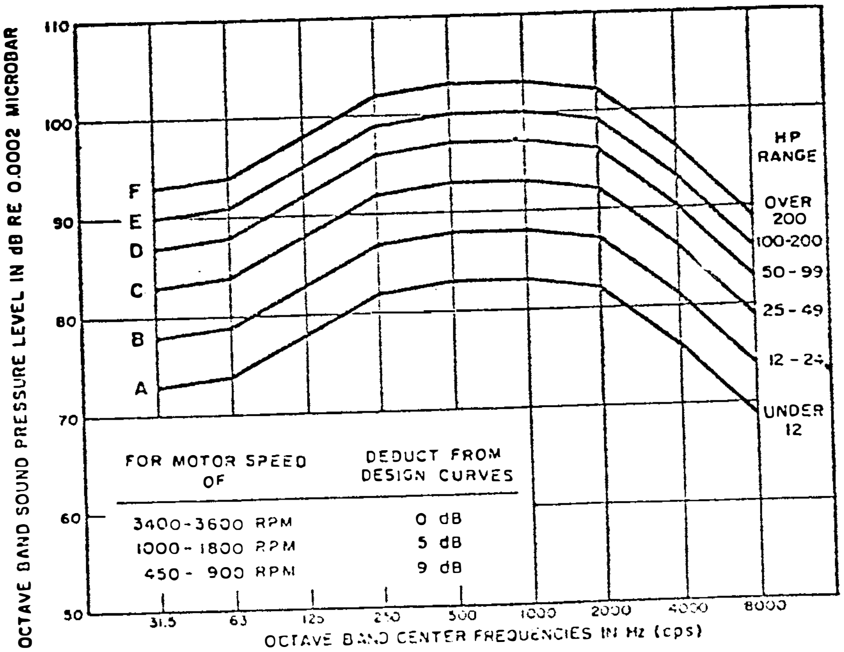
Measurement Sites

Table F-5 Pump Requirements - Big Hill

Pump Task	Quantity	Horse-Power	Discharge Pressure (psi)	Total Design Flow Rate (B/D)
Oil Injection	4 1 (Stand-by)	700 700	900	117,000
Blanket Oil	1	100	1000	3,500
Displacement	10 1 (Charge)	1150 90	650 50	700,000
Water Supply	4 1 (Stand-by)	700 700	150	700,000
Oil Transfer: Dock to Site	1 1 (Stand-by)	500 500	150	117,000
Oil Transfer: Site to Dock	5	500	150	667,000
Brine Disposal	6 6 (Charge)	500 50	150 50	700,000
Tanker Load	2	1470	100	667,000



Pump Noise Levels at 3-ft Distance
(Suggested design curves for various powers and speeds)



Noise Levels of Electric Motors at 3-ft Distance
(Suggested Design Curves for Various Power and speed ranges)

Figure F-2 Noise Levels of Pumps and Motors for Various Horsepower

Source: Department of Army, Technical Manual TM-5-305-4

Measurements were made at:

Location 1 - Center of mining activity, Cote Blanche Island
Location 2 - Ferry crossing to Cote Blanche Island, north of intracoastal waterway
Location 3 - Village of Kemper
Location 4 - Village of Boudreaux
Location 5 - Along Route 83, 4 miles north of Weeks Island

The ambient sound survey was conducted at the above locations on typical weekdays during daytime (0700-2200) and nighttime (2200-0700) periods. These time periods are in accordance with the daytime and nighttime periods as defined by the U.S. Environmental Protection Agency.

Measurements at Location 1 are representative of existing sound climate on the site for an operating mine. Sound levels are mainly from the mining activites and facility operation.

At Location 2, the ferry crossing to Cote Blanche Island, the background ambient sound level data consist of the noise due to a barge passby, but does not include any sound from the ferry. Sound levels at this location are mainly contributed by barge traffic and wind, thus representing the ambient sound levels along the intracoastal waterways.

Locations 3 and 4 are noise sensitive land uses; sound levels are mainly from vehicular traffic, wind, and community activities. Train passbys also contributed to the sound levels at Location 3.

Sound levels at undeveloped areas along country roads are represented by measurements made at Location 5, a location along Route 83, where major sound sources are road traffic and wind rustling through the trees.

A summary of the background ambient sound survey results is presented in Table F-6. This table contains the statistical A-weighted sound level, L_{90}, L_{50}, L_{10}, and L_{eq} for each measurement location. These data represent the background ambient sound levels of the existing environment at and near the project area. They were made during periods when there were no uncharacteristic activities on the site and thus do not contain any intrusive sounds. Nighttime measurements at Locations 2, 4 and 5 were not obtained due to adverse weather conditions during the ambient survey. Ambient nighttime sound levels at these locations were estimated from other data.

Table F-1 Summary of Ambient Sound Levels

Statistical Sound Levels	Daytime (0700-2200)	Nighttime (2200-0700)	Day/Night Sound Levels
Location 1			
L_{90}	62	64	-
L_{50}	64	68	-
L_{10}	68	70	-
L_{eq}	65.5	67.9	-
L_{d}	-	-	65.5
L_{n}	-	-	67.9
L_{dn}	-	-	74.0
Location 2			
L_{90}	44	-	-
L_{50}	50	-	-
L_{10}	59	-	-
L_{eq}	58.5	54 (estimated)	-
L_{d}	-	-	58.5
L_{n}	-	-	54 (estimated)
L_{dn}	-	-	61.4 (estimated)
Location 3			
L_{90}	42	33	-
L_{50}	47	35	-
L_{10}	58	44	-
L_{eq}	59.6	38.7	-
L_{d}	-	-	59.6
L_{n}	-	-	38.7
L_{dn}	-	-	57.8
Location 4			
L_{90}	41	-	-
L_{50}	47	-	-
L_{10}	55	-	-
L_{eq}	55.1	39 (estimated)	-
L_{d}	-	-	55.1
L_{n}	-	-	39 (estimated)
L_{dn}	-	-	53.7 (estimated)
Location 5			
L_{90}	40	-	-
L_{50}	41	-	-
L_{10}	51	-	-
L_{eq}	54.6	39 (estimated)	-
L_{d}	-	-	54.6
L_{n}	-	-	39 (estimated)
L_{dn}	-	-	53.2 (estimated)

DEFINITIONS AND TERMINOLOGY

A-Weight - A frequency weighting network which is used in sound analysis to simulate the response of the human ear. (A-weighted sound levels are expressed in units of dBA).

Environmental Noise - By section 3 (11) of the Noise Control Act of 1972, the term "environmental noise" means the intensity, duration, and character of sounds from all sources.

Equivalent Sound Levels (L_{eq}) - The level of a constant sound which, in a given situation and time period, has the same sound energy as does a time varying sound. Technically, equivalent sound level is the level of the time weighted, mean square, A-weighted sound pressure. The time interval over which the measurement is taken should always be specified.

Sound Level - The quantity of decibels measured by a sound level meter satisfying the requirements of American National Standards Specification for Sound Level Meters S1.4 -1971. Sound level is the frequency-weighted sound pressure level obtained with the standardized dynamic characteristic "fast" or "slow" and weighting A, B, or C; unless indicated otherwise, the A-weighting is understood. The unit of any sound level is the decibel, having the unit symbol dB.

Sound Pressure Level - In decibels, 20 times the logarithm to the base ten of the ratio of a sound pressure to the reference sound pressure of 20 micropascals (20 micronewtons per square meter). In the absence of any modifier, the level is understood to be that of a mean-square pressure.

SYMBOLS

L_{eq}	Equivalent A-weighted sound level over a given time interval.
L_d	Daytime equivalent A-weighted sound level between the hours of 0700 and 2200.
L_n	Nightime equivalent A-weighted sound level between the hours of 2200 and 0700.
L_{dn}	Day-night average sound level - the 24 hour A-weighted equivalent sound level, with a 10 decibel penalty applied to nighttime levels.

i.e., $L_{dn} = 10 \log$

L_{90}	The sound level exceeded 90 percent of the time during the measurement period and is often used to represent the "residual" sound level.
L_{50}	The sound level exceeded 50 percent of the time during the measurement period and is used to represent the "median" sound level.
L_{10}	The sound level exceeded 10 percent of the time during the measurement period and is often used to represent the "intrusive" sound level.

FEDERAL GUIDELINES

The Federal Environmental Protection Agency has identified levels for limits of L_{dn} requisite for the protection of public health and welfare.*

Summary of Noise Levels Identified As
Requisite to Protect Public Health and
Welfare with an Adequate Margin of Safety

Effect	Level	Area
Hearing Loss	$L_{eq}(24) \leq 70dB$	All areas
Outdoor Activity interference and annoyance.	$L_{dn} \leq 55dB$	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq}(24) \leq 55dB$	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor Activity interference and annoyance.	$L_{dn} \leq 45dB$	Indoor residential areas.
	$L_{eq}(24) \leq 45dB$	Other indoor areas with human activities such as school, hospitals, etc.

$L_{eq}(24)$ represents the sound energy averaged over a 24-hour period.

L_{dn} represent the L_{eq} with a 10 dB nighttime weighting.

*Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, USEPA, 550/9-74-004, March 1974.

STATE REGULATIONS

No known noise regulations have been found in the States of Louisiana and Texas pertaining to the construction or operation of the proposed project.

REFERENCES

1) Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances, U.S. Environmental Protection Agency, 12/31/1971.

2) Background Document for Proposed Portable Air Compressor Noise Emission Regulations, U.S. Environmental Protection Agency, October 1974.

3) Final Environmental Impact Statement for Cote Blanche Mine FES 76/77-7, January 1977.

APPENDIX G

OIL SPILL RISK AND OIL POLLUTION INCIDENTS

APPENDIX G.1

RISK OF OIL SPILL RESULTING FROM SHIP COLLISION

1. Introduction

The risk estimates that are derived and presented in this appendix are for the incremental risk of oil or chemical spills associated with the marine transport of oil for the Strategic Petroleum Reserve program. It is assumed that the oil is transported a 45,000 dwt tanker, and the results are presented as the probability of spill per transit. The specific transit under consideration in this case is that from the Gulf of Mexico standing in Sabine Pass, through the Sabine-Neches Canal past Port Arthur, Texas, and up the Neches River 7.2 miles to a berth at the Sunoco Ship Loading Wharf, where the oil is to be transferred ashore for further transport by land pipeline. Section 2 provides a general description of the computer code used to calculate the spill risk for the case of interest, as well as a discussion of the results obtained. In succeeding sections are presented the detailed analytic methodology and techniques utilized in calculating these results.

The analysis used for ship collision probabilities in channels is described in Section 3. Section 4 documents the use of historical data for quantification of ship collision risks. A spill can only result from a ship collision if either ship's structure is sufficiently penetrated. The analysis used for penetration probabilities is described in Section 5.

2. Oil Spill Probabilities Due to Collision Involving SPR Tank Vessel

The analytic model for ship collision hazards described in Section 3, and the methodology described in Section 4 for estimating the probability of spill due to cargo tank rupture, were integrated to form a single computer code. One of the most important inputs to this computer code is a normalization factor α that represents the fraction of time during which ships may be assumed to operate randomly. Proper utilization of this factor in the calculations provides a correct normalization to historical ship collision data, as is explained in greater detail in Section 4.

Additional inputs required to make a complete analysis are the projected marine traffic density for specific segments of the ship channels being considered, the lengths of these segments, and the average speeds for each type of vessel comprising this traffic. Data for the marine traffic for the two channel segments from seaward up the Sabine Pass and Sabine-Neches Canal (24.3 miles) and Neches River (7.2 miles) to the Sunoco Wharf were taken from Waterborne Commerce of the U.S. for 1973.[1] Although ship traffic density has been increasing in recent years, the generally increasing size of merchant vessels is expected to lead to cessation of such traffic increases and perhaps even a decrease in total ship traffic in most ports. Data for the year 1973 may therefore be as good an estimate of marine traffic density for the years 1978 through 1980 as any projections based on this data.

It is further convenient to refine the ship traffic data base by establishing a ship size threshold including only those vessels capable of penetrating the hull of the considered Strategic Petroleum Reserve vessel. This traffic data base must also be consistent with the data base used in Section 4 for normalization to historical accidents. A ship displacement threshold of 1,000 tons was chosen for this purpose. The lengths and beams of individual ships are data required for calculation of the ship collision hazard in the computer code as well. Since the marine traffic data presented in Reference[1] give only vessel type, draft, and a count of the number of transits, it was necessary to derive values of displacement, length, and beam for each ship type and draft listed. To accomplish this, the characteristics of ships were sampled from The Record published by the American Bureau of Shipping;[2] relationships derived from these sampled characteristics were used to provide the required data.

Table G.1-1 is a small sample of the type of ship and barge traffic in the Neches River during 1973, and shows the derived characteristics as well as average vessel speeds. The average vessel speeds were arrived at by consultation with the U.S. Coast Guard's Captain of the Port in Port Arthur, Texas.

Another item of information required to assess the probability of penetration is the average angle of incidence of the striking vessel in the case of a collision. There is very little data from which to develop the distribution of this

Table G.1-1 Sample Channel Traffic for Nechez River

Ship Type	Number of Transits	Draft (feet)	Speed (knots)	Length (feet)	Beam (feet)	Displacement (1,000 tons)
Tankers	34	40	6	713	121	60.7
"	61	39	7	692	118	56.0
"	79	25	6	408	56	11.1
"	158	20	8	310	46	5.3
"	26	15	7	225	36	2.0
"	6	13	6	195	31	1.0
Passenger/Cargo	14	40	8	795	106	39.4
"	1	38	6	746	100	35.0
"	39	26	6	441	63	10.7
"	31	25	7	417	60	9.2
"	516	14	7	190	34	1.4
"	1,047	11	6	150	26	1.0
Tank Barges w/tug	6	26	7	907	180	38.7
"	6	19	6	853	180	35.8
"	3	18	7	825	170	33.4
"	14	18	7	587	88	13.7
"	8	18	8	508	70	9.2
Barges w/tug	47	14	7	780	74	22.6
"	36	8	6	582	41	3.1
SPR Vessel	1	36.6	9	642	111	45.0

angle of impact, and it is believed that narrow channels will in general cause this angle θ, as shown in Figure G.1-1, to be smaller. Since the channels being considered are reasonably narrow, but have junctions with Intracoastal Waterway where larger collision angles could easily occur, a relatively small angle, θ of 30° was specified for large ($\geq$30,000 dwt) vessel collisions with other large vessels and a larger angle θ of 45° was chosen for all other cases.

Transits of the Strategic Petroleum Reserve vessel from seaward comprises a 24.3 mile run through the Sabine Pass and Sabine-Neches Canal to the Neches River, and a 7.2 mile stretch to the Sunoco Wharf on the Neches River. These two channel segments have been separately analyzed, since distinctly characteristic traffic data for each are available in Reference 1. The traffic data shown in Table G.1-1 are just a small sample of the total traffic in one of these segments, the Neches River. The vessel traffic was actually characterized in terms of 111 vessel types for Sabine Pass and Sabine-Neches Canal, and 101 types for the Neches River.

The incremental risk of oil spills being considered is that increment which can be attributed to the addition to existing traffic of the planned Strategic Petroleum Reserve vessel transits. In general, any collision between the Strategic Petroleum Reserve vessel and another vessel may result in a spill, and that spill might come from either the Strategic Petroleum Reserve vessel if it is struck, or another tank vessel or barge if it is struck. The probability for each of these possibilities has been analyzed separately within the computer code. For the case of a passenger ship, dry cargo ship, or barge being struck, the spill probability was taken to be zero since no bulk liquid cargo is involved. Sample resultant probabilities for collision, penetration, and spills are shown in Table G.1-2 for the same vessel types listed in Table G.1-1; the probabilities for penetration are conditional that the collision has occurred, and all other probabilities are expressed as per transit of a Strategic Petroleum Reserve vessel of the type and size listed at the bottom of Table G.1-1.

In the interest of increased safety, the Pilots Association in this port area have worked out a formal agreement placing specific constraints on the vessel traffic. For example, one rule followed is that, if a vessel of greater than 85,000 dwt is transiting the Sabine-Neches Canal above buoys 12 and 13, no other sea-going vessel will be piloted in the opposite direction in this channel. Another similar

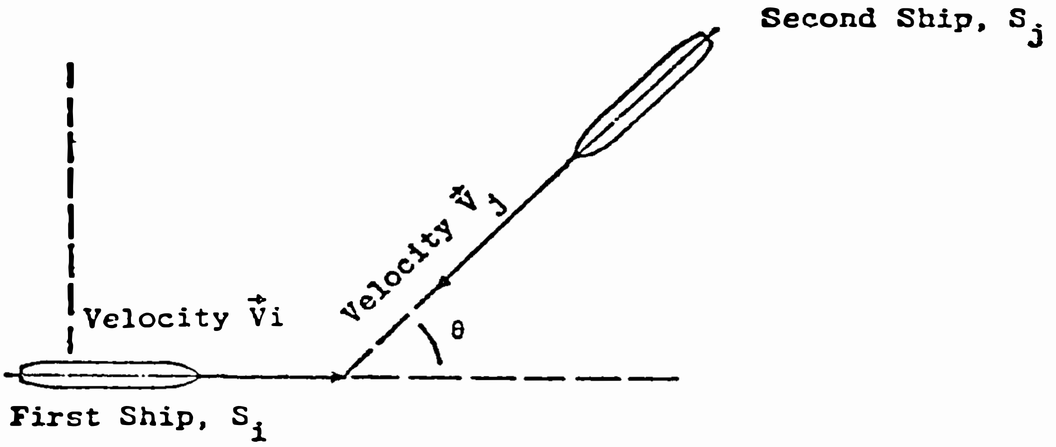


Figure G.1-1 Two Colliding Ships

Table G.1-2 Probabilities of Collision, Penetration, and Spill for Sample Cases in Neches River (Per Transit of 45,000 dwt SPR Vessel)

Other Vessel Type	Probability of Collision of SPR Vessel with Other Vessel Type	Probability of Penetration if SPR Vessel Struck	Overall Probability of Spill (SPR Vessel Struck	Probability of Penetration if SPR Vessel Strikes Other Vessel	Overall Probability of SPill (SPR Vessel Strikes)
Tankers	$.955\times10^{-7}$	.532	$.192\times10^{-7}$	.520	$.309\times10^{-7}$
"	$.152\times10^{-6}$	.522	$.337\times10^{-7}$	.513	$.452\times10^{-7}$
"	$.163\times10^{-6}$	.401	$.295\times10^{-7}$	.458	$.411\times10^{-7}$
"	$.255\times10^{-6}$	.168	$.242\times10^{-7}$	.271	$.299\times10^{-7}$
"	$.404\times10^{-7}$	0(a)	0(a)	0(b)	0
"	$.961\times10^{-8}$	0(a)	0(a)	0(b)	0
Passenger/Cargo	$.341\times10^{-7}$	.471	$.682\times10^{-8}$	-(c)	0(c)
"	$.282\times10^{-8}$	.451	$.461\times10^{-9}$	-(c)	0(c)
"	$.838\times10^{-7}$	.139	$.515\times10^{-8}$	-(c)	0(c)
"	$.596\times10^{-7}$	.350	$.102\times10^{-7}$	-(c)	0(c)
"	$.770\times10^{-6}$	0(a)	0(a)	-(c)	0(c)
"	$.157\times10^{-5}$	0(a)	0(a)	-(c)	0(c)
Tanker Barge w/Tug	$.179\times10^{-7}$	.436	$.309\times10^{-8}$	.629	$.681\times10^{-8}$
"	$.193\times10^{-7}$	.422	$.299\times10^{-8}$	.622	$.759\times10^{-8}$
"	$.849\times10^{-8}$	.409	$.143\times10^{-8}$	.616	$.308\times10^{-8}$
"	$.317\times10^{-7}$	.177	$.247\times10^{-8}$	.498	$.882\times10^{-8}$
"	$.156\times10^{-7}$	.026	$.198\times10^{-9}$	.418	$.329\times10^{-8}$
Barges w/Tug	$.120\times10^{-6}$	.323	$.147\times10^{-7}$	-(c)	0(c)
"	$.852\times10^{-7}$	0(a)	0(a)	-(c)	0(c)

(a) The probabilities of penetration are zero for these cases because vessels of these smaller tonnages cannot penetrate the SPR Vessel hull at the specified representative collision angle of 45°. Hence the spill probabilities are also zero.

(b) As the mass (or tonnage) of a struck vessel is considered to decrease, a smaller and smaller fraction of the total kinetic energy of the striking vessel contributes to collision damage, the remainder contributing to acceleration of the struck vessel. Hence the penetration probability for such cases is zero, according to the Minorsky theory.

(c) The penetration probabilities were not calculated for this case. Since passenger/cargo vessels generally do not carry oil or other liquids as bulk cargo, it is very unlikely that any substantial oil spill can result. Fuel tanks aboard such vessels are also much smaller
of tank vessels, which also minimizes both the likelihood and the size of spills.

rule is that no two vessels of 48,000 dwt minimum, loaded to greater than a 30 foot draft, are maneuvered so as to meet in the channel. These rules have the effect of nullifying specific intership collision probabilities, and this beneficial effect has been incorporated into the computer calculation.

The overall probability of a spill, per transit of a Strategic Petroleum Reserve vessel, is simply the sum of all the individual spill probabilities, only a sample of which have been listed. The relevant sums are shown in Table G.1-3, broken down into the two separate channel segments, as well as the distinct cases of being struck or being the striking vessel. In addition, subtotals of these probabilities are shown for a complete transit of the channel for the struck and striking cases. Finally, the total probability for a spill resulting from collision of a Strategic Petroleum Reserve vessel is given as 1.75 x 10^{-5} per transit for the case of a 45,000 dwt tank vessel.

It should be noted also that the spill probability per transit of the 45,000 dwt alternative vessel, ~1,75 x 10^{-5}, is approximately equal to the overall average spill probability per transit calculated for the entire Gulf Coast region.

Table G.1-3 Overall Spill Probabilities Resulting from Possible Collisions of 45,000 dwt SPR Vessel with Other Vessel Traffic in Transit from Gulf of Mexico to Sunoco Wharf in Neches River

Channel Segment	Spill Probability Per Transit (SPR Vessel Struck)	Spill Probability Per Transit (SPR Vessel Striking)
Gulf of Mexico to Neches River (24.3 mi)	0.531×10^{-5}	0.921×10^{-5}
Neches River to Sunoco Wharf (7.2 mi)	0.821×10^{-6}	0.216×10^{-5}
Entire Transit	0.613×10^{-5}	0.114×10^{-4}

Total Spill Probability per SPR Vessel Transit = 1.75×10^{-5}

3. SHIP COLLISION HAZARD MODEL

The probability of shipping accidents in the future can best be predicted by statistics of the past by use of a model to account for changes in the volume and characteristics of ships. An analytical model has been developed[3] to predict the probability of ships colliding in similar zones. This model characterizes the ship collision probability in terms of the various elements which are factors in ship collisions such as speed, length and width of ship, number of ship transits and the dimensions of the zone in question. The basic assumption of the model is that for ships to collide, they must, for some short period of time, be moving at random, rather than in accordance with rules and plans. Using this assumption, it becomes possible to ignore the interaction of the ships before a collision occurs and to solve the problem of interacting bodies as involving only the two colliding ships illustrated in Figure 1. This model analyzes the problem of two colliding ships in a coordinate system fixed on one of the ships so that in effect, a single ship is moving about another ship, which is stationary, at a velocity equal to the two ships' relative velocity. This coordinate transformation is accomplished by performing a simple transformation from the original frame to that of the moving frame.

As illustrated in Figure G.1-2, the angle which the path of the second ship makes with the first ship is defined as θ_R which is in general different from the heading of the second ship. For a collision course, this angle θ_R is the constant angle at which the first ship continually observes the second ship to be.

An analytical expression for the number of collisions of a given ship during a single transit of a zone is now formulated. If the speed of each ship is constant in a roughly square zone of characteristic dimension, d, the number of collisions expected for a single ship, S_i, in each transit is equal to the product of the time it requires to transit the zone and the probabilities of finding another ship in the same zone and colliding with that ship.

If t_i is the time ship S_i requires to transit the zone of dimension d,

P_j is the probability of finding another ship, S_j, in the zone area d^2,

P_{ij} is the probability per unit time of a collision

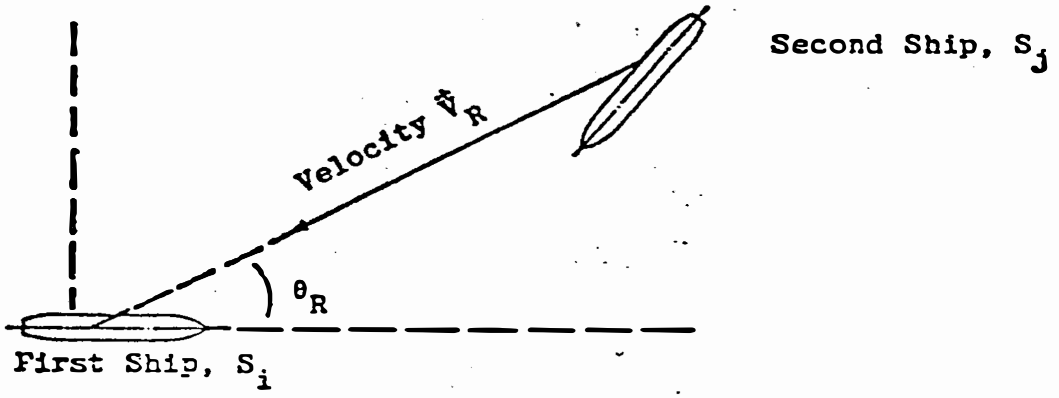


Figure G.1-2 Coordinate System for Analysis

P_{ij} is the probability per unit time of a collision between S_i and S_j given that S_j is in d^2, and

N-1 is the annual number of transits by other ships through zone

then, the number of collisions C_i, which involves S_i, is approximately

$$C_i = t_i \sum_{j=1}^{N-1} P_j P_{ij} \tag{1}$$

Each of the functions, t_i, P_j, and P_{ij} is now to be derived. The transit time of the ship S_i is equal to the zone dimension divided by its speed

$$t_i = \frac{d}{V_i} \tag{2}$$

The probability that another ship, S_j, is in the zone is equal to the fraction of a year that one transit of the zone requires:

$$P_j = \frac{t_j}{Y} = \frac{d}{V_j Y} \tag{3}$$

where, if velocity is specified in feet per second, Y is the number of seconds in a year.

To obtain the probability per unit time of a collision between the two ships, given that both ships are in the zone, it is necessary to determine the rate that ships on any collision course will be encountered. Since this rate, and hence the probability, is directly proportional to both the size of the two ships, and the relative motion of the ships, it is convenient to formulate a function expressing these relationships. This is accomplished by constructing an expression for the flux of colliding ships at a specific angle, and later integrating this flux over all collision angles.

If the cross section of a ship is defined in this two-dimensional problem as the apparent linear dimension of a ship when viewed from a specific angle, the flux of colliding ships at any specific angle is proportional to the relative velocity times the cross section of both ships at that angle. Thus, the magnitude of the flux will increase or decrease with the apparent cross section and the velocity of the ships. That is if ϕ is the flux of colliding ships, $\vec{\sigma}$ is the cross section of both ships and $\vec{V}_R$ is the relative velocity,

then

$$\phi \propto \vec{\sigma} \cdot \vec{V}_R \tag{4}$$

The cross section of the ships is defined as

$$\vec{\sigma} = w_i \hat{m}_i + \ell_i \hat{n}_i + w_j \hat{m}_j + \ell_j \hat{n}_j$$

w_i is the width of ship S_i

$\hat{m}_i$ is the unit vector normal to the width of ship S_i

ℓ_i is the length of ship S_i

$\hat{n}_i$ is the unit vector normal to the length of ship S_i

w_j is the width of ship S_j

$\hat{m}_j$ is the unit vector normal to the width of ship S_j

ℓ_j is the length of ship S_j

$\hat{n}_j$ is the unit vector normal to the length of ship S_j

It is important that the direction of each normal unit vector be chosen to maximize the flux. For example, the unit vectors associated with the width and length of both ships depicted in Figure G.1-2, are illustrated in Figure G.1-3.

To completely determine the flux, the proportionality factor for Equation (4) must be obtained. This factor is equal to the probability density function of the second ship being at any position and angle. The appropriate normalization is given by the factor $1/2\pi d^2$. Therefore, ϕ is given by the expression

$$\phi = \frac{\vec{\sigma}\cdot\vec{V}_R}{2\pi d^2}$$

Finally, the probability, P_{ij}, for a collision between S_i S_j, given that both ships are in d^2 , can be obtained by integrating over all collision angles:

$$P_{ij} = \int_{\substack{\text{all collision}\\ \text{angles}}} \lambda\, \phi\, d\theta_R \qquad (5)$$

where λ is the weight function corresponding to the transformation to the moving coordinate system

$$\lambda = \frac{V_R^{\,2}}{V_j^{\,2} - V_i^{\,2} + V_i V_R \cos\theta_R}$$

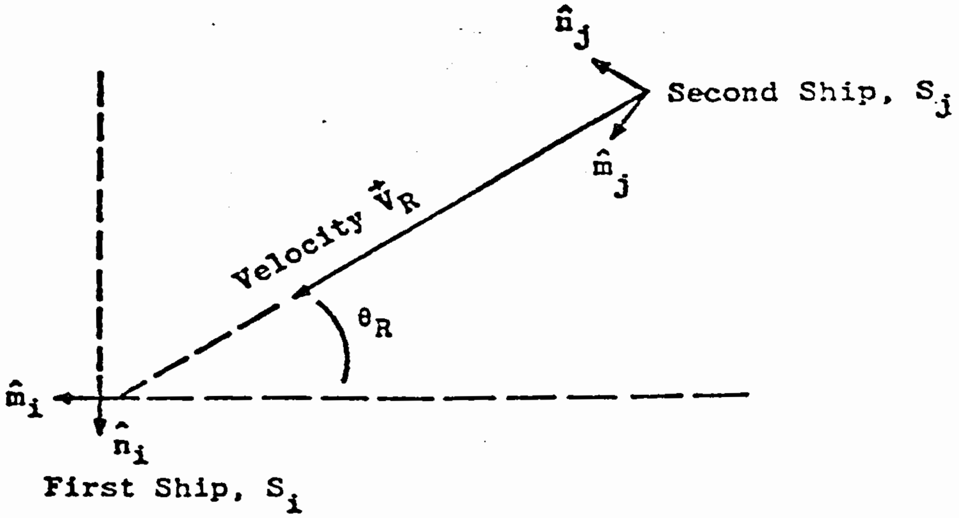


Figure G.1-3 Unit Normal Vectors

Substituting the expressions in Equations 2, 3, and 5 for the function in Equation 1, the number of collisions experienced per transit of zone d^2 by S_i is

$$C_i = \frac{1}{2\pi Y V_i} \sum_{j=1}^{N-1} \int \frac{\lambda \vec{\sigma} \cdot \vec{V}_R}{V_j} \, d\theta_R$$

To evaluate this integral, it is convenient to transform to the variable θ where

$$\theta_R = \operatorname{ctn}^{-1} \left(\operatorname{ctn} \theta + \frac{V_i}{V_j} \csc \theta \right)$$

The number of collisions per transit of the zone d^2 by ship S_i is determined to be, for $V_j \geq V_i$,

$$C_i = \frac{1}{\pi Y} \sum_{j=1}^{N-1} \left[\frac{w_i}{V_j} \left(2 \cos^{-1} \left(- \frac{V_i}{V_j} \right) - \pi \right) + 2 \frac{w_i}{V_i} \sin \cos^{-1} \left(- \frac{V_i}{V_j} \right) + \frac{w_j}{V_i} \pi + 2 \frac{\ell_i}{V_i} + 2 \frac{\ell_j}{V_j} \right] \tag{6a}$$

where w_i, ℓ_i and w_j, ℓ_j are the width and length of ships S_i and S_j, respectively.

By symmetry, the number of collisions for $V_i \geq V_j$ is

$$C_i = \frac{1}{\pi Y} \sum_{j=1}^{N-1} \left[\frac{w_j}{V_i} \left(2 \cos^{-1} \left(- \frac{V_j}{V_i} \right) - \pi \right) + 2 \frac{w_j}{V_j} \sin \cos^{-1} \left(- \frac{V_j}{V_i} \right) + \frac{w_i}{V_j} \pi + 2 \frac{\ell_i}{V_i} + 2 \frac{\ell_j}{V_j} \right] \tag{6b}$$

The model discussed above applies to a roughly square zone. A non-square region such as an inland channel can be approximated by assembling an appropriate number of square zones whose dimensions equal the width of the channel. This process increases the number of random collisions by a factor of L/d where L is the length of the channel and d is the width. (Alternatively, the same analytical result is obtained by considering a single rectangular zone using transit times proportional to L, and the density of ship S_j proportional to $(Ld)^{-1}$).

Having determined the collision rate for completely random ship movements, the last step of this analysis is to consider the rate of expected collisions for more orderly ship movements. Since either ship, S_i or S_j, behaves randomly during only a very small portion of the transit time in the zone of interest, the probability of a collision involving S_i is greatly reduced from the completely random probability by a factor equal to the probability that at least one of the two ships is operating in a random manner. That is, if α is the fraction of time that a ship behaves randomly in the zone of interest, the probability of a collision involving S_i is then approximately

$$C_i(\alpha) = 2\alpha C_i$$

since 2α is approximately equal to the fraction of time that at least one of the two ships obeys the random collision probability equations (Equations 6a, 6b). The parameter, α, reflects absence of the factors that normally avoid collisions.

The total number of expected collisions, $C^{(\alpha)}$ can be written as

$$C^{(\alpha)} = \frac{1}{2}\sum_{i=1}^{N} C_i(\alpha)$$

where the factor 1/2 has been included to avoid double counting. α is determined from the analysis of specific accidents as will be described in Section 3.

The probability of being the struck ship in a collision can be obtained from equations 6a and 6b by counting only those collisions involving the side (or length) of ship S_i and the end (or width) of all ships S_j. This is accomplished by setting $w_i = \ell_j = 0$. Thus, the final probabilities for ship S_i of length ℓ_i, width w_i, and speed V_i, being struck by ships S_j of length ℓ_j, width w_j, and speeds V_j are, for $V_j \geq V_i$,

$$C_{i,\text{struck}}^{(\alpha)} = \frac{2\alpha}{\pi Y} \sum_{j=1}^{N-1} \left[\frac{w_j \pi}{V_i} + \frac{2\ell_i}{V_i} \right]$$

and, for $V_i \geq V_j$,

$$C_{i,\text{struck}}^{(\alpha)} = \frac{2\alpha}{\pi Y} \sum_{j=1}^{N-1} \left[\frac{w_j}{V_i} \left(2 \cos^{-1} \left(\frac{-V_j}{V_i} \right) - \pi \right) + \frac{2 w_j}{V_j} \sin \cos^{-1} \frac{-V_j}{V_i} + \frac{2\ell_i}{V_i} \right]$$

4. NORMALIZATION OF MODEL TO HISTORICAL ACCIDENT DATA

The analytic model developed in the previous section must be normalized to actual ship collision statistics, i.e., historical data, in order to be of use in estimating future probabilities. More specifically, a value for the parameter α, the fraction of time during which ships are assumed to behave randomly, is sought for by analyzing relevant data. The most statistically significant and relevant data base was previously analyzed by SAI for the Federal Power Commission[1] in order to assess the risks of LNG marine operations. A detailed analysis was made of the historical traffic and accidents in the Delaware River and New York Harbor. The historical accidents that occurred in each of the 9 channel regions were normalized to the ship traffic, ship mix, and channel length. The Ship Collision Hazard Model was then used to allocate the accidents over the population of ships transiting the channel. The procedure used below for estimating channel collision probabilities is derivable from the basic model by shrinking the square zone to a narrow channel of length D.

New York Harbor and the Delaware River were subdivided to account for changes in traffic density. Three zones were defined for the Delaware River and 6 zones were defined for New York Harbor. The traffic data was compiled from Waterborne Commerce of the United States.[1] Further details of the marine traffic analysis are described in Reference 3.

The basic source of accident statistics is the U.S. Coast Guard (USCG) incident data base. Each ship involved in an accident in U.S. waters with damage of $1,500 or greater is required by law to complete and submit an accident form to the USCG. Some relatively small cases close to the lower limit may not be reported. It is considered highly unlikely that there is failure to report any significant collision involving major penetration of the hull or loss of life; i.e., the type that could produce tank penetration of a vessel. A file is maintained for each case at USCG Headquarters, Washington, D.C. In addition, a coded record is generated for each ship involved in each incident for purposes of automated computer processing. The USCG prepares a summary statistical report based on these records annually. Complete computer printouts are available for the period FY 69 through FY 74.

These printouts were initially screened to identify moving collisions involving two ships of gross tonnage 100 tons or greater. The Coast Guard files on each accident thus identified were examined to determine the precise location and the displacement of the ships involved and to verify the nature of the accident. Finally, only those accidents involving two ships with a displacement greater than 1,000 tons were included in the final count. There were a total of 30 accidents identified in the 9 channel regions during the 6 year period 1969-1974 which passed all of these criteria.

The ship collision model was exercised for the 9 channel regions being analyzed, and the results expressed as the number of collisions expected for entirely random operations, A_r. The actual number of historical accidents is to be represented by A for this 6 year period. From the data an α for each channel area was calculated according to the formula

$$\alpha = \frac{A}{A_r \cdot L}$$

where A_r is proportional to the square of the traffic transiting the region, N. The method chosen to combine the α's was to weight each one according to the square of the traffic transiting that length of channel. This is appropriate since the basic scaling of accidents according to the number of transits is proportional to N^2 (actually to $N(N-1)/2$ -- since each ship interacts with each of the N-1 other ships and division by two avoids double counting).

The weighted average of α, 1.54×10^{-4}, is based on a data base which contains 30 collisions for more than a million transits in the 9 channels of ships greater than 1,000 tons over the 6 year period (1969-1974). This data base is obtained from 6 years of the average annual traffic, which was developed from Reference 1.

Having determined a value for α from historical traffic and accident experience, it is possible to estimate the frequency of collisions in a similar harbor in the future. The channel length, vessel speeds, and projected traffic density and distribution by draft and ship type are the only additional inputs required. The total numberof collisions expected and the probability per transit that a given ship will have a collision can then be calculated.

5. CARGO TANK RUPTURE PROBABILITY

Considerable attention has been devoted to the analysis of the complex phenomenon of ship collisions. Many major studies have been undertaken internationally to investigate the statistical, analytical, and experimental approaches to this problem. In the United States, statistical and analytical studies were performed in the course of designing the nuclear merchant ship Savannah.[4] The principal product of these efforts was a semi-empirical method formulated by Minorsky[5] to correlate the absorbed collision energy to the amount of deformed structural material in the ships. Other studies were conducted in Japan, Italy, and West Germany to determine the collision behavior of other nuclear ships and tankers. While the Minorsky method has been modified, and many experimental tests have been conducted for the purposes of verification or augmentation of actual collision data, the basic Minorsky method provides the most efficient technique for estimating the penetration of the striking ship into the struck ship. Hence, this recognized procedure is utilized for the analysis of the probability of a cargo tank rupture for vessel collisions involving the planned Strategic Reserve Program tank ships.

The Minorsky method relates the structural resistance to deformation of the colliding ships to the total effective kinetic energy of the collision. If the resistive pressure of a ship's structure is denoted by $\vec{R}(\vec{x})$, the entire Minorsky result can be expressed as

$$\int\left(\int \vec{R}(\vec{x})\, dA\right) \cdot d\vec{x} = \int \vec{F}(\vec{x}) \cdot d\vec{x} = \int \frac{\vec{p}}{\mu} \cdot d\vec{p} = \frac{p^2}{2\mu}$$

where dA is a differential area normal to $\vec{R}$,

$\vec{F}(\vec{x})$ is the force along $\frac{\vec{R}}{|R|}$,

$\vec{p}$ is the momentum, and

μ is the effective reduced mass of the ships.

In effect, the problem simply is one of obtaining the "resistance factors" and the effective or hydrodynamic mass of the struck ship from an inspection of ship design specifications and collision statistics. Experience has shown that $\vec{R}(\vec{x})$ can be attributed to the volume of structural material parrallel to $\vec{p}$ since this material absorbs most of the energy by bending and crushing during the collision.

To calculate the penetration depth into the struck ship only the velocity component, $v_\perp$, of the striking ship normal to the side of the struck ship enters into the calculation. Thus, the struck ship is considered as having no forward motion since data obtained by Minorsky indicate that forward motion only contributes to the length of the opening and not the depth. The effective collision energy of the completely inelastic collision is

$$1/2\mu\ (v_\perp)^2 = 1/2\ \frac{m_1 m'_2}{m_1 + m'_2}\ (v_1 \sin \theta)^2$$

where m_1 is the mass of the striking ship,

m'_2 is the hydrodynamic mass of the struck ship.

v_1 is the velocity of the striking ship, and

θ is the orientation of the striking ship relative to the struck ship.

According to Koch,[6] Dieudonné,[7] and Johnson,[8] the effective hydrodynamic mass of the struck ship is 1.4 m_2, so that the effective collision energy becomes, where m_2 is mass of the struck ship,

$$\frac{1.4\ m_1\ m_2\ (v_1 \sin \theta)^2}{2\ m_1 + 2.8\ m_2} = \frac{m_1\ m_2\ (v_1 \sin \theta)^2}{1.43\ m_1 + 2\ m_2}$$

For the purpose of analysis, it is assumed that the ships maintain their orientation during the collision process. Therefore, the only relevant components of the "resistance factor," $\vec{R}(\vec{x})$, are also normal to the side of the struck ship. The penetration analysis conservatively assumes that the point of impact on the struck vessel is at its weakest point, midway between webs, on soft plating, and that the strong transverse bulkheads do not assist in resisting the penetration. The final spill probability is thus considered to be a conservative overestimate, since the slightest penetration of the outer hull of the struck vessel is assumed to result in a spill. The threshhold speed for the striking vessel to cause cargo tank rupture is then easily calculated.

The distribution of impact speeds in collisions is not well documented. The available data seem to support the assumption that impact speeds are uniformly distributed between zero and the maximum speed at which ships transit a given region. The penetration calculations were based on uniform impact speed distributions of 0-12 knots for ships and 0-8 knots for barges in order to be conservative.

If P^c_s is the probability of being struck by a ship in category c,

P_t is the probability of a collision in an area where cargo tanks are located (note: this probability is independent of striking ship category),

P^c_v is the probability of the normal component of the striking ship's velocity being greater than the threshold velocity,

N_c is the population of ships in category c,

N is the number of ship categories being considered,

the normalized probability of a Strategic Petroleum Reserve vessel tank rupture can be expressed to first order, as

$$P_{rupture} = \frac{\sum_{c=1}^{N} N_c P^c_s P_t P^c_v}{\sum_{c=1}^{N} N_c}$$

The determination of these probabilities is discussed below.

The probability, P^c_s, that the Strategic Petroleum Reserve ship is struck by another ship is equal to the probability that the Strategic Petroleum ship is involved in collision multiplied by the probability that the Strategic Petroleum Reserve ship is the struck ship. Both probabilities are obtained by category from the procedures described in Section 3.

The value used for the probability P_t that a collision would occur in a region where the cargo tanks are located is generally 0.8 or above for tank vessels. In this case, it has been taken equal to unity, again assuring a conservatively high final estimate of the spill probability.

The probability P_V^C of the striking ship being capable of producing a spill is equal to the fraction of ships whose velocity component perpendicular to the side of the struck ship exceeds the threshold velocity. The probability that the striking ship will exceed the speed is then calculated using the appropriate impact speed distribution discussed above.

REFERENCES

[1] U. S. Army Corps of Engineers, Waterborne Commerce of the United States, 1969-1974.

[2] The Record, American Bureau of Shipping 1969-1973.

[3] Federal Power Commission, Draft Environmental Impact Statement for the Construction and Operation of a LNG Import Terminal at Raccoon Island, Gloucaster County, New Jersey, July 1974.

[4] U.S. AEC and U.S. Maritime Administration, "Analysis of Hypothetical Accidents," N.S. Savannah Safety Assessment, Volume IV, 1960.

[5] V. V. Minorsky, "The Analysis of Ship Collision with Reference to Protection of Nuclear Power Plants," Journal of Ship Research, October 1959.

[6] J. J. Koch, "Experimental Method for Determining Virtual Mass for Oscillations of Ships," Ingenieus Archives, Vol. 4, Part 2, 1953.

[7] J. Deudonne, "Vibration in Ships," Transactions of the Institution of Naval Architects, January 1959.

[8] A. J. Johnson, "Vibration Tests of All Welded and All Riveted 10,000 Ton Dry Cargo Ship," Transactions of the North East Coast Institution of Engineers and Shipbuilders, Vol. 67, 1950-1951.

APPENDIX G.2

PETROLEUM TANKER TRAFFIC AND OIL POLLUTION INCIDENTS IN THE GULF OF MEXICO AND CARIBBEAN SEA

This appendix tabulates historical data concerning the relationship between tanker traffic density and polluting incidents, i.e., polluting spills/incidents per tanker trip.

Data has been gathered for the years 1969 through 1975. Data for 1975 is, however, the most complete, therefore that year has been selected as the baseline year.

During the subject year there were 4,316 trips into 20 U.S. Gulf Coast ports (Table G.2-1) by Foreign Flag tankers.[1] A breakdown of trips by area of origin[2] appears in Table G.2-2.

Additionally, during 1975, 182 trips were made into U. S. Gulf Coast ports (Table G.2-1) by U. S. Flag tankers engaged in foreign trade. As there is no data at hand as to the origin of these voyages* and no evidence to the contrary, it is assumed they traveled from one of the aforementioned areas (Table G.2-2), and/or from one of transhipment facilities at Bonaire, Aruba, Curacoa, or the Bahamas. In any case, they constituted a portion of the total 4,498 Gulf-Caribbean tanker trips to U. S. Gulf Coast ports for delivery of foreign petroleum and products.

The 4,498 trips by foreign flag and U. S. Flag-Foreign trade tankers resulted in the landing of some 54,075,914 short tons of oil imports. The U. S. Army Corps of

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[1] Engineers' Annual (Report AE 495, 1975), prepared by the Bureau of Census for the U. S. Army Corps of Engineers.

[2] Mineral Industry Surveys, Bureau of Mines, Table 5, 1975.

*Data is available on customs manifests located in the archives of the ports of entry, but time limitations precluded search of these records.

Table G.2-1 Selected* U.S. Gulf Coast Ports

- Orange
- Houston
- Freeport
- Corpus Christi
- Galveston
- Brownsville
- Port St. Joe
- Pensacola
- Pascagoula
- Lake Charles
- Beaumont
- Texas City
- Matagorda Ship Channel
- Port Arthur
- Harbor Island
- Tampa
- Panama City
- Mobile
- Gulfport
- New Orleans

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*These ports were selected simply because they were the ones for which trip counts of foreign flag and U. S. Flag-Foreign trade tankers were listed in the Engineer's Annual Report AE 495). A port listed does not necessarily indicate final destination of cargo. For example: a ship counted as a New Orleans trip could be destined for offload at Baton Rouge.

Table G.2-2

Area of Origin	No. of Trips Into Gulf Ports
Central America	112
South America	561
Europe	60
Middle East	1,338
Asia	173
Africa	2,072

Engineers[3] however, states a total of 67,142,256 short tons of petroleum were imported into Gulf Coast ports during 1975. This indicates that about 20 percent of the total imports was transported by other than foreign flag and U. S. Flag-Foreign trade tankers. This portion of the total imports was most likely brought in to ports by lightering operations. Lightering will be addressed in more detail later in this report.

Above, the U. S. Army Corps of Engineers[3] was quoted regarding total oil import tonnage. Information as to total import tonnage was also provided by other government agencies, but certain disparities were noted which could have a bearing on the numbers of tanker trips. In order to try to determine which information source was most accurate and/or to understand the reasons for the differences noted, an investigation of primary/raw data sources was initiated. The investigation indicated various sources and combinations thereof were used. In cases where the same data source was used, different elements were used and different interpretations made, counting methods and things counted differed, and there were differences in categorization of products, etc. Upon considering the comparatively small differences in totals, the relatively short, nearly direct path Corps of Engineers data traveled from raw source to published report, consistency of categorization and standardized counting procedures, it was decided to use Corps of Engineers reports as a principal data source for establishing trip totals.

The Corps of Engineers reported, in 1975, in addition to the 4,498 trips by foreign flag and U. S. flag-foreign trade tankers, 6,407 trips by U. S. flag tankers into and out of Gulf Coast ports. This latter number of trips comprised the coast-wise traffic, i.e., trips between Gulf Coast ports (Brownsville around to Tampa), and between the various Gulf Coast ports and ports along the East Coast of the U. S. Coast-wise domestic (U.S. port to U. S. port) traffic volume is shown in Table G.2-3. It will be noted that some of the tankers are obviously not petroleum carriers although they are included in the total coast-wise trip count.

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[3] Waterborne Commerce in the United States, Part 2, 1975, U.S. Army Corps of Engineers

The average size of specialized U. S. Flag tankers (non-petroleum) operating in the Gulf of Mexico and along the East Coast of the U. S. is 12,700 dwt.[4] Assuming that this is the size tanker used in coastwise trade for the transport of non-petroleum liquid products (4,241,274 tons of liquid sulphur and 919,102 tons of alcohols, Table G.2-3) which total 5,160,376 tons, it is presumed that some 407 trips were made by these ships. The total coastwise/domestic trips made by petroleum carrying tankers then becomes 6,000.

It has been previously noted that about 20 percent of the total petroleum imports arrive at Gulf Coast ports by lighters. Only U. S. flag tankers are used for lightering and of the 24 U. S. tankers currently operating in the Gulf of Mexico, only four are in excess of 40,000 dwt. The draughts of these vessels exceed the published channel depths of the Gulf Coast ports[5] and therefore, unless only partially loaded, they could not be used for lightering operations. The assumption will be made that those vessels are not used for lightering. The remaining 20 U. S. tankers operating in the Gulf range in size from 16,700 dwt to 37,900 dwt; the average size being about 28,000 dwt. Presuming the 28,000 dwt tanker as the size generally used for lightering, indications are that about 467 trips per year would be required to land the 13,066,342 tons of petroleum that is not landed by foreign or U. S. flag-foreign trade tankers. This estimate of the volume of lightering agrees satisfactorily with previously developed data.[6]

Tanker trips, or some portion thereof, that transit Gulf of Mexico and Caribbean Sea waters are summarized in Table G.2-4.*

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[4] U. S. Department of Commerce, MARAD Report E2-11, January 1977.

[5] Waterborne Commerce of the United States, Part 2, 1975, U. S. Army Corps of Engineers.

[6] DOT, USCG, Report No. CG-M-06-77, October 1976 (by ORI).

*Not included in the above are coast-wise tanker trips along the shores of other nations which bound the Gulf and Caribbean, nor are tanker trips which originated in other parts of the world and transit Gulf and Caribbean enroute to and from other Gulf and Caribbean nations. Therefore, the total of trips shown in Table G.2-4 does not represent the true total of tanker traffic in the Gulf of Mexico and Caribbean Sea.

Table G.2-3

Commodity	Receipts (tons)	Shipments (tons)
Crude	8,279,198	9,195,393
Gasoline	5,442,370	23,336,751
Jet Fuel	427,421	2,469,775
Kerosene	95,917	1,155,022
Distillate Fuel	1,605,720	20,687,674
Residual Fuel	2,507,247	11,841,169
Lubricants and Grease	389,604	1,358,725
Liquified Gases	89,335	137,905
Liquid Sulphur	2,370,308	1,870,966
Alcohols (Wines)	160,801	758,301
Naptha and Petroleum Solvents	157,070	1,013,248
Benzene and Toluene	228,759	262,189
	21,753,749	74,087,118

Total Coast-wise Tonnage 95,840,867.
Total Coast-wise Petroleum Shipments (liquid sulphur and alcohols deleted) 90,680,491 tons.

Table G.2-4

Ship	No. Trips
Foreign Flag Tankers	4,316
U. S. Flag-Foreign Trade Tankers	182
Lighter Tankers	467
Non-Petroleum Tankers	407
U. S. Flag-Domestic Trade Tankers	5,533
(Total Trips, 1975)	10,905

Information regarding spill/pollution incidents has been taken from two sources: (1) "USCG (G-MMt) Working Papers: Table 1, Tankship Accident Involvements, Oil Outflows, Total Losses, 1969-1973, Tankships over 3,000 DWT," and (2) "FY 70-75 Vessel Casualties Gulf of Mexico Sort FY/NA/VTYP, USCG, Office of Merchant Marine Safety." Fortunately, the data sources have a certain amount of time overlap which has provided the opportunity for a "double check" during that period.

The focus of this investigation is on incidents that occurred in coastal and open sea waters as opposed to incidents which occurred in waters governed by "Inland Rules of the Road." Therefore, incidents which took place in areas governed by the Inland Rules will not be considered.

In 1975, one polluting incident occurred in the open sea waters of the Gulf of Mexico. A Liberian Flag, steel tanker, (data regarding GWT and length are missing) of between 20 to 30 years of age was involved in a collision with another ship in a crossing situation. The primary cause was attributed to fault on the part of the other ship. The accident occurred at night. There is no report regarding sky conditions, precipitation, or fog. The visibility was over two miles and the surface wind was between 11 and 16 knots. There is no data regarding monetary damage to the cargo of the tanker, but medium pollution was reported. In the absence of any additional data (neither the name nor official number of the ship was obtained so further investigation cannot be pursued), the assumption is made that the amount of pollution amounted to about 30,000 gallons.

As previously noted in connection with Table G.2-4, total tanker traffic in the Gulf-Caribbean area waters is not comprised of only those tankers entering and leaving U. S. Gulf Coast ports, but because of lack of adequate data regarding the movement of tankers in and out of foreign ports in the Southern Caribbean, the assumption has been made that the traffic volume is small enough that it can safely be disregarded for the purposes of this investigation. The assumption has also been made that the tankers moving in and out of U. S. Gulf Coast ports constitutes the total traffic (i.e., freight and passenger shipping trips are not included).

There were 10,498 petroleum tanker trips in 1975 (Table G.2-4).1.

In 1974, total tanker trips numbered 10,758.[7] In that year there were no incidents in the Gulf-Caribbean coastal or open sea areas.

In 1973 there were a total of 10,471 tanker trips into U. S. Gulf Coast ports.[8]

In March of that year a German tanker, the Zoe Colotron, 25,716 dwt, traveling in coastal waters grounded. The pollution amounted to some 1,461,700 gallons.

The 1972 count of tanker traffic into U. S. Gulf Coast ports was 8,471.[9]

In February of 1972 an American chemical tanker, V. A. Fogg, in ballast, was traveling in coastal water when it exploded and subsequently sank; a total loss. The ship was 20,765 dwt, between 500 and 600 feet in length, steel hulled, and was between 20 and 30 years old. The accident occurred during the day under partly cloudy skies, visibility was over two miles, and the wind velocity somewhere between four and ten knots. Improper safety precautions (in the presence of vapors) was listed as the cause of the accident which, besides loss of the vessel, resulted in 11 fatalities, 8 injuries, and pollution in the amount of some 470,000 gallons, principally bunker fuel. This was the only incident in 1972 in the waters (coastal) of the Gulf-Caribbean area.

The total tanker trip count for 1971 was 8,797.[10]

In March of the subject year, a Liberian flag tanker, Vassiliki, 69,119 dwt, built in 1965, was traveling, fully loaded in the open sea waters of the Gulf-Carribean area when she suffered structural failure. The report indicates pollution resulted, but it was undetermined whether a spill greater than 500 long tons ocurred.

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[7] Waterborne Commerce of the United States, Part 2, 1974, U. S. Army Corps of Engineers

[8] Waterborne Commerce of the United States, Part 2, 1973, U. S. Army Corps of Engineers.

[9] Waterborne Commerce of the United States, Part 2, 1972, U. S. Army Corps of Engineers.

[10] Waterborne Commerce of the United States, Part 2, 1971, U. S. Army Corps of Engineers.

In June the Norwegian tanker, Stolt Sveve, 16,350 dwt, built in 1951 suffered a breakdown while traveling in the open sea waters of the Gulf-Caribbean area. The report indicates pollution resulted, but it was undetermined whether a spill of greater than 500 long tons occurred.

In August, the Liberian flag tanker, Mar Star, 17,505 dwt, built in 1953 was traveling in ballast in the open sea waters of the Gulf-Caribbean area when she suffered a breakdown which caused heavy damage. The report indicates pollution resulted, but it was undetermined whether a spill greater than 500 long tons occurred.

The 1970 tanker trip count report shows 8,932 trips were made into U. S. Gulf Coast ports.[11]

In the course of the year, 1970, there were no incidents reported as having occurred in the coastal or open waters of the Gulf of Mexico and Caribbean Sea areas.

Tanker trips into U. S. Gulf Coast ports during 1969 totaled 8,463.[12]

In July of that year, the U. S. flag tanker, Texaco Nevada, 19,924 dwt, built in 1944, was traveling, fully loaded, in the open sea waters of the Gulf-Caribbean area when she suffered structural failure. The report indicates pollution resulted, but it was undetermined whether a spill of greater than 500 long tons occurred.

In summary, the relationship between the total tanker trips to Gulf Coast ports during the years 1969 through 1975 and the total number of incidents/spills in the coastal and open sea waters of the Gulf of Mexico and Caribbean Sea was:

$$\frac{7 \text{ incidents}}{(7 \text{ years}) \times (66{,}390 \text{ trips})} = 1.05\text{x}10^{-4} \text{ incidents per trip, and the average loss of } 40.06 \text{ gallons per trip}$$

In order to compare the results of this investigation to the findings of others, the total of polluting incidents per trip during the years 1969 through 1975 have been converted to polluting incidents per tanker year.

The assumption was made that each tanker trip involved 3.5 days underway within the confines of the Gulf-Caribbean area waters. This provided a figure of 663 tanker years for the period 1969 through 1975. During this period, there were seven polluting incidents in the coastal and open sea waters of the area of interest. Therefore:

$\frac{7}{637}$ = .011 polluting incidents per tanker year
(including trips in ballast)

The report, CG-D-81-74, "An Analysis of Oil Outflows Due to Tanker Accidents 1971-1972," prepared by J. J. Henry Company, Inc. indicates, on a worldwide basis, 0.028 polluting incidents per tanker year during the time period analyzed.

The report, "Tankship Accidents and Resulting Outflows, 1969-1973," LCDR James C. Card, LCDR Warren D. Snider, USCG Office of Merchant Marine Safety analyses 452 polluting incidents which occurred (worldwide) during the years 1969 through 1973. During this period, the world tankership year exposure averaged 31,964. It therefore can be estimated that the relationship was:

$\frac{452}{31,964}$ = .014 polluting incidents per tanker year.

APPENDIX H

ECOLOGICAL IMPACTS OF OIL SPILLS

APPENDIX H

Introduction

This appendix contains a state of the art summary of the known impacts to biota resulting from accidental releases of oil. The general behavior of oil in aquatic and terrestrial environments, mechanisms of oil toxicity, and impacts to various taxa of organisms are addressed.

General Behavior of Spilled Oil

The behavior of spilled oil is a function of several factors, including the amount of the oil spilled, the environment in which the spill occurred (dry land, freshwater, ocean, marsh, swamp, etc.), and the physical and chemical characteristics of the oil.

Oil in an aquatic environment will spread at the water's surface under the influence of forces of gravity, surface tension, viscosity, surface currents and surface winds. Weathering and other degradation can change the oil's physical characteristics and influence the rate of movement. The oil is affected after release and/or during transport by separating processes of evaporation, dissolution, emulsification, sedimentation, and chemical oxidation, as well as biological degradation. The lighter, more toxic oil components (aromatics) are eventually lost by evaporation, but initially these components go into solution in the water column. Evaporation creates a heavier surface oil residue which may become heavy enough to sink. Particles in suspension (silt, clay, organic material) may combine with the oil so that sedimentation is increased. Conditions of increased turbidity, such as during periods of high surface water runoff or water turbulance would increase this effect. Bacterial masses in the slicks can increase sedimentation also. Emulsification results in suspended globules which, it is believed, eventually settle out after contact with suspended particles.

Oil Toxicity

Crude oil is a complex of chemical compounds which when released or spilled into the environment produces stresses to ecological communities. Many species of organisms are known to suffer lethal or sublethal effects when they contact oil, and the mechanisms of oil toxicity vary appreciably depending on the taxa of organisms. Organisms may be physiologically poisoned, covered by oil and suffocated, lose insulation and freeze or contract pneumonia, lose waterproofing and drown, have mating abilities reduced by inhibition of phermone reception, and have habitat and food supplies reduced by oil coating.

As a general rule, refined petroleum products are more toxic than crude oils, and lighter crude oils are more toxic than heavier crude oils. The SPR program will consist of crude oil storage only; no refined product storage is anticipated for the Texoma salt dome group.

A chronic release, such as a ballast water discharge, generally differs from a spill in magnitude and duration. A continuous or chronic release of oil may still produce harmful effects in a relatively localized area because of the cumulative stresses produced by the long duration of the release.

Microorganisms

Several studies have been conducted on microbial responses to chronic levels of oil pollution. Over 200 species of bacteria, filamentous algae and yeasts have been shown to oxidize hydrocarbons (Friede, et al., 1972; Klug, et al., 1971, as reported by ZoBell, 1973).

Colwell, et al. (1973) studied the relationship between the numbers of oil degrading microorganisms found in water and sediment and the concentration of oil in samples taken from two stations in Chesapeake Bay. They found that the concentrations of the bacteria degrading microorganisms were directly related to oil concentrations and that these organisms, when isolated in laboratory experiments, grew on substrates representative of the aliphatic, aromatic, and refractory hydrocarbons.

Oppenheimer, et al. (1977) studied the distribution of oil degrading bacteria and showed abnormally high ratios of hydrocarbon bacteria to heterotrophic bacteria in the water and sediment of an active oil field in the North Sea.

Therefore, it appears that ecosystems have built-in response mechanisms to degrade oil which is introduced into these systems.

However, Myers, et al. (1973), found increases in oil degrading microorganisms in areas of oil exposure in a Louisiana *Spartina* habitat. They found that oil-induced yeast populations are not as metabolically active in regard to carbohydrate breakdown as the indiginous mycota. Therefore, the impacts of oil spills on a marshland system could negatively impact system productivity in terms of detrital breakdown and nutrient availibility.

Plankton

Planktonic organisms are among the first to experience the effects of an oil release in an aquatic habitat. Phytoplankton and zooplankton are comprised of very small organisms whose movements are greatly influenced by currents produced by tides, winds, and other factors. Vertical movement is exhibited by some forms, but the capacity for avoiding an oil spill by plankton is limited. Fish eggs and larvae of many marine and estuarine benthic organisms are major components of the temporary zooplankton, but many forms are planktonic throughout their life cycles.

Laboratory studies have indicated that phytoplankton are among the most sensitive marine organisms (Anderson, 1975) and reduction in growth and photosynthesis have been demonstrated for several species at relatively low oil concentrations (Table H-1). The concentration of oil necessary to produce a given deleterious effect is a function not only of the species but of the type of oil as well. For example, species listed in Table H-1 are more sensitive to Louisiana crude than Kuwait crude and most organisms, including phytoplankton, are more sensitive to refined oils such as #2 fuel oil than to crude oils. Such differences in toxicities are generally ascribed to the relative percentages and types of aromatic compounds contained in the oils. It should be noted that in laboratory studies constant temperature, salinity, oxygen levels, etc., are used and responses of some species may vary with changes in those parameters. Data in Table H-2 indicate the relative toxicities for four aromatic compounds on a growth culture of a common soil alga, *Chlorella vulgaris*. Clearly, quantitative reductions in growth occurred when benzene concentrations were increased from 500 to 1000 ppm, when toluene concentrations were increased from 250 to 505 ppm, and when o-xylene concentrations were increased

Table H-1. The Effects of Various Types of Oil on Plankton. Oil Concentration Levels in Water, Test Conditions, and Specimen Localities are Indicated.

Taxa	Oil Type	Oil Concentration (ppm)	Effects	Conditions	Locality of Specimens
Phytoplankton					
Isochrysis galbana[1]	Kuwait crude	73-65	50% reduction in algal growth in 72 hours	counts	Galveston, Texas
	Louisiana crude	9-17	"	counts	"
	Louisiana crude	4-4.7	"	chlorophyll a	"
Cyclotella nana[1]	Kuwait crude	55-60	"	counts	"
	Louisiana crude	17-19	"	counts	"
	Louisiana crude	3.8-4.2	"	chlorophyll a	"
Glenodinium halli[1]	Kuwait crude	18-22	"	counts	"
	Louisiana crude	12-13	"	counts	"
	Louisiana crude	7.5-9.0	"	chlorophyll a	"
Monochrysis lutheri[2]	#2 fuel oil	0.9	50% reduction in photosynthesis	undispersed oil	Washington State
	S. Louisiana crude	250	"	"	"
Chlamydomonas spp.[2]	#2 fuel oil	7.2	"	"	"
	Kuwait crude	550	"	"	"
Zooplankton					
Mysidopsis almyra (mysid crustacean)[1]	S. Louisiana crude	165	TLm24*	static bioassay	Galveston, Texas
	Kuwait	72	"	"	"
	#2 fuel oil	2	"	"	"
Palaemonetes pugio (grass shrimp)[1]	S. Louisiana crude	1700	"	"	"
	Kuwait crude	13,500	"	"	"
	#2 fuel oil	4	"	"	"
Penaeus aztecus post larvae (brown shrimp)[1]	S. Louisiana crude	>1000	"	"	"
	#2 fuel oil	9	"	"	"
Pagettia producta (kelp crab larvae)[1]	#2 fuel oil	<10	TLm96*	static bioassay	California, British Columb
	Kuwait	500	"	"	"
	S. Louisiana crude	450	"	"	"
Rock crab larvae[3]	#2 fuel oil	4	"	"	"
	Kuwait	200	"	"	"
	S. Louisiana crude	250	"	"	"
Copepods (including *Acartia tonsa*)[3]	#2 fuel oil	0.5	some mortality	lab	
	#2 fuel oil	0.2-0.5	paralysis (with recovery in 24 hours)	lab	

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[1] J.W. Anderson, Laboratory Studies on the Effects of Oil on Marine Organisms: An Overview. American Petroleum Institute Publication 4249. 1975. 82 p.

[2] B.E. Vaughan, Effects of Oil and Chemically Dispersed Oil on Selected Marine Biota--A Laboratory Study. American Petroleum Institute Publication 4191. 1973.

[3] R.F. Lee, Fate of Petroleum Hydrocarbons in Marine Zooplankton, pp. 549-553. Proceedings of the Joint Conference on Prevention and Control of Oil Spills, March 25-27, 1975.

*TLm = median tolerance limits; number indicates hours of exposure

Table H-2. Growth of Chlorella vulgaris in Different Concentrations of Benzene, Toluene, O-xylene and Naphthalene Expressed as a Percentage of Growth in Controls.*

Hydrocarbon	ppm	Days of Growth:	% of cell numbers in control 1	2	4	6	8	10
Benzene	25		85	87	92	105	100	99
	50		83	78	87	97	97	92
	100		76	76	92	99	86	94
	250		63	72	77	93	89	97
	500		51	66	78	87	94	98
	1000		34	19	10	4	3	6
	1744		36	21	12	6	3	1
Toluene	25		97	83	82	92	90	95
	50		75	83	70	82	86	89
	100		71	84	77	82	85	88
	250		46	30	34	60	64	68
	505		39	19	7	4	2	2
O-xylene	25		62	90	83	85	97	87
	50		57	63	68	82	80	75
	100		34	29	12	17	26	38
	171		34	28	13	6	3	2
Naphthalene	3.0		90	97	94	63	72	83
	7.5		80	101	85	57	68	80
	15		71	68	71	42	65	64
	27		52	40	48	33	43	51

*The solubilities of benzene, toluene and o-xylene in water at 25° C are 1780, 515 and 175 ppm respectively, on a weight basis; the solubility of naphthalene is about 30 ppm.

Source: P. Kauss, T.C. Hutchinson, C. Soto, J. Hellebust, and M. Griffiths. The Toxicity of Crude Oil and Its Components to Freshwater Algae, pp. 703-714. Proc. Joint Conference on Prevention and Control of Oil Spills. March 13-15, 1973.

from 100 to 171 ppm (Table H-2). Napthalene reduced algal growth at lower concentrations than the other compounds tested (Table H-2).

Some field evidence, on the other hand, has not shown oil to produce ill effects in phytoplankton populations; however, planktonic organisms are readily transported by water currents and effects would be difficult to discern in the field (Boesch, et al., 1974). In any case, immigration of these species from unaffected areas can rapidly repopulate affected areas. In addition, phytoplankton are generally characterized by high growth rates and populations can rapidly replace losses.

Because phytoplankton species vary in their sensitivities to oil, short term changes in community structure can occur. Changes in the relative abundance of phytoplankton may be influenced by differential grazing pressure exerted by zooplankton, which also differ in oil sensitivity. Some algae may be able to utilize non-toxic water soluble crude oil components or by-products of microbial degradation as a nutrient source, and this increased nutrient availability can affect plankton communities (Kauss, et al., 1973). The extent to which this occurs when oil is spilled into aquatic habitats is, for the most part, unknown.

Zooplankton, as a rule, are sensitive to oil, and like phytoplankton, are more sensitive to refined than crude oils (Table H-1). Since many temporary zooplankton species have long life cycles, and larval and juvenile stages are more sensitive than adult stages, oil can affect these groups to a greater extent. This is particularly important in that heavy mortality of these forms can affect density and population structure of these populations for up to several years beyond the initial kill.

Although oil may be ingested by some species and toxic fractions can be transmitted to higher trophic levels, there is little evidence of food chain magnification (Boesch, et al., 1974). This is true despite the virtually complete retention of napthalene by the green alga, Chlamydomonas, which is fed upon by some zooplankton species. Most zooplankton can void (depurate) hydrocarbons as the level of oil in the water column decreases. Depuration time varies with species and circumstances. Lee (1975), using zooplankton caught in the field under laboratory conditions, found that in eight days hydrocarbons were depurated to less than 1 percent of the amount originally taken up. In addition to depuration, some zooplankton can metabolize oil fractions. All of the crustaceans examined by Lee, which included copepods, amphipods, crab zoea*, and euphausiids, had the ability to metabolize napthalene, benzypyrene, methylcholoroanthene, and octadecane.

Mobile Forms

The response of mobile aquatic forms, such as fish and shrimp, to oil is varied. Many species of fish are known to avoid oil and ability to detect oil is highly developed in some species (Rice, 1973). However, those species which exhibit some form of territorial behavior are more likely to be adversely affected than those that actively avoid oil.

Some bottom dwelling marine forms (crabs, some fish, and during the day, penaeid shrimp) are less mobile due to dependence on the bottom for food, cover, and breeding grounds. Heavier and thicker fractions of oil may submerge and by covering the bottom reduce these resources for bottom dependent species. Oil may produce other sublethal effects by inhibiting chemical communication. Chemical senses predominate in the marine environment and chemical cues are involved in food detection, substrate selection, gamete fusion, homing and aggregation behavior, and, in many species, the location and selection of a sexual partner (Takahashi and Kittredge, 1973). Low concentrations of crude oil fractions have been shown to inhibit feeding and mating behavior in crabs (Takahashi and Kittredge, 1973).

Sublethal physiological effects of oil on fish are reported from the large Shell Oil Spill near Timbalier Bay in 1971. These include sloughing of epithelial cells of fish gill filaments and swollen gill filaments (Stone and Robbins, 1973).

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*Zoea is a larval stage of crustaceans.

Generally, eggs and larvae (as discussed earlier for plankton) are more sensitive to oil than are adults. For example, the eggs and larvae of the sand sole, Psettichthus melanosticus, were exposed for 6 days to varying concentrations of South Louisiana crude oil. Between 80% and 100% mortality was suffered at concentrations as low as 10 ppm (Vaughan, 1973). This concentration is much lower than crude oil concentrations usually required to kill or harm adult fish.

Several fish species have been shown to take up and metabolize petroleum hydrocarbons (Lee, 1975). Other "mobile" species such as the ctenophore*, Pleurobranchia pileus, and an unidentified jellyfish showed no metabolism of benzyprene, although they took up this compound when fed contaminated copepods (Lee, 1975).

Dixit and Anderson (1977) exposed adult Fundulus simulus to concentrations of #2 fuel oil for 20 hours. They found that those fish which survived the exposure to sea water which contained 2 ppm napthalene had eliminated all but a small amount of the napthalene from their tissues after 366 hours of depuration in clean water.

Benthos

Benthic organisms, by virtue of their relatively sessile life style, do not readily avoid oil. Some species (oysters and barnacles, for example) are permanently attached to the substrate and are unable to avoid oil which settles to the substrate; groups such as crabs and stomatopods† which are territorial may not leave in time to avoid harm; and groups, such as clams and some worms, may be too slowmoving to effectively vacate an oil contaminated area.

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*Ctenophores are small, marine organisms which are related to and resemble medusoid coelenterates (jellyfish), and are commonly known as sea walnuts or comb jellies.

†Stomatopods are burrowing crustaceans known for their aggressive behavior toward conspecifics (members of the same species); called mantis shrimp.

On the other hand, unless directly covered by a sinking oil mass, benthic organisms are often protected by body coverings (clams, mussels, oysters, and barnacles) and by the substrate (worms and some insect larvae). These factors, combined with reduced feeding for several days following a substantial increase in oil concentrations in the water column, contribute to the resistance of benthic species to oil effects (Vaughan, 1973) (see Table H-3). Mackin and Sparks 1957) indicate that a continuous 2-week release of crude oil from an oil well in coastal Louisiana did not significantly affect oyster survivorship. Although evidence suggesting the absence of synergistic effects of oil and disease incidence exists, the roles of oil stress and disease incidence are complicated and the relationship between these factors is probably best viewed as unresolved.

Oysters take in oil from water suspensions by filter feeding and store it in lipids (Ehrhardt, 1972). These hydrocarbons once in lipids may remain essentially unchanged for months (Ehrhardt, 1972; Blumer, 1970) and may result in oysters which are oily-tasting (Menzel, 1948). The duration of edibility effects obviously depends on many factors such as the initial amounts of oil consumed and storage in body tissues and whether the sources of recontamination (new spills, seepage from sediments, etc.) exist. Oysters maintained in a flowing seawater system on Galveston Island in Texas depurated to background levels in from 24 to 52 days (Boesch, et al., 1974) and clams depurated much more rapidly than oysters. Oysters placed in clean water after 2 weeks exposure to either Kuwait or South Louisiana crudes rapidly eliminated both paraffin (n-alkanes) and aromatic (methyl and di-methyl substituted napthalenes) oil fractions (Vaughan, 1973). As a rule napthalenes are retained the longest by a wide variety of benthic organisms (Boesch, et al., 1974).

Influences on oyster reproduction and/or larval survival from contaminated adults is unknown; however, the high reproductive potential of oysters and the probability of immigration of larval oysters from other areas are mitigating factors. Direct fouling of the suitable oyster substrate by crude oil would reduce the carry capacity of the environment for some time. Removal of oil from oyster beds is a very time consuming, labor-intensive and thus costly endeavor.

Table H-3. The Effects of Various Types of Oil on Benthic Organisms. Oil Concentration Levels in Water, Test Conditions, and Specimen Localities are Indicated.

Taxa	Oil Type	Oil Concentration (ppm)	Effects	Conditions	Specimen Locality
oysters[1]	Empire Crude Oil Mix	250*	no apparent stress; no mortality	estuarine pond	coastal Mississippi
oysters (*Crassotrea gigas*)[2]	Kuwait crude	2500	uptake of 25 mg/gram wet weight	exposed 12 hours	California, British Columbia
	S. Louisiana crude	2500	" <0.5 "	"	"
Uca sp. (fiddler crab)[1]	Empire Crude Oil Mix	250*	no apparent stress; no mortality	estuarine pond	coastal Mississippi
Dungeness crab (*Cancer* sp.)[2]	#2 fuel oil	4778	TLm96	metered inflow	California, British Columbia
Crabs (Blue, stone, and Pacific shore crab)[3]	napthalene and alkayl napthalene	0.1 to 1	completely inhibited response (detection of food poor); when oil extracts mixed with food, feeding intensity reduced	24 hour exposure	California

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[1] J.S. Lytle, Fate and Effects of Crude Oil on an Estuarine Pond, pp. 595-600. Proceedings of the Joint Conference on Prevention and Control of Oil Spills, March 25-27, 1975.

[2] B.E. Vaughan, Effects of Oil and Chemically Dispersed Oil on Selected Marine Biota--A Laboratory Study. Battelle Pacific Northwest Laboratories for the American Petroleum Institute (API publication 4191), 1973.

[3] J.S. Kittredge, Effects of Crude Oil on Marine Invertebrates, Office of Naval Research, Final Report.

*estimate of oil concentration at low tide

Most other benthic organisms, whether occurring on the substrate or in the muds, are likewise susceptible to oil due to their generally low mobility and dependency on the substrate for cover and/or attachment.

Mortality of sea urchins, starfish and other subtidal and intertidal benthic invertebrates due to oil spills has been recorded and short-term changes in community structure can be expected in the event of larger spills. Recovery of communities can occur by immigrating individuals reestablishing populations.

Bottom sediments can act as reservoirs of oil contaminants which occasionally release oil to water bodies and serve as a source of chronic pollution. This occurs most readily when sediments are stirred by water currents, dredging, or other disturbances. Oil in sediment may be degraded fairly rapidly in Gulf coastal waters (Mackin and Sparks, 1957), and it appears to be less toxic when released from the sediment than when the original spill occurred. This is probably due to the loss of much of the aromatic fraction of the oil by weathering and degradation processes.

Freshwater benthos reacts to oil much the same as marine or estuarine benthos. Some forms are more tolerant based on survivorship than others. For example,(Shultz and Tebo, 1975), showed Diptera or true fly larvae and dragonfly nymphs were most tolerant of oil while caddisfly larvae, mayfly and stonefly nymphs were the most sensitive.

Birds and Mammals

Mortality of birds and mammals as a result of oil spillage is well documented from a number of major tanker spills with diving sea birds suffering substantially greater mortality than other groups since they can emerge from under an oil slick and be covered.

In the case of swimming birds, buoyancy is lost when oil destroys the water-proofing quality of birds' feathers. An affected bird may drown, rapidly lose body heat and starve because of the increased metabolic rate required to sustain heat production, or succumb to pneumonia. The probability of an oil-coated bird surviving varies with the species of bird involved and the degree of contamination, but survival generally is less than 50%, even when the bird is treated to remove the oil (Boesch et al, 1974). Accidental consumption of crude oil (12.5 to 50 ppm) via preening interferes with certain physiological processes and results in dehydration (Crocker, 1974). Outright poisoning may not result from ingesting the oil, but other physiological disturbances may occur. Oil exposed birds may not lay eggs, or eggs that they do lay may not hatch. Roosting and nesting sites which are contaminated by oil are generally uninhabitable.

Vegetation

Damage to plants occurs when oil penetrates cell membranes and enters the cell (Baker, 1970). Oil can block stomata and intercellular spaces and reduce transpiration rates. Photosynthesis may also be inhibited by oil. The extent of the actual impact depends on several factors. Many studies have shown that marsh plants survive light to moderate coatings of oil in a single application (Blumer, 1970; Stebbins, 1970; Baker, 1971a). Adverse but short-term effects are: death of oil coated shoots, reduced germination of contaminated seeds, and a numerical reduction of annual species (Baker, 1971a). Successive spillages within a few months of one another can produce longer lasting effects and can substantially degrade plant communities (Baker, 1971b).

The timing of an oil spill has different effects on marsh vegetation and probably other types as well. Coating with oil during the active, growing stages causes more damage than at other times (Boesch, et at, 1974). Annual plants suffer more than perennials when coated with oil during the growing season. The opposite appears to be true at other times (Cowell, 1969). Lytle, (1975), studying a Mississippi estuarine pond, demonstrated that a 250 ppm concentration of Empire Crude Oil Mix in pond water, killed exposed parts of marsh plants (*Spartina alterniflora*, *Juncus roemerianus* and *Distichlis spicata*). Plants turned yellow in 3 days and borwn within 10 days; however, production of new shoots occurred after 3 weeks.

Recovery by marsh vegetation is relatively rapid after a single coating with oil. This is due, at least in part, to vegetative regrowth from the surviving subsurface parts of marsh plants. Successive spillages within a few months of one another, however, can produce longer lasting effects. It has been demonstrated that four or more coatings with oil within a year will retard the vegetative recovery process (Baker, 1971a, 1971b).

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APPENDIX I

THERMAL ANALYSIS OF BRINE

APPENDIX I

A. Temperature in Local Areas Surrounding the Brine Pipeline

From the Texoma group of SPR sites brine would be transported from West Hackberry, Black Bayou or Big Hill to the Gulf of Mexico across marsh and dry land. At the time that the brine leaves the salt dome and enters the disposal system it is warm (100°F - 150°F) due to geothermal heating in the salt formation. Upon entering the disposal system the brine would either enter a surge tank (approx. 40,000 bbl) or a four hour holding pond (175,000 bbl per 150 mmb storage site capacity). The two scenerios are similar because this component would have little effect on the temperature of the brine entering the pipeline. The pipeline would be buried approximately four feet below the ground surface for dry land and four feet below the marsh bed in the marshlands. It would also be four feet below the gulf bottom for that segment of the pipeline extending out to the diffusors.

In order to evaluate the potential effects of heated brine on the habitats through the dry land, marsh and gulf, a heat flow analysis was performed to predict the rise in temperature of the surface directly over the buried pipe. The line directly above the pipe centerline will experience the highest temperature rise in the area and therefore its temperature was analyzed as a conservative case.

Pictured below in Figure I.1 is the model used for this thermal analysis. The average ambient temperature of the water above the marsh bed would experience temperature variations greater than the air above dry land, so water was chosen as a conservative view.

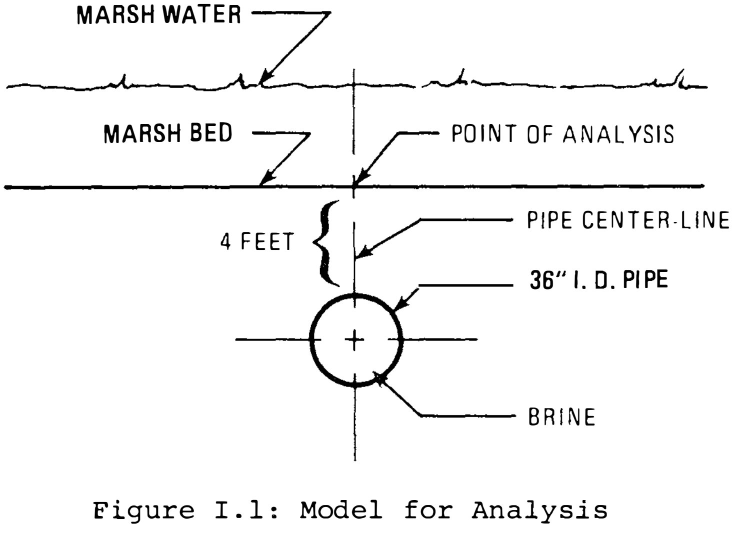

Figure I.1: Model for Analysis

It was assumed that the brine did not cool significantly in the tank or pond so it is entering the pipeline at a temperature of 150°F. For simplicity a straight line heat path was assumed from the brine to the surface along the centerline as shown in Figure I.1. Calculations were performed for the highest brine temperature and lowest water temperature (or air temperature)so as to reflect the "worst cast" or highest temperature rise of the surface.

The equations describing the heat flow are:

$$(1) \quad q/A = \frac{K_p}{t_p} (T_B - T_P),$$

this equation described the heat flow rate from brine to pipe outer surface. Assumes that pipe inner surface is at brine temperature.

Parameters:

q/A = heat removal per unit area (BTU/hr-ft^2)

K_p = thermal conductivity of pipe (BTU/hr-ft-F)

t_p = pipe wall thickness (ft)

T_B = brine temperature (°F)

T_P = outer pipe temperature (°F)

$$(2) \quad q/A = \frac{K_s}{t_s} (T_p - T_s)$$

This equation describes heat flow rate from pipe outer surface to marsh bed (sediment) surface or ground surface.

Parameters:

q/A = same as in equation (1)

K_s = thermal conductivity of sediment (BTU/hr-ft-F)

t_s = distance from pipe to surface (4 feet)

T_s = marsh bed (surface) temperature (°F)

$$(3) \quad q/A = h_w (T_s - T_w)$$

This equation describes heat flow rate from sediment surface to marsh water

Parameters:

q/A = same as in equation 1
h_w = heat transfer coefficient of water (BTU/hr-ft^{2}F)
T_w = temperature of marsh water ($^\circ$F)

Combining equations (1), (2) and (3) yields:

$$(4) \quad q/A = \frac{T_B - T_W}{t_p/K_p + t_s/K_s + 1/h_w}$$

This equation describes the overall heat flow rate from the brine to the water.

By solving equation (4) first the heat flow rate or removal from the brine into the water will be known. This quantity (q/A) remains constant throughout the entire heat path so that equations (1) and (2) can be solved for T_p and T_s, respectively. The temperature at the point of interest T_s is then known. As a check for the calculations, equation (3) can be used with all of the input variables now known to see if it is in fact an equality.

To evaluate the parameters or thermal properties for these equations, certain assumptions must be made. The parameters such as K_p, K_s, h_w which describe the amount of heat that can travel through a given object, are dependent on material composition and temperature. K_p and K_s are readily available after assumptions are made as to the types of materials.

Assumptions for pipe: (to get K_p)

1 - 1" thick (t_p = 1/12 feet)
2 - material is plain cast iron (uncoated)
3 - inside wall temperature is at brine temperature

From these assumptions a table can be used:[1]

K_p = 32 BTU/hr-ft-F

Assumptions for sediment: (to get K_s)

1 - material is Fairbanks silky clay loam
2 - 60% water content by volume
3 - temperature = 40°F
4 - density = 80 lb/ft^3

From these assumptions,[2]

K_s = 1.2 BTU/hr-ft-F

For the dry land along the pipeline route, K_s would be in the order of 0.6 BTU/hr-ft-F(2). Since it is less than the K_s for the marsh bed less heat would reach the surface and therefore would have less impact. Thus K_s = 1.2 was used as a "worst case."

Assumptions for marsh water: (to get h_w)

1 - non-flowing
2 - 60°F (winter)
3 - 85°F (summer)

By applying equation 7-21[1]

@ 60°F h_w = 25.17 $BTU/hr-ft^2$-F
@ 85°F h_w = 45.82 $BTU/hr-ft^2$-F

If these parameters are varied over a range of values, bracketing the first value, then in all likelihood the actual value would be encompassed. As the equations are used, varying one parameter at a time, the relative importance of each can be determined.

Range of Parameters:

For Pipe: K_p = 20, 25, 30, 35, 40

For Sediment: K_s = .5, 1.0, 1.5, 2.0, 2.5, 3.0

For Water: $h_w(60^oF)$ = 11.68, 19.97, 25.17, 28.81, 31.71*

$h_w(85^oF)$ = 16.17, 27.57, 34.73, 39.76, 43.76*

By varying the heat transfer coefficient of wayer h_w (see Table I.1) a difference of 1.41°F (range was 62.25-60.84°F) was observed for T_s. From these results, an average value of h_w = 18 BTU/hr-ft-°F will be used hence forth.

Table I.2 showed the sensitivity of T_s to variations in thermal conductivity of the steel pipe (K_p). As observed, it is insensitive and K_p = 30 will be used hence forth.

By varying the thermal conductivity of the marsh sediment (K_s) a substantial change in T_s was observed (see Table I.3). This indicates that the equations are most sensitive to the parameter K_s and is therefore the most important factor of the three tested.

Table I.1: Variation of h_w

T_b	T_w	K_p	K_s	h_w	q/A	T_s (°F)	T_p (°F)
150	60	30	1.2	11.68	26.30	62.25	149.93
150	60	30	1.2	19.97	26.58	61.33	149.93
150	60	30	1.2	25.17	26.66	61.06	149.93
150	60	30	1.2	28.81	26.70	60.93	149.93
150	60	30	1.2	31.71	26.72	60.84	149.93

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* The values are a result of varying change in temperature (ΔT) in eqn. 7-21, ref 1.

Table I.2: Variation of K_p

T_B	T_w	K_p	K_s	h_w	q/A	T_s (°F)	T_p (°F)
150	60	20	1.2	18	26.52	61.47	149.89
150	60	25	1.2	18	26.53	61.47	149.91
150	60	30	1.2	18	26.54	61.47	149.93
150	60	35	1.2	18	26.54	61.47	149.94
150	60	40	1.2	18	26.54	61.47	149.94
150	60	45	1.2	18	26.54	61.47	149.95

Table I.3: Variation of K_s

T_B	T_w	K_p	K_s	h_w	q/A	T_s (°F)	T_p (°F)
150	60	30	0.5	18	11.17	60.62	149.97
150	60	30	1.0	18	22.18	61.23	149.94
150	60	30	1.5	18	33.03	61.83	149.91
150	60	30	2.0	18	43.72	62.43	149.88
150	60	30	2.5	18	54.27	63.02	149.85
150	60	30	3.0	18	64.67	63.59	149.82

Conclusions

Since the actual materials for the system are not known, the accuracy of these calculations cannot be precisely determined. However, in all probability, the sediment surface temperature increase would be in the order of 1°F to 2°F. Bearing in mind that this would occur close to the brine pond, and as the brine cools during the trip the effects to the surface will become negligible. The hottest brine (150°F) and coolest weather (60°F) could conceivably cause a 3.59°F temperature rise (Table I.3), but this is doubtful. Any protective coating on the pipe (i.e. tar) will reduce the heat flow at any time to significantly lower values, thus decreasing surface temperature rises.

B. Brine Plume Thermal Analysis

The brine which would be discharged from Texoma Group diffusers at West Hackberry, Black Bayou, or Big Hill would originate either from the initial leaching of caverns or from water displacement of stored oil during a cavern fill period. Because of the earth's thermal influence in these deep caverns, the effluent brine would be elevated in temperature. The temperature of the brine before disposal in the Gulf of Mexico would thus be influenced by this geothermal heating and is related to the depth of the leached caverns in the earth, the residence time in the caverns, the temperature of the displaced oil, the retention time of the brine in the holding ponds and any heat loss or gain in the pipeline offshore. Although it has been conservatively estimated that the temperature of the brine would be up to 150°F, observations made for various flow rates at several operational salt domes show that the temperature of the brine before injection into a brine holding pit would be more realistically at a temperature of 120°F or less.

Observed Temperature and Flow Rates for Brine at
Three Gulf Coast Salt Domes

Salt Dome	Brine Temperature (°F)	Oil Temperature (°F)	Flow Rate (BPH)	Well Number
Bryan Mound	120	80	1500	2
			1500	4
Bayou Choctaw	80-90	80	1250[a]	15
West Hackberry	80-90	80	1500	6
			1000	11

An analysis of heat transfer properties in the proposed brine disposal pipeline was conducted to determine the expected heat loss in the disposal when the brine is pumped from the brine pond to the diffuser head. The analysis was carried out for conditions where the temperature of the brine at the inlet ranged from 70°F to 140°F and ambient ground temperatures ranged from 50°F to 70°F. The results of the analysis in the table below indicate that the maximum temperature differential (ΔT) between the inlet and the outlet (i.e., the diffuser ports) would occur for the case when the inlet temperature was 140°F and the ground temperature was 50°F, but this difference would only amount to 3.2°F due to the insulating effect of the pipe coatings of tar wrap and concrete. Therefore the temperature of the brine at the diffuser head considered below should conservatively remain within the temperature range of about 115° to 120°F.

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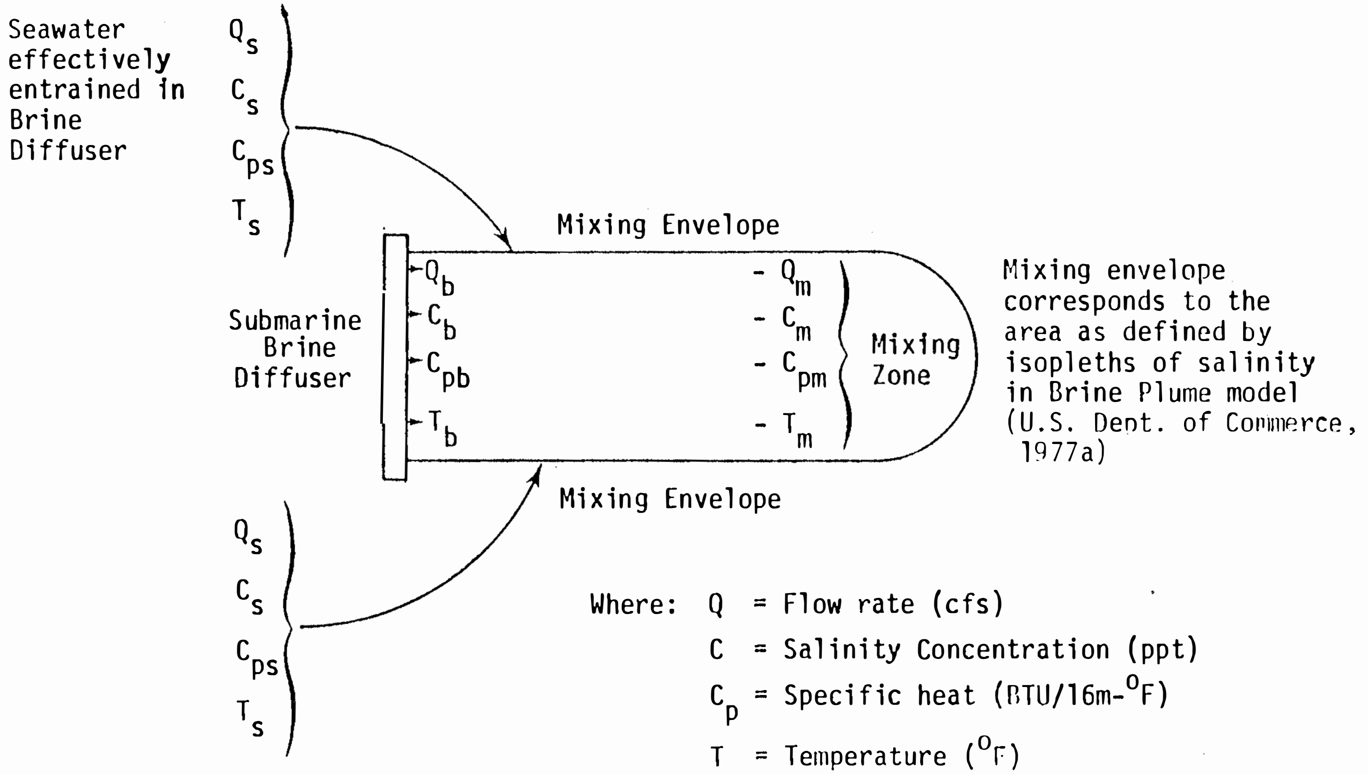
[a] Fill at Bayou Choctaw is intermittent; the average is 1250 BPH but actual injection rate is 2200 BPH.



Mixing envelope corresponds to the area as defined by isopleths of salinity in Brine Plume model (U.S. Dept. of Commerce, 1977a)

Figure I-2 Schematic model of mixing zone relationships for brine plume temperature analysis.

Brine Temperature (^{0}F) at the Proposed Diffuser Ports as a Function of Ground Temperature and Brine Temperature at the Pipeline Inlet

Brine Inlet Temperature (^{0}F)	Ground Temperature (^{0}F) 50	60	70
140	136.8	137.2	137.6
130	127.2	127.6	128.1
110	108.1	108.5	108.9
90	88.9	89.3	89.6
70	69.6	69.9	70.0

General Approach

To estimate the potential impacts from excess temperatures a simplistic heat flow model (Figure I.2) was evaluated and analyzed. A correlation was made between excess temperature and excess salinity profiles, assuming 90^{0}F seawater (probable maximum) and brine temperatures varying from 90^{0}F to 150^{0}F. The brine dispersion model as discussed above in Section G.3.1.1 provided a basis for applying this correlation to expected mixing conditions in the Gulf of Mexico at the diffuser sites. The simplified analysis presented here does not account for buoyancy effects in the water column due to elevated brine temperatures. The analysis should be reasonably accurate within the mixing zone which is located close to the brine diffuser.

Since the temperature of the brine within the salt dome is not accurately known and temperature will vary with residence time and the other factors described above, a parametric analysis was used to relate the difference in the temperature in the brine plume compared to the ambient water temperature (ΔT_1) with the temperature of the brine (T_b) (see Figure I.2).

Salinity Dilution Calculation

The basic analysis for the salinity dilution effects corresponds to the area at the diffuser site defined by the MIT model (section G.3.1.1) above; in this analysis salt is conserved throughout mixing zones such that:

$\rho m\ Q_m\ C_m = \rho b\ Q_b\ C_b + \rho s\ Q_s\ C_s$; where $\rho m\ Q_m = \rho b\ Q_b + \rho s\ Q_s$,

and ρ is the specific gravity of the corresponding fluid.

$$C_m = \frac{\rho b\ Q_b\ C_b + \rho s\ Q_s\ C_s}{\rho b\ Q_b + \rho s\ Q_s}$$

$$\text{Define } \Delta C_1 = C_m - C_s = \frac{\rho b\ Q_b\ C_b + \rho s\ Q_s\ C_s}{\rho b\ Q_b + \rho s\ Q_s} - C_s$$

Or $$\Delta C_1 = \frac{\rho b\ Q_b\ (C_b - C_s)}{\rho b\ Q_b + \rho s\ Q_s}$$

Solve for Q_s: $$Q_s = \frac{\rho b\ Q_b\ (C_b - C_s) - \rho b\ Q_b\ (\Delta C_1)}{\rho s\ \Delta\ C_1}$$

Define: $C_b - C_s = \Delta C_2 = \text{constant}$

Then $$Q_s = Q_b\ \frac{\Delta C_2}{\Delta C_1} - 1\ \ \ \frac{\rho b}{\rho s}$$

Heat Dilution Calculation

Assume conservation of energy in mixing zone:

$\rho_m\ Q_m\ C_{pm}\ T_m = \rho_b\ Q_b\ C_{pb}\ T_b + \rho_s\ Q_s\ C_{ps}\ T_s$; where $_m\ Q_m = \ _b\ Q_b + \ _s\ Q_s$ and within most of mixing zone, $C_{pm} \simeq C_{ps}$ (i.e., substantial dilution)

Also, heat capacity per unit volume is nearly independent of salinity, or $\rho_s\ C_{ps} = \rho_b\ C_{pb} = \rho_m\ C_{pm}$

then;

$$T_m = \frac{\rho_b\ Q_b\ C_{pb}\ T_b + \rho_s\ Q_s\ C_{ps}\ T_s}{(\rho_b\ Q_b + \rho_s\ Q_s)\ C_{pm}} = \frac{\rho_s\ C_{ps}\ (Q_s\ T_s + Q_b\ T_b)}{C_{pm}\ (\rho_b\ Q_b + \rho_s\ Q_s}$$

Define:

$$\Delta T = T_m - T_s = \frac{\rho_s\ Q_b\ T_b - \rho_b\ Q_b\ T_s}{\rho_s\ Q_s + \rho_b\ Q_b}$$

Using equation (1); $$\Delta T = \frac{\Delta C_1}{\Delta C_2}\ \frac{\rho_s}{\rho b}\ T_b - T_s \qquad (2)$$

Using equations (1) and (2) and site specific data for $Qb, C_b, C_s, \rho_s, \rho_b$, and T_s, we solve for Q_s and ΔT, as a function of T_b and ΔC_1.

Application To Texoma Group Diffuser

Now Equations (1) and (2) can be combined to yield

$$\Delta T_1 = \frac{\Delta C_1}{\Delta C_2} \quad \frac{C_{pb}}{C_{ps}} \; T_b - T_s \qquad (3)$$

Notice should be taken that ΔT_1 is not a function of either flow rate, Q_b or Q_s. For the diffuser at West Hackberry the following data are applicable.

$$C_b = 260 \text{ ppt}$$

$$C_s = 30 \text{ ppt}$$

$$\Delta C_2 = C_b - C_s$$

$$= 230 \text{ ppt}$$

$$C_{pb} = .787 \text{ BTU/lb}_m \, {}^{o}\text{F}$$

$$\frac{C_{pb}}{C_{ps}} = .819$$

Then from Equation (3),

$$\Delta T_1 = \frac{\Delta C_1}{230} \quad (.819 \, T_b - 90)$$

For a given value of T_b the preceding relation provides an approximate method of calculating the excess temperature ΔT_1 (in a specified region) based on the excess salinity ΔC_1 (for the same region) as calculated by means of the MIT Transient Plume Model.

Figure I-3 provides a plot of ΔT_1 as a function of ΔC_1 for five different values of T_p = ranging from 110^{0} F to 150^{0} F. By means of this figure the excess salinity contours presented in Appendix D.25 and D.28 can be converted to excess temperature contours (isotherms). An examination of the excess salinity contours reveals that for the far field the maximum plotted excess salinity contour is 3 ppt. Based on the plots of excess salinity versus exposed bottom area, such a contour encloses less than 166 acres. Figure 1-3 indicates that such a value of ΔC_1 corresponds to excess temperatures of less than 1^{0} F. This result suggests that in the far field with an ambient seawater temperature of 90^{o} F the maximum temperature rise would be less than 1^{o} F, and such a temperature increase would be limited to a bottom region of no more than 166 acres. Significant excess temperatures ($>5^{o}$F) should only occur in the immediate vicinity of the diffuser, corresponding to the near field of the plume.

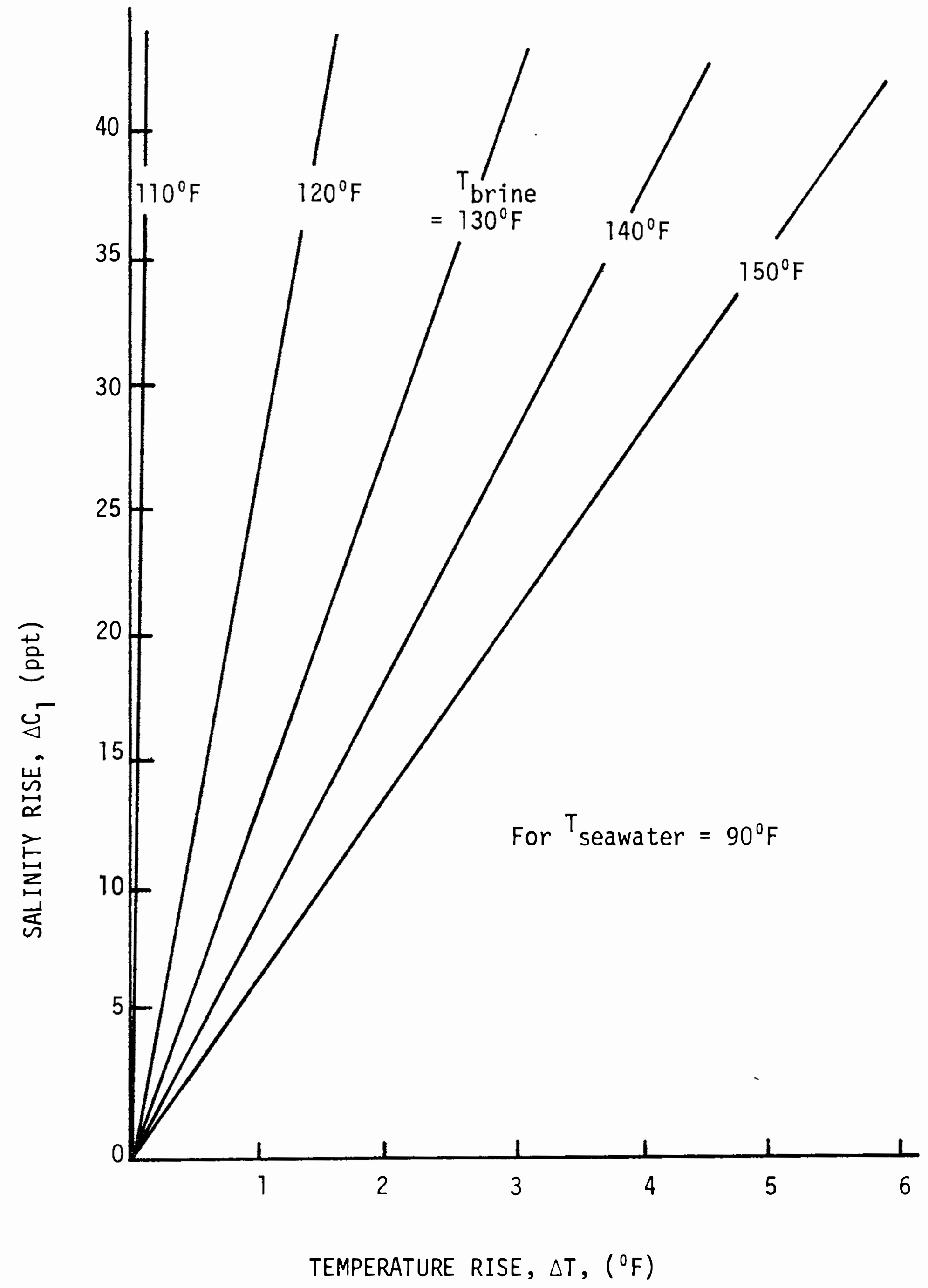


Figure I-3. Correlation of Temperature Rise with Salinity Rise

These conclusions are based on the similarity between the dispersion of salinity and temperature. No effects due to buoyancy have been taken into account. Thus, in the presence of large density gradients the trajectory of the plume could be shifted either upwards or downwards. Such a shift would alter the excess temperature for a given region. Significant changes, however, would generally be limited to the near field.

REFERENCES

1. W. L. McCabe and J. C. Smith, Unit Operations of Chemical Engineering, McGraw-Hill Book Company, Inc., 1956.
2. Frank Krieth, Principles of Heat Transfer, Third Edition, Intext Press, Inc., 1973.

APPENDIX J

SUMMARY OF CAVERN CONSTRUCTION PROCESS

APPENDIX J

SUMMARY OF CAVERN CONSTRUCTION PROCESS

Storage cavities in large salt deposits are hollowed out or "leached" by circulating fresh or brackish water through concentric tubing in a well drilled into the salt mass. Approximately 7 barrels of fresh water or 8 barrels of sea water must be pumped into the well to create each barrel of storage capacity. The resulting brine would be displaced and disposed of.

The placement and depths of storage cavities in a salt dome depend upon the structure and depth of the salt mass. At West Hackberry, the average depth to salt is 1,960 feet. The area of this large salt dome is 1,750 acres within the -2000 ft depth to salt contour. The proposed solution mined caverns would be developed in the interval from -2500 to -3500 feet. Plans are to develop roughly cylindrical caverns of 10 million barrel capacities with approximate diameters of 275 feet and heights of 1000 feet.

Oil stored in a solution type cavern is removed by pumping displacement water into the bottom of the cavern to push the oil out. Each time the oil is displaced, the cavern capacity would be enlarged due to the additional leaching caused by the introduction of fresh water in the salt. Five fill and withdrawal cycles are planned for the SPR storage program. Only the original crude oil storage capacity of 10 million barrels, however, would be refilled after each displacement, thus reducing progressive cavern enlargement. After five fill and withdrawal cycles, the gross volume enlargement is expected to be about 77 percent, creating caverns approximately 400 feet in diameter but with the same height.

The following is a general discussion of the cavern construction process as it applies to the proposed SPR oil storage program.

J.1 DRILLING PROCEDURES

Drilling operations would begin after sufficient site preparations to allow drill rig access. Wells would be drilled using conventional "oil field" drilling technology as it offers advantages in availability for materials and equipment. The required finished casing size for the storage wells would be up to 16 inches diameter, and the total depth of each borehole would be from 3,600 to 3,800 feet.

First, 60 to 100 feet of 42-inch conductor pipe would be installed prior to mobilizing the drilling rig. The pipe would be driven into place under marshy conditions, or a bucket rig would be used to set the casing on dry ground. Next a sufficient borehole would be made to set a 30-inch surface casing through the potable water zones. The pipe would be connected by field welding or special connectors. It would be cemented from the bottom to the surface by pumping cement down the drill pipe into a specially designed cementing shoe which would cause material to be squeezed up between the pipe casing and the walls of the borehole. At this time, a blowout preventor would be installed to control a possible escape of liquid which may occur if drilling through high pressure zones.

Drilling would continue to caprock and a 24 inch intermediate casing would be set and cemented from the bottom to the surface. Drilling would then continue through the caprock and at least 500 feet into the salt mass. The finished 16-inch product casing would be set to this depth which would become the roof of the storage cavern. Then a borehole would be continued through the salt to the bottom of the planned sump interval. See Figure J-1 for a graphic depiction of the finished borehole with the various casings in place.

In an estimated 20 percent of the wells drilled, trouble in drilling through the caprock is expected. This happens most often when cavernous zones resulting from natural leaching of the anhydrite and gypsum formations cause a loss of the drilling fluid. Drilling fluid, commonly called "mud", is necessary for lubricating the drill bit and for transporting spoil to the surface. Most cases of lost circulation are temporary and circulation can be re-established. But if caprock conditions at one of the wells causes complete loss of circulation, the well could be completed at greater expense without circulation or a smaller drill bit could be used to complete the well, necessitating smaller casing sizes.

Hence, at some of the storage sites, extra wells have been included in the facility design to accommodate the expectation that a few of the wells would require smaller casings and could only be developed to a 5 million barrel capacity due to the limited flow rates through the smaller well tubings. Current engineering thinking, however, indicates that reduction of casing size and cavern capacity is not necessary.

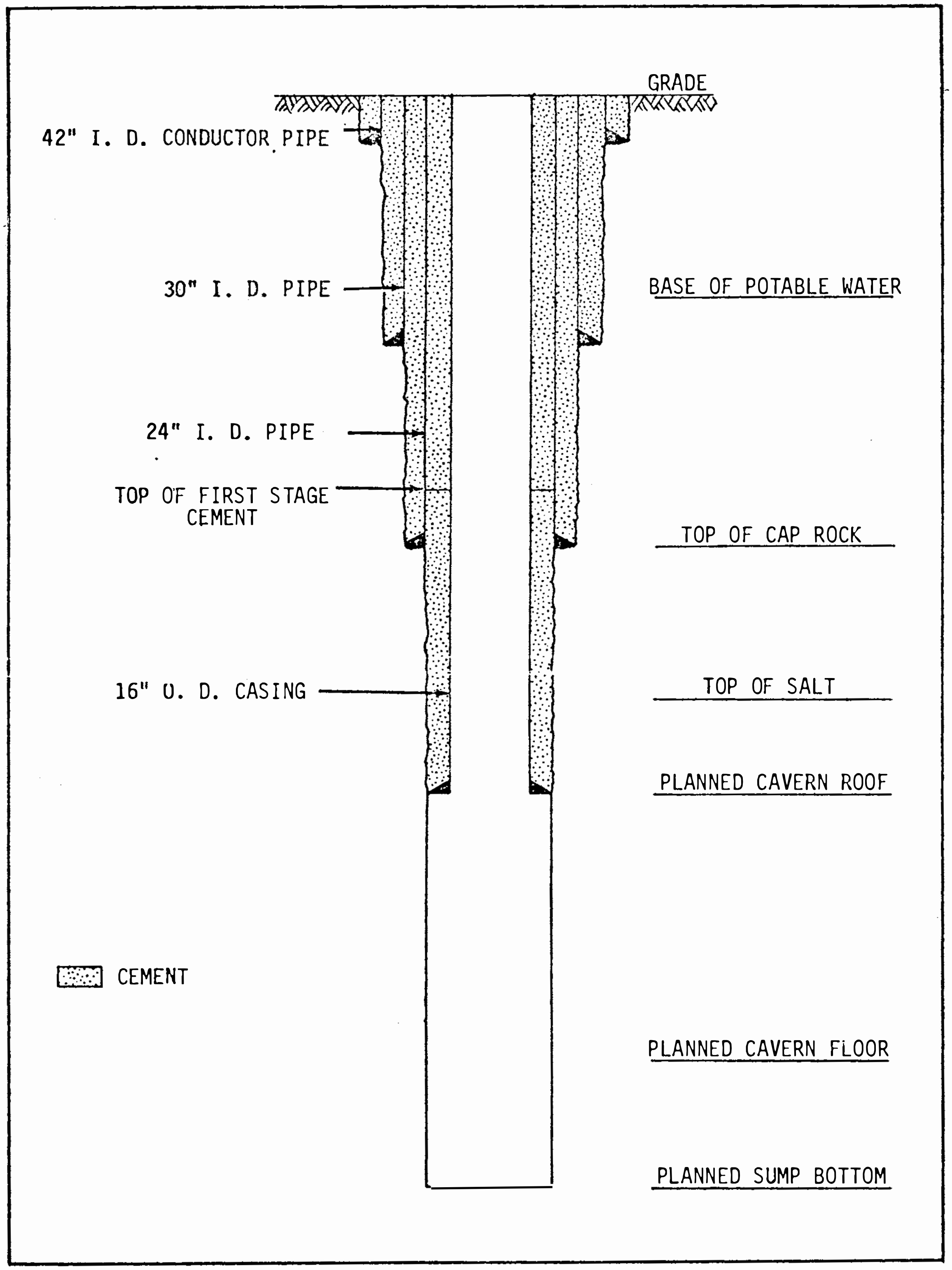


Figure J-1 Leaching Well Design

Therefore, most of the SPR site designs have been amended so that only 10 million barrel caverns would be assessed.

Drilling fluid, "mud", could be of a variety of constitutions, depending on drilling conditions. "Highly inhibited muds" may be required in difficult shales, but non-exotic clays would be used when possible. The least costly mud that would do the job would be used, but the actual formulation would be determined by experience on the site. It may be possible to use "native muds" until the "top hole" is cased off, and then to convert to saturated brine. The salt must be drilled with salt saturated mud or brine to prevent premature hole enlargement by leaching.

Disposal of used muds is also an important consideration. Normal procedure would be to transfer; the mud with the rig, continually recycling a volume equal to twice the estimated borehole volume. There would be mud pits which would have to be cleaned up and buried. In the Gulf Coast region, the humidity is too high to economically dry the waste. Therefore, mud would have to be hauled away when drilling operations are completed.

J.2 CAVERN LEACHING PROCEDURES

The fundamental technique of cavern development is to inject raw water (fresh or low salinity water) into the borehole, allow time for the water to dissolve the salt, and then displace the resulting brine from the hole. As the salt dissolves, the borehole enlarges ane eventually forms a cavern. The cavern would remain full of brine or stored oil at all times. To remove stored oil would involve the injection of raw water into the bottom of the cavern to displace the oil out of the top. Figure J-2 is a simplified diagram showing a cavern equipped with necessary displacement tubing and wellhead.

The leaching process involves two basic washing methods; direct circulation and reverse circulation. In direct circulation, the raw water is injected into the lower portion of the borehole and the brine is forced out through the casing anulus near the top of the cavern. This tends to create a bell shaped cavern with the maximum cavern diameter at the bottom. The reverse circulation method injects raw water down the casing anulus into the upper portion of the cavern while the brine is withdrawn through the tubing near the bottom. This method creates a funnel shaped cavern with the maximum diameter near the top.

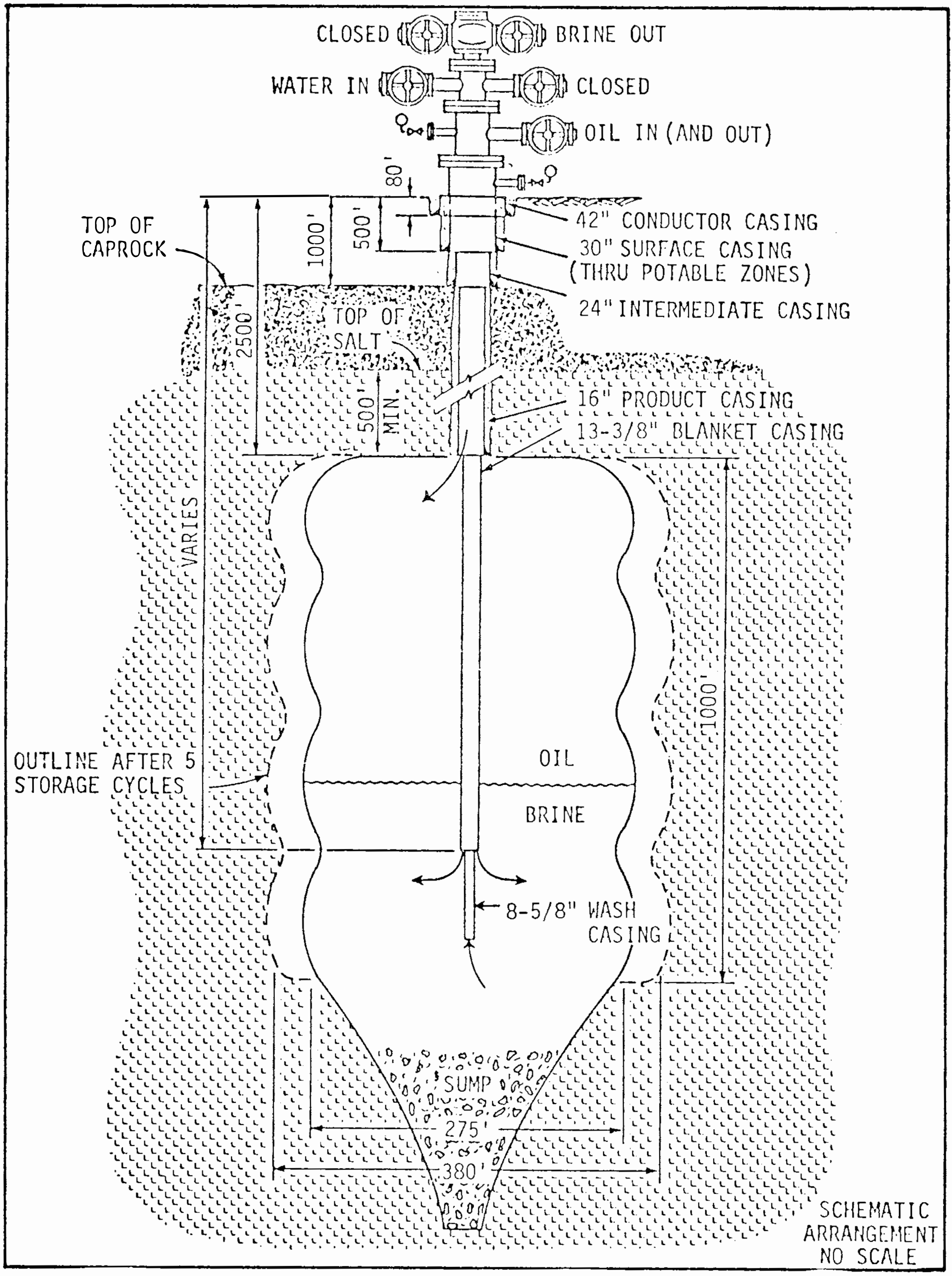


Figure J-2. Schematic of Well and Storage Cavern

To construct large storage caverns, both methods of circulation would be utilized to create more cylindrical cavern shapes. Direct circulation is used initially, and reverse circulation is used during primary leaching with a blanket material for control of upward growth. Blanket material is any noncorrosive substance lighter than water (usually oil or gas), which occupies the space in the topmost interval of the cavern. The purpose of blanket material is to prohibit the leaching of salt from around the cemented casing and to help control the shape of the developing cavern.

J.2.1 Separate Leach Then Fill Process

The present plans for cavern development are to first leach the caverns to full size by injecting only raw water and disposing of the resulting brine. In this method, a layer of blanket oil is maintained at the ceiling of the proposed cavern by a high pressure low volume blanket oil pump while the leach water is circulated at high rates to create the main body of the cavern. By using a combination of direct and reverse flow circulation, the entire cavern can be formed without repositioning the suspended wash strings.

After leaching is completed and a sonar survey has verified the size and shape of the new cavern, the two suspended wash strings are replaced by a single displacement string to allow the injection of oil and the withdrawal of brine at higher flow rates. This conversion of the well string and wellhead requires that a "workover rig" be brought to each well site before oil fill operations can begin. Once converted, the initial oil fill and subsequent withdrawal or refill operations can be conducted by opening or closing valves on the wellheads and pipeline systems.

J.2.2 Simultaneous Leach and Fill Process

As a co-proposal, a newer simultaneous leach and fill process can be implemented. Since crude oil or some other blanket material is needed to control the development of the cavern, crude oil can be stored in the upper portion of the cavern while leaching continues in the lower portion. This process allows for the early storage of oil as the cavern leaching progresses, and consequently spreads the initial crude oil supply rate over the 3 year period required for cavern development.

The following is an outline of the steps planned for creating the storage cavities using both methods of circulation with simultaneous fill during leaching:

I. Blanket casing (B) would be suspended to the projected cavern floor, and a concentric displacement tubing (C) would be extended to the bottom of the borehole (see Figure J-3). Blanket oil would be filled to the bottom of the blanket casing, and by direct circulation the bottom of the sump interval would be leached. After removing 2 joints (120 ft) of tubing (C), reverse circulation would be used to enlarge the sump to its proper size. An adequate sump size would be determined by examination of well logs and core data to calculate the amount of insolubles present in the salt (normally 3 to 7 percent).

II. The blanket oil would be withdrawn to the base of outer product casing (A) at the projected cavern ceiling, but the blanket casing (B) would be set at 60 ft. below this point. This measure would reduce the turbulence near the oil-water interface. Tubing (C) would be relocated at the projected cavern floor. With direct circulation the borehole in the salt would be enlarged. Then by reverse circulation, the cavern ceiling would be leached, gradually creating a ceiling of proper diameter.

III. At this point in the process, crude oil would be stored in conjunction with the leaching operations. The blanket casing and oil level would be lowered as needed until the cavern reaches full size.

IV. When the leaching is completed, the remainder of the cavern is filled with crude oil, the two concentric wash strings would be withdrawn and replaced by a single string for displacement during withdrawal operations.

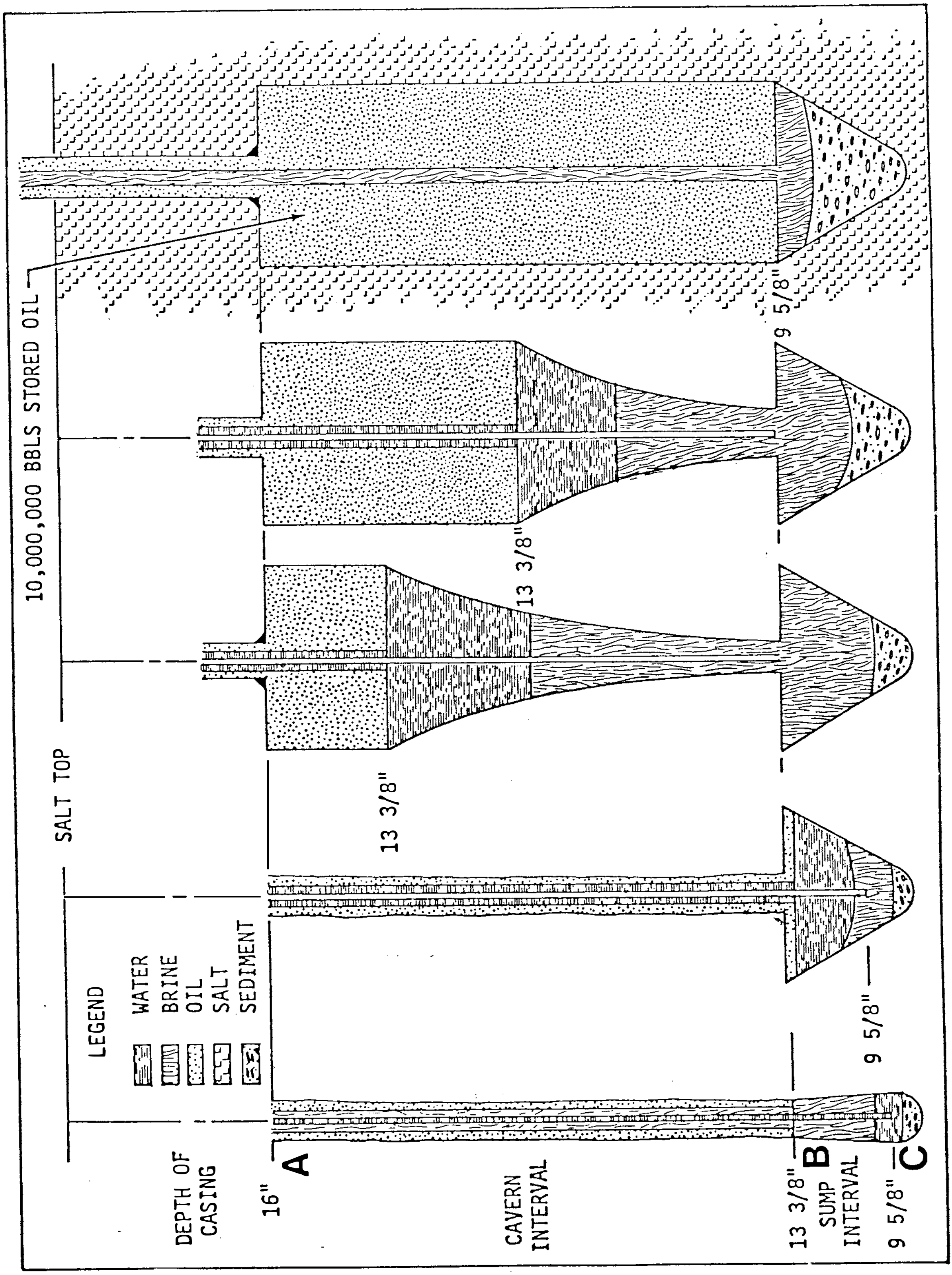


Figure J-3. Concurrent Storage & Leaching Process

APPENDIX K

LISTS OF SPECIES AND ECOSYSTEMS CHARACTERISTIC OF THE LOUISIANA AND TEXAS GULF COAST

Table K.1-1 Soil and Water Chemical Characteristics of the Marsh Vegetative Types in Hydrologic Unit 9.

FRESH MARSH

Variable	No. of Samples	Mean	Standard Deviation	Range
Water salinity (ppt)	6	1.27	.89	.33 - 2.89
Total soil salts (ppt)	3	1.60	1.32	.27 - 2.92
Organic matter (%)	3	11.92	8.07	6.14 - 21.14
Nitrogen (%)	3	.54	.38	.27 - .98
C/N ratio	3	12.58	.34	12.51 - 13.18
Phosphorus (ppt)	3	.03	.02	.009 - .06
Potassium (ppt)	3	.14	.12	.06 - .29
Calcium (ppt)	3	.71	.60	.04 - 1.22
Magnesium (ppt)	3	1.04	.29	.75 - 1.35
Sodium (ppt)	3	1.00	.16	.81 - 1.10
pH	3	5.60	.60	5.00 - 6.20

INTERMEDIATE MARSH

Variable	No. of Samples	Mean	Standard Deviation	Range
Water salinity (ppt)	10	2.43	1.45	.90 - 6.04
Total soil salts (ppt)	11	5.12	4.52	.55 - 16.53
Organic matter (%)	11	28.35	22.51	2.60 - 69.19
Nitrogen (%)	11	1.05	.53	.39 - 2.20
C/N ratio	11	15.62	4.49	8.19 - 24.14
Phosphorus (ppt)	11	.01	.01	.002 - .05
Potassium (ppt)	11	.16	.09	.05 - .31
Calcium (ppt)	11	.63	.42	.13 - 1.45
Magnesium (ppt)	11	1.30	.72	.40 - 3.06
Sodium (ppt)	11	2.20	1.50	.42 - 5.88
pH	11	5.78	.38	5.30 - 6.30

BRACKISH MARSH

Variable	No. of Samples	Mean	Standard Deviation	Range
Water salintiy (ppt)	21	6.41	4.38	.49 - 15.79
Total soil salts (ppt)	21	6.60	3.11	1.48 - 12.56
Organic matter (%)	21	18.93	10.48	7.65 - 52.05
Nitrogen (%)	21	.72	.30	.27 - 1.49
C/N ratio	21	14.74	2.49	10.50 - 20.26
Phosphorus (ppt)	21	.03	.03	.004 - 1.29
Potassium (ppt)	21	.32	.14	.11 - .59
Calcium (ppt)	21	.51	.33	.12 - 1.28
Magnesium (ppt)	21	1.37	.35	.78 - 2.10
Sodium (ppt)	21	3.34	1.23	1.27 - 5.68
pH	21	6.16	.36	5.20 - 6.80

Table K.1-1 Continued

SALINE MARSH

Variable	No. of Samples	Mean	Standard Deviation	Range
Water salinity (ppt)	--	--	--	---
Total soil salts (ppt)	1	3.07	--	3.07 - 3.07
Organic matter (%)	1	2.14	--	2.14 - 2.14
Nitrogen (%)	1	.06	--	.06 - .06
C/N ratio	1	20.66	--	20.66 - 20.66
Phosphorus (ppt)	1	.13	--	.13 - .13
Potassium (ppt)	1	.29	--	.29 - .29
Calcium (ppt)	1	7.28	--	7.28 - 7.28
Magnesium (ppt)	1	3.22	--	3.22 - 3.22
Sodium (ppt)	1	2.55	--	2.55 - 2.55
pH	1	7.70	--	7.70 - 7.70

Source: Chabreck, R. H., 1972. Vegetation, Water and Soil Characteristics of the Louisiana Coastal Region, Bulletin No. 664, Louisiana State University, Agricultural Experiment Station, 72. pp.

Table K.1-2 Species Composition of Marsh Types[a] Within Hydrologic Unit 9 of the Louisiana Coastal Marshes.

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	---------------- Percent -----------------			
Acnida alabamensis	--	--	1.21	--
Alternanthera philoxeroides	--	--	2.24	25.87
Bacopa monnieri	--	5.33	2.49	2.99
Batis maritima	20.24	--	--	--
Cynodon dactylon	--	--	--	2.99
Daubentonia texana	--	--	--	1.29
Distichlis spicata	54.66	8.96	--	1.99
Echinochloa walteri	--	--	--	2.19
Eleocharis sp.	--	--	--	8.46
Juncus effusus	--	--	3.00	--
Leptochloa fascicularis	--	--	--	1.99
Nymphaea ordorata	--	--	--	1.99
Paspalum vaginatum	--	7.22	13.29	5.77
Ruppia maritima	--	1.18	--	--
Phragmites communis	--	--	3.97	--
Sagittaria falcata	--	--	4.59	22.88
Scirpus californicus	--	--	6.73	4.98
Scirpus olneyi	--	6.99	6.21	--
Scirpus robustus	--	2.49	1.21	--
Sesbania exaltata	--	--	2.07	--
Setaria glauca	--	1.38	--	--
Spartina alterniflora	24.29	--	--	--
Spartina patens	--	59.81	46.83	7.96
Spartina spartineae	--	1.58	1.73	--
Stricularia cornuta	--	--	--	3.98
Other species[b]	.81	5.06	4.43	2.68

[a] Includes only natural marshes.

[b] Includes only plants making up less than 1.00 percent of the species composition.

Source: Chabreck, R. H., 1972. Vegetation, Water and Soil Characteristics of the Louisiana Coastal Region, Bulletin No. 664, Louisiana State University, Agricultural Experiment Station, 72 pp.

Table K.2-1 Monthly average salinity, temperature, and catch per unit effort in estuarine areas of southwestern Louisiana from April 1968 through March 1969.

	Apr.	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Year*
Number of seine samples	2	2	2	2	2		2	1	2	2	1	2	20
Salinity ppt	11.1	1.9	1.5	6.7	14.4		17.6	3.8	3.8	6.8	19	2.8	9.9
Temperature C°	24.1	24.9	31.9	34.5	31.4		21.3	13.5	13.5	15.7	14	17.7	21.6
Commercial Species													
Vertebrate													
Lepisosteus spatula												1	.1
Brevoortia patronus	53	52	607	109	28		64	3	2	46	11	8	122
Dorosoma cepedianum	.5						.5			3		2	.6
Bagre marinus					5								.5
Galeichthys felis			.5	.5									.1
Ictalurus furcatus									.5				.1
Caranx hippos			7		3								1
Trachinotus carolinus			9	3			2						1
Bairdiella chrysura			1	1									.2
Cynoscion arenarius		2	11										1
Leiostomus xanthurus		1	2	3	4		6	1	5	1		2	2
Menticirrhus americanus		.5	.5	.5									.2
Micropogon undulatus	4	2	10		8		1	66	65	272	21	68	47
Archosargus probatocephalus							.5						.1
Lagodon rhomboides			.5										.1
Trichiurus lepturus												.5	.1
Scomberomorus maculatus			.5	.5	2		.5						.4
Mugil cephalus	5	2	16	11			15	15	3	4	1	6	7
Menidia beryllina	20	53	2	28	6			2	1	37		9	15
Invertebrate													
Penaeus setiferus								136	18				9
Callinectes sapidus	13	2	31	26	1		3	4	4		1	2	9
Other Species													
Vertebrate													
Alosa chrysochloris							.5	1	.5				.2
Dorosoma petenense	2	.5	50		13		.5	5	.6	1		5	8
Harengula pensacolae				23	6								3
Anchoa hepsetus					12								1
Anchoa mitchilli	12	47	107	9	2		199	28	74	116	5	76	65
Strongylura marina			4				2						.6
Cyprinodon variegatus								1	1	13	1	21	4
Fundulus grandis	1	3	2	1	3		1						1
Chloroscombrus chrysurus			13	13	22		1						4
Oligoplites saurus			.5	3	.5		.5						.5
Peprilus paru					.5								.1
Polydactylus octonemus	96	156	69	8	12		6						34
Sphaeroides nephelus		3	6	7									2
Invertebrate													
Lolliguncula brevis							.5						.1
Livoneca ovalis		1		1				1				.5	.4
Acetes americanus	2												.2
Palemonetes vulgaris										2		2	.4
Pagurus longicarpus							1						.1

Table K.2-1 Continued

	Apr.	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Year*
Number of trawl samples	17	17	17	17	17	17	17	13	17	17	17	15	198
Salinity ppt	8.4	5.1	9.2	5.7	7.4	7.9	9.3	23.5	6.2	5.7	7.3	5.2	8.4
Temperature C°	21	25.3	28.6	33.5	31.4	27	25.1	16.2	12.5	10.9	14.2	13.2	20.7
Commercial Species													
Vertebrate													
Lepisosteus spatula									2	.1			T
Brevoortia patronus	9	247	296	42	15	10	8	11	4	1	35	36	61
Dorosoma cepedianum	.1			2	2	1	.4	1	.1	2	1	6	1
Bagre marinus				.6	3	3	.2						.6
Galeichthys felis	.5	.1	.6	.2	5	6	1						1
Ictalurus furcatus	.1	.1	2	.6	1	.4		1	5	3	.1	4	1
Roccus mississippiensis									.1			.1	T
Caranx hippos					.2	.2	.1						.1
Trachinotus carolinus					T								T
Cynoscion arenarius	2	6	32	36	23	41	30	3	.2		.1		15
Cynoscion nebulosus	.3					.1		.2		.1		.1	.1
Leiostomus xanthurus	89	121	64	103	33	10	3	10	6	2	3	2	38
Menticirrhus americanus				.1	.1	.5	.2						.1
Micropogon undulatus	510	393	258	252	77	51	10	27	33	140	208	252	187
Pogonias cromis	.2	.1	.1	.1	.1			1	.5	.1	.5	.1	.2
Archosargus probatocephalus	.3			.1		.1		.3	.2	.1	.3	.2	.1
Lagodon rhomboides							.1						T
Chaetodipterus faber			.1	2	10	6	2		.1				2
Trichiurus lepturus	.1	.2	.2	.1			.1	.2	.2		.1	1	.2
Scomberomorus maculatus					.2	.2	.1						T
Prionotus tribulus	.2											.1	T
Mugil cephalus	.1	.1	.1	1	.1			.2	3	2	1	11	2
Menidia beryllina								.1	.5	.1	.1		.1
Citharichthys spilopterus		1	3		1	2	.3	.2			.1		.7
Etropus crossotus				.1		.3	.5						.1
Paralichthys lethostigma	.5		.1	.1	.2	.1	.2	.1	1	.5	.1	.3	.2
Trinectes maculatus	.3	.3	2	1	1	3	.2	4	.5	.4	.1	.5	1
Invertebrate													
Rangia cuneata	.1	.4	.1	.1			.1	.1	.1	.1			.1
Penaeus setiferus	5	6	1	39	96	131	71	87	5				35
Penaeus aztecus	1	103	148	40	38	33	2	.4	1				31
Callinectes sapidus	9	8	8	5	3	110	8	13	10		2	13	7
Other Species													
Vertebrate													
Dasyatis sabina						.1							T
Dorosoma petenense	.1	.1			5			1	1	.4	1	12	2
Harengula pensacolae					.4	.1							T
Anchoa mitchilli	19	80	121	54	254	177	136	135	51	18	82	41	89
Synodus foetens				.1		.1	.1	.1					T
Ophichthus gomesi					.1			.1	.1				T
Cyprinodon variegatus									.2	.1			T
Fundulus grandis									.1			.1	T
Urophycis floridanus											.6		.1
Chaenobryttus gulosus								.1				.1	T
Stellifer lanceolatus			.1	.1	.1	.1							T
Gobioides broussonneti			.1				.1					.4	T
Gobionellus hastatus		.2	.1	.1	.1			.1	.2	.1		.5	.1
Gobiosoma bosci								.1	.1				T
Microgobius gulosus	.1								.1				T

Table K.2-1 Continued

	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year
Peprilus paru				.1		.6	.1			.1	.1	.2	.1
Polydactylus octonemus	19		290	134	60	2	4	.1					32
Achirus lineatus		.1			1	4	.3	.5	.1				.5
Symphurus plagiusa		.3	1	.2	1	1	.6	.2			.1	.2	.6
Gobiesox strumosus			.1				.1						T
Sphaeroides nephelus			.2	1	1	2	.1	.1					.4
Opsanus beta	.1												T
Invertebrate													
Lolliguncula brevis				.1		.1							.1
Livoneca ovalis	.1	.4	.1	2		.1	.1		.1	.1		.1	.3
Acetes americanus						.1	.1				.1		T
Alpheus heterochaelis	.1												T
Palemonetes vulgaris	23	8	20	1	2	.1			11	17	.3	9	8
Squilla empusa								.1					T
Pagurus longicarpus		.1											T
Panopeus herbstii									.1				T

[a] Commercial species are defined as those listed in Fishery Statistics of the United States, 1966.

[b] Denotes a catch of less than 0.1 per tow.

T = Trace

Source: Perret, W.S., et al., 1971, Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana: Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana.

Table K.3-1 Benthic, Epiphytic, and Periphytic Algae Commonly Found In Coastal Louisiana Waters Near the Gulf Intracoastal Waterway

Bacillariophyceae (Diatoms)

- *Amphiphora* sp.
- *Amphora augusta*
- *Amphora* sp.
- *Caloneis* sp.
- *Camphylodiscus* sp.
- *Cocconeis disculoides*
- *Cocconeis disculus*
- *Cocconeis placentula*
- *Cylindrotheca closterium*
- *Cylindrotheca fusiforma*
- *Denticula* sp.
- *Diploneis bombus*
- *Diploneis interrupta*
- *Grammatophora marina*
- *Grysogima terryanum*
- *Hantzschia* sp.
- *Isthmia nervosa*
- *Mastogloia* sp.
- *Melosira distans*
- *Melosira* spp.
- *Navicula directa*
- *Navicula* spp.
- *Nitzschia* spp.
- *Opephora* sp.
- *Paralia* sp.
- *Pleurosigma* sp.
- *Rhopalodia gibberula*
- *Surirella americana*

Chlorophyceae (Green Algae)

- *Caulerpa prolifera*
- *Cladophora delicatula*
- *Cladophora fascicularis*
- *Cladophora gracilis*
- *Cladophora repens*
- *Cladophoropsis membranacea*
- *Enteromorpha clathra*
- *Enteromorpha flexuosa*
- *Enteromorpha intestinalis*

Table K.3-1 Continued

- *Enteromorpha lingulata*
- *Phaeophila dendroides*
- *Rhizoclonium kochianum*
- *Rhizoclonium riparium*
- *Spyridea filamentosa*
- *Ulothrix* sp.
- *Ulva lactuca*
- *Ulvella lens*
- *Ulvella* sp.
- *Vaucheria* sp.

Cyanophyceae (Blue-green Algae)

- *Anacystis* sp.
- *Chroococcus* sp.
- *Lyngbya gracilis*
- *Lyngbya majescula*
- *Lyngbya* spp.
- *Merismopedia* sp.
- *Oscillatoria* sp.
- *Spirulina subsalsa*
- *Spirulina* sp.

Source: U.S. Army Corps of Engineers, 1975, Draft Environmental Impact Statement, Gulf Intracoastal Waterway Petit Anse, Tigre and Carlin Bayous; and Bayou Grosse Tete, Louisiana, U.S. Army Corps of Engineers, New Orleans, Louisiana.

Table K.4-1 Species Composition and Relative Abundance of Major Plankters in Monthly Plankton Aliquots With Settled Volume Per 100m^3, Salinity (PPT), and Water Temperature (C^o) as Collected April 1, 1968, Through March 31, 1969, in the Southwestern Louisiana Coastal Zone

	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Settled Vol. cc	98.6	9.6	51	8.0	4.6	6.3	5.0	4.6	4.6	12.0	20.7	10.2
Salinity ppt	10.8	12.2	18.1	17.3	16.4	11.9	20.5	24.2	21.3	13.9	...	...
Temperature C°	22.0	24.9	31.2	34.4	31.6	26.2	24.4	14.8	12.5	8.0	...	...
Taxon												
PROTOZOA												
Dinoflagellida												
Noctiluca scintillans	5154									105	2500	192
COELENTERATA	P	P				P		P	P	P	P	P
CTENOPHORA	P	P			P	P	P	P		P	P	P
ANNELIDA												
Polychaeta LAR												25
ARTHROPODA												
Crustacea NAU	2099	233			70	503	81	85		54	85	37
Cladocera												
Evadne tergestina									81		27	160
Penilia auirostris	391		91			1692						85
Copepoda COP	T	T	T			T	T	T	T	T	T	T
Acartia sp.	3070	997	236	56	105	3373	2333	9378	500	157	236	2253
Caligus sp.								2				
Centropages sp.	520					2693	20	136	136	26	174	75
Corycaeus sp.		296					86					
Eurytemora hirundoides		100				1215						
Labidocera aestiva	556	324	48	20	57	1485	290	134	22			43
Sapphirina nigromaculata							25	60				
Temora sp.			91			523	430	72	15			25
Tortanus sp.							47	45				
Undinula vulgaris						128	104	165	174		120	69
Halicyclops fosteri							80	198	121	25	20	59
Isopoda												
Aegathoa oculata					3		40		1			
Decapoda LAR	1056	480	116	80	93	2240	623	289			20	50
Caridea												
Leander tenuicornis	9	18	110									
Brachyura MEG										2		
Callinectes JUV												

Table K.4-1 Continued

	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
CHAETOGNATHA												
Sagitta hispida	143					125	728	410				25
CHORDATA												
Urochordata												
Oikopleura sp.		200					104	120			20	250
Doliolida						5						
Osteichthyes EGG	295	2200					10					
Osteichthyes LAR	36	16				60	36	2	2	49	50	1

P = Present in fair numbers
T = Trace

Source: Gillespie, M.C., 1971, Analysis and treatment of zooplankton of estuarine waters of Louisiana, In: Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana: Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana.

Table K.5-1 Representative Freshwater Fish Species in Coastal Louisiana

Name	Status	Large River Channels	Small Rivers, Large Tributary Creeks	Oxbow, Swamps, Flood Plain Sloughs Borrow Pitts
Blue Catfish*	U	X	U	X
Channel Catfish*	X	X	X	X
Black Bullhead	X	U	X	X
Yellow Bullhead*	X	U	X	X
Flathead Catfish*	U	X	U	X
Freshwater Drum*	U	X	U	X
Paddlefish	U	X	U	X
Bowfin*	X	X	U	X
Spotted Gar*	X	U	X	X
Alligator Gar*	U	X	U	X
Longnose Gar*	X	X	X	X
Shortnose Gar	U	X	U	X
Carp (Introduced)	X	-	-	-
Smallmouth Buffalo*	U	X	U	X
Bigmouth Buffalo*	U	X	U	X
Gizzard Shad*	X	X	X	X
White Bass*	X	X	U	X
Yellow Bass*	U	X	U	X
Largemouth Bass*	X	U	X	X
Spotted Bass	X	U	X	U
White Crappie*	X	X	U	X
Black Crappie*	X	X	U	X
Warmouth*	X	X	X	X
Bluegill*	X	X	X	X
Redear Sunfish*	X	U	X	X
Green Sunfish	X	U	X	U
Orange Spotted Sunfish*	U	X	U	U
Spotted Sunfish*	X	U	X	X
Longear Sunfish	X	X	X	X
Flier	X	U	U	-

From U.S. Army Engineers, New Orleans District, 1975.
*Species that frequently occur in brackish or saline water.

U = expected or known occurrences, but probably uncommon
X = definitely known occurrence and existence of well established population

Table K.6-1 High Marsh Vegetation

Osmunda cinnamonea L.	Cinnamon fern
Osmunda regalis L.	Royal fern
Sphenopholis obtusata (Michx.) Scribn.	Prairie wedgescale
Panicum virgatum L.	Switchgrass
Echinochloa walteri (Pursh.) Heller	Saltmarsh cockspur grass
Setaria magna Griseb.	Giant bristlegrass
Setaria geniculata (Lam.) Beauv.	Knotroot bristlegrass
Setaria glauca (L.) Beauv.	Yellow foxtail
Schizachyrium scoparium (Michx.) Nash	Little bluestem
Cynodon dactylon (L.) Pers.	Bermuda grass
Spartina spartinae (Trin.) Hitchc.	Gulf cordgrass
Sesbania macrocarpa Muhl.	Hemp sesbania
Tilia americana L.	American basswood
Hibiscus militaris Cav.	Scarlet rose-mallow
Hibiscus cubensis A.	Mallow
Spartina patens (Ait.) Muhl.	Saltmeadow cordgrass
Distichlis spicata (L.) Greene	Saltgrass
Juncus roemerianus Scheele.	Black rush
Smilax laurifolia L.	Bamboo-vine
Salix nigra Marsh	Black willow
Myrica cerifera L.	Wax-myrtle
Batis maritima L.	Maritime saltwort
Liquidambar styraciflua L.	Sweet-gum
Platanus occidentalis L.	Sycamore
Rubus duplaris Shinners	Blackberry
Vigna luteola (Jacq.) Benth.	Wild cowpea
Amorpha fruticosa L.	Indigo bush
Sesbania vesicaria (Jacq.) Ell.	Bladder pod
Boltonia asteroides (L.) L'Her.	Doll's daisy
Pluchea camphorata (L.) D.C.	Camphor-weed
Pluchea purpurascens (SW) D.C.	Marsh-fleabane
Iva frutescens L.	Marsh-elder

Table K.6-1 Continued

Hydrocotyle umbellata L.
Marsh pennywort

Ipomoea sagittata Poir.
Arrow-leaf morning glory

Mikania scandens (L.) Willd.
Climbing hemp-weed

Baccharis halimifolia L.
Sea-myrtle

Solidago sempervirens L.
Seaside goldenrod

Heliopsis gracilis Nutt.
Bushy sea ox-eye

Borrichia frutescens (L.) D.C.
Sea ox-eye daisy

Helenium tenuifolium Nutt.
Bitterweed

Pyrrhopappus carolinianus
(Walt.) D.C.
False dandelion

Source: U.S. Army Corps of Engineers, Galveston District, 1975, Final environmental statement maintenance dredging Sabine-Neches Waterway, Texas.

Table K.7-1

Terrestrial, Swamp, and Marsh Ecosystems, Plant Species - Jefferson County, Texas

Total Land = 608,704 Acres[1]

Prairie Grassland presently <60,000 acres before cultivation 369,280 acres	bluestem (*Andropogon* spp.), Indiangrass (*Sorghastrum* spp.), (*Paspalum* spp.) mesquite and *Prosopis* spp.), Johnson grass (*Sorghum halepense*), hackberry (*Celtis* spp.), huisache (*Acacia farnesiana*), chaparral, cactus, switchgrass (*Panicum virgatum*), prairie wildgrass (*Sphenopholis obtusata*)
Cropland 114,114 acres (harvested and fallow)	rice, soybeans, hay weed species (jungle-rice, barnyard grass, red rice, knotgrass)
Pastureland 37,000 acres	naturally occurring prairie grass and marsh species, improved pasture grass (ryegrass, alyceclover, white clover, dallisgrass) legumes, longtom, bermuda grass
Swamps 3,840 acres	*Deep Swamp* bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), water oak (*Quercus nigra*), dwarf palmetto (*Sabal minor*), gum (*Nyssa biflora*), grape (*Vitis* spp.), yaupon (*Ilex vomitoria*), saw grass (*Cladium jamaicense*), breakrush (*Rhynchospora corniculata*) *Shallow Swamp* swamp tupelo (*Nyssa sylvatica* var. *biflora*), overcup oak (*Quercus lyrata*), water hickory (*Carya aquatica*), swamp hickory (*Carya leiodermis*), black willow, red maple (*Acer rubrum* var. *drummondi*), water oak (*Fraxinus carolinia*), pumpkin ash (*Fraxinus tomentosa*), water locust (*Gleditsia aquatica*), pecan (*Carya illinoensis*), swamp privet (*Forestiera acuminata*), common buttonbush (*Cephalanthus occidentalis*), water elm or plannertree (*Planera aquatica*)

---

[1] 1974 Statistics

Terrestrial, Swamp, and Marsh Ecosystems, Plant Species - Jefferson County, Texas (continued)

Total Land = 608,704 Acres[1]

Fluvial Woodland 21,120 acres	pecan (*Carya illinoensis*), hickory *Carya* spp.), live oak (*Quercus virginiana*), water oak (Q. nigra), blackjack oak (*Q. marilandica*), swamp Chestnut oak (*Quercus michauxii*), elm (*Ulmus* spp.), hackberry (*Celtis* spp.), magnolia (*Magnolia* spp.), sweetgum (*Liquidambar styraciflua*), red haw (*Crataegus viburnifolia*), ash (*Fraxinus* spp.), shortleaf pine (*Pinus echinata*), loblolly pine (*Pinus taeda*), carpet grass (*Axonopus* spp.), bermuda grass (*Cynodon dactylon*), greenbriar (*Smilax* spp.), yaupon (*Ilex vomitoria*), grape (*Vitis* spp.), willow oak (*Quercus phellos*)
Mixed Pine-Hardwood Forest 50,560 acres	loblolly pine (*Pinus taeda*), longleaf pine (*P. palustris*) shortleaf pine (*P. echinata*) hickory (*Carya* spp.), slash pine live oak (*Quercus virginiana*), blackjack oak (*Q. marilandica*), white oak (*Q. alba*), post oak (*Q. stellata*), hackberry (*Celtis occidentalis*), blackberry (*Rubus* sp.)

Salt Marsh	- 6,400 acres	Plant species for all marsh types are listed in Appendix A, Table 1
Brackish Marsh	-35,840 acres	
Intermediate Marsh	-76,224 acres	
Fresh Marsh	- 9,472 acres	

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[1] 1974 Statistics

Terrestrial, Swamp, and Marsh Ecosystems, Plant Species - Jefferson County, Texas (continued)

Total Land = 608,704 Acres[1]

Vegetated Strand Plain Flat 5,760 acres	bluestem (*Andropogon littoralis*), sea-oats (*Uniola paniculata*), Gulf-dune paspalum (*Paspalum monostachyum*), coastal sandbur (*Cenchrus incertus*), milkpea (*Galactia* sp.), groundsel (*Senecio* spp.), sumpweed (*Iva ciliata* var. *annua*), marsh plants such as glasswort (*Salicornia bigelovii*), cordgrass (*Spartina alterniflora*)

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[1] 1974 Statistics

Sources: Fisher, W. L., Brown, L.F., Jr., McGowen, and Groat, C. G., 1973, Environmental geologic atlas at the Texas coastal zone - Beaumont - Port Arthur Area: Bureau of Economic Geology, University of Texas at Austin.

Bureau of Census, Department of Commerce, 1974, Census of agriculture preliminary report for Jefferson County, Texas, Washington, D.C.

Earles, J. M., 1976, Forest statistics for southeast Texas counties: U. S. Dept. of Agriculture Forest Service Resource Bulletin SO-58.

Table K.7-2 Plants and Animals Probably Present in Jefferson County Aquatic Ecosystems

	PLANTS	ANIMALS
Ocean Ecosystems:	*Phytoplankton*:	*Zooplankton*:
Gulf of Mexico	Diatoms: *Nitzschia*, *Thalassiothrix*, *Skeletonema*, *Asterionella*, *Chaetoceros*, *Rhizosolenia* *Dinoflagellates*: *Triposolenia*, *Cladopyxis*, *Heterodinium*, *Amphisolenia*, *Gymnodinium*	a. Holoplankton (remain zooplankton throughout life cycle): Chaetognaths (arrow worms), Ctenophores (sea walnuts), Medusae (jellyfish, etc.), Crustaceans: copepods, ostracods, cladocerans, mysids, amphipods Pteropods (molluscs), Salps (tunicates), Pyrosomes (tunicates). b. Meroplanktonic (are zooplankton only in early life stages) Ascidians (sea squirts) Echinoderms (starfish, urchins, etc.) Cephalopods (squids, octopods) Ectoprocts (mass animals) Porifera (sponges) Annelids (worms) Nemerteans (worms) fish larvae (vertebrates) *Benthic Fauna*: *Upper Shoreface*: *Dinocardium*, *Dosinia*, *Tellina*, *Anadara*, *Mercenaria*, and *Anomia* (clams); *Terebra*, *Polinices*, *Oliva*, and *Olivella* (snails); *Mellita* (urchin); *Luidia*, and *Astropecten* (starfish); *Callianassa* (mud shrimp).

Plants and Animals Probably Present in Jefferson County Aquatic Ecosystems

(continued)

PLANTS	ANIMALS
Ocean Ecosystems:	*Shoreface*: *Petricola* (clam); *Anachis* (snail); *Neathes*, *Polydora*, *Lumbrinereis* (marine worms); *Corophium*, *Amphithoe* (crustaceans), and inner shelf fauna. *Inner shelf*: *Atrina*, *Dinocardium*, *Dosinia*, *Spistula*, *Tellina*, *Varicorbula*, *Nuculana*, *Pitar* (clams); *Architectonica*, *Busycon*, *Oliva*, *Phalium*, *Terebra*, *Anachis*, *Nassarius* (snails); *Luidia* (starfish); *Mellita* (urchin). *Fishes*: bluefish (*Pomatomus saltatrix*), black drum (*Pogonias cromis*), Gulf kingfish (*Menticirrhus littoralis*), southern kingfish (*M. americanus*), Gulf menhaden (*Brevoortia patronus*), finescale menhaden (*B. gunteri*), striped mullet (*Mugil cephalus*), spotted sea trout (*Cynoscion nebulosus*), red snapper (*Lutjanus campechanus*), tuna (*Thunnus* spp.), spot (*Leiostomus xanthurus*), sand seatrout (*Cynoscion arenarius*), ocellated flounder (*Ancylopsetta quadrocellata*).

Plants and Animals Probably Present in Jefferson County Aquatic Ecosystems

(continued)

	PLANTS	ANIMALS
Fresh to Brackish Lakes and Ponds: Clam Lake, Salt Lake, Salt Bayou, etc.	*Phytoplankton*: diatoms *Melosira* spp., *Coscinodiscus* spp. and *Pleurosigma* spp., the green algae *Scenedesmus* spp., *Pediastrum* spp. and *Staurastrum* spp., and the blue-green algae *Anabaena* spp. and *Oscillatoria* spp. Other genera which may be present include the diatoms *Asterionella*, *Tabellaria*, and *Fragilaria*; Chrysophyceae such as *Dinobryon* and *Uroglena*; colonial green algae such as *Volvox*, *Pandorina*, and *Eudorina*; dinoflagellates such as *Ceratium* and *Peridinium*.	*Zooplankton*: copepod genera *Eucyclops*, *Eurytemora*, *Diaptomus* and *Cyclops*, the dipteran larvae *Chaoborus* spp., the cladocerans *Bosmina* and *Daphnia*; and the rotifers *Brachionus*, *Keratella*, *Platyias* and *Kellicottia*. *Benthic fauna*: the dipteran larvae *Procladius* spp., *Cryptochironomus* spp., and *Bezzia* spp.; the oligochaete worms (*Limnodrilus* spp. and *Peloscolex* spp.); and the amphipod *Corophium* spp. *Fish*: channel catfish (I. *punctatus*), largemouth bass (*Micropterus salmoides*) sunfish (*Lepomis* spp.), gar (*Lepisosteus* spp.), Mosquitofish (*Gambusia affinis*), *Fundulus* spp., freshwater drum (*Aplodinotus grunniens*) buffalo (*Ictiobus* spp.).

Plants and Animals Probably Present in Jefferson County Aquatic Ecosystems

(continued)

	PLANTS	ANIMALS
Estuaries: Sabine Lake, Tidal Reaches of the Neches River, Taylor Bayou, Hillebrant Bayou	*Phytoplankton*: diatom species of the genera *Cyclotella*, *Melosira*, *Navicula* and *Nitzschia* and species in the dinoflagellate genera *Ceratium*, *Peridinium*, and *Dinophysis*. Several genera of green, blue-green and flagellated forms are found.	*Zooplankton*: rotifers, (*Brachionus*, and *Synchaeta*), also copepods, (*Acartia*, *Eucyclops*, and *Cyclops*) and cladocerans (*Bosimina* and *Daphnia*). *Benthic fauna*: Diptera (*Chaoborus*, *Procladius*, *Coelotanypus*, *Polypedilum* and *Bezzia*) and Oligochaetes (*Peloscolex* and *Limnodrilus*), fiddler crab (*Uca* sp.), mud crab (*Pagurus* sp.), marsh periwinkle (*Littorina irrotata*), olive snails (*Olivella* sp.), ribbed mussels (*Brachidontas demisseus plicatilis*), blue crab (*Callinectes sapidus*), brown and white shrimp (*Penaeus aztecus*, and *P. setiferus*), pink shrimp (*Penaeus duorarum*), mysids (*Mysis* sp.), oysters (*Crassostrea virginica*) polychaete worms, amphipods, sponges, bryozoans, gastropods.

Plants and Animals Probably Present in Jefferson County Aquatic Ecosystems

(continued)

	PLANTS	ANIMALS
Estuaries (continued)		Fishes: Gulf menhaden (*Brevoortia patronus*), pompano (*Trachinotus carolinus*), red drum (*Sciaenops ocellata*), sand sea trout (*Cynoscion arenarius*), spotted sea trout (*C. nebulosus*), spot (*Leiostomus xanthurus*), pinfish (*Stenotomus aculeatus*), Atlantic croaker (*Micropogon undulatus*), southern flounder (*Paralichthys lethostigma*), mackerel (*Scomberomorus sp.*), striped mullet (*Mugil cephalus*), gafftopsail catfish (*Bagre marinus*), bay anchovy (*Anchoa mitchilli*)
Fresh Water Rivers and Streams: Upper reaches of Neches River, Taylor Bayou, Hillebrant Bayou, Big Hill Reservoir, Lowell Lake, etc.	*Phytoplankton*: Crysophyta, Euglenophyta, Chlorophyta, Cyanophyta *Pennales* sp., *Synura* sp., *Spirulina* spp., *Chroococcus* spp.	*Zooplankton*: *Keratella*, *Daphnia*, *Moina*, *Diaphanosoma*, *Ceriodaphnia* *Benthic fauna*: Tubificidae, Chironomidae oligochaetes, *Cambarus* and other crawfish, bivalves, insect larvae and naiads

Plants and Animals Probably Present in Jefferson County Aquatic Ecosystems

(continued)

Fresh Water Rivers and Streams (continued):	Fishes: channel catfish (Ictalurus punctatus), black bullhead (I. nebulosus), yellowbullhead (I. natalis), bowfin (Amia calva), spotted gar (Lepisosteus oculatus), longnose gar (L. osseus), gizzard shad (Dorosoma pentenense), white bass (Roccus chrysops), largemouth bass (Micropterus salmoides), spotted bass (M. punctulatus), white crappie (Pomoxis annularis), black crappie (P. nigromaculatus), warmouth (Lepomis gulosus), bluegill (L. macrochirus), redear sunfish (L. microlophus), flier (Centrarchus macropterus), freshwater drum (Aplodinotus grunniens).

Sources: Bureau of Land Management, Department of the Interior, 1975, Final Environmental Statement, Proposed Increase in Oil and Gas Leasing on the Outer Continental Shelf, Volume 1.

Chabreck, R. H., 1972, Vegetation, Water, and Soil Characteristics of the Louisiana Coastal Region, Bulletin No. 644: Louisiana State University, Agricultural Experiment Station.

Federal Energy Administration, 1977, Final Environmental Impact Statement, West Hackberry Salt Dome: Federal Energy Administration,Washington, D.C.

U. S. Corps of Army Engineers, New Orleans District, 1975. Draft Environmental Statement, Gulf Intracoastal Waterway; Petit Anse, Tigre, and Carlin Bayous; and Bayou Grosse Tete, Louisiana.

Table K.8-1

MAMMALS IN THE TEXOMA STUDY AREA

Common Name	Abundance* Locally
Opossum (*Didelphis virginiana*)	A
Eastern mole (*Scalopus aquaticus*)	U
Short-tailed shrew (*Blarina brevicauda*)	U
Least shrew (*Cryptotis parva*)	C
Georgia bat (*Pipistrellus subflavus*)	O
Big brown bat (*Eptesicus fuscus*)	O
Red bat (*Lasiurus borealis*)	C
Seminole bat (*Lasiurus seminolus*)	C
Greater yellow bat (*Lasiurus intermedius*)	O
Evening bat (*Nycticeius humeralis*)	O
Raccoon (*Procyon lotor*)	A
Ringtail (*Bassaricus astutus*)	O
Long-tailed weasel (*Mustela frenata*)	U
Mink (*Mustela vison*)	C
River otter (*Lutra canadensis*)	U
Spotted skunk (*Spilogale putorius*)	U
Striped skunk (*Mephitis mephitis*)	A
Red fox (*Vulpes fulva*)	U
Gray fox (*Urocyon cinereoargenteus*)	U
Coyote (*Canis latrans*)	C
Gray wolf (*Canis lupus*)	H
Red wolf (*Canis rufus*)	U
Ocelot (*Felis pardalis*)	H
Bobcat (*Lynx rufus*)	C
Eastern gray squirrel (*Sciurus carolinensis*)	C
Fox squirrel (*Sciurus niger*)	C
Eastern flying squirrel (*Glaucomys volans*)	C
Plains pocket gopher (*Geomys bursarius*)	A
Hispid pocket mouse (*Perognathus hispidus*)	U
Beaver (*Castor canadensis*)	U
Fulvous harvest mouse (*Reithrodontomys fluvescens*)	U
Pygmy mouse (*Baiomys taylori*)	U
White-footed mouse (*Peromyscus leucopus*)	O
Cotton mouse (*Peromyscus gossypinus*	O
Northern rice rat (*Oryzomys palustris*)	A

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*A - Abundant
C - Common
U - Uncommon

Common Name	Abundance* Locally
Hispid cotton rat (Sigmodon hispidus)	A
Florida wood rat (Neotoma floridana)	C
Muskrat (Ondatra zibethicus)	C
House mouse (Mus musculus)	A
Roof rat (Rattus rattus)	A
Norway rat (Rattus norvegicus)	A
Nutria (Myocastor coypus)	A
Eastern Cottontail (Sylvilagus floridanus)	A
Swamp rabbit (Sylvilagus aquaticus)	A
White-tailed deer (Odocoileus virginianus)	U
Nine-banded armadillo (Dasypus novemcinctus)	A
Caribbean mantee (Trichechus manatus)	U
Blue whale (Balaenoptera musculus)	U
Common finback whale (Balaenoptera physalus)	U
Black right whale (Eubalaena glacialis)	U
Sperm whale (Physeter catodon)	H
Pygmy sperm whale (Kogia breviceps)	U
Dwarf sperm whale (Kogia simus)	U
Gulf stream beaked whale (Mesoplodon europaeus)	U
Goose-beaked whale (Ziphius cavirostris)	U
Atlantic bottlenose dolphin (Tursiops truncatus)	C
Pygmy killer whale (Feresa attenuata)	U

Source: U. S. Army Corp of Engineers, Galveston District, 1975, Final Environmental Statement, Maintenance Dredging Sabine-Neches Waterway, Texas.

Table K.8-2

BIRDS IN THE TEXOMA STUDY AREA

Bird	Abundance* Locally
Common Loon (*Gavia immer*)	U
Red-throated Loon (*Gavia stellata*)	U
Horned Grebe (*Podiceps auritus*)	U
Eared Grebe (*Podiceps nigricollis*)	U
Least Grebe (*Podiceps dominicus*)	U
Pied-billed Grebe (*Podilymbus podiceps*)	A
Audubon's Shearwater (*Puffinus lherminieri*)	U
White-tailed Tropicbird (*Phaethon lepturus*)	U
American White Pelican (*Pelecanus erythrorhynchos*)	C
Brown Pelican (*Pelecanus occidentalis*)	U
Masked Booby (*Sula dactylatra*)	U
Northern Gannet (*Morus bassanus*)	U
Double-crested Cormorant (*Phalacrocorax auritus*)	A
Olivaceous Cormorant (*Phalacrocorax olivaceus*)	C
American Anhinga (*Anhinga anhinga*)	C
Great Blue Heron (*Ardea herodias*)	A
Green Heron (*Butorides virescens*)	C
Little Blue Heron (*Florida caerulea*)	U
Cattle Egret (*Bubulcus ibis*)	A
Reddish Egret (*Dichromanassa rufescens*)	U
Great Egret (*Casmerodius albus*)	A
Snowy Egret (*Egretta thula*)	A
Louisiana Heron (*Hydranassa tricolor*)	A
Black-crowned Night Heron (*Nycticorax nycticorax*)	A
Yellow-crowned Night Heron (*Nyctanassa violacea*)	A
Least Bittern (*Ixobrychus exilis*)	C
American Bittern (*Botaurus lentiginosus*)	C
Wood Stork (*Mycteria americana*)	U
White-faced Ibis (*Plegadis chihi*)	A
White Ibis (*Eudocimus albus*)	A
Roseate Spoonbill (*Ajaia ajaja*)	C
Canada Goose (*Branta canadensis*)	U
Common Brant (*Branta bernicla*)	U
White-fronted Goose (*Anser albifrons*)	A
Snow Goose (*Chen caerulescens*)	A
Ross' Goose (*Chen rossii*)	U
Black-bellied Tree-duck (*Dendrocygna autumnalis*)	U

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*A - abundant
C - common
U - uncommon

Bird	Abundance Locally
Fulvous Tree-duck (*Dendrocygna bicolor*)	U
Mallard (*Anas platyrhynchos*)	C
Black Duck (*Anas rubripes*)	U
Mottled Duck (*Anas fulvigula*)	A
Gadwall (*Anas strepera*)	A
Northern Pintail (*Anas acuta*)	A
Green-winged Teal (*Anas crecca*)	A
Blue-winged Teal (*Anas discors*)	A
Cinnamon Teal (*Anas cyanoptera*)	U
Northern Shoveler (*Anas clypeata*)	A
American Wigeon (*Anas americana*)	A
Wood Duck (*Aix sponsa*)	C
Redhead (*Aythya americana*)	A
Ring-necked Duck (*Aythya collaris*)	U
Canvasback (*Aythya valisineria*)	A
Greater Scaup (*Aythya marila*)	U
Lesser Scaup (*Aythya affinis*)	A
Common Goldeneye (*Bucephala clangula*)	U
Bufflehead (*Bucephala albeola*)	U
Oldsquaw (*Clangula hyemalis*)	U
White-winged Scoter (*Melanitta deglandi*)	U
Surf Scoter (*Melanitta perspicillata*)	U
Ruddy Duck (*Oxyura jamaicensis*)	U
Masked Duck (*Oxyura dominica*)	U
Hooded Merganser (*Lophodytes cucullatus*)	U
Common Merganser (*Mergus merganser*)	U
Red-breasted Merganser (*Mergus serrator*)	A
Turkey Vulture (*Cathartes aura*)	A
Black Vulture (*Coragyps atratus*)	U
White-tailed Kite (*Elanus leucurus*)	U
Mississippi Kite (*Ietinia misisippiensis*)	U
Sharp-shinned Hawk (*Accipiter striatus*)	U
Cooper's Hawk (*Accipiter cooperii*)	U
Red-tailed Hawk (*Buteo jamaicensis*)	A
Red-shouldered Hawk (*Buteo lineatus*)	U
Broad-winged Hawk (*Buteo platypterus*)	U
Swainson's Hawk (*Buteo swainsoni*)	U
Rough-legged Hawk (*Buteo lagopus*)	U
Ferruginous Hawk (*Buteo regalis*)	U
Golden Eagle (*Aquila chrysaetos*)	U
Bald Eagle (*Haliaeetus leucocephalus*)	U
Marsh Hawk (*Circus cyaneus*)	A
Osprey (*Pandion haliaetus*)	U
Audubon's Caracara (*Caracara cheriway*)	U
Peregrine Falcon (*Falco peregrinus*)	U

Bird	Abundance Locally
American Kestrel (*Falco sparverius*)	A
Merlin (*Falco columbarius*)	U
Atwater's Greater Prairie Chicken (*Tympanuchus cupido*)	U
Bobwhite Quail (*Colinus virginianus*)	A
Whooping Crane (*Grus americana*)	U
Sandhill Crane (*Grus canadensis*)	C
King Rail (*Rallus elegans*)	A
Clapper Rail (*Rallus longirostris*)	A
Virginia Rail (*Rallus limicola*)	U
Sora (*Porzana carolina*)	U
Black Rail (*Laterallus jamaicensis*)	U
Purple Gallinule (*Porphyrula martinica*)	A
Common Gallinule (*Gallinula chloropus*)	A
American Coot (*Fulica americana*)	A
Black-necked Stilt (*Himantopus mexicanus*)	U
American Avocet (*Recurvirostra americana*)	C
Semipalmated Plover (*Charadrius semipalmatus*)	U
Wilson's Plover (*Charadrius wilsonia*)	A
Killdeer (*Charadrius vociferus*)	A
Piping Plover (*Charadius melodus*)	U
Snowy Plover (*Charadius alexandrinus*)	U
American Golden Plover (*Pluvialis dominica*)	A
Black-bellied Plover (*Pluvialis squatarola*)	A
Hudsonian Godwit (*Limosa haemastica*)	U
Marbled Godwit (*Limosa fedoa*)	U
Whimbrel (*Numenius phaeopus*)	U
Long-billed Curlew (*Numenius americanus*)	A
Upland Sandpiper (*Bartramia longicauda*)	U
Greater Yellowlegs (*Totanus melanoleuca*)	A
Lesser Yellowlegs (*Totanus flavipes*)	A
Solitary Sandpiper (*Tringa solitaria*)	A
Willet (*Catoptrophorus semipalmatus*)	A
Spotted Sandpiper (*Actitis macularia*)	A
Ruddy Turnstone (*Arenaria interpres*)	U
Wilson's Phalarope (*Steganopus tricolor*)	A
American Woodcock (*Philohela minor*)	U
Common Snipe (*Capella gallinago*)	A
Short-billed Dowitcher (*Limnodromus griseus*)	U
Long-billed Dowitcher (*Limnodromus scolopaceus*)	A
Red Knot (*Calidris canutus*)	U
Sanderling (*Calidris alba*)	U
Semipalmated Sandpiper (*Calidris pusilla*)	A
Western Sandpiper (*Calidris mauri*)	A
Least Sandpiper (*Calidris minutilla*)	A
White-rumped Sandpiper (*Calidris fuscicollis*)	U

Bird	Abundance Locally
Baird's Sandpiper (*Calidris bairdii*)	A
Pectoral Sandpiper (*Calidris melanotos*)	A
Dunlin (*Calidris alpina*)	A
Stilt Sandpiper (*Calidris himantopus*)	A
Buff-breasted Sandpiper (*Tryngites subruficollis*)	U
Parasitic Jaeger (*Stercorarius parasiticus*)	U
Long-tailed Jaeger (*Stercorarius longicaudus*)	U
Herring Gull (*Larus argentatus*)	U
Ring-billed Gull (*Larus delawarensis*)	A
Laughing Gull (*Larus atricilla*)	A
Franklin's Gull (*Larus pipixcan*)	U
Bonaparte's Gull (*Larus philadelphia*)	C
Gull-billed Tern (*Gelochelidon nilotica*)	A
Forester's Tern (*Sterna forsteri*)	A
Common Tern (*Sterna hirundo*)	U
Least Tern (*Sterna albifrons*)	A
Royal Tern (*Thalasseus maximus*)	C
Sandwich Tern (*Thalasseus sandvicensis*)	U
Caspian Tern (*Hydroprogne caspia*)	U
Black Tern (*Chlidonias niger*)	A
Black Skimmer (*Rynchops niger*)	U
Rock Pigeon (*Columba livia*)	C
White-winged Dove (*Zenaida asiatica*)	U
Mourning Dove (*Zenaida macroura*)	A
Common Ground Dove (*Columbina passerina*)	U
Inca Dove (*Scardafella inca*)	U
Yellow-billed Cuckoo (*Coccyzus americanus*)	A
Black-billed Cuckoo (*Coccyzus erythropthalmus*)	U
Greater Roadrunner (*Geococcyx californianus*)	U
Smooth-billed Ani (*Crotophaga ani*)	U
Groove-billed Ani (*Crotophaga sulcirostris*)	U
Barn Owl (*Tyto alba*)	U
Common Screech Owl (*Otus asio*)	C
Great Horned Owl (*Bubo virginianus*)	U
Burrowing Owl (*Speotyto conicularia*)	U
Barred Owl (*Strix varia*)	C
Long-eared Owl (*Asio otus*)	U
Short-eared Owl (*Asio flammeus*)	U
Northern Saw-whet Owl (*Aegolius acadicus*)	U
Chuck-will's-widow (*Caprimulgus carolinensis*)	A
Whip-poor-will (*Caprimulgus vociferus*)	U
Common Nighthawk (*Chordeiles minor*)	A
Chimney Swift (*Chaetura pelagica*)	U
Ruby-throated Hummingbird (*Archilochus colubris*)	U
Belted Kingfisher (*Megaceryle alcyon*)	A

Bird	Abundance Locally
Common Flicker (*Colaptes auratus*)	C
Red-bellied Woodpecker (*Centurus carolinus*)	C
Red-headed Woodpecker (*Melanerpes erythrocephalus*)	U
Yellow-bellied Sapsucker (*Sphyrapicus varius*)	U
Hairy Woodpecker (*Dendrocopos villosus*)	C
Downy Woodpecker (*Dendrocopos pubescens*)	C
Red-cockaded Woodpecker (*Dendrocopos borealis*)	U
Ivory-billed Woodpecker (*Campephilus principalis*)	U
Eastern Kingbird (*Tyrannus tyrannus*)	A
Western Kingbird (*Tyrannus verticalis*)	U
Scissor-tailed Flycatcher (*Muscivora forficata*)	U
Great Crested Flycatcher (*Myiarchus crinitus*)	U
Eastern Phoebe (*Sayornis phoebe*)	A
Yellow-bellied Flycatcher (*Empidonax flaviventris*)	U
Acadian Flycatcher (*Empidonax virescens*)	C
Eastern Wood Pewee (*Contopus virens*)	U
Olive-sided Flycatcher (*Nuttallornis borealis*)	U
Vermilion Flycatcher (*Pyrocephalus rubinus*)	U
Horned Lark (*Eremophila alpestris*)	U
Tree Swallow (*Iridoprocne bicolor*)	A
Bank Swallow (*Riparia riparia*)	U
Rough-winged Swallow (*Stelgidopteryx ruficollis*)	U
Barn Swallow (*Hirundo rustica*)	A
Cliff Swallow (*Petrochelidon pyrrhonota*)	U
Purple Martin (*Progne subis*)	A
Blue Jay (*Cyanocitta cristata*)	C
Common Crow (*Corvus brachyrhynchos*)	C
Fish Crow (*Corvus ossifragus*)	U
Carolina Chickadee (*Parus carolinensis*)	C
Tufted Titmouse (*Parus bicolor*)	C
White-breasted Nuthatch (*Sitta carolinensis*)	U
Red-breasted Nuthatch (*Sitta canadensis*)	C
Brown-headed Nuthatch (*Sitta pusilla*)	C
Brown Creeper (*Certhia familiaris*)	U
Northern House Wren (*Troglodytes aedon*)	U
Winter Wren (*Troglodytes troglodytes*)	U
Bewick's Wren (*Thryomanes bewickii*)	U
Carolina Wren (*Thryothorus ludovicianus*)	C
Marsh Wren (*Telmatodytes palustris*)	A
Gray Catbird (*Dumetella carolinensis*)	A
Northern Mockingbird (*Mimus polyglottos*)	A
Brown Thrasher (*Toxostoma rufum*)	A
Sage Thrasher (*Oreoscoptes montanus*)	U
American Robin (*Turdus migratorius*)	A
Eastern Bluebird (*Sialia sialis*)	C

Bird	Abundance Locally
Wood Thrush (*Hylocichla mustelina*)	U
Hermit Thrush (*Catharus guttatus*)	U
Swainson's Thrush (*Catharus ustulatus*)	A
Gray-cheeked Thrush (*Catharus minimus*)	U
Veery (*Catharus fuscescens*)	U
Blue-gray Gnatcatcher (*Polioptila caerulea*)	A
Golden-crowned Kinglet (*Regulus satrapa*)	U
Ruby-crowned Kinglet (*Regulus calendula*)	U
Water Pipit (*Anthus spinoletta*)	A
Sprague's Pipit (*Anthus spragueii*)	U
Cedar Waxwing (*Bombycilla cedrorum*)	A
Loggerhead Shrike (*Lanius ludovicianus*)	C
European Starling (*Sturnus vulgaris*)	A
White-eyed Vireo (*Vireo griseus*)	C
Yellow-throated Vireo (*Vireo flavifrons*)	C
Solitary Vireo (*Vireo solitarius*)	U
Red-eyed Vireo (*Vireo olivaceus*)	U
Philadelphia Vireo (*Vireo philadelphicus*)	U
Black-and-white Warbler (*Mniostilta varia*)	U
Golden-winged Warbler (*Vermivora chrysoptera*)	U
Blue-winged Warbler (*Vermivora pinus*)	U
Tennessee Warbler (*Vermivora peregrina*)	A
Orange-crowned Warbler (*Vermivora celata*)	U
Nashville Warbler (*Vermivora ruficapilla*)	U
Northern Parula Warbler (*Parula americana*)	U
Yellow Warbler (*Dendroica petechia*)	A
Chestnut-sided Warbler (*Dendroica pensylvanica*)	U
Cerulean Warbler (*Dendroica cerulea*)	U
Black-throated Blue Warbler (*Dendroica caerulescens*)	U
Pine Warbler (*Dendroica pinus*)	U
Yellow-throated Warbler (*Dendroica dominica*)	U
Black-throated Green Warbler (*Dendroica virens*)	A
Prairie Warbler (*Dendroica discolor*)	U
Blackburnian Warbler (*Dendroica fusca*)	U
Magnolia Warbler (*Dendroica magnolia*)	A
Myrtle Warbler (*Dendroica coronata*)	A
Palm Warbler (*Dendroica palmarum*)	U
Black Poll Warbler (*Dendroica striata*)	U
Bay-breasted Warbler (*Dendroica castanea*)	U
American Redstart (*Setophaga ruticilla*)	A
Ovenbird (*Seiurus aurocapillus*)	C
Northern Waterthrush (*Seiurus noveboracensis*)	A
Louisiana Waterthrush (*Seiurus motacilla*)	U
Worm-eating Warbler (*Helmitheros vermivorus*)	U
Prothonotary Warbler (*Protonotaria citrea*)	U

Bird	Abundance Locally
Common Yellowthroat (*Geothlypis trichas*)	A
Kentucky Warbler (*Geothlypis formosa*)	U
Hooded Warbler (*Wilsonia citrina*)	U
Canada Warbler (*Wilsonia canadensis*)	U
Yellow-breasted Chat (*Icteria virens*)	U
House Sparrow (*Passer domesticus*)	A
Bobolink (*Dolichonyx oryzivorus*)	U
Eastern Meadowlark (*Sturnella magna*)	A
Western Meadowlark (*Sturnella neglecta*)	U
Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*)	U
Red-winged Blackbird (*Agelaius phoeniceus*)	A
Orchard Oriole (*Icterus spurius*)	A
Baltimore Oriole (*Icterus galbula*)	C
Rusty Blackbird (*Euphagus carolinus*)	C
Brewer's Blackbird (*Euphagus cyanocephalus*)	C
Great-tailed Grackle (*Cassidix mexicanus*)	U
Boat-tailed Grackle (*Cassidix major*)	C
Common Grackle (*Quiscalus quiscula*)	A
Brown-headed Cowbird (*Molothrus ater*)	A
Scarlet Tanager (*Piranga olivacea*)	U
Summer Tanager (*Piranga rubra*)	U
Northern Cardinal (*Cardinalis cardinalis*)	C
Rose-breasted Grosbeak (*Pheucticus ludovicianus*)	A
Blue Grosbeak (*Guiraca caerulea*)	C
Indigo Bunting (*Passerina cyanea*)	A
Painted Bunting (*Passerina ciris*)	U
Dickcissel (*Spiza americana*)	A
Purple Finch (*Carpodacus purpureus*)	C
Pine Siskin (*Spinus pinus*)	U
American Goldfinch (*Spinus tristis*)	U
Rufous-sided Towhee (*Pipilo erythrophthalmus*)	U
Savannah Sparrow (*Passerculus sandwichensis*)	A
Grasshopper Sparrow (*Ammodramus savannarum*)	C
LeConte's Sparrow (*Ammospiza leconteii*)	U
Sharp-tailed Sparrow (*Ammospiza caudacuta*)	U
Seaside Sparrow (*Ammospiza maritima*)	A
Vesper Sparrow (*Pooecetes gramineus*)	U
Lark Sparrow (*Chondestes grammacus*)	U
Bachman's Sparrow (*Aimophila aestivalis*)	U
Slate-colored Junco (*Junco hyemalis*)	U
Chipping Sparrow (*Spizella passerina*)	U
Field Sparrow (*Spizella pusilla*)	U
Harris' Sparrow (*Zonotrichia querula*)	U

Bird	Abundance Locally
White-crowned Sparrow (*Zonotrichia leucophrys*)	U
White-throated Sparrow (*Zonotrichia albicollis*)	U
Lincoln's Sparrow (*Melospiza lincolnii*)	U
Swamp Sparrow (*Melospiza georgiana*)	A
Song Sparrow (*Melospiza melodia*)	U

Source: U.S. Army Corp of Engineers, Galveston District, 1975, Final Environmental Statement, Maintenance Dredging Sabine-Neches Waterway, Texas.

Table K.8-3

REPTILES AND AMPHIBIANS IN THE TEXOMA STUDY AREA

Common Name	Abundance* Locally
American alligator (*Alligator mississipiensis*)	C
Common snapping turtle (*Chelydra serpentina*)	A
Alligator snapping turtle (*Macroclemys temmincki*)	C
Stinkpot (*Sternothaerus odoratus*)	A
Razor-backed musk turtle (*Sternothaerus carinatus*)	C
Mississippi mud turtle (*Kinosternon subrubrum hippocrepis*)	C
Three-toed box turtle (*Terrapene carolina triunguis*)	C
Ornate box turtle (*Terrapene ornata ornata*	U
Texas diamondback terrapin (*Malaclemys terrapin*)	C
Mississippi map turtle (*Graptemys kohni*)	C
Sabine map turtle (*Graptemys pseudogeographica sabinensis*)	C
Red-eared turtle (*Pseudemys scripta elegans*)	A
Mobile cooter (*Pseudemys coninna hieroglyphica*)	U
Missouri slider (*Pseudemys floridana hoyi*)	C
Western chicken turtle (*Deirochelys reticularia miaria*)	C
Atlantic green turtle (*Chelonia mydas mydas*)	U
Atlantic hawksbill turtle (*Eretmochelys imbricata imbricata*)	U
Atlantic loggerhead turtle (*Caretta caretta caretta*)	U
Atlantic ridley turtle (*Lepidochelys kempi*)	U
Leatherback turtle (*Dermochelys coriacea coriacea*)	U
Midland smooth softshell (*Trionyx muticus*)	C
Spiny softshell (*Trionyx spiniferus*)	C
Mediterranean gecko (*Hemidactylus turcicus*)	U
Green anole (*Anolis carolinensis carolinensis*)	A
Eastern fence lizard (*Sceloporus undulatus*)	A
Texas horned lizard (*Phrynosoma cornutum*)	C
Six-lined racerunner (*Cnemidophorus sexlineatus*)	A
Ground skink (*Lygosoma laterale*)	C
Five-lined skink (*Eumeces fusciatus*)	C
Broad-headed skink (*Eumeces luticeps*)	C
Western slender glass lizard (*Ophisaurus attenuatus attenuatus*)	C
Green water snake (*Natrix cyclopion cyclopion*)	C
Diamondback water snake (*Natrix rhombifera rhombifera*)	C
Yellow-bellied water snake (*Natrix erythrogaster fluvigaster*)	C
Broad-banded water snake (*Natrix sipedon confluens*)	C
Gulf salt marsh snake (*Natrix sipedon clarki*)	C

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*A - Abundant
C - Common
U - Uncommon

Common Name	Abundance* Locally
Graham's water snake (*Natrix grahami*)	C
Gulf glossy water snake (*Natrix rigida*)	C
Brown snake (*Storeia dekayi*)	C
Eastern garter snake (*Thamnophis sirtalis sirtalis*)	C
Western ribbon snake (*Thamnophis proximus*)	C
Rough earth snake (*Huldera striatula*)	U
Eastern hognose snake (*Heterodon platyrhinos*)	C
Mississippi ringneck snake (*Diadophis punctatus stictogenys*)	C
Western mud snake (*Farancia abacura reinwardti*)	C
Eastern yellow-bellied racer (*Coluber constrictor flaviventris*)	C
Eastern coachwhip (*Masticophis flagellum flagellum*)	C
Rough green snake (*Opheodrys aestivus*)	C
Texas rat snake (*Elaphe obsoleta lindheimeri*)	C
Corn snake (*Elaphe guttata guttata*)	U
Great Plains rat snake (*Elaphe guttata emoryi*)	U
Speckled kingsnake (*Lampropeltis getulus holbrooki*)	C
Louisiana milk snake (*Lampropeltis doliata amaura*)	U
Prairie kingsnake (*Lampropeltis calligaster calligaster*)	U
Scarlet snake (*Cemophora coccinea*)	U
Texas coral snake (*Micrurus fluvius tenere*)	U
Southern copperhead (*Agkistrodon contortrix contortrix*)	C
Western cottonmouth (*Agkistrodon piscivorus leucostoma*)	A
Western pygmy rattlesnake (*Sistrurus miliarius streckeri*)	C
Canebrake rattlesnake (*Crotalus horridus atricaudatus*)	C
Western lesser siren (*Siren intermedia nettingi*)	C
Three-toed amphiuma (*Amphiuma means tridactylum*)	C
Marbled salamander (*Ambystoma opacum*)	C
Small-mouthed salamander (*Ambystoma texanum*)	C
Central newt (*Diemictylus viridescens louisianensis*)	C
Southern dusky salamander (*Desmognathus auriculatus*)	A
Dwarf salamander (*Manculus quadridigiatus*)	C
Hurter's spadefoot (*Scaphiopus hurteri*)	C
Woodhouse's toad (*Bufo woodhousei*)	A
Fowler's toad (*Bufo woodhousei fowleri*)	A
Gulf coast toad (*Bufo valliceps*)	A
Northern cricket frog (*Acris crepitans crepitans*)	C
Green treefrog (*Hyla cinera cinera*)	A
Squirrel treefrog (*Hyla squirella*)	A
Southern gray treefrog (*Hyla versicolor chrysoscelis*)	C
Upland chorus frog (*Pseudacris triseriata feriarum*)	C
Eastern narrow-mouthed toad (*Gastrophryne carolinensis*)	C
Bullfrog (*Rana catesbeiana*)	A
Pig frog (*Rana grylio*)	U
Bronze frog (*Rana clamitans clamitans*)	C

Common Name	Abundance* Locally
Southern leopard frog (*Rana pipiens sphenocephala*)	A
Southern crawfish frog (*Rana areolata areolata*)	C
Pickerel frog (*Rana palustris*)	U

Source: U. S. Army Corp of Engineers, Galveston District, 1975, Final Environmental Statement, Maintenance Dredging Sabine-Neches Waterway, Texas.

APPENDIX L

MODIFIED MERCALLI INTENSITY SCALE OF 1931 (ABRIDGED, RICHTER)

APPENDIX L

MODIFIED MERCALLI INTENSITY SCALE OF 1931 (ABRIDGED, RICHTER)

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonary D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, on heard to rustle--CFR).

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonary D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, titles, cornices (also unbraced parapets and architectural ornaments--CFR). Some cracks in masonary C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonary C; partial collapse. Some damage to masonry B; none to masonary A. Fall of stucco and some masonary walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonary D destroyed; masonary C heavily damaged. sometimes with complete collapse; masonary B seriously damaged. (General damage to foundations--CFR.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake foundations, sand craters.

X. Most masonary and frame structures destroyed with their foundations. Some well-build wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

<u>Masonary A.</u>	Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
<u>Masonary B.</u>	Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
<u>Masonary C.</u>	Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
<u>Masonary D.</u>	Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

APPENDIX M

SOCIOECONOMIC ANALYSIS

APPENDIX M

SOCIOECONOMIC ANALYSIS

Economic Base Analysis

Economic base analysis is a widely used tool in regional economic forecasting and regional impact analysis. The economic base of a region refers to those activities supported either by the export of goods and services to points outside the region or to the marketing of goods and services to buyers who come from outside the region's boundaries. The definition of an appropriate region is more difficult since the boundaries of the region will determine the amount of goods and services which will be exported. In this study, the basic region chosen was that defined by the Bureau of Economic Analysis as a local labor market. This is a regional grid with a minimum amount of worker commuting across boundaries, providing an approximation to trade market areas.

That portion of regional economic activity supported by the regional economic base is referred to as service activity. These activities include enterprises providing goods and services for final consumption to those buyers located within the region. In some cases these firms may import goods and services from outside the region, but in no instance will any service enterprise engage in export activity. Service and base activities are closely related, with changes in profitability and employment in the service area following the same changes in base activity.

Generally, economic base analysis proceeds in four distinct stages:

(1) calculation of the total basic activity (measured by employment, earnings, etc.) in a region;

(2) estimation of the proportion of basic to service activity;

(3) estimation of the future trend in basic activity brought about by changes in the region or changes in the demand for the region's output;

(4) estimation of total future activity, or changes in forecasted trends, on the basis of future trends in basic activity.

Several weaknesses exist in the economic base analysis. First, there is a problem of accurately identifying basic activities of a region within a reasonable time frame. Often firms within the same industry category will serve two different markets, one inside the region and the other outside. A good example of this problem can be found in areas heavily dependent on tourist activity; it becomes a problem to identify that portion of food activity which should be classified as basic activity. Along this same vein, it is also difficult to distinguish products which are produced and sold locally but serve as inputs to products which are exported outside the region.

A second weakness of economic base analysis concerns its forecasting tool, the multiplier. This base activity multiplier exhibits some weaknesses of other similar multipliers in the form of various assumptions: namely, the input-output relationships are unchanging; excess capacity exists in all relevant sectors of the economy; goods and services can be supplied at constant costs; consumer tastes do not change; interregional trade flows remain stable. As can be interpreted from this list, the economic base multiplier is a short-hand input-output model for regional economic activity. The results of the analysis must be tempered by the degree to which any of these assumptions are not fulfilled.

The measure of economic activity chosen for this study was total worker earnings measured in 1967 dollars. Implicit in this choice is that the underlying production functions have not changed from 1967 to the present. With this condition, the index chosen will reflect regional output of goods and services.

The computations of the multiplier for each of the two relevant BEAs are given in Tables M-1 and M-2. When basic earnings in a particular occupation were not easily identifiable, the location quotient was used to derive that portion of total earnings which could be attributed to basic activity in the particular industry.* This earnings multiplier reflects long term economic trends in the region, but, as discussed previously, it incorporates one crucial assumption, namely that any change in export demand can be met with no change in input prices. This means the results lose reliability as the size of a change in basic income increases.

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*The location quotient reflects employment distribution in a particular region versus the distribution in the nation. The location quotient of 1.75 for agriculture, forestry, and fisheries indicates that the proportion of employment in this occupation within the Lake Charles BEA exceeds the national distribution by 75%. Therefore, an estimate of the amount of earnings attributable to export from this sector would be

$$\left(\frac{1.0}{1.75}\right) \times 119{,}200 = 51{,}256.$$

As noted, this method was only used for those industries which could not easily be classified.

A multiplier value of 2.04 for the Lake Charles BEA means that for every $1 of basic activity there is $1.04 of secondary or service activity supported in the region. Therefore, to assess changes in economic activity in the region, it is necessary to 1) obtain a measure of the change in basic activity in 1967 dollars and 2) multiply this measure by 2.04.

Estimated regional dollar flows were computed from cost estimates provided to FEA by Fenix and Scisson. Adjustments were made to account for the fact that all purchases would not be made within the particular region in question.

Table M-1

Earnings Multiplier - Lake Charles BEA (1970)*

	Location Quotient**	Earnings (000 of 1967 dollars)	Earnings
Agriculture, Forestry, Fisheries	1.75	119,200	51,256
Mining	11.40	141,049	126,944
Contract Construction	1.39	113,950	31,906
Manufacturing	0.57	199,552	101,269
Transportation, Communication, Public Utilities	1.26	99,976	19,995
Wholesale & Retail Trade	1.11	211,657	21,166
Finance, Insurance, & Real Estate	0.22	33,592	
Services	0.87	159,355	
Government		347,919	347,919
Total		1,426,250	700,455
Multiplier			2.04

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*Estimates computed for 1971 were not substantially different. Earnings data from OBERS projections.

**Computed with data from County Business Patterns. The formula for computing the location quotient is:

$$LQ = \left(\frac{S_{ij}}{\sum_i S_{ij}}\right) \Big/ \left(\frac{S_{in}}{\sum_i S_{in}}\right)$$

S_{ij} = number of employed workers in industry i in BEA j,

S_{in} = number of employed workers in industry i in the nation.

Table M-2

Earnings Multiplier - Beaumont-Port`Arthur-Orange BEA (1970)

	Location Quotient	Earnings (000 of 1967 dollars)	Earnings
Agriculture, Forestry, Fisheries	0.75	4,252*	
Mining	1.90	11,499**	5,405
Contract Construction	1.28	84,602	18,612
Manufacturing	1.13	424,657	335,103
Transportation, Communication, Public Utilities	1.36	87,942	22,867
Wholesale & Retail Trade	0.87	133,040	
Finance, Insurance, & Real Estate	0.59	30,073	
Services	0.82	121,143	
Government		105,314	105,314
Total		1,002,522	487,301
Multiplier			2.06

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*Agriculture only.

**Crude petroleum and natural gas only.

APPENDIX N

AIR QUALITY IMPACT OF BRINE PONDS AT FOUR TEXOMA SITES

APPENDIX N

AIR QUALITY IMPACT OF BRINE PONDS AT FOUR TEXOMA SITES

N.1 Introduction

Brine displaced to the brine holding ponds from storage cavities at an oil storage site would contain entrained crude oil which would eventually reach the atmosphere, forming a hydrocarbon cloud over the pond. Depending upon the ambient, meteorological conditions, the impact of this volatile, hydrocarbon cloud might extend beyond the site boundaries and therefore constitute a limiting factor with regard to the environmental feasibility of the concept of the brine settling pond. In view of the potential air quality impact, an analysis has been performed to (1) determine the magnitude of crude oil dissolved in brine during the fill operation, (2) determine the major pathways for emission of hydrocarbons to the atmosphere and estimate the average and maximum emissions related to the brine ponds, and (3) assess the air quality resulting from these emissions.

N.2 Magnitude of Crude Oil in Brine

The solubility of crude oil in various liquids is strongly dependent upon the composition of the liquids and the particular hydrocarbon fractions composing the crude oil, as well as the temperature and pressure conditions. Experimental data for crude oil components in salt water (20 ppt) salinity under laboratory conditions at about 75°F and 1 atm pressure, are shown in Table N-1 (Anderson et al., 1974). The concentrations of individual dissolved compounds (Y_i) correspond to those of a typical Kuwait oil sample. These concentrations would be altered by turbulence, salinity, and pressure and temperature changes. However, there is little information available on the solubility of hydrocarbons in saturated brine (250-350 ppt) with elevated temperature and pressure, and it is necessary to estimate correction factors to account for these conditions.

The temperature and pressure in the storage cavity are expected to be higher than the standard values at the earth's surface. The average depth of the brine is about 3,000 ft where ambient temperatures are roughly 125°F. The crude oil would be introduced into the cavern in the fill stage at about 630 psia. For a typical crude oil, Table N-1 summarizes the estimated solubility in brine at 125°F and 630 psia.

Table N-1 Concentrations of Dissolved Hydrocarbon Fractions in Brine at 125°F and 1 and 43 Atm (630 PSIA) for Kuwait Crude Oil Sample

Components	Y_i (ppm) 1 atm, 75°F Seawater	Temperature Correction TC_i (1)	Salinity Correction, SC_i (2)	Y_i (ppm) 1 atm, 125°F Brine	Pressure Correction PC_i (3)	YC_i (ppm) 43 atm, 115°F Brine (4)
Ethane (C_2)	0.23	0.5	0.15	0.02	23	0.40
Propane (C_3)	3.30	0.5	0.15	0.25	7	1.73
Butane (C_4)	3.66	0.7	0.15	0.38	7	2.69
Heavy Paraffins ($>C_4$)	4.43	0.7	0.15	0.46	7	3.26
Aromatics($>C_5$)	10.03	2	0.15	3.01	5	15.05
TOTAL	21.65			4.12		23.13

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(1) Bland and Davison, 1967

(2) Price, 1973

(3) McKetta and Wehe, 1962

(4) $YC_i = Y_i \times TC_i \times SC_i \times PC_i$

As can be seen in Table N-1, the resulting solubilities for hydrocarbons in the saturated brine weighted according to the components of the Mid-Eastern oil sample would be 4.1 and 23.1 ppm at 1 atm and 43 atm (630 psia), respectively. These values depend sensitively on the crude oil fractions. If the oil pumped into the caverns contains lesser quantities of light saturates and aromatics than those in the sample of Table N-1, the total solubility would be reduced. On the other hand, if the quantity of dissolved benzene (C_6 compounds) or light aliphatic fractions (C_2-C_5 compounds) were increased, the solubility would be correspondingly larger.

N.3 Hydrocarbon Emissions to the Atmosphere

For direct transfer of the brine to the settling ponds, the largest portion of the dissolved hydrocarbons would flash vaporize to the atmosphere upon depressurization en route to the earth's surface (Pirson, 1950). If the brine were to discharge into brine tanks these hydrocarbons would largely be contained. However, since brine is to be released into open brine ponds, direct emissions to the atmosphere would result. The average and maximum hydrocarbon emission due to depressurization can be estimated assuming that the oil remaining in the brine has a solubility of 4.1 ppm. The resulting rates for annual emissions and for maximum, short-term emissions are summarized in Table N-2 for each of the four sites. Chemical reactions in the atmosphere, such as photocatalytic oxidation, would convert an unknown amount of these hydrocarbons into less volatile non-hydrocarbon compounds. The fate of these compounds, however, is unknown, so this effect is neglected.

Some of the entrained hydrocarbons would remain in solution or in emulsion until the brine reaches the settling pond. Visible oil would be removed with skimmers. Fine suspensions of oil would present a potentially significant water quality problem, and would need to be treated with separation facilities. In this case there would presumably not be a significant impact on the air quality, since separation facilities for ballast water have negligible emissions. The major portion of the remaining dissolved hydrocarbons would then transfer to the atmosphere within 10 days due to evaporation (Kreider, 1970) and direct transfer to air (Baier, 1970) although about half of the single-benzene ring compounds would remain in solution (Gordon, 1976). Other pathways of removal from the water column such as biological degradation or adsorption to a solid phase which collects at the edge or bottom of the pond should be negligible for the dissolved hydrocarbons (Gordon et al., 1976). The resulting emission rates for this case are also shown in Table N-2.

Table N-2 Annual and Short-Term Hydrocarbon Emissions to the Atmosphere for Four Texoma Sites

SOURCE OF EMISSIONS	WEST HACKBERRY	BLACK BAYOU	VINTON	BIG HILL
FLASH VAPORIZATION				
Annual Emissions, ton/yr.	165	165	55	110
Short-Term Emissions g/sec.	6.5	6.5	2.2	4.3
EVAPORATION				
Annual Emissions, ton/yr.	45	45	15	30
Short-Term Emissions g/sec.	1.8	1.8	0.6	1.2
TOTAL				
Annual Emissions ton/yr.	210	210	70	140
Short-Term g/sec.	8.3	8.3	2.8	5.5

The emission from the ponds would be increased over these values if oil in a film on the surface or in emulsion were allowed to degrade. For oil films, approximately 20% of the surface oil would evaporate in less than 2 hours (Sivadier and Mikolaj, 1973) while approximately 30% more would reach the atmosphere in less than 20 days by other means (Gordon et al., 1976). The remainder of the slick, if not periodically skimmed and removed, would form tar balls which could be removed by standard engineering practices.

N.4 Impact on Ambient Air Quality

The downwind concentrations associated with the hydrocarbon emissions from brine ponds have been calculated using short-term dispersion models PTMAX and PTDIS. The worst case downwind hydrocarbon concentrations are predicted to be not over 200 $\mu g/m^3$ at very close-in locations (< 100 meters). The non-bouyant nature of the hydrocarbon plume maintains these concentrations largely in the vicinity of the West Hackberry site. The typical case downwind concentration from the total emissions in Section N.3 are presented in Table N-3 as a function of downwind distances.

The downwind concentrations of hydrocarbon under typical meteorological conditions (i.e., stability Class D, wind speed 4.4 m/s) are all in compliance with the existing standard (i.e., 160 $\mu g/m^3$) except for West Hackberry and Black Bayou at 0.5 kilometers. It is, therefore, concluded that the air quality impact from the disposal pond would be a localized phenomena and would definitely be confined within each of the four Texoma sites for the sample of crude oil considered in Table N-1.

Table N-3 Downwind Concentrations from the Total Emissions for Four Texoma Sites

Downwind Distance (Km)	3-HOUR CONCENTRATION ($\mu g/m^3$) West Hackberry	Black Bayou	Big Hill	Vinton
0.5	297	213	147	76
1.0	103	74	53	34
1.5	57	41	30	16
2.0	37	26	19	10
3.0	30	21	14	7
4.0	14	10	7	4
5.0	10	7	5	3
10.0	3	2	2	1

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APPENDIX O

BACKGROUND OCEANOGRAPHIC INFORMATION

APPENDIX O

BACKGROUND OCEANOGRAPHIC INFORMATION

1. Bathymetry

Bottom topography in the region from 93° to 95°W longitudes is generally regular, with no prominent features to break the pattern of isobaths*paralleling the shoreline, except in regions offshore the major rivers, the Sabine and the Calcasieu. The 20 meter isobath lies some 75 kilometers offshore from the mouth of the Calcasieu River.

The shoaling conditions so far offshore have led to extensive alterations to allow unhindered navigation in the approaches to waterways in the region. For example, Calcasieu Pass is a channel, dredged to some 12 meters (see Figures 1 and 2), lying directly offshore of the Calcasieu mouth 15 kil meters, thence south eastward 15 kilometers, thence south 6 kilometers to water 12 meters deep; dredge spoil abuts on the west. Similar channelizing occurs off Sabine Lake. The Sabine Bank shoals lie due south of the Calcasieu mouth at a depth of some six meters. Several drilling platforms stand northeast of the Sabine Bank, between the Bank and Sabine Pass.

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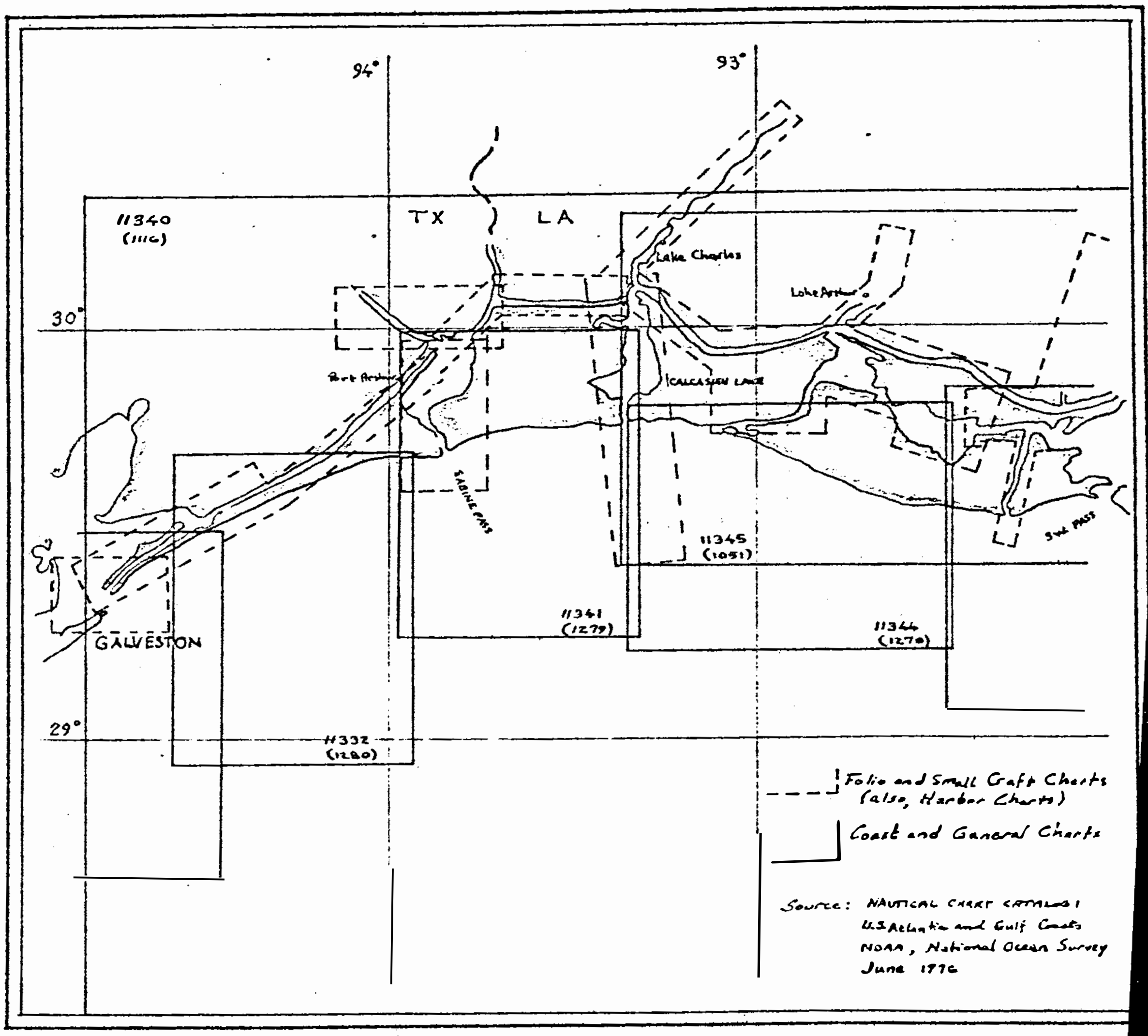
*isobath - a line on a map or chart that connects all points having the same depth below a water surface (ocean, sea, lake).



Source: NAUTICAL CHART CATALOG 1
U.S. Atlantic and Gulf Coasts
NOAA, National Ocean Survey
June 1976

Figure 1 Nautical Chart Index for the West Hackberry Investigation Area

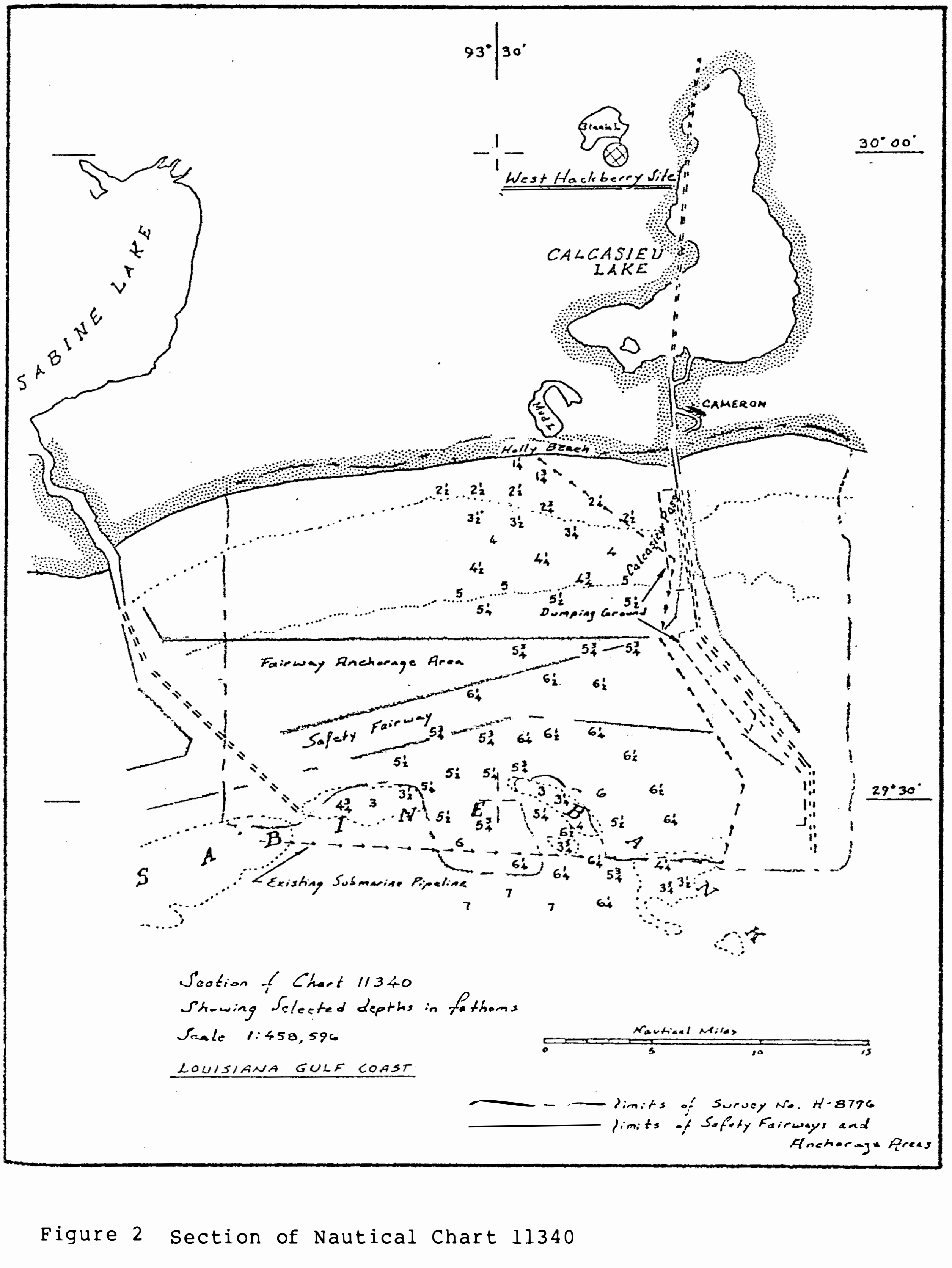


Figure 2 Section of Nautical Chart 11340

2. Hydrology

(a) Surface Properties

General

In a study sponsored by NOAA entitled "Seasonal Variations of Temperature, Salinity and Density of Texas Shelf Waters" Whitaker and Vastano analyzed the monthly distributions of water properties in the area north of latitude 24°N and west of longitude 93°W. This probably represents the best information on the mean temperature, salinity, and density field available. The data was accumulated by the Department of Oceanography, Texas A&M University (TAMU) and was provided by the National Oceanographic Data Center. These data were supplemented and updated with temperature and salinity recordings from TAMU departmental data files, the University of Texas Marine Sciences Institute, the U.S. Geological Survey (Corpus Christi), and the National Marine Fisheries Service (Galveston). Additional data, collected by the Mexican Navy, Instituto Nactional de Pesca, and others were also incorporated.

Monthly surface charts of temperature, salinity, and density, computed from the observations, were constructed by machine plotting the values. The resulting fields were scanned for trends, and isopleths were drawn to reflect the observed tendencies (Figures 3-8).

Sea Surface Temperature Field

Monthly maps of sea surface temperature indicate that isotherms generally parallel the coast. The sea surface temperature gradient is a maximum during January

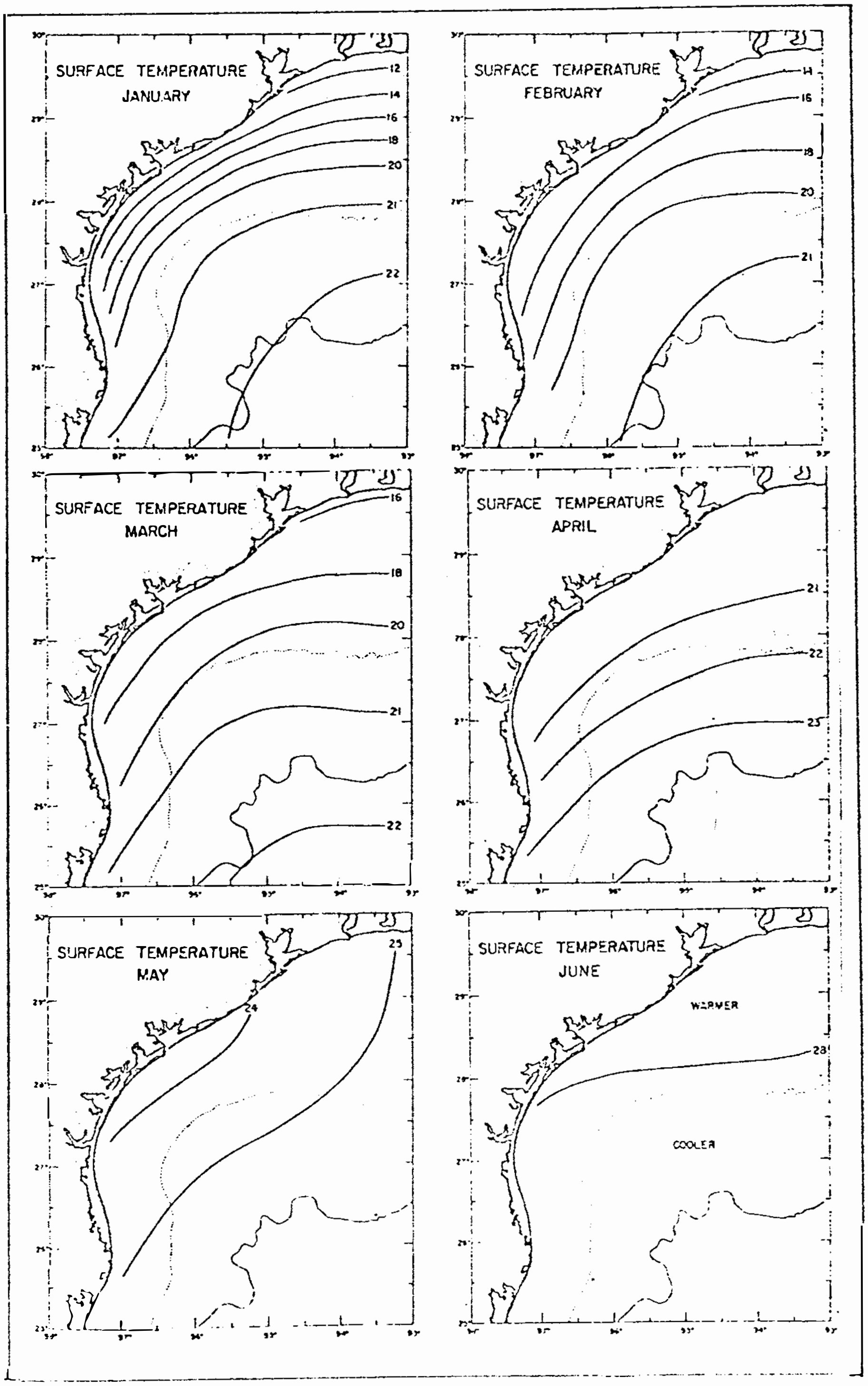
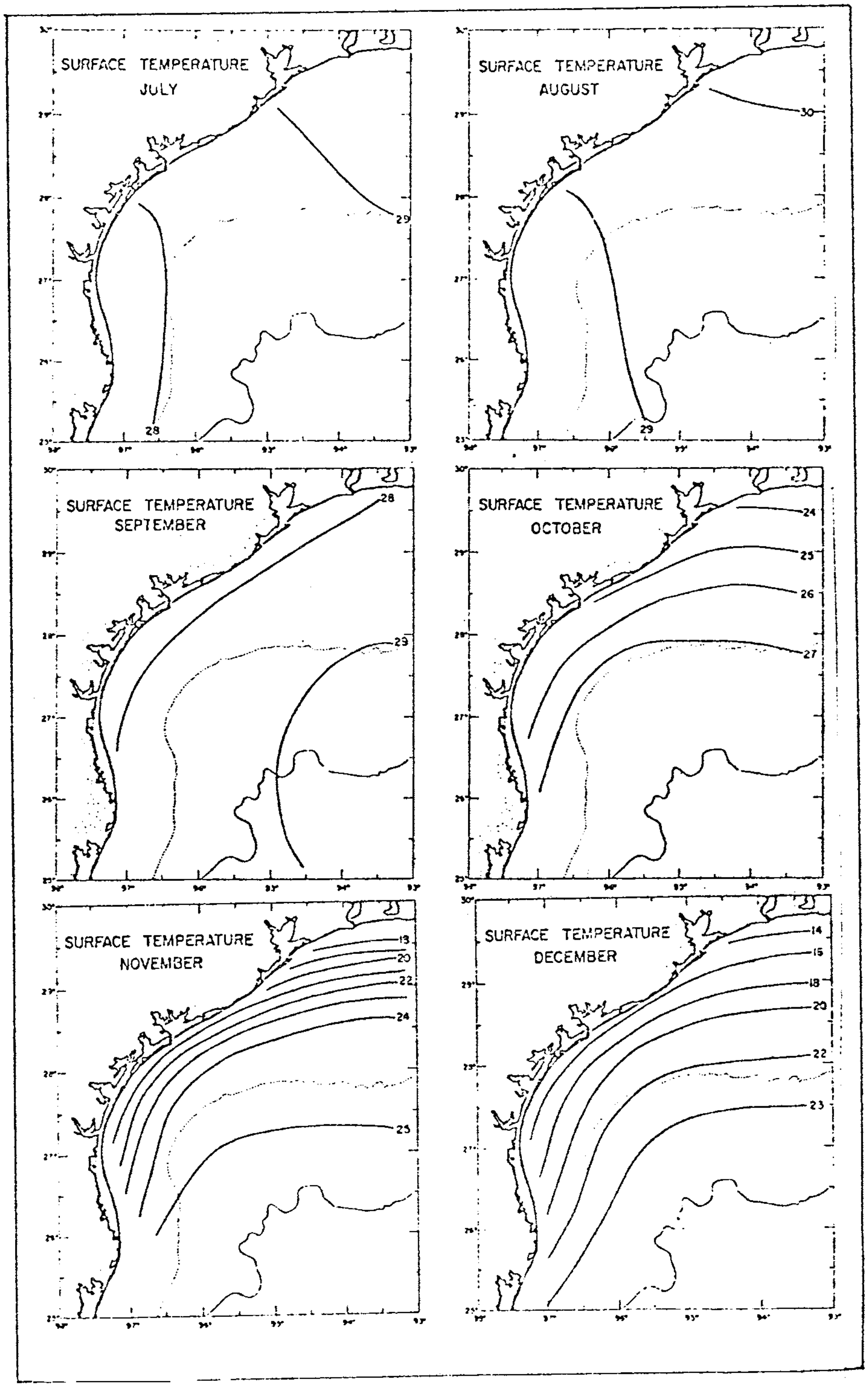


Figure 3. (from Whitaker and Vastano, 1976).



SURFACE TEMPERATURE JULY

SURFACE TEMPERATURE AUGUST

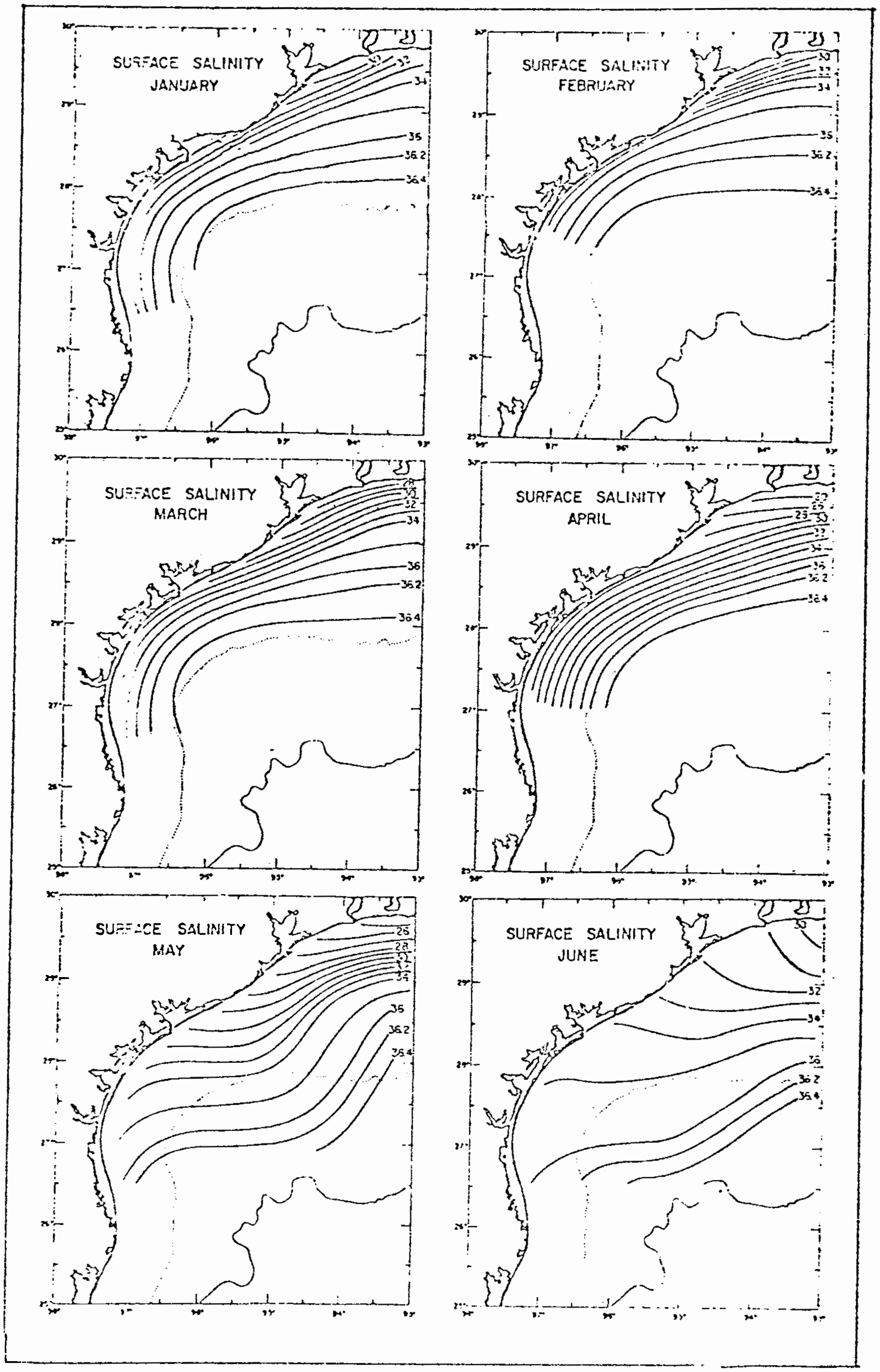
SURFACE TEMPERATURE SEPTEMBER

SURFACE TEMPERATURE OCTOBER

SURFACE TEMPERATURE NOVEMBER

SURFACE TEMPERATURE DECEMBER

Figure 4   (From Witaker and Vastano, 1976)


SURFACE SALINITY JANUARY

SURFACE SALINITY FEBRUARY

SURFACE SALINITY MARCH

SURFACE SALINITY APRIL

SURFACE SALINITY MAY

SURFACE SALINITY JUNE

Figure 5 (From Witaker and Vastano, 1976)

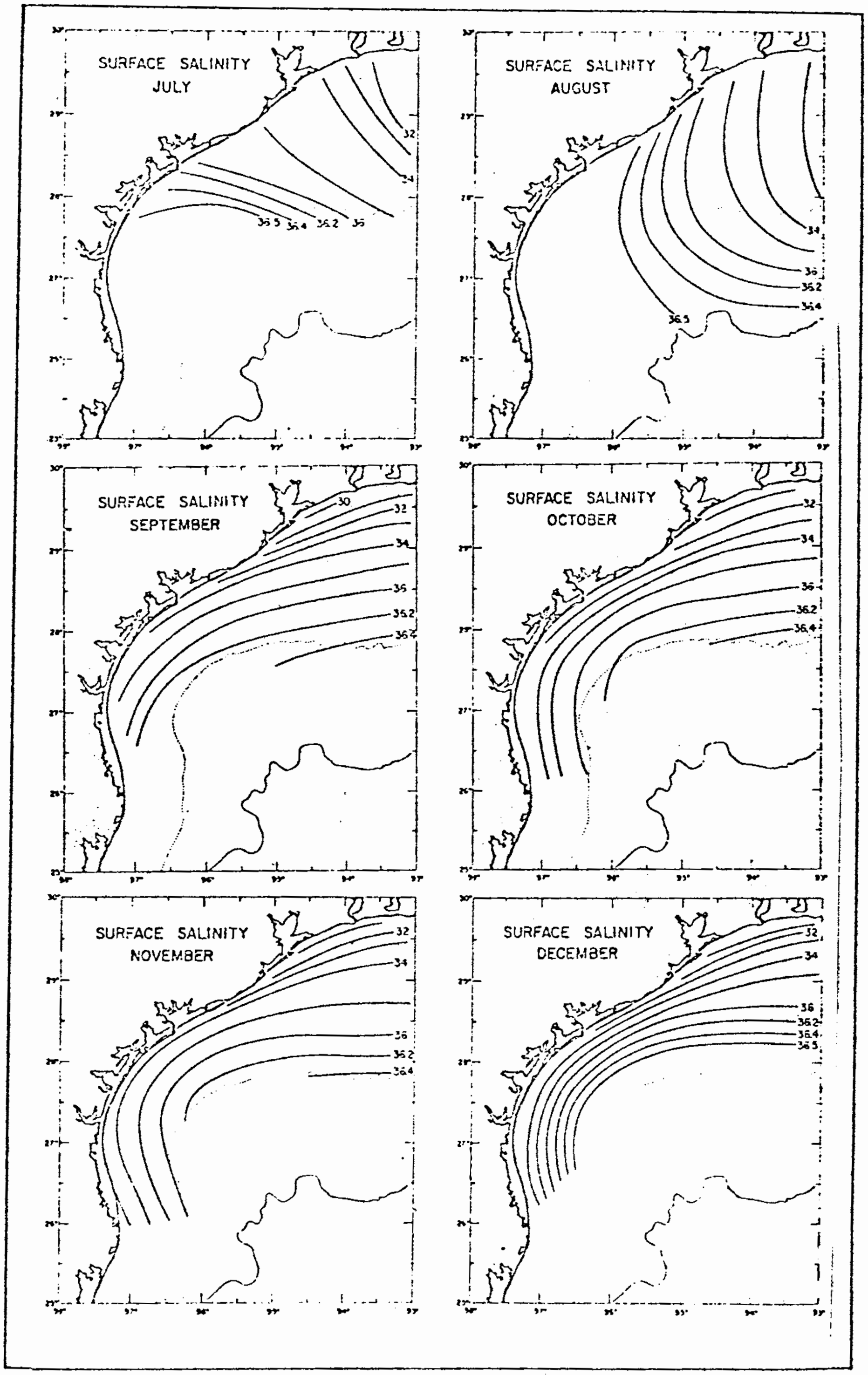


Figure 6 (From Witaker and Vastano, 1976)

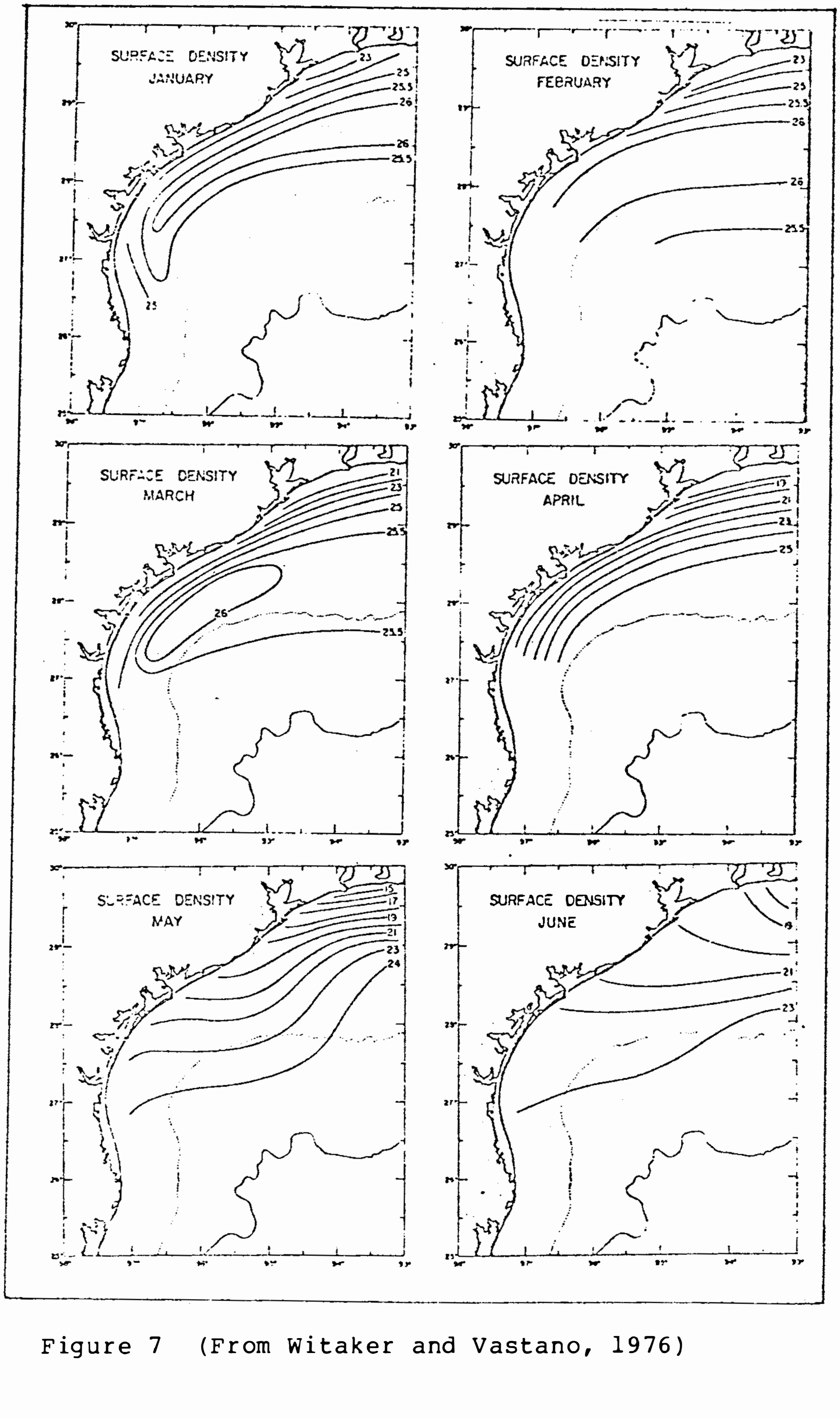


Figure 7 (From Witaker and Vastano, 1976)

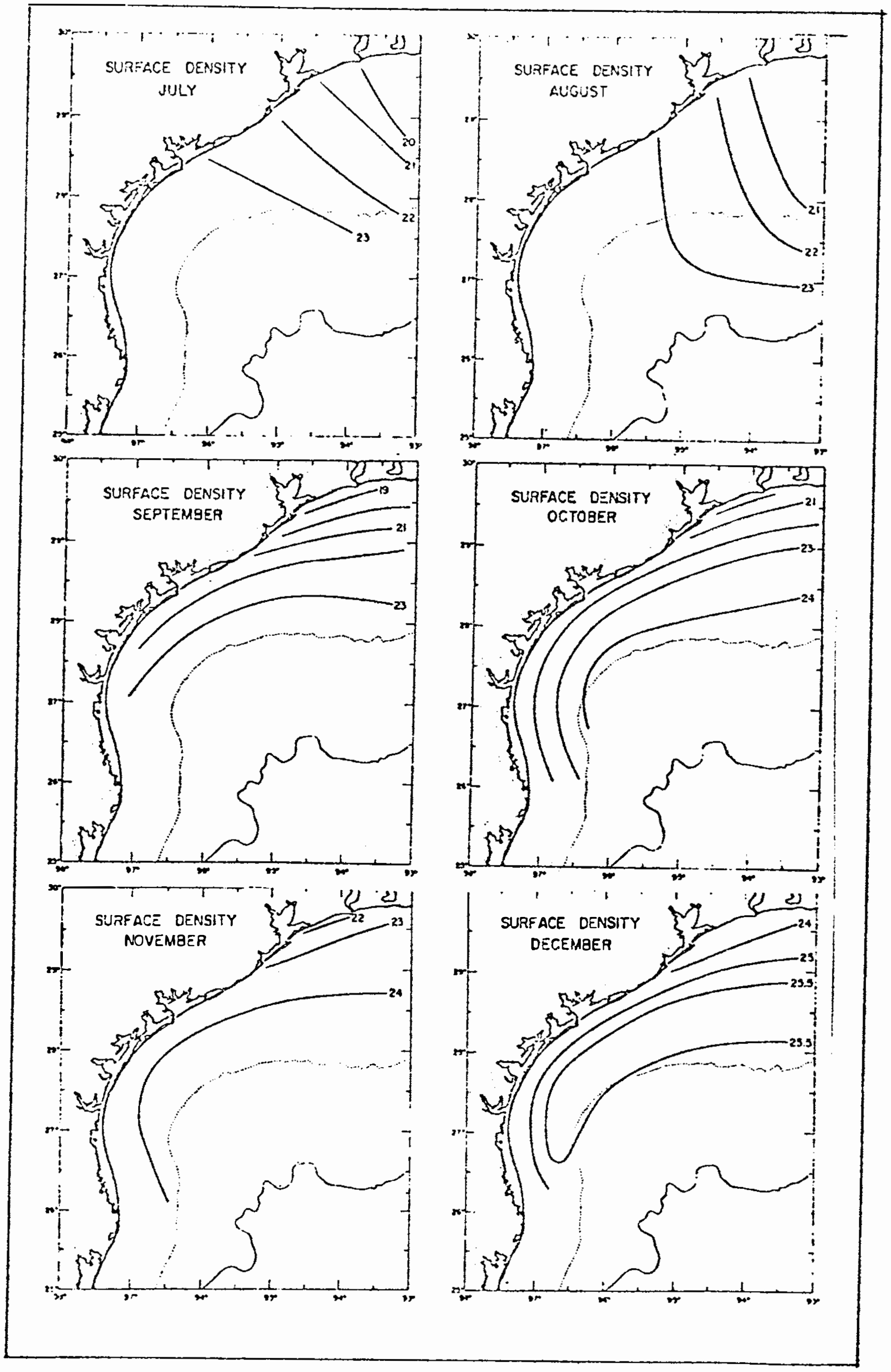


Figure 8 (From Witaker and Vastano, 1976)

over the study area. Through the following four-month period, the gradient progressively relaxes under the influence of increasing seasonal heating. From June through September, the sea surface is in a near isothermal condition. During October, November, and December, seasonal cooling produces an increasing temperature gradient.

For most of the year, cooler water is found nearshore and the temperature in the shallow water increases as one moves south along the coast. The exceptions are June, July, and August, when the surface temperature increases from south to north over the entire shelf. The surface temperature east of Galveston is greater than 29°C during July and greater than 30°C in August.

Sea Surface Salinity Field

The monthly pattern of isohalines, like surface isotherms, parallel the coast during most of the year. Beginning in May, the isohalines, under influence of less saline water introduced from the east, become increasingly perpendicular to the coast. In September, the isohalines are again parallel to the coast, and they maintain this pattern through the remainder of the year. Throughout the year, the freshest water is found nearshore east of Galveston.

From January through April, the 36.4 ppt isohaline is found offshore over the shelf break. Nearshore, about 29°N, the salinity changes from the low thirties in January to the twenties in April. In the period of January through March, the largest surface salinity gradients are found nearshore in the area east of Galveston.

The influence of increasing river outflow, first seen in April, becomes more evident during May, June, July, and August. The surface salinity increases along the coast from east to west as well as in the offshore direction in this time period.

Monthly surface salinity patterns, from September through December, inclusive, are quite similar. Salinities of 30.0 ppt to 31.0 ppt are found east of Galveston. Proceeding offshore from Galveston, the salinity increases to 36.4 ppt over the shelf break, except for December when the maximum salinity is 36.5 ppt.

Sea Surface Density Field

Through the year, the least dense surface water is found east or southeast of Galveston. These densities range from 1.015 gm/cm^3 during May to 1.024 gm/cm^3 in December. The occurrence of the minimum density in May reflects, as the May temperature and salinity fields, the influence of the fresher water originating in the east. From April through June, and in the period September through November, the temperature and salinity experienced in this more oceanic environment is indicative of the density variation, 1.023 to 1.025 gm/cm^3.

The sequence of surface isopycnals found during the December through March period is interesting because of the persistence of very dense surface waters. In December, a tongue of water (density = 1.0255 gm/cm^3 and greater) extends from 93 degrees west along the outer reaches of the shelf. During January, the 1.0255 gm/cm^3 isopycnal outlines a slightly smaller area compared with the previous month, but a tongue of density 1.026 and greater is found within the 1.0255 gm/cm^3 isopleth.

Surface densities of 1.026 gm/cm^3 and larger are found over a large portion of the shelf during February. Offshore, in the open Gulf, the surface water density is less than or equal to 11.025 gm/cm^3; by March, the denser waters of greater than or equal to 1.026 gm/cm^3 exist as an elongated cell centered at latitude 28°N, longitude 95° 50'W.

(b) Water Column Properties

Hydrographic sections have been taken offshore between longitudes 92°W and 96°W by Texas A&M University and the National Marine Fisheries Service (Figure 9). The relatively shallow water column is observed to respond rapidly to meteorological phenomena, such as cold fronts, resulting in vertically homogeneous temperature and salinity profiles for some 50 to 100 kilometers offshore in mid-winter after passage of a front.

Salinity and temperature conditions (Figures 10-15) reflect seasonal circumstances. Winter storms, acting to mix the upper layer and inshore waters, result in vertically homogeneous waters, fresher onshore due to river discharge. Conditions on the Outer Continental Shelf reflect the presence of the subtropical underwater mass present in the west-central Gulf of Mexico, a cooler, lower salinity water mass which remains below the 75 meter depth.

Spring and summer conditions are determined by a combination of increased discharge, enhanced surface evaporation, and the large-scale current structure in the Gulf of Mexico. Fresher, warmer river discharge substantially determines

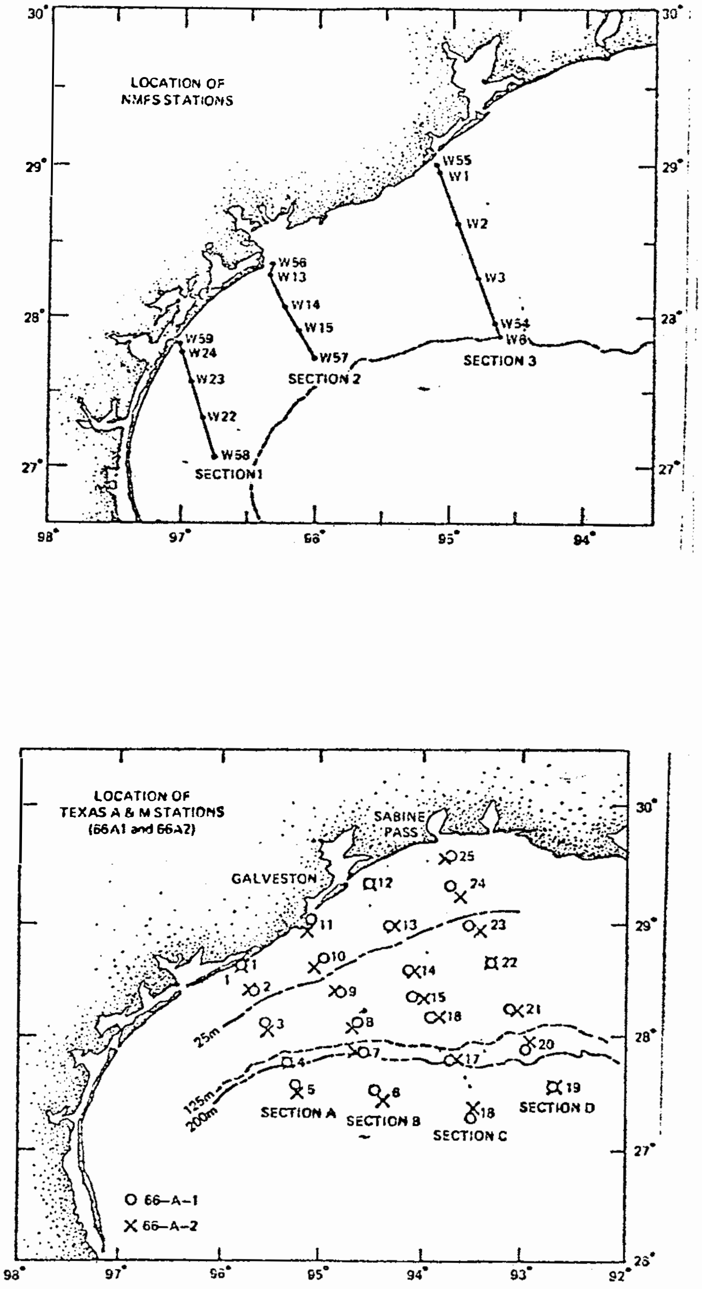


Figure 9 Location of NMFS and TAMU Stations Used for Vertical Sections

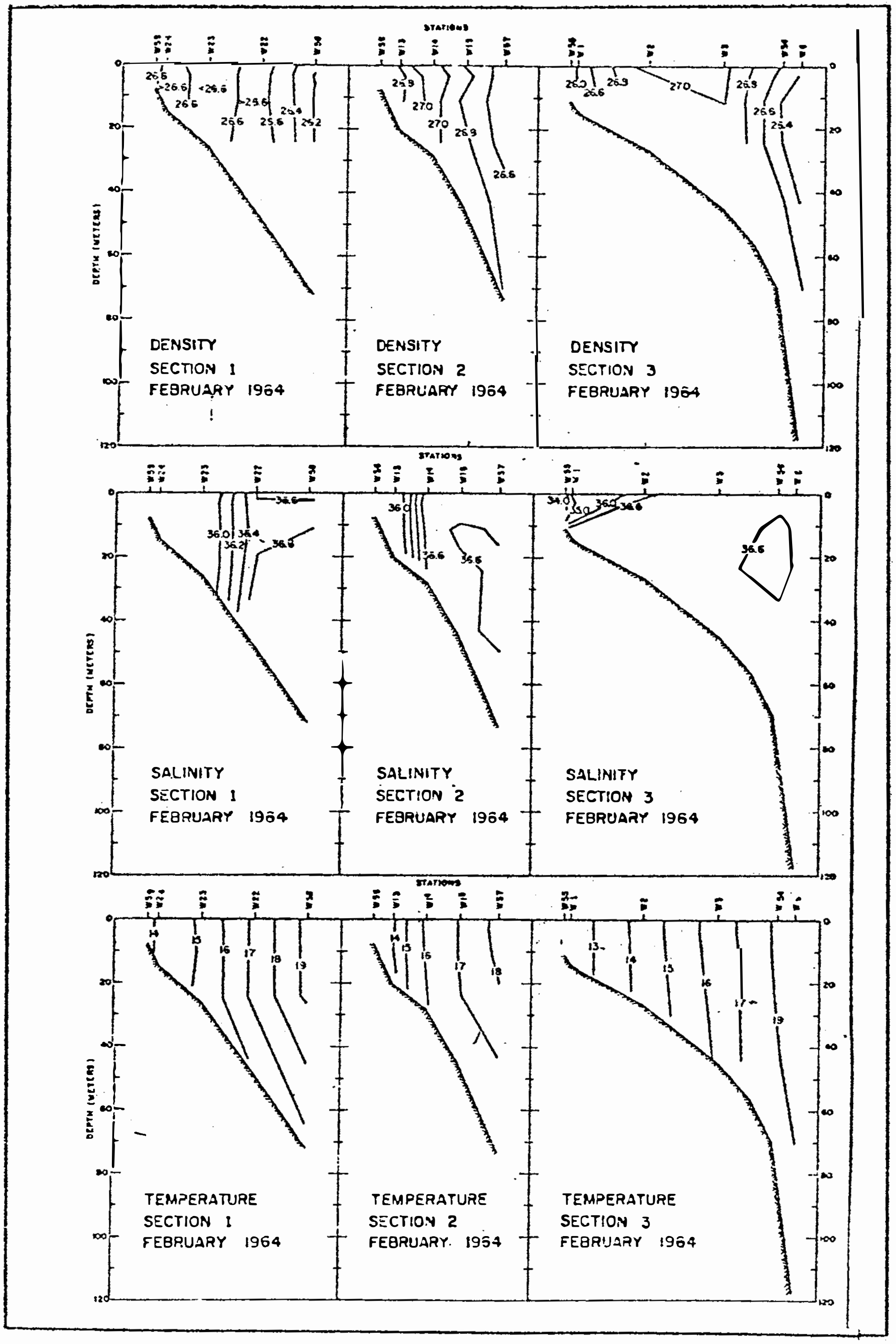
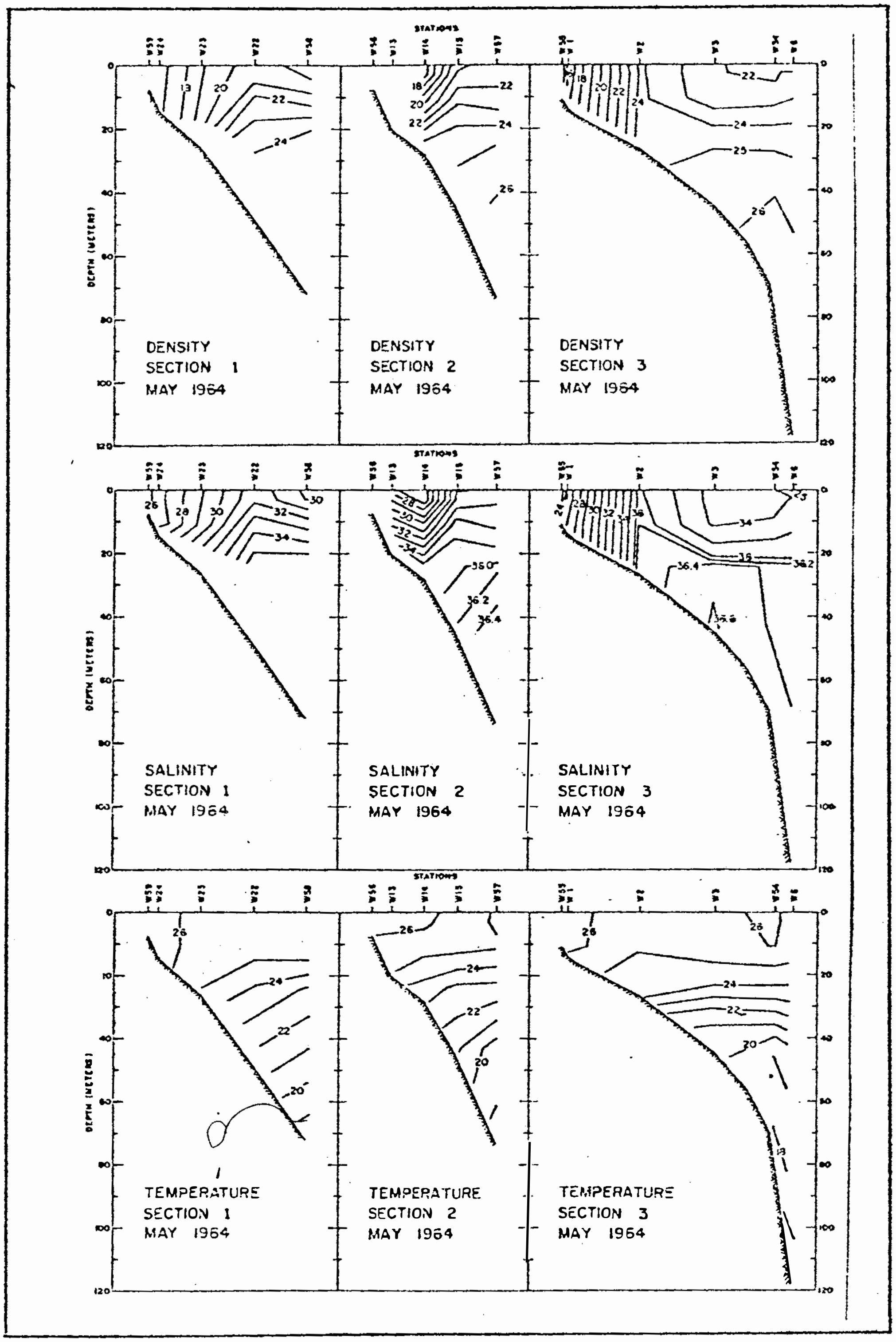


Figure 10 Temperature, Salinity, and Density Anomaly Sections for Febuary 1964 (data from NMFS, Galveston).



DENSITY SECTION 1 MAY 1964

DENSITY SECTION 2 MAY 1964

DENSITY SECTION 3 MAY 1964

SALINITY SECTION 1 MAY 1964

SALINITY SECTION 2 MAY 1964

SALINITY SECTION 3 MAY 1964

TEMPERATURE SECTION 1 MAY 1964

TEMPERATURE SECTION 2 MAY 1964

TEMPERATURE SECTION 3 MAY 1964

Figure 11 Temperature, Salinity, and Density Anomaly Sections for Febuary 1964 (data from NMF S Galveston).

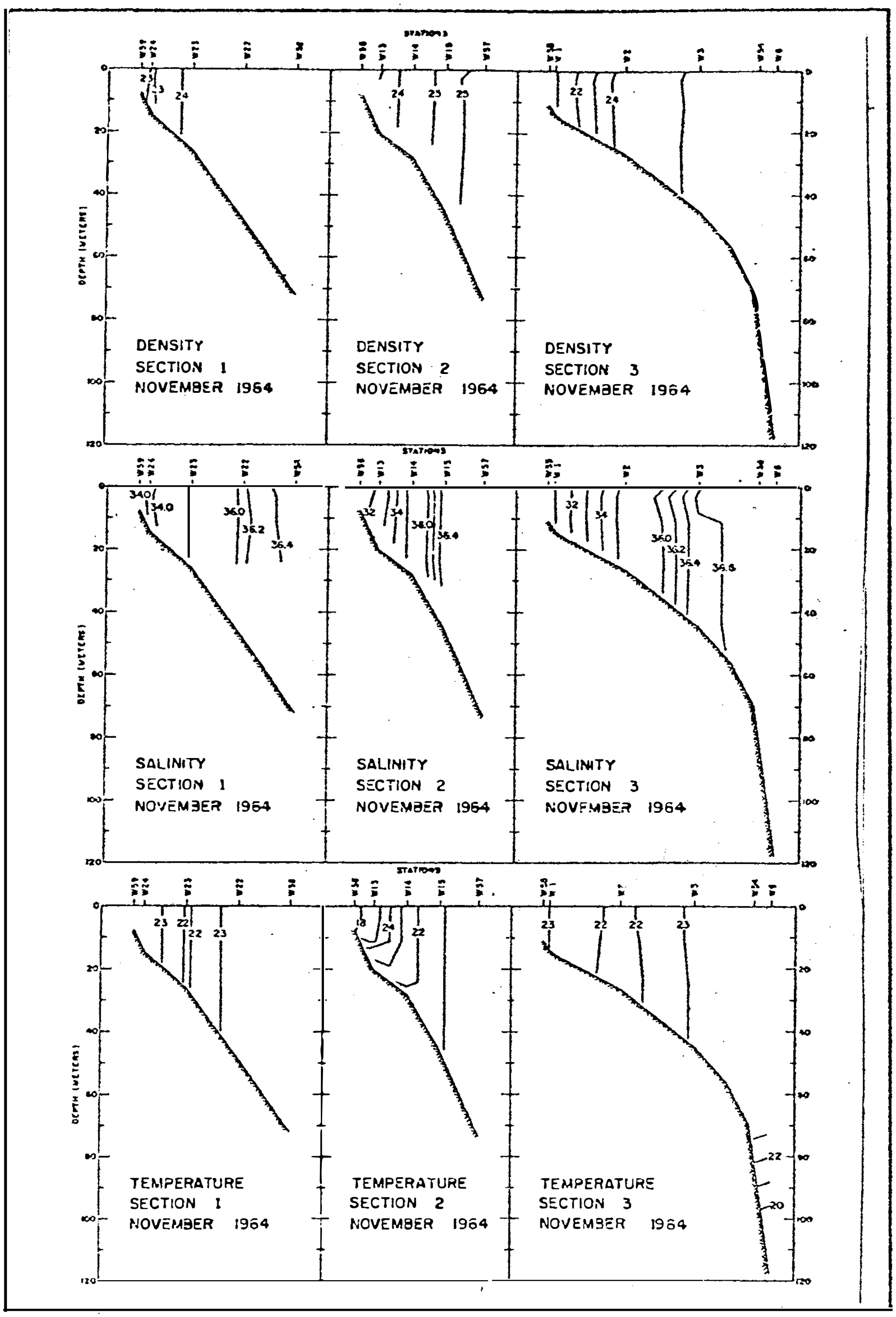
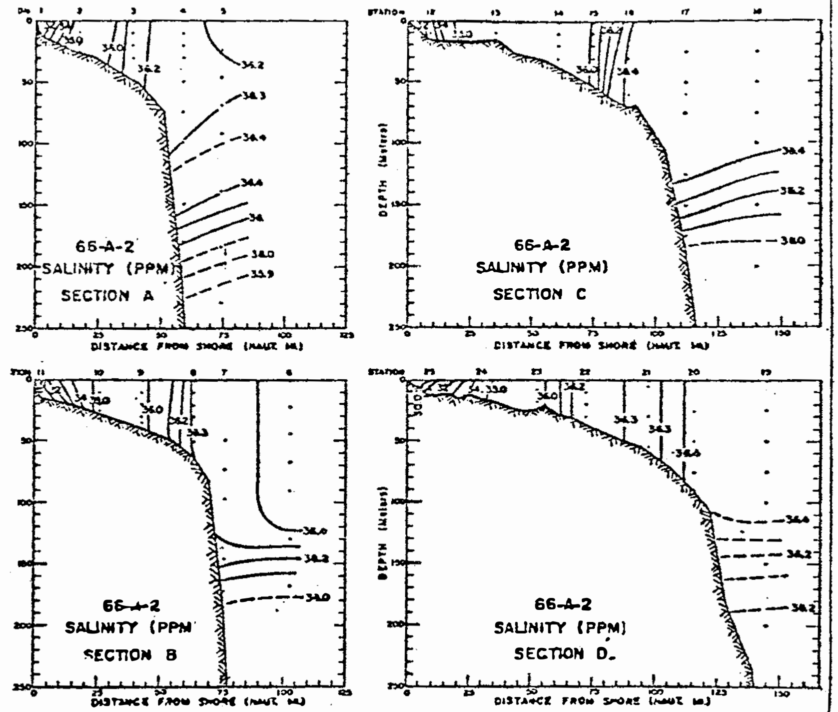
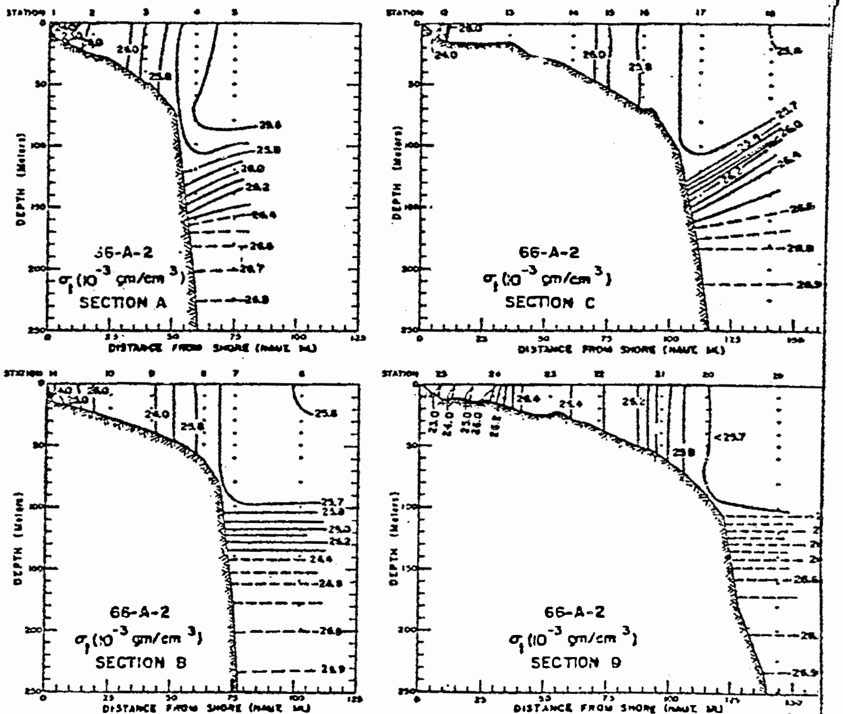


Figure 12 Temperature, Salinity, and Density Anomaly Sections for November, 1964 (data from NMFS, Galveston)

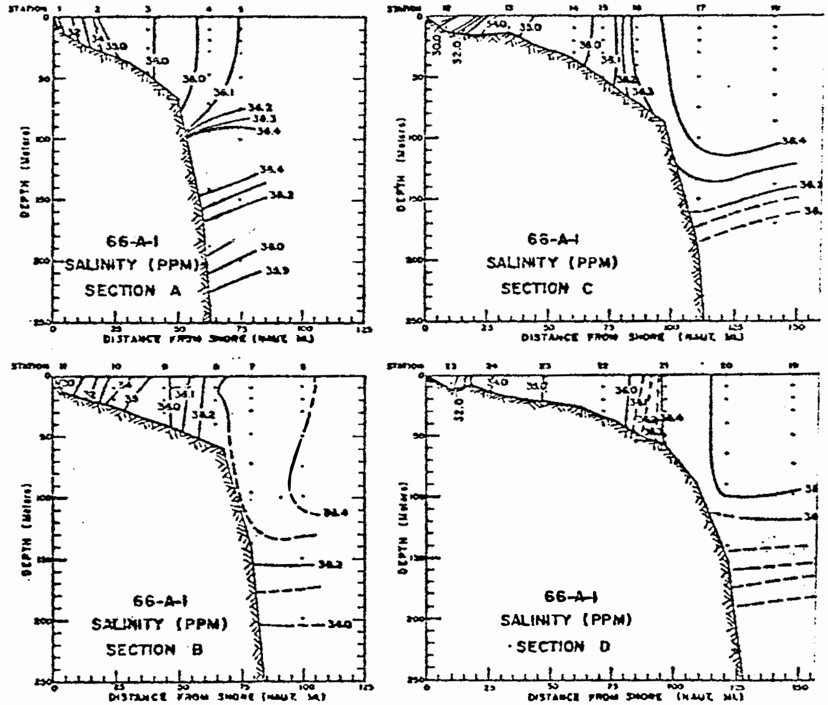


Salinity sections for January, cruise 66A2 (from Nowlin and Parker, 1974).



Density anomaly sections for January, cruise 66A2 (from Nowlin and Parker)

Figure 13 Density Anomaly Sections for January, Cruise 66A2 (Nowlin and Parker, 1974)



Salinity sections for January, cruise 66A1 (from Nowlin and Parker, 1974).

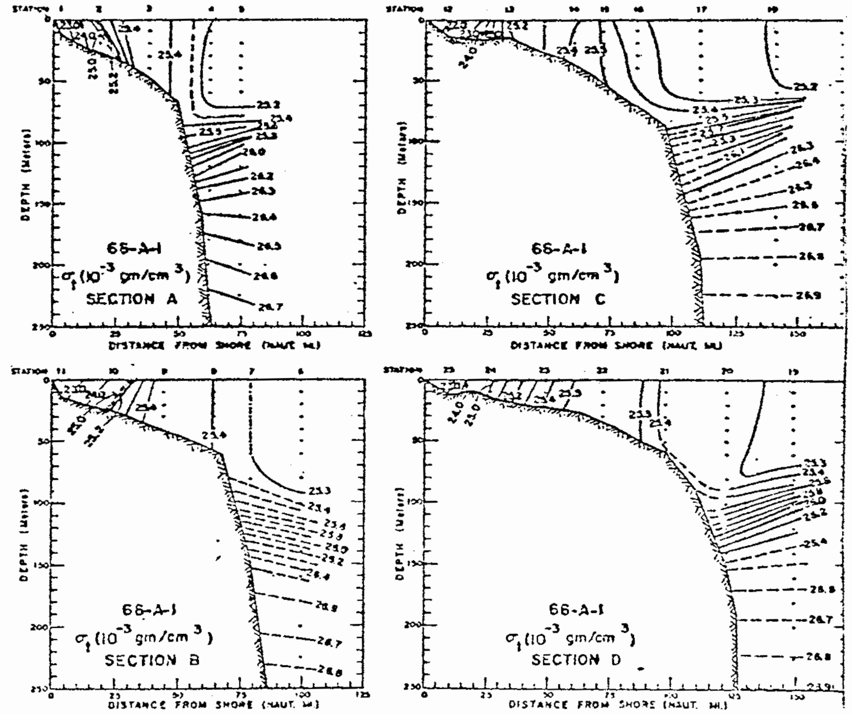


Figure 14 Density Anomaly Sections for January, Cruise 66A1 (Nowlin and Parker, 1974)

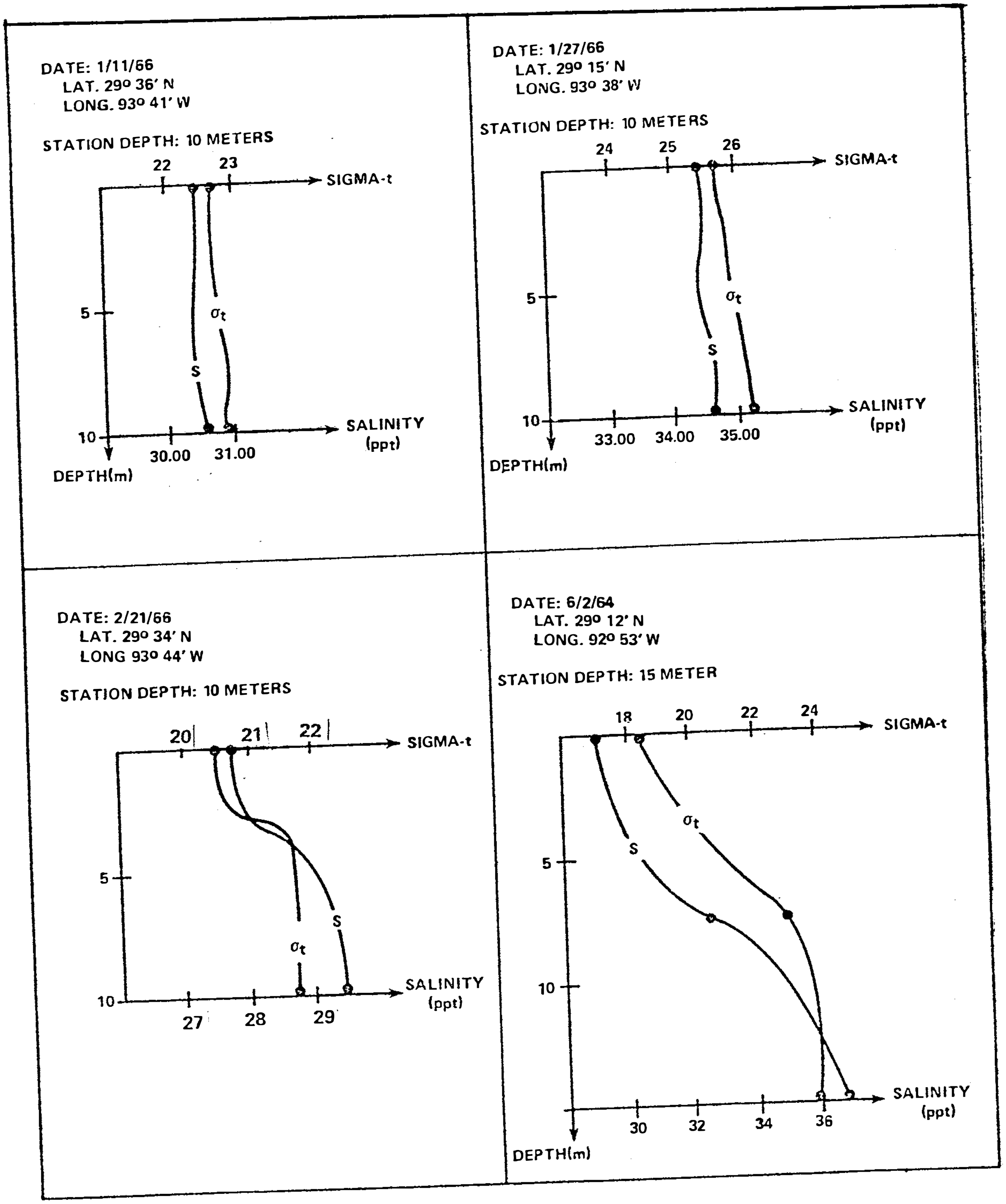


Figure 15 Typical NODC Oceanographic Data in the West Hackberry Study Region

onshore surface and water column salinity and temperature in the region offshore of West Hackberry to the area of Galveston Bay. In that region, fresher, warm surface water lies onshore, enhanced by the generally westward surface currents drawing Mississippi discharge into the region. Further southwest, surface temperature and salinity maxima occur well offshore as fresh discharge is transported out of the region by the eastward return flow.

Autumn sees a return to increased mixing, with low river discharge, hence a pattern of a relatively homogeneous water column but lessened horizontal density gradients with respect to spring conditions. Colder water is periodically driven onshore by strong easterly and southeasterly winds as fall progresses into winter time conditions.

Water mass types are influenced by position in the Gulf. More westward regions show strong evidence of remnant Subantarctic Intermediate water flow salinity and low temperature, while mixing with Caribbean water increases both salinity and temperature eastward. Thus, transects show a salinity minimum offshore in the west, but not to the east.

3. Tides

The tidal regime in the region is mixed (Figure 16), with diurnal tides dominant over semidiurnal components. Spring tides tend to be semidiurnal, while neap tides are primarily diurnal (see Figure 17). Tidal cophase lines, connecting points with simultaneous occurrence of high tides, tend to parallel the coastline, so that the western Gulf of Mexico acts somewhat as a circular basin in co-oscillation with tidal driving forces. There is, however, a rotary component to the tide, so that tidal currents shift direction continuously, rather than passing through periods of slack water. Tidal range is measured at one to two feet in open water, and somewhat less in coastal waterways.

Tidal harmonic analysis reveals that the dominant diurnal (K_1) component of tide is nearly in phase throughout the western Gulf basin, while the semidiurnal component (M_2) is of much lower amplitude and acts as a perturbing factor on the dominant diurnal component. The geographic extent of mixed versus diurnal tides on the coast is a function of how much phase difference exists between the two components, as well as other, secondary, components at a particular point.

Examination of the distribution of cophase/corange lines for observed tides can be instructive. Cophase (or cotide) lines connect points of simultaneous high tide (or any other point in the tidal cycle), and are referred to a common datum point in hours before high tide at that datum. Published tide tables for the Gulf Coast, however, include many stations which are in enclosed bays, or are subject to topographic effects. Murray (1976; personal communication 1977) used the tide tables to derive a cophase map (See Figure 18).

GALVESTON BAY ENTRANCE (BETWEEN JETTIES), TEXAS, 1977

F-FLOOD, DIR. 300° TRUE   E-EBB, DIR. 100° TRUE

JANUARY

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1 SA	1110 2001	0552 1421 2201	2.5E 1.9F 0.3E	16 SU	1103	0643 1425 *2215	3.4E 2.7F *
2 SU	1145	*0045 0725 1455 *2250	* 2.8E 2.1F *	17 M	1150	*0033 0728 1511 *2245	* 3.6E 2.8F *
3 M	1220	*0122 0801 1530 *2333	* 2.9E 2.2F *	18 TU	0234 1236	0128 0314 1549 *2312	0.3F 3.7E 2.7F *
4 TU	1255	*0157 0930 1604	* 3.0E 2.3F	19 W	0333 1321	0219 0900 1629 *2328	0.4F 3.5E 2.5F *
5 W	1330	*0039 *0230 0903 1642	* * 3.0E 2.3F	20 TH	0428 1404	0309 0945 1704 *2347	0.4F 3.2E 2.2F *
6 TH	1405	*0153 *0255 0938 1720	* * 3.0E 2.2F	21 F	0520 1447 2230	0402 1027 1733	0.4F 2.7E 1.9F
7 F	0218 1440	1007 1757	2.8E 2.0F	22 SA	0309 0612 1529 2234	0019 0455 1109 1815	0.3E 0.3F 2.2E 1.5F
8 SA	1517	*0049 *0100 1042 1839	* * 2.4E 1.8F	23 SU	0433 0707 1612 2225	0053 0556 1158 1854	0.5E 0.3F 1.5E 1.1F
9 SU	1556 2330	*0121 *0304 1117 1918	* * 2.0E 1.5F	24 M	1700 2209	0133 *0705 1259 1933	0.7E * 0.9E 0.8F
10 M	1637 2300	0201 *0704 1206 2000	0.5E * 1.3E 1.1F	25 TU	0702 1010 1806 2205	0217 0522 1418 2016	1.0E 0.3F 0.4E 0.4F
11 TU	1724 2253	0241 *0935 1357 2042	0.9E * 0.7E 0.7F	26 W	0757	0311 0950 *1811 *2104	1.2E 0.5F * *
12 W	0805 2301	0327 1005 *1559 2124	1.4E 0.6F * 0.4F	27 TH	0844	0409 1256 *1929 *2153	1.5E 0.9F * *
13 TH	0846	0413 1126 *1939 *2213	1.9E 1.2F * *	28 F	0926 1820	0457 1325 2019 *2248	1.8E 1.3F 0.3E *
14 F	0930	0502 1243 *2045 *2301	2.5E 1.8F * *	29 SA	1007 1903	0543 1352 2107 *2337	2.1E 1.6F 0.3E *
15 SA	1016	0556 1339 *2134 *2350	3.0E 2.3F * *	30 SU	1047 1943	0626 1409 2142	2.4E 1.9F 0.3E
				31 M	1125	*0019 0707 1435 *2221	* 2.7E 2.0F *

FEBRUARY

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1 TU	1201	*0103 0742 1504 *2237	* 2.9E 2.2F *	16 W	0259 1225 2012	0139 0811 1523 2200	0.5 3.2E 2.2F 0.4E
2 W	0250 1237	0143 0317 1539 *2227	0.3F 3.0E 2.2F *	17 TH	0010 0403 1307 2020	0221 0357 1552 2215	0.7F 2.9E 2.0F 0.5E
3 TH	0340 1312	0226 0853 1614 *2234	0.3F 3.0E 2.1F *	18 F	0048 0502 1349 2024	0307 0937 1627 2237	0.8F 2.6E 1.7F 0.7E
4 F	0430 1348 2130	0307 0928 1646 2257	0.4F 2.8E 1.9F 0.3E	19 SA	0131 0558 1429 2018	0359 1022 1556 2305	0.5F 2.1E 1.3F 0.5E
5 SA	0052 0523 1423 2119	0348 1008 1718 2325	0.5F 2.5E 1.7F 0.5F	20 SU	0219 0655 1509 2003	0449 1105 1731 2334	0.6F 1.8E 1.0F 1.0E
6 SU	0149 0622 1453 2058	0441 1046 1753 2354	0.5F 2.1E 1.3F 0.8E	21 M	0313 0757 1554 1957	0542 1146 1805	0.8F 1.1E 0.6F
7 M	0302 0732 1536 2049	0547 1139 1832	0.6F 1.5E 0.9F	22 TU	0417 0918 1658 1958	0009 0642 1249 1840	1.1E 0.7F 0.6E 0.3F
8 TU	0427 0904 1612 2052	0036 0701 1242 1907	1.1E 0.7F 0.8E 0.5F	23 W	0523	0049 0749 *1415 *1922	1.2E 0.7F * *
9 W	0551	0118 0818 *1425 *1942	1.4E 0.8F * *	24 TH	0640 1605	0141 0707 1841 *2011	1.3E 0.8F 0.3E *
10 TH	0704	0220 0351 *1906 *2031	1.8E 1.2F * *	25 F	0744 1706	0250 1035 1923 2114	1.4E 1.0F 0.4E 0.3E
11 F	0809	0325 1127 *2005 *2135	2.2E 1.6F * *	26 SA	0940 1745	0401 1239 2011 2215	1.6E 1.3F 0.5E 0.3E
12 SA	0907 1859	0434 1245 2040 *2239	2.6E 2.0F 0.3E *	27 SU	0930 1817	0501 1259 2045 *2311	1.9E 1.5F 0.5E *
13 SU	1001 1930	0537 1335 2113 *2339	2.9E 2.3F 0.3E *	28 M	1014 1843	0555 1327 2109	2.2E 1.7F 0.4E
14 M	1052 1951 2314	0631 1416 2135	3.1E 2.4F 0.3E				
15 TU	0145 1140 2003 2339	0035 0723 1446 2152	0.3F 3.2E 2.4F 0.3E				

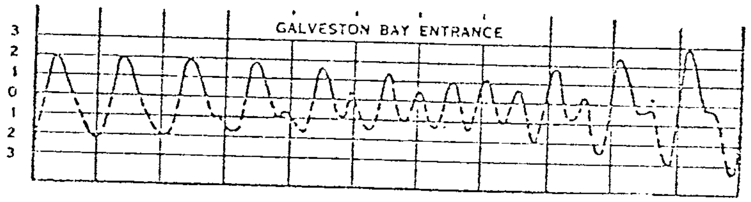


Figure 16. Tidal Currents, Galveston Bay Entrance (Source: Tidal Current Tables, NOAA, 1977).

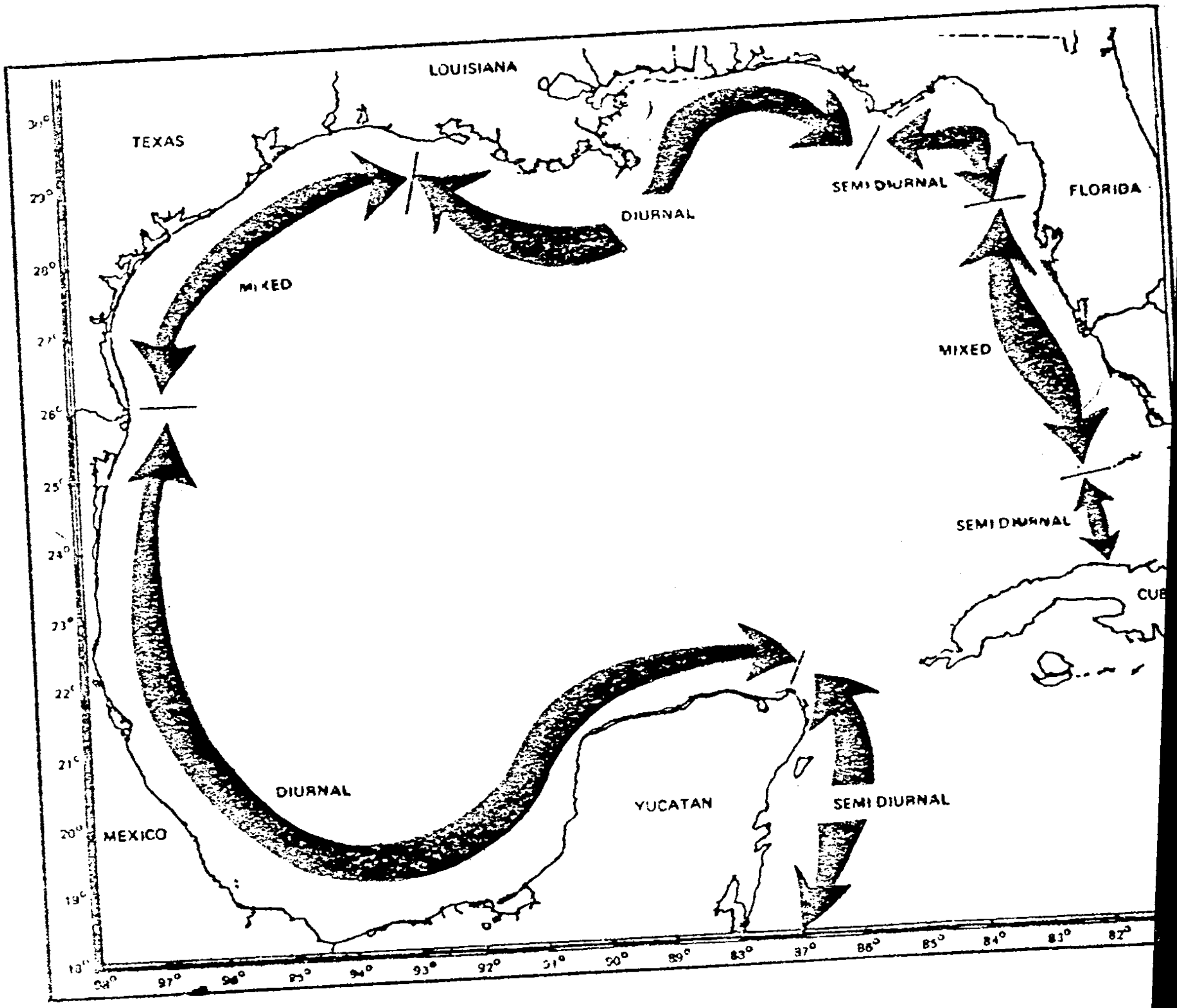


Figure 17 Gulf of Mexico Tidal Regimes (from Eleuterius, C. K., 1974. Mississippi Superport Study, Environmental Assessment).

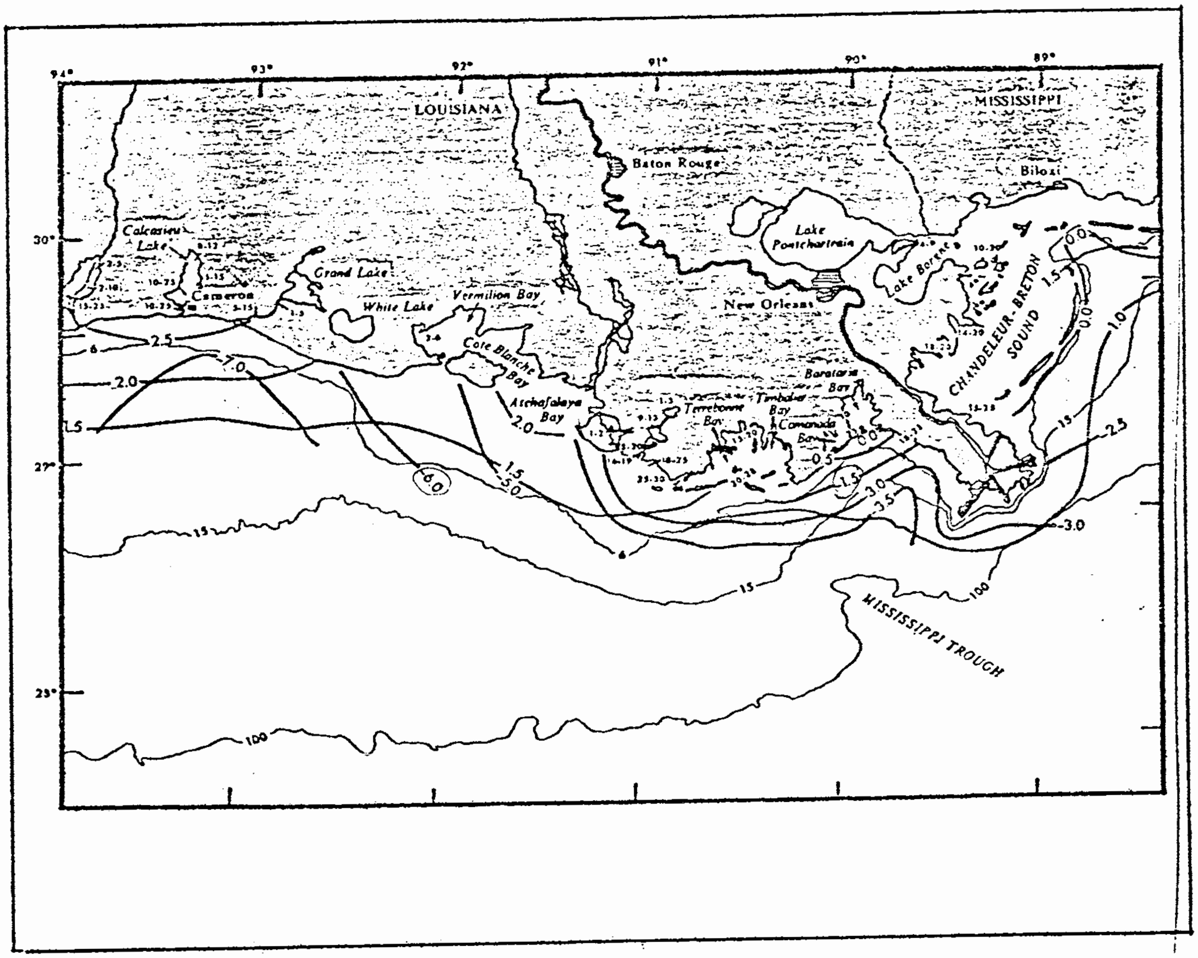


Figure 18 Location Map of Louisiana Coastal Waters. Cophase lines of the tide in hours before high water at Baratara Pass are shown as heavy solid lines. Co-range lines of the tide in feet are shown as dashed lines. Smnall numbers indicate observed salinity ranges (ppt) in bays and estuaries (After Murray, 1976). Extension of the chart westward would show a pattern which mirrors the above moving westward.

The results indicate the Calcasieu Pass region is a point where the cophase lines shift direction, i.e., tides occur at Calcasieu Pass earlier than points either to the West or to the East, up to the nearest datum points (Galveston Bay to the West, Barataria Pass to the East). Thus, tidal crests move shoreward at Calcasieu, thence east and west, confirming the behavior of the western Gulf of Mexico as a quasi-co-oscillating basin.

4. Currents

Currents in coastal waters are related to winds, river outflow, and large-scale flow patterns. Both shallow-water wind-driven currents and barotropic, wind-induced slope currents nearly parallel isobaths. Density-driven currents also tend to follow bottom contours. This flow component is a result of offshore dynamic gradient due to freshwater input near the coast. In addition, the large scale circulation of the Gulf of Mexico influences the nearshore low dynamics.

(a) Surface Currents Observations Derived from Ship Drift

The National Oceanographic Data Center (NODC) of the NOAA's Environmental Data Service has developed a Surface Current Data System (SCUDS) using ship drift data acquired from the U. S. Naval Oceanographic Office. This technique of observing surface currents is one source of supporting observations for analytic studies of large-scale ocean current systems. Individual current vectors can be averaged either by vectoral or scalar procedures. These methods can lead to different results. Differences can be rationalized by a calculation of current stability, S, defined in terms of the averaged vectoral velocity, $\bar{V}$ and the averaged arithmetic velocity; $|V|$, expressed as:

$$S = \frac{\bar{V}}{|V|} \times 100$$

Stability, thus defined, ranges between zero and 100. When each vector is in the same direction S = 100; in this case the vectorial mean equals the scalar mean.

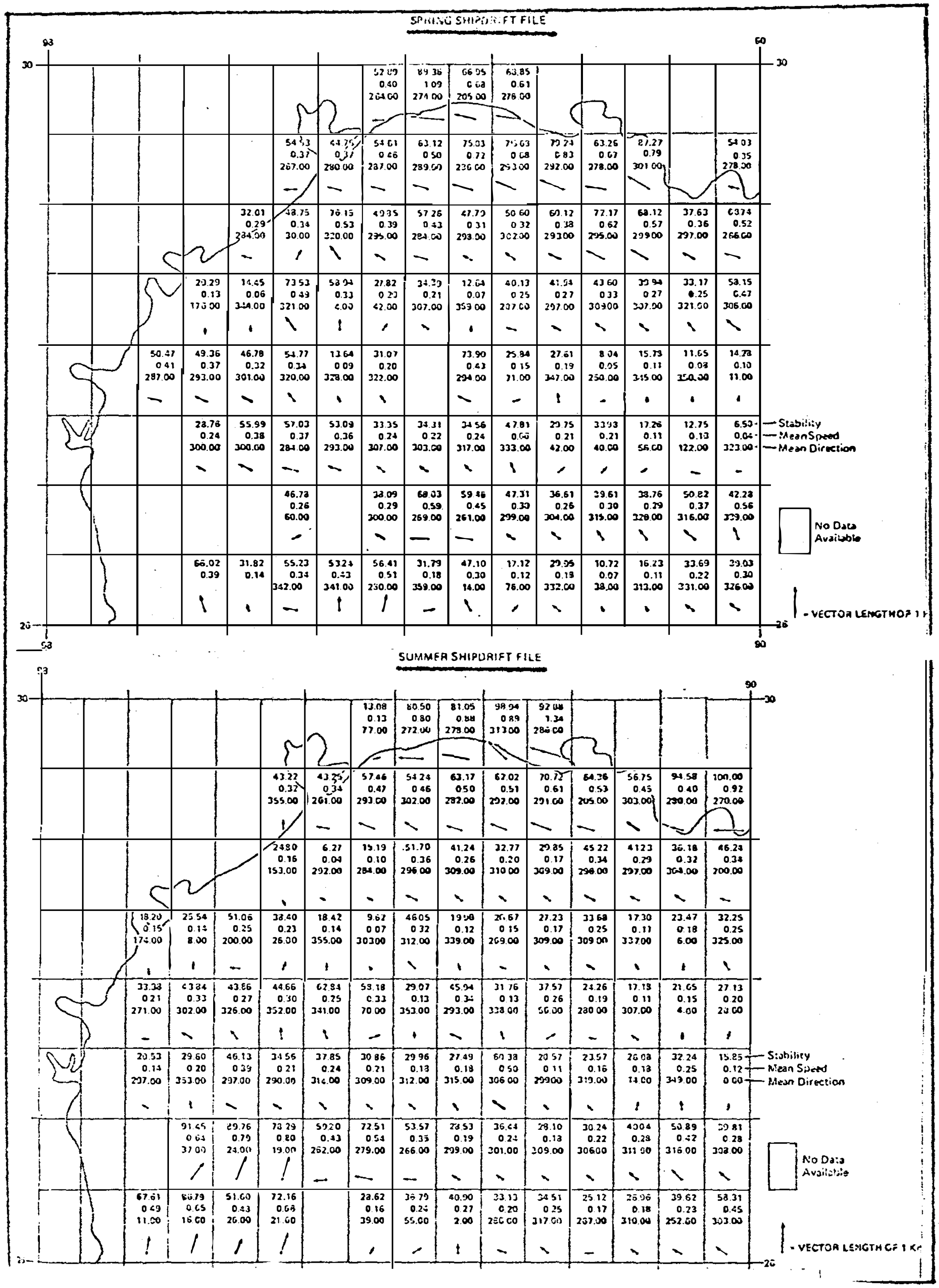
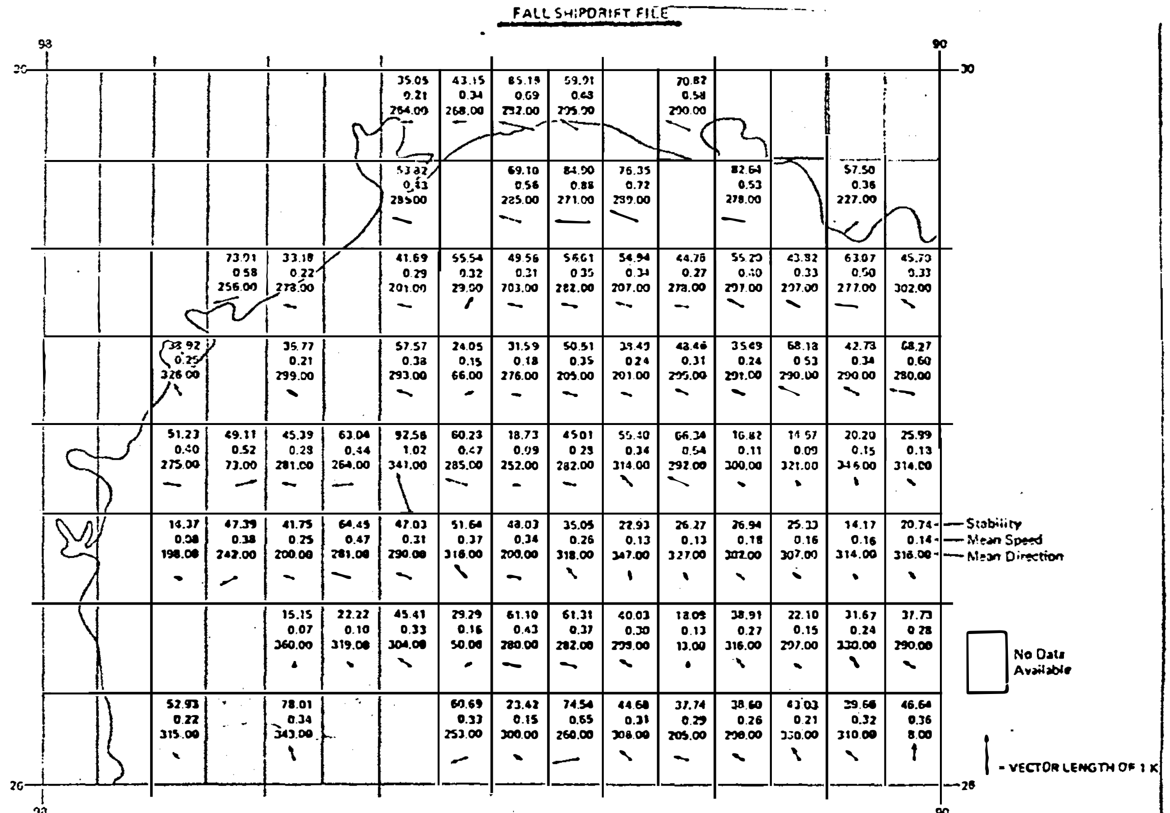


Figure 19. Spring Shipdrift File and Summer Shiptdrift File.



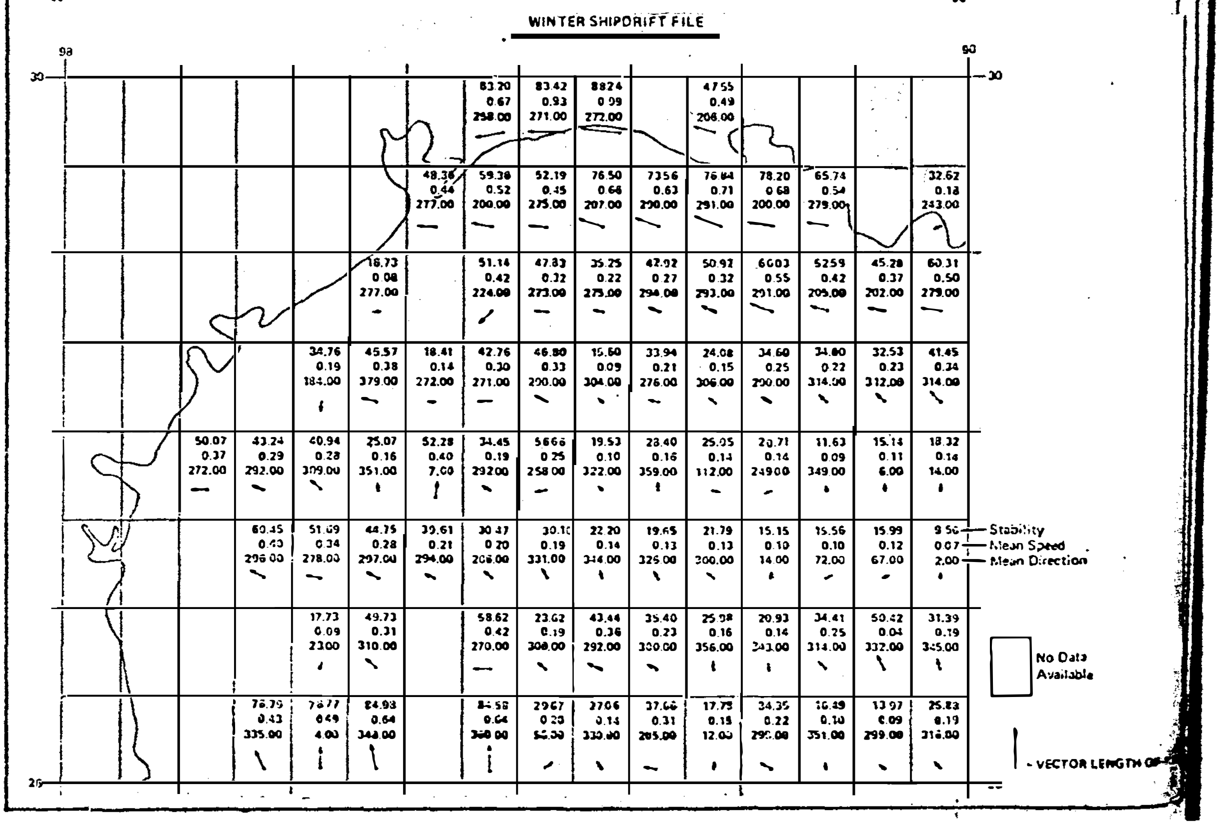


Figure 20 Fall Shipdrift File and Winter Shipdrift File

Analyses of the SCUDS file data indicate that a current flows in a westerly direction along the Texas-Louisiana coast approximately parallel to the shoreline with speeds from 0.2 to 0.4 knots (see Figures 19 and 20). Flow is parallel to isobaths in the study area and relatively stable ($S \approx 50$). These surface currents are related both to wind conditions and baroclinic effects due to river runoff.

(b) Mean Coastal Currents

In the shallow waters of the study region, mean currents are driven by winds, density differences, and larger scale offshore flow patterns. The wind field drives an Ekman transport directed approximately 90° to the right of the wind. In the late fall and winter, winds flow predominantly from the east driving a northward flowing Ekman transport. During spring and summer, winds are stronger and generally shift toward the northwest. Ekman transport now flows toward the northeast. February and September are transition periods between these flow fields. A second component in the mean current field is the baroclinic flow. From September through April, the lowest density waters are nearshore and isopycnals parallel the shoreline and isobaths. During March, an anticyclonic eddy pattern is centered at about latitude 28°N, longititude 95°30'W. May through August is a transition period with isopycnals becoming more perpendicular to the coastline. Such a pattern is not typical for coastal waters in other areas and is probably related to the strong spring river runoff.

(c) Vertical Current Variability

The region west of the Mississippi Delta to the Texas border has not been well surveyed for either water column properties or current fields. The few recorded ships reports are far too sparse for definitive characterization of the region. One long current record from a single station does, however, exist.

Current meter observations were obtained from the Buccaneer platform (latitude 28°53'N, longititude 94°42'W) from October, 1971 through August, 1973. Observations were taken at depths of 3.7 m (12 feet), 10 m (32 feet), and 17 m (57 feet), below the water surface. Monthly current roses for these three sets of observations are shown (see Figures 21 through 23).

The surface water currents were predominantly towards the west from March through June. From July through September, the surface water currents are predominantly towards the northeast. From October through February, the current direction was variable. Surface water currents greater than 51 cm/sec (1 kn) occurred most often from May through August.

Mid-depth water currents were more directional than the surface currents. Currents were mainly towards the west during March through June and mainly towards the northeast from July through January. Currents greater than 51 cm/sec (1 kn) occurred most often in July and August.

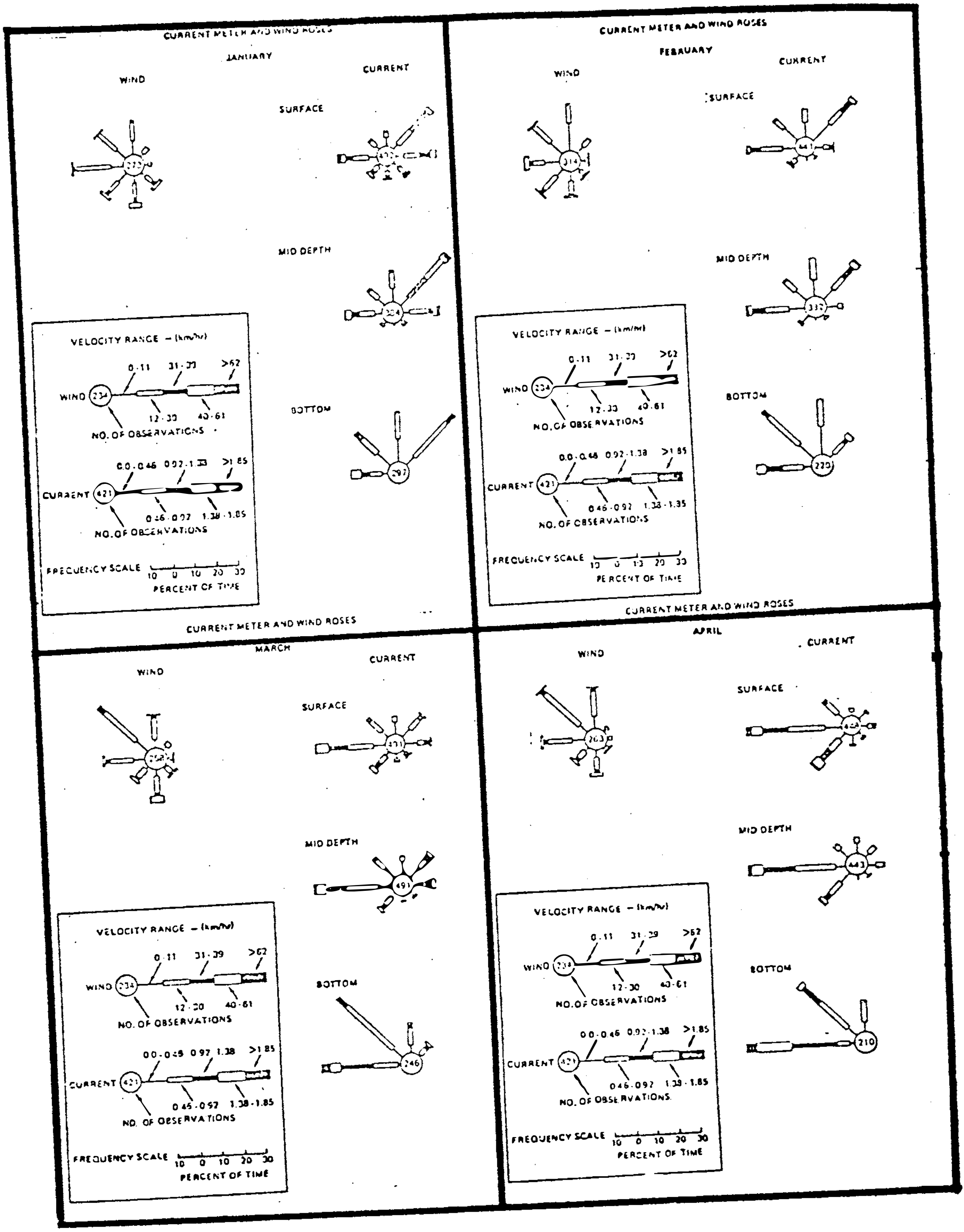


Figure 21 Seadock Current Roses and Wind Roses Taken Near Buccaneer Platform for January, February, March, and April

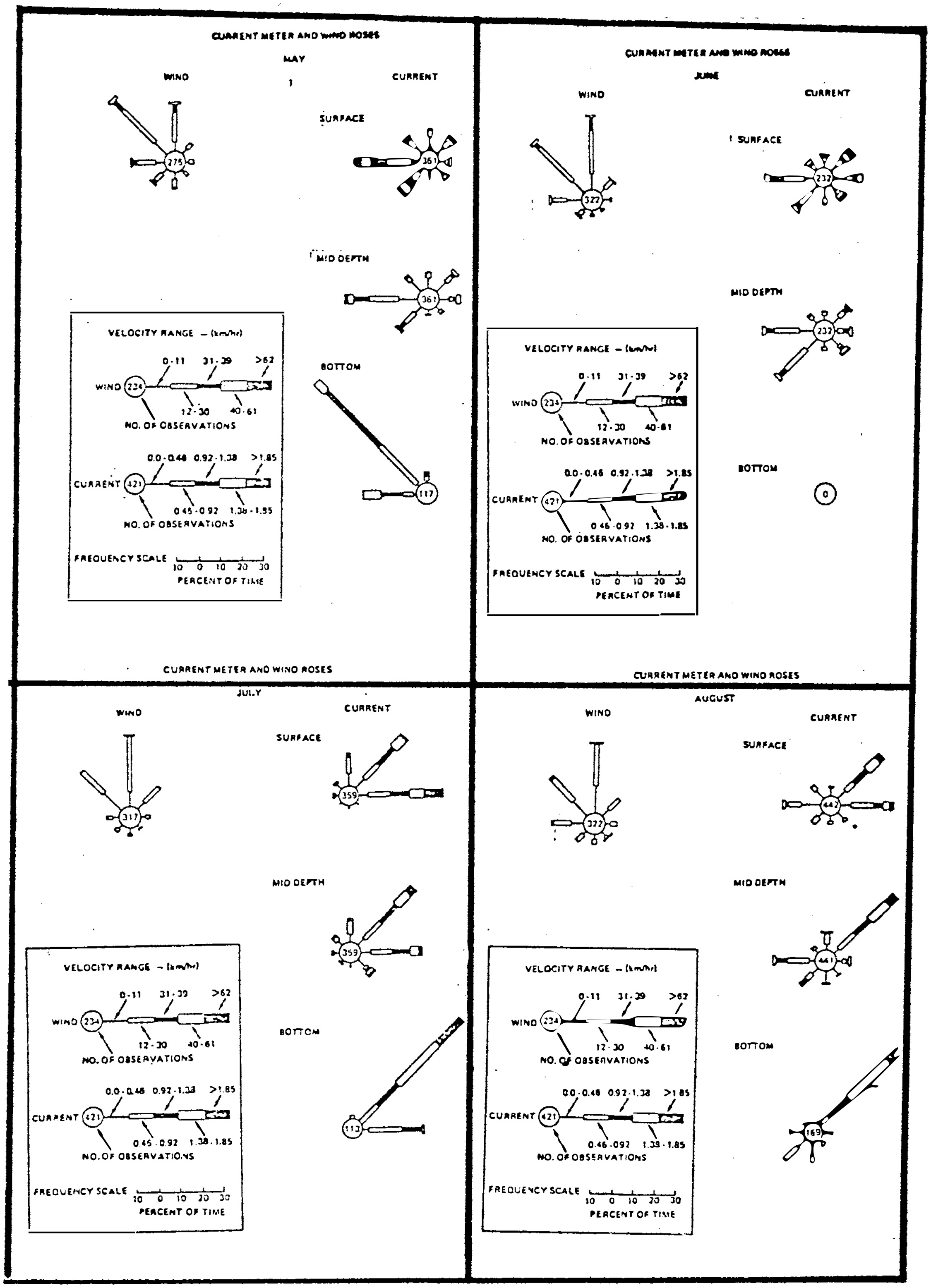


Figure 22. Seadock Current Roses and Wind Roses Taken Near Buccaneer Platform for May, June, July, and August.

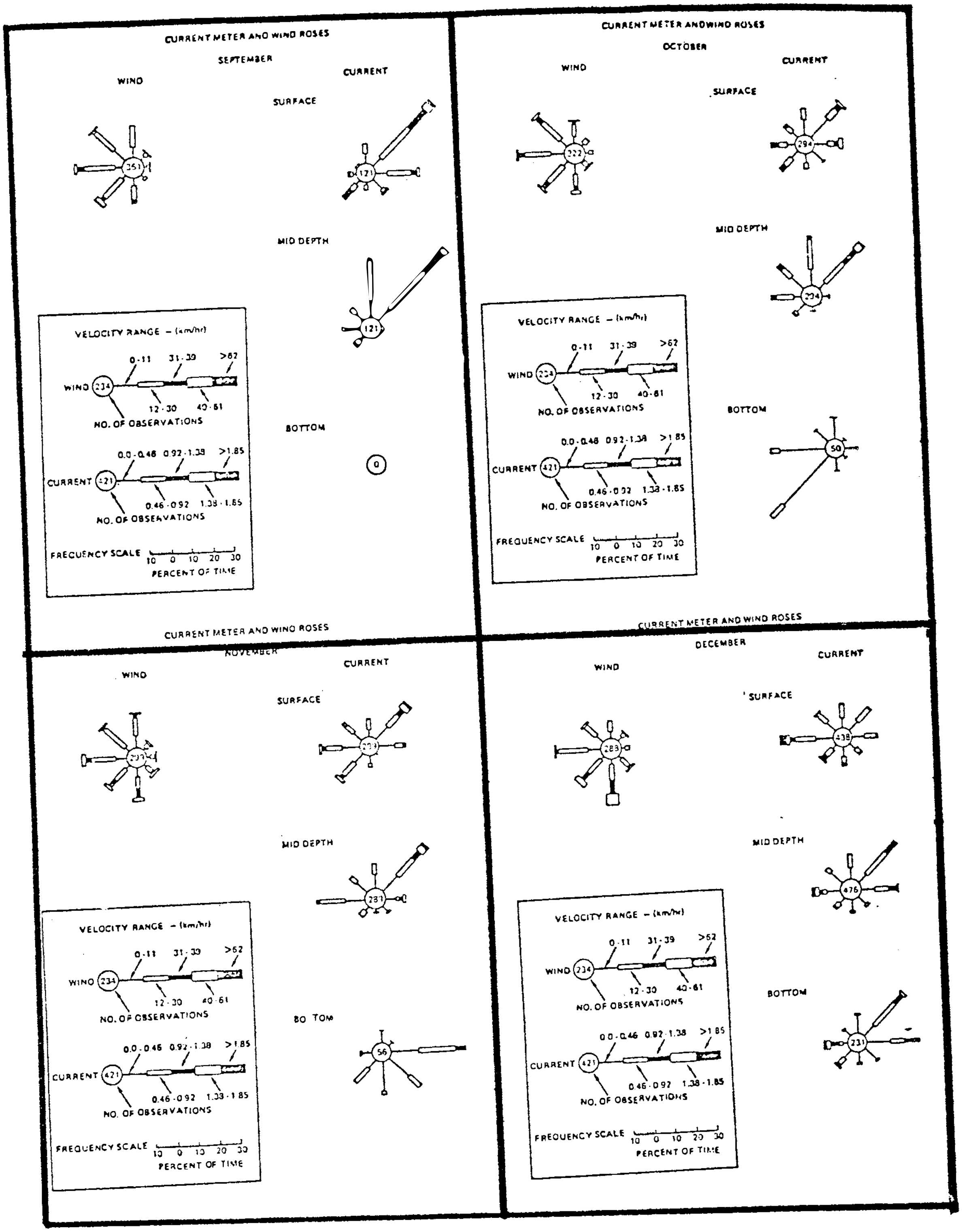


Figure 23 Seadock Current Roses and Wind Roses Taken Near Buccaneer Platform for September, October, November, and December

Bottom currents had predominantly westward components from February through May and during October and a predominantly eastward component in July, August, November, and December. No observations were recorded in June or September. The strongest current occurred in July and August with currents over 51 cm/sec (1 kn) approximately 15 percent of the time towards the northeast.

(d) Tidal Currents

The range of tides in the Gulf is on the order of one meter, with the diurnal tides dominant over the semidiurnal tides in most regions. Zetler and Hansen (1972) estimate mean tidal currents on the shelf to be about 0.5 kn. The NOAA Tidal Current Tables state that the tidal currents near Sabine Bank are rotary in nature and seldom exceed 0.3 knots (NOAA, 1977). Although tides in the Gulf have a small range, they do have important roles in modifying currents and accelerating the movement of water through narrow passages.

(e) Serial Data from GUS III Surveys (1963-1965)

Detailed serial surveys of the Continental shelf region of the northwestern Gulf of Mexico, conducted by the NMFS during the period 1963-1965 has afforded a special opportunity to describe the physical oceanographic conditions and variability in the study area. These surveys were conducted adjacent to the study area by the Galveston Laboratory of the Bureau of Commercial Fisheries (now the National Marine Fisheries Service) using the RV GUS III. During the three years, standard stations were occupied monthly over the Continental Shelf off Texas (See Figure 24).

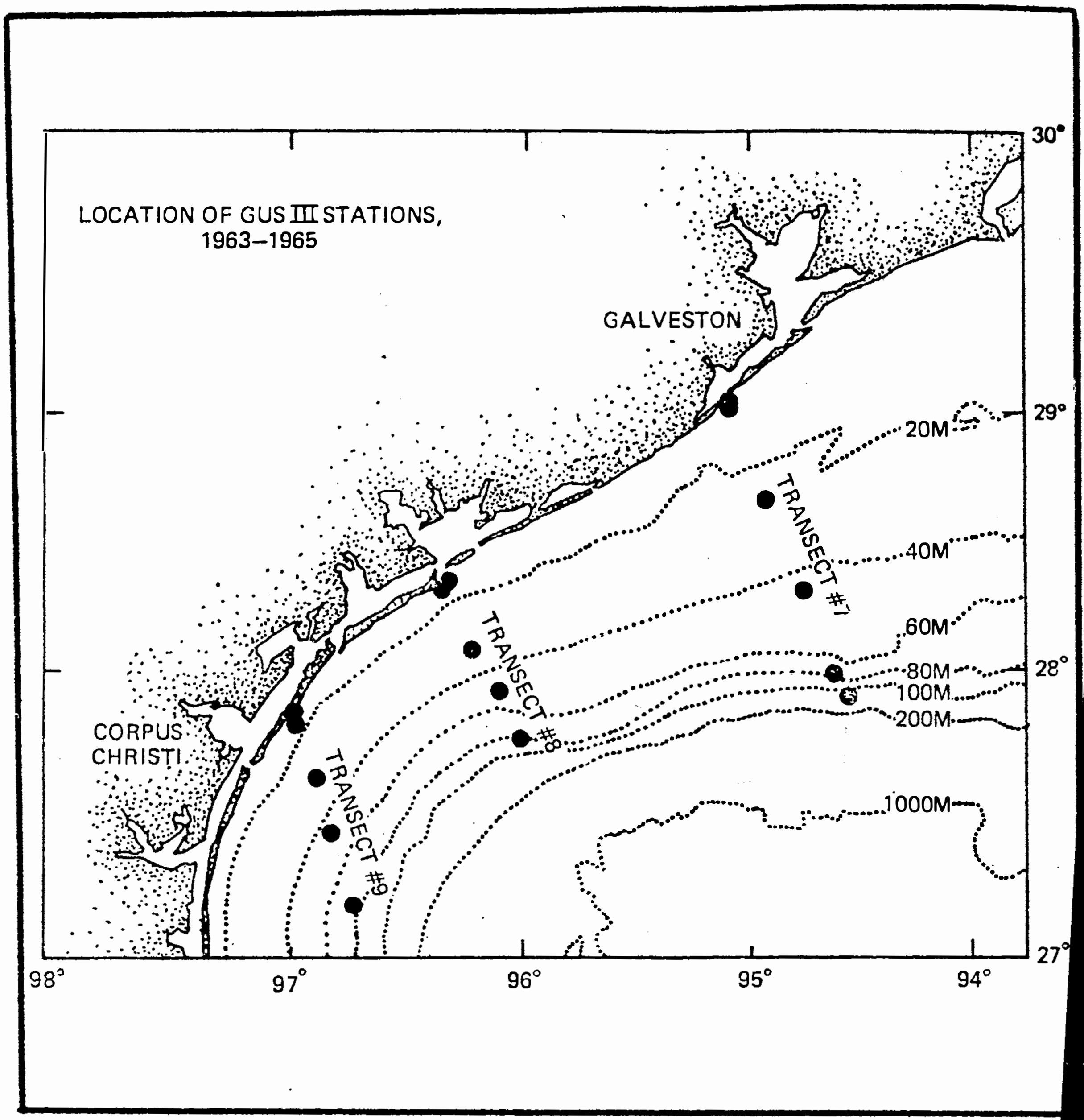


Figure 24 Location of GUS III stations for Water Circulation and Surface Salinity

The circulation pattern representative of the entire water column, along with the surface salinity distribution is shown (see Figures 25 and 26). In winter, isohalines parallel bathymetry, with low salinity water (33 ppt) near the coast and high salinity water (36.5) covering the outer shelf. During spring, salinity decreases as fresh water discharge from the rivers increases and spreads offshore Also, the higher salinity water offshore shifts eastward. Through summer, water of greater than 36 ppt covers most of the shelf, with remants of the low salinity water appearing to have been transported back to the east. In fall, despite the fact that river discharge is at near minimum amounts, the amount of low salinity water again increases, and spreads to the west and south over the inner shelf.

The data indicate that over the outer shelf, flow is to the north and east from mid-March through September, and to the west and south from October through February. In the nearshore waters, from Galveston westward, flow was typically to the southwest from October through mid-June, and north-eastward only in July and August. A zone of convergence developed in the waters of the inner and middle shelf and was most pronounced in spring. The nature of this zone is such that the nearshore location of the convergence zone tends to shift up the coast during spring through early summer. This convergence apparently develops because of contrasting flows of nearshore and offshore water. These data represent the best observations near the study area, and are likely to apply within the region of interest as well.

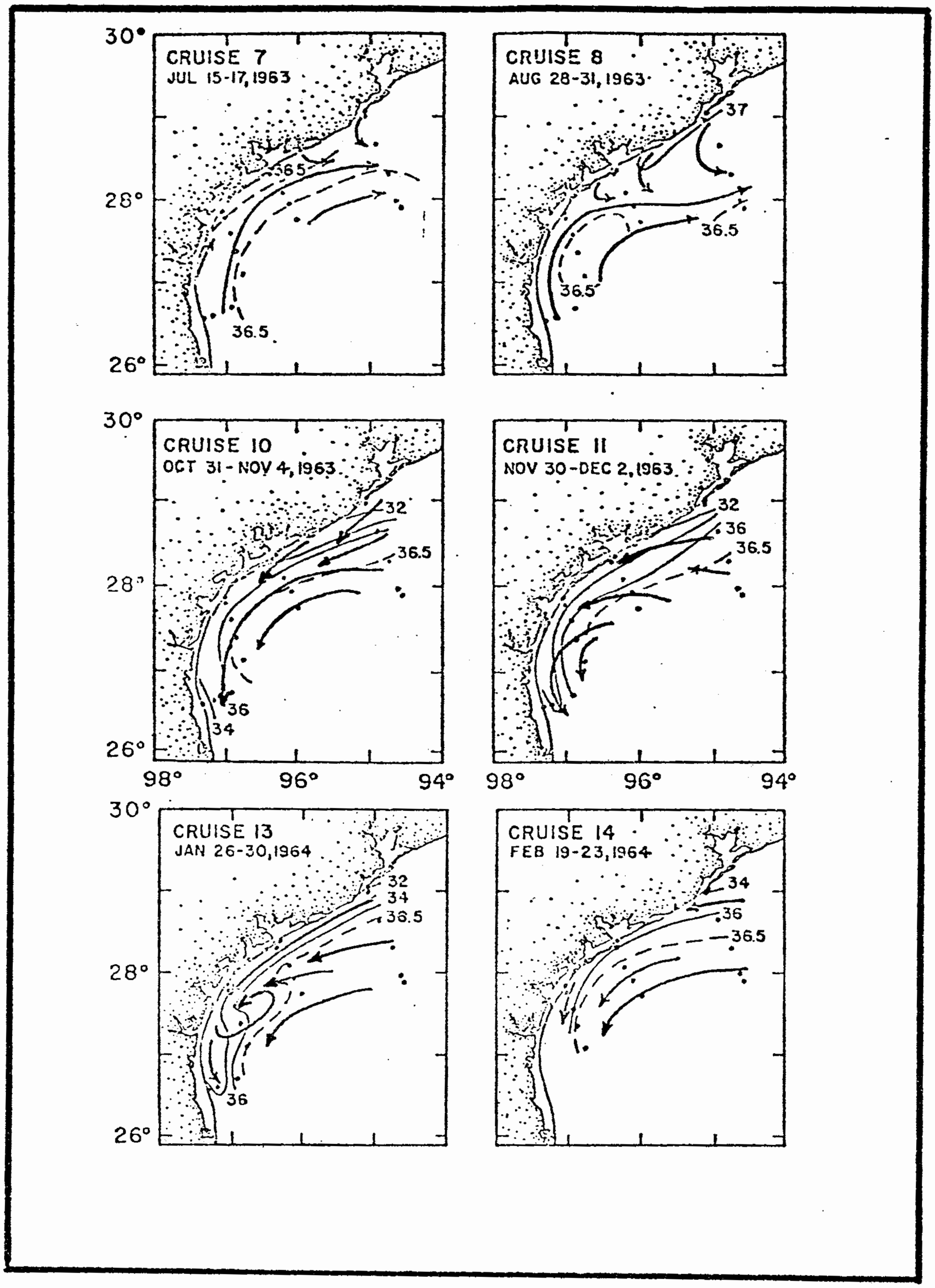


Figure 25 Shelf water circulation and surface salinity $(^{o}/_{oo})$ GUS III cruises (1963-1965).

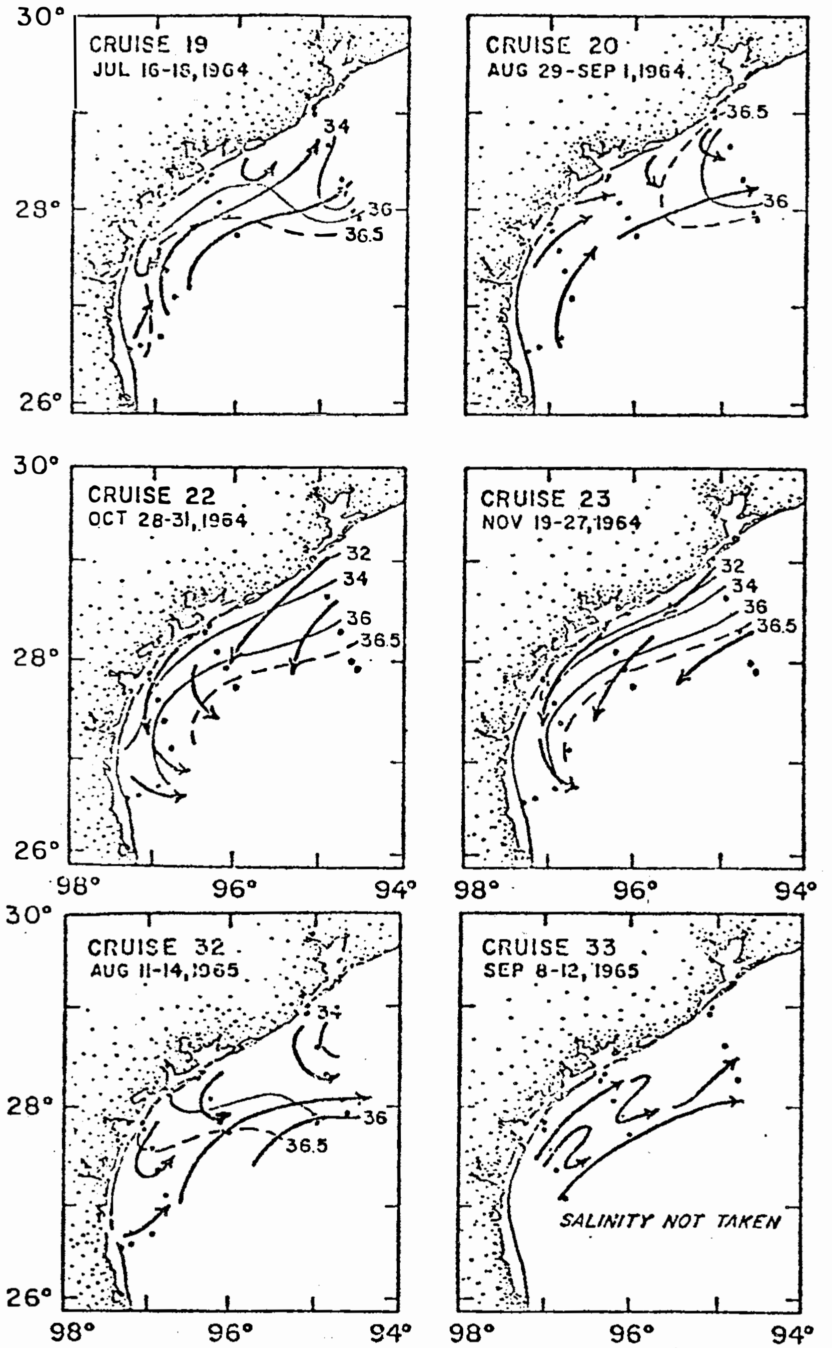


Figure 26 Shelf water circulation and surface salinity ($^o/_{oo}$) GUS III cruises (1963-1965).

5. Waves

The distribution of wave heights follows that of the winds for the area. Waves greater than 11 feet have been observed for all months of the year. Heights of 20 feet or greater have been observed from September to April and in June. A wave height of 28 feet was observed during hurricane Audrey in June 1957.

As there are insufficient data for a climatological conclusion on waves, the information below shows statistical estimates for the areas given by the NCC:

Mean Recurrence Interval	5 yr	10 yr	25 yr	50 yr
Maximum Significant Wave Height (feet)	30	33	38	42

On the average, one occurrence every 10 years will have a significant wave height (average of the one-third highest waves) of 33 feet. These values refer only to the deeper waters within the study area. In shallow waters, wave heights are limited by breaking to about 0.78 of the water depth.

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APPENDIX P

Sedimentology and Geomorphology of the Gulf Coast

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Sedimentology and Geomorphology of the Gulf Coast

The history of the Gulf Coast of the United States is the history of the development of the Gulf Coast geosyncline, which has a landward limit at the onlap of Mesozoic and basal Tertiary rocks approximately 200 miles north of the present shoreline. The southern limit is considered to be in the proximity of Sigsbee Scarp with an axis south of the present shoreline (Ewing and Antoine, 1966, Figure P-1).

The Gulf of Mexico has undergone five different Quaternary depositional episodes coupled with four intervening erosional episodes. These episodes are the result of sea-level fluctuations (as low as -450 ft.) accompanied by the growth and melting of the continental ice caps (Figure P-2). These different formations grade from coarse (gravel) to fine sediments (sand, silt, and clay) with decreasing age of deposition, both between and within formations. Doering (1956) states that there was continental (interior) uplifting and warping during the beginning of the Pleistocene, and the accelerated erosion that succeeded caused coarse material to be deposited on the coast (as the base of the Willana formation). Succeeding interglacial cycles began with a progressively more degraded erosional surface; therefore, the basal sediments for succeeding formations were not as coarse. The second process occurred during each glacial cycle and involved the normal depositional alterations taking place during establishment of grading into a river environment. As sediments are deposited, the shore progrades seaward. The stream's gradient decreases, and subsequently, its competency*decreases. Only the finer sediments reach the coast. This difference in stream gradient between the upland portions and the coastal portions is enhanced by the natural processes of coastal subsidence accompanied by an uplift in the interior of the geosyncline. The oldest deposits slope at approximately 15-20 ft/mile, whereas the youngest deposits slope less than 1 ft/mile.

Besides textural differences, other factors contribute to the marked non-conformities, not only between the various Pleistocene formations, but also at the Pliocene-Pleistocene and Pleistocene-Holocene boundaries. These boundaries are easily observed by the sharp color contrast between the bright upper surface of the older formation and the dull gray of the basal younger formation. As sea level decreased, the recently deposited surface became exposed to atmospheric conditions, and therefore oxidation processes occurred. When transgressions of the sea took place in response to increasing sea level, the succeeding deposits were not exposed to atmospheric conditions and remained in a reducing condition.

*Competency the ability of a stream to transport materials

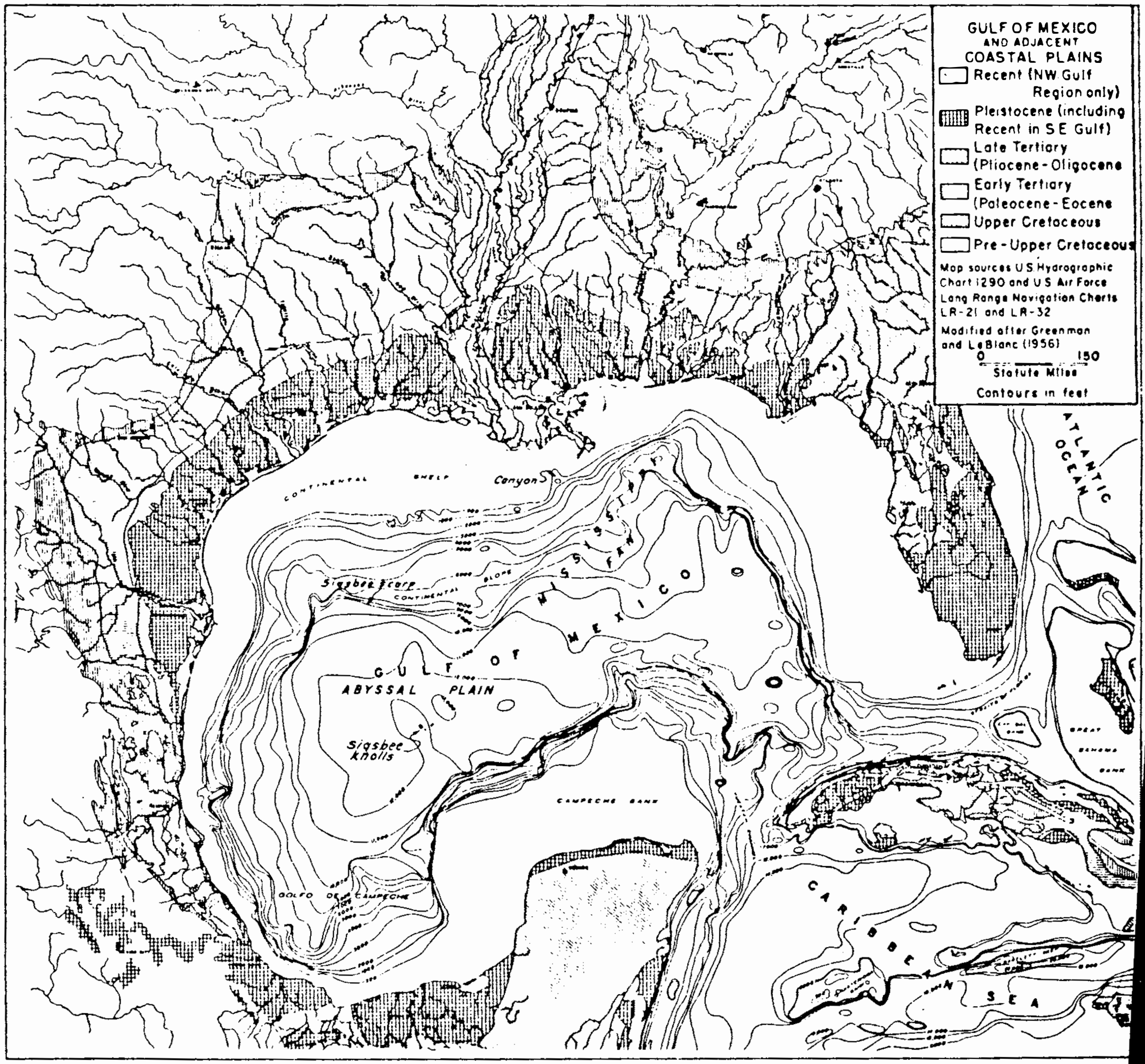


Fig.P-1 - Generalized geologic map of the Gulf coastal plains and the principal hydrographic features of the Gulf of Mexico. Modified after Greenman and LeBlanc (1956) and Ewing, Ericson and Heezen (1958).

Essentially, the glacial stages (fluxuation of sea levels) were periods of erosion and interglacial stages were periods of deposition. Deposition was predominately in the form of coalescing alluvial deltaic and coastal interdeltaic plains principally developed by the major river and coastal regimes during higher standing sea level (Figure P-3). Deposition occurred in an offlap manner (i.e., each formation was deposited further gulfward than the preceding one). In this respect, a part of the preceding formation was left exposed (Doering, 1956).

Evidence of a previous Pleistocene shoreline can be seen in Jefferson and Orange County, Texas by a series of strandplain or barrier island deposits (sand) presumably formed during the Sangamon (or later interglacial stage). This ancient shoreline was eventually overlain by late Pleistocene Trinity and Neches River deltaic sediments that prograded gulfward to the proximity of the present coastline during the Peorian Period (forming the Beaumont Prairie terraces). Remnants of these delta distributary systems (sand) are also evident on the Prairie surface. Wilhelm and Ewing (1972) state that the Peorian Beaumont Prairie Terrace forms a thin veneer of sediments extending to the edge of the continental shelf. They presume that for all the areas where the prairie terrace retreats from the shelf edge (with the exception of the Mississippi River Delta area), the present shelf was delineated during Peorian time. With regard to the coastal marsh system in Louisiana and the present coastline of Texas, the resulting depositional phase occurred during the last, high standing sea level stage and, thus, are known as Holocene deposits.

The continental shelf off the Texas-Louisiana border is approximately 120 nautical miles wide. It slopes gradually (3-3 ft./mile) out to the 300 foot contour after which it slopes approximately 30 ft./mile to the 600 foot contour (continental slope, Figure P-4. The portion of the continental slope in this region is considered to be very rugged with respect to topography and it is the greatest width in the northern gulf. The entire shelf and slope is predominantly a region of clastic deposition.

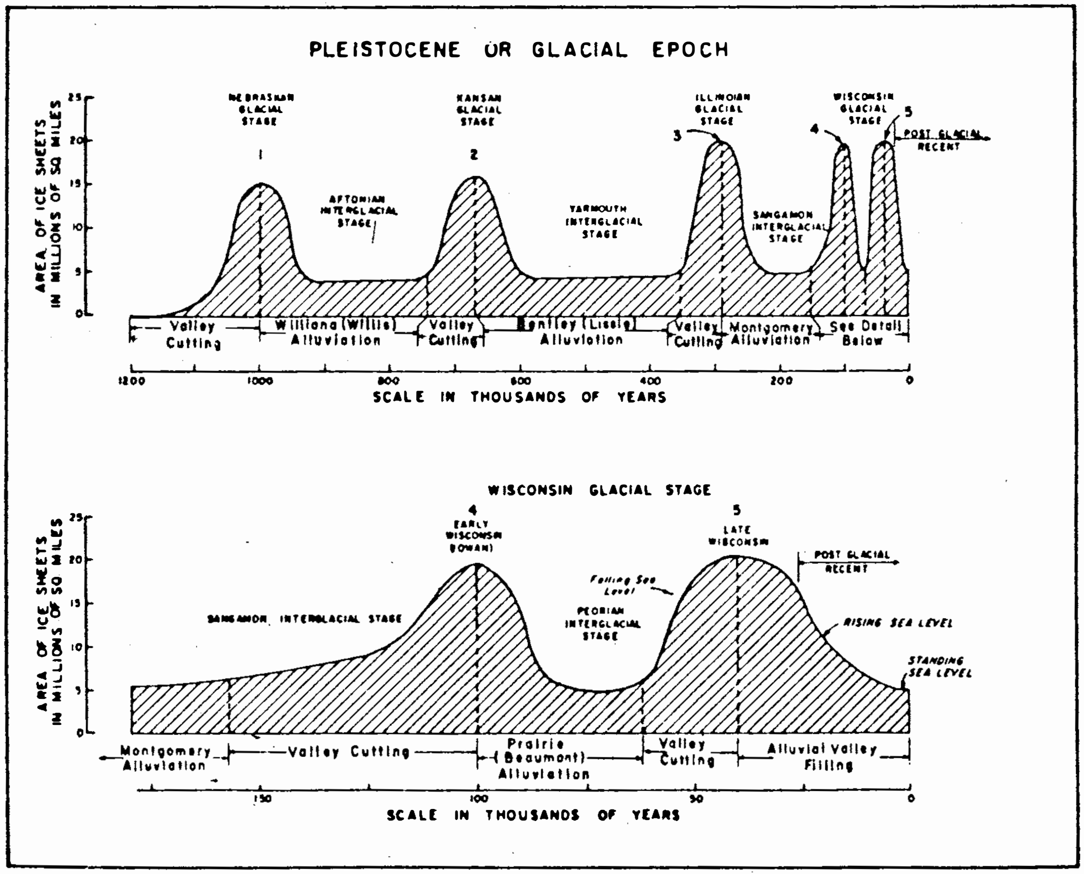
Lowman (1949) primarily developed the concept that the continental shelf and slope are mobile features which have advanced into the open sea during the Eocene to Pleistocene overall, regressive sedimentation. This sequence was aquitted to the numerous cycles of fluxuating sea levels and the continental subsidence of the deposits due to gravitational adjustment. However, the rate of subsidence was less than the rate of deposition and the sediments prograded into the open gulf. Moore and Curray (1963), from sonic profiles taken off Port Aransas, Galveston and Cameron (FIGURES 5 and 6) on the continental shelf and slope, found essentially horizontal, stratified deposits underlying the shelf. The smooth

Hays and Kennedy (1903)	Deussen (1914 and 1924)	Doering (1935)	Doering (1956)	Bernard (1950) (East Texas)	Fisk (1938, '40, '44) (Louisiana)	This Paper 1965
Beaumont*	Beaumont	Beaumont	Eunice*	Prairie	Prairie*	Prairie, or Beaumont
			Oberlin*			
Columbia	Lissie*	Lissie	Lissie	Montgomery	Montgomery*	Montgomery, or Upper Lissie
				Bentley	Bentley*	Bentley, or Lower Lissie
Lafayette	Reynosa	Willis*	Citronelle	Williana	Williana*	Williana, or Willis

(a)

*Denotes original definition

Figure P-2. Correlation of Pleistocene formations of Texas and Louisiana modified after Fisk (1944).



(b)

Figure P-3. Pleistocene events of Texas and Louisiana modified after Fisk (1944).

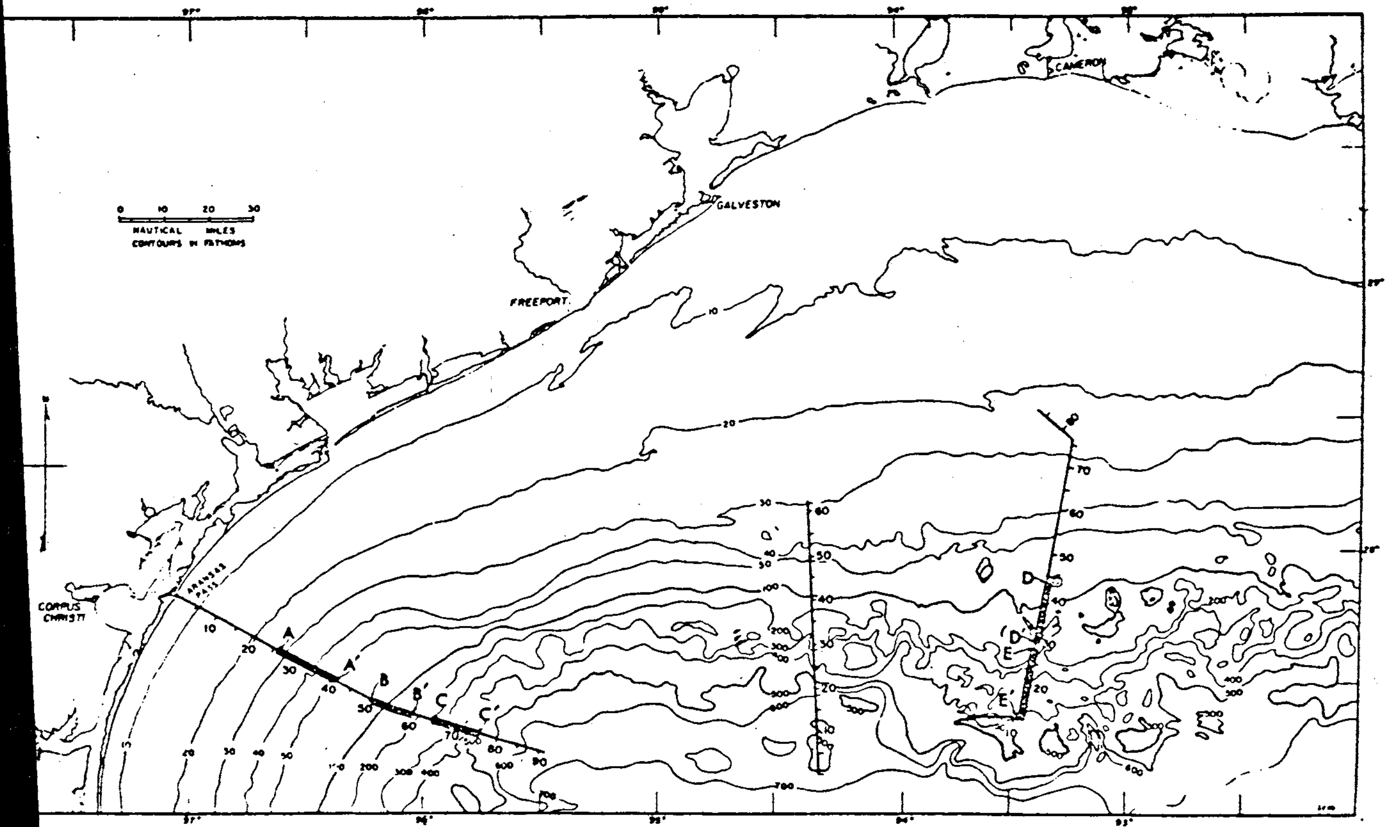


Figure P-4. Continental shelf and slope off the Texas-Louisiana coast showing contour slopes (Moore and Curray, 1963).

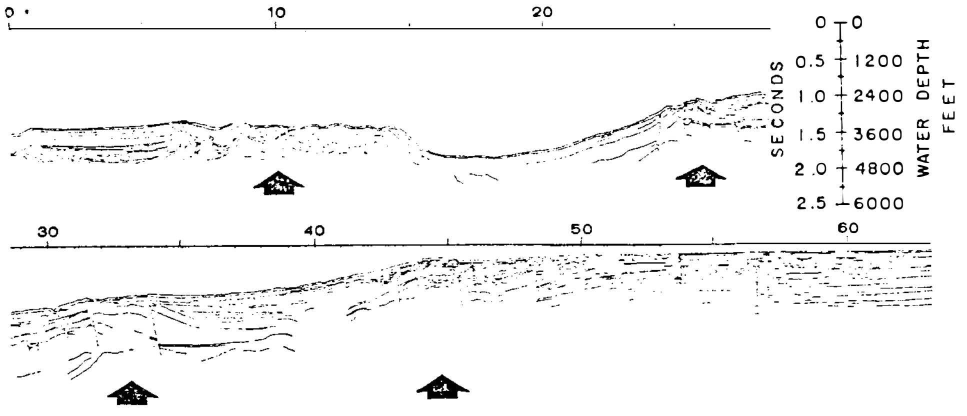


Figure P-5 Line drawing of Electro-Sonic Profiler record of the Galveston line. (Moore and Curray, 1963). Arrows indicate centers of upthrusting.

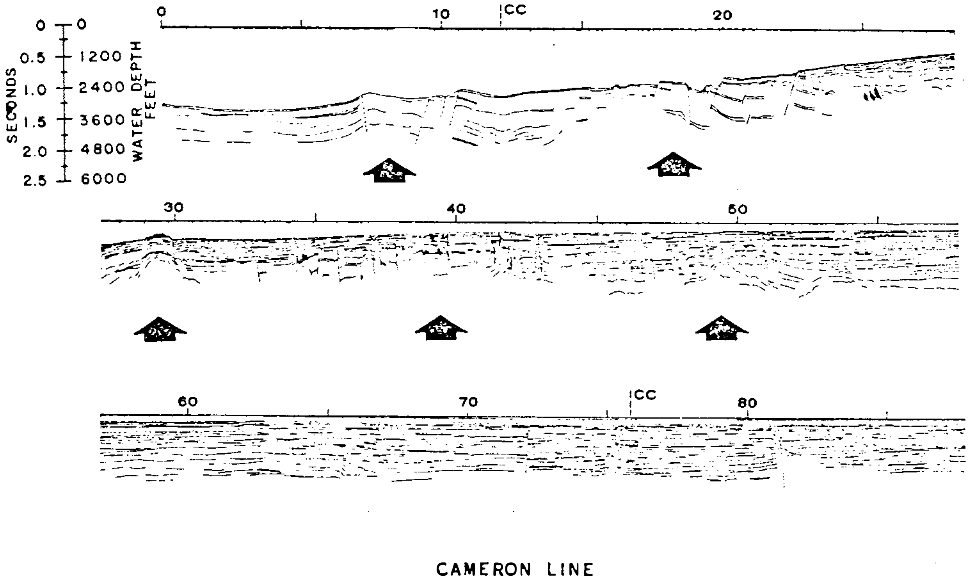


Figure P-6 Line drawing of Elecgto sonic Profiler record of the Cameron line. (Moore and Curray, 1963). Arrows indicate centers of upthrusting.

change extends over the shelf break into the seaward dipping continental slope deposits. The authors proposed that this stratification could be traced all the way to the Sigsbee Deep. Conclusions were that this sedimentation pattern could only be the result of a prograding upward and outward process (Figure P-7). The upward prograding sequence occurred during high-standing sea level stages, and the outward processes during the rising and low-standing sea level stages. During pre-Pleistocene times, the balance between deposition and subsidence reflected changes in the coastline and fostered deposition on both the continental shelf and slope.

During periods of lower-standing sea level, coastal river regimes cut channels across the exposed continental shelf and deposited their load at the then-existing coastline. During periods of maximum regression of the shoreline, the rivers debouched directly onto the continental slope. The topography of the present shelf reveals remnants of past drainage networks (e.g., the Mississippi and Alaminas Canyons). Bouma (1971) proposed that this later feature is the integration of the drainage networks from the north supplied by Texas and southwest Louisiana Rivers (e.g., Calcasieu, Sabine, Neches, Trinity, Brazos and Colorado Rivers). Bernard and LeBlanc (1965) state that sequences similar to the Pleistocene coastal plain deposits can be traced in the subsurface offshore, almost to the edge of the continental shelf. At this location, the sediments grade into progressively thicker deltaic and interfingering, thickening wedges of marine sediments which possibly represent both glacial and interglacial stages.

Ballard and Uchupi (1970) describe the last shoreline transgression sequence which occurred during the Wisconsin glacier recession. Previously, sea level during this period was at its minimum (-450 ft.) and substantial amounts of sediments were being deposited on the continental slope. It is presumed that during this time of maximum regression that the extensive Mississippi cone/fan was formed with the last major clastic sediment being deposited on the Mississippi cone during early Holocene time (Wilhelm and Ewing, 1972). The Holocene transgression was shown not to have been a continuous process of increasing sea levels, but as a direct sequence of increasing and standing sea levels. With this in mind, the authors recognize three distinct zones that are parallel to the coast. The first two zones (approximately 60 and 160 m in depth) are relict shorelines on the middle and outer shelves, respectively. The third zone, located on the inner shelf, represents both a recent and modern province. Evidence for these relict shorelines are recognized by the presence of ancient reefs (approximately 20 m deeper than present shorelines), the presence of spit-bar remnants also at the shorelines, ancient channels which dissect the continental shelf and terminate at the contours, and by distinct bulges which are indicative of previous deltaic deposits. The increase in sea level from approximately 60 m to present levels was also erratic and is well documented in Figure P-8

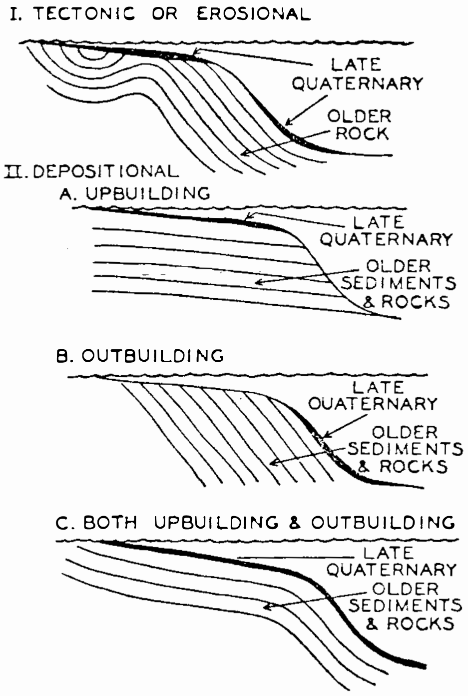


Fig. P-7 Basic descriptive classification of continental terrace structural types. (Moore and Curray, 1963).

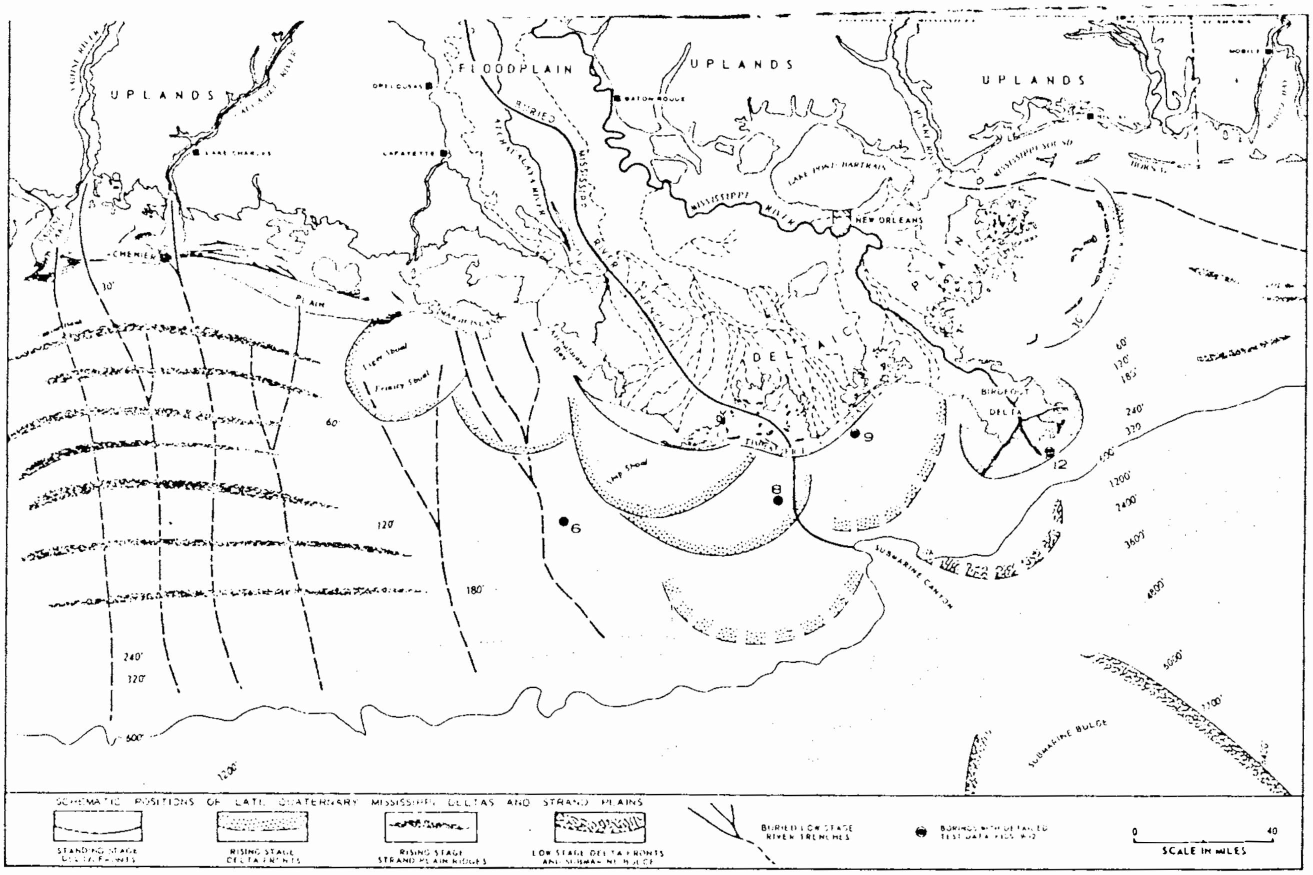


Fig. P-8 Positions of Late Quaternary Buried Trenches, Strand Plains, and Deltas off Louisiana Coast.

(Fisk and McLellan, 1959).

(Fisk and McLellan, 1959). This is observed by the numerous presence of delta bulges and rising sea level strand plain ridges from 60 m to near the present shoreline conditions.

Parker and Curray (1956) had previously observed three zones of coal growth at 18, 55 and 82 meters, attributing to the standing sea levels approximately 20 m further landward. Poag and Sweet (1971) also agree that three levels of shoreline features exist in the Gulf at 160, 60 and approximately 40 meters (depth contours). The conclusion is that the prominences are known as clay pile. Stetson and Flower Garden Banks, originating as evaporite intrusions, were occupied by reefal assemblages during the 40 meter stillstand during mid-Holocene times (approximately 8000 BP). Following, rising sea levels caused drowning and mortality of the reefal environment. Speculations are that continual upward movement of salt may have accelerated the reefs to grow upward, and this upward growth may have ceased with the decreasing sedimentation rates which occurred during late Holocene. Curray (1960) concluded that the present sedimentation rates are lower than during early Holocene.

Much has been learned within the past few years concerning the Gulf of Mexico topography. It has been known for some time that the continental slope of the northern shelf was hummocky and Carsey (1950) postulated that this irregular upper slope topography was indicative of diapiric structures. This has since been confirmed by sonic profiles (Moore and Curray, 1963; Ewing and Antoine, 1966; Uchupi and Emery, 1968), and from core drilling (Lehner, 1969). Seismic evidence also suggests that the swells in the lower slope are due to intrusive structures. Wilhelm and Ewing (1972) state that since no evaporite structures have been observed on the Sigsbee wedge, that there is a question as to whether or not the evaporites on the escarpment are autochthonous.

The abrupt termination of the slope at the Sigsbee scarp is suggestive of a massive forward movement of evaporites from the slope toward the abyssal gulf. The bulging of the scarp (between 94° and 93° W) appears to be related to the degree of deposition and, thus, suggests further evidence. Therefore, it appears that the evaporite ridge which forms the excarpment has had a major effect on sddimentation in this area of the shelf.

The knolls in the Sigsbee deep of the abyssal gulf were also speculated to be indicative of evaporite diapirs (Ewing and Antoine, 1966). This was confirmed in 1968, when the Challenger Knoll was successfully drilled (Wilhelm and Ewing, 1972). Ewing and Antoine (1966) suggest that evaporites do not form a continuous blanket over the gulf floor (Figure P-9) and is distinctl absent from the abyssal plain. They state that deposition from the geosyncline to the north did not initiate these knolls to rise, but rather they were originated from a lateral northward flow from under the Campechne Bank. The later (formed by carbonates),

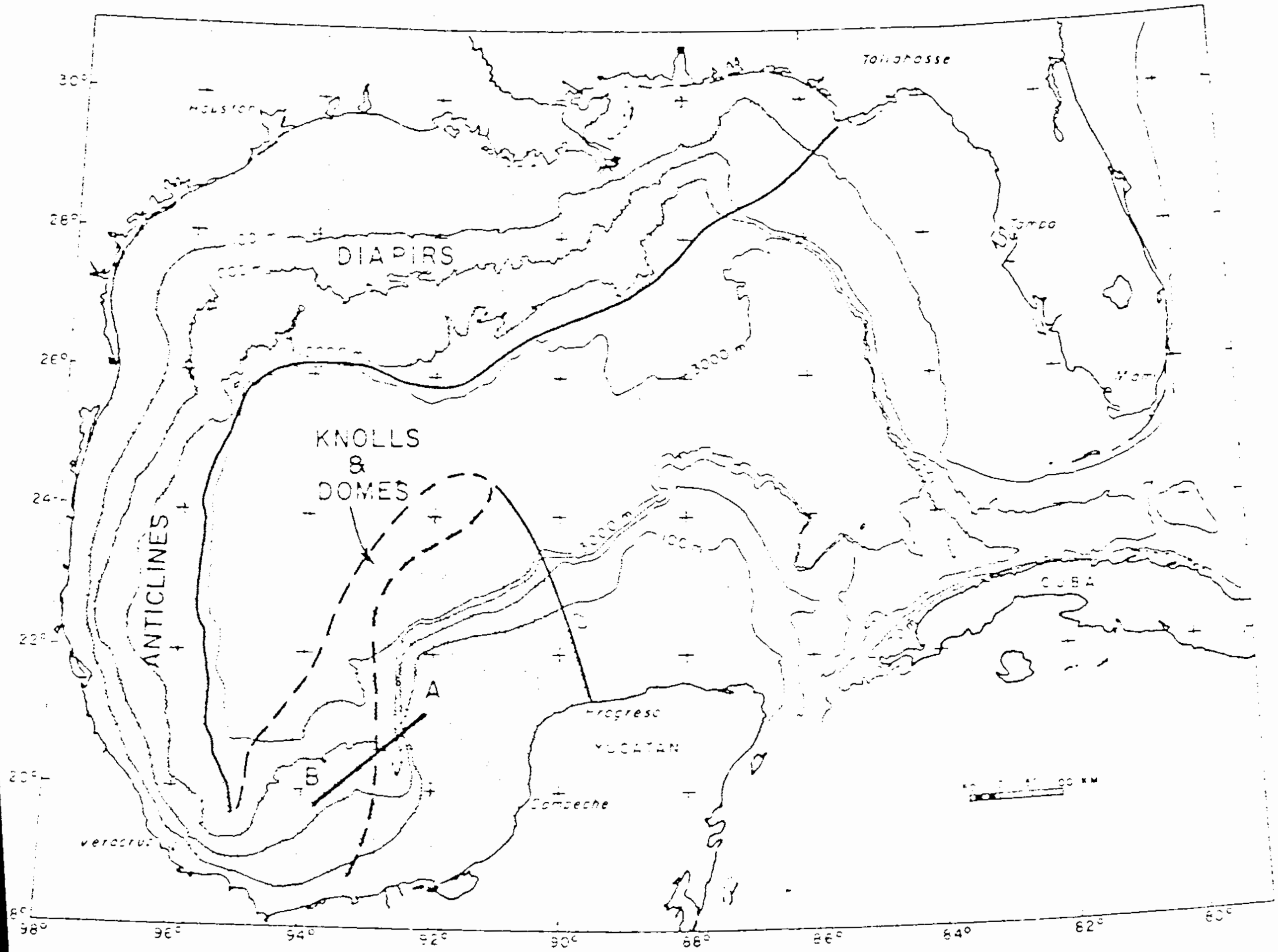


Figure P-9. Chart of Gulf of Mexico. Shaded area represents offshore distribution of buried salt (Antione and Bryant, 1969). Dashed area represents boundary of knolls and domes on abyssal plain and in Bay of Campeche as surveyed by Worzel et al. (1968).

(after Ewing and Antione, 1966).

prevented the evaporites from rising within its confines. Thus, the evaporites moved offshore until it contacted less resistence and rose in the abyssal deep.

The abyssal gulf (approximately 1600-2000 fm at maximum depth) is composed of a western part, the Sigsbee plain and continental rise, and an eastern part, the Mississippi Cone (Ewing, *et al*, 1955) which was formed from deposits from the Mississippi River during Pleistocene and early Holocene rising sea level stages. After sea levels rose to near present levels, sediments were deposited on the shelf. Uchupi and Emery (1968) demonstrated, using seismic profiles, the presence of diapiric structures in the cone, with a maximum surface expression of approximately 300 m. The continental rise (Sigsbee wedge) is presumed to have been originated from gravitational flow on the unstable continental slope. A thin, post-Wisconsin layer has been deposited on the abyssal plain overlapping the Sigsbee wedge and Mississippi Cone. The abyssal plain sediments below the cone and wedge are approximately 11,000 feet thick and are level bedded (being derived from rivers to the north). The continental rise which reaches 1,600 fathoms stops abruptly at the base of the Sigsbee scarp.

Little new sediment has been reaching either the chenier or strandplain shoreline (southwest Louisiana-southeast Texas gulf coast) since the Mississippi River has been discharging through its Plaquemine delta lobe. Sedimentation from smaller rivers (e.g., Trinity, Neches, Sabine, and Calcasieu) did not remain stationary with increasing sea level. The result has been drowned river valleys located far inland of the hinge line, with the boundary between alluvial and deltaic environments for these streams lying at the bay heads--not at the coastline. Therefore, little sediment is deposited off the coast by these rivers (Bernard and LeBlanc, 1965).

At present, the modern strandplain systems (southeast Texas) continues to be erosional in character and is continuing its landward retreat. The chenier coastline (southwest Louisiana) is also exhibiting incipient erosion which may continue to increase with the diminishing longshore sediment supply. Moore and Curray (1963) state that large areas of the outer continental shelf have been receiving little or not sedimentation since the present seal level was established. Curray (1960) states that the locus of deposition is within 20 miles of the coast, and that deposition has been progressively more rapid on the shelf in the western part of the Gulf than in the east. Scruton (1956) observed that as must as 75 percent of the Mississippi River sediments load is deposited to the west with the majority of transport occurring during the winter-spring high discharge months corresponding to the period when easterly winds predominate.

The recent standing sea level stage is generally accepted as having begun approximately 5000 years BP (Greenman and LeBlanc, 195

During this time, the Mississippi Delta is thought to have been located near Marsh Island and the Gulf shoreline to the west of the delta bay along the inner edge of the chenier plain. Since 5000 years BP, there have been only minor changes in sea level (approximately 15 feet) resulting from compaction of the sediment and slow subsidence of the basin. The coastal zone has evolved to its present condition by erosion, deposition, compaction and subsidence; processes which are cohtinuously active at the present. Active, but gradual faulting continues as Pleistocene and older gulf basin delta muds continue to compact. The following scenario of the last 5000 years of coastal processes can be given:

.4000-5000 BP - Maringouin or Sale Cypremont was depositing sediments in the region of Iberia and St. Mary Parishes.

.4000-3800 BP - Rivers shifted to Cocodrie-Mississippi Delta resulting in a decrease in longshore sediment supplied to the western marginal areas.

.3800 BP - Deltaic sedimentation shifted to the Tech-Mississippi system and clastic detritus again flooded the western coast and the beaches were stranded by prograding mud floods.

.2800 BP - Shift to St. Bernard Delta--coastal progradation ceased along southwest Louisiana and southeast Texas.

.1200 BP - Sedimentation again shifted westward with great influx of sediment. Average progradation rates were in excess of 50 ft./year.

.500 BP - Shift to present course.

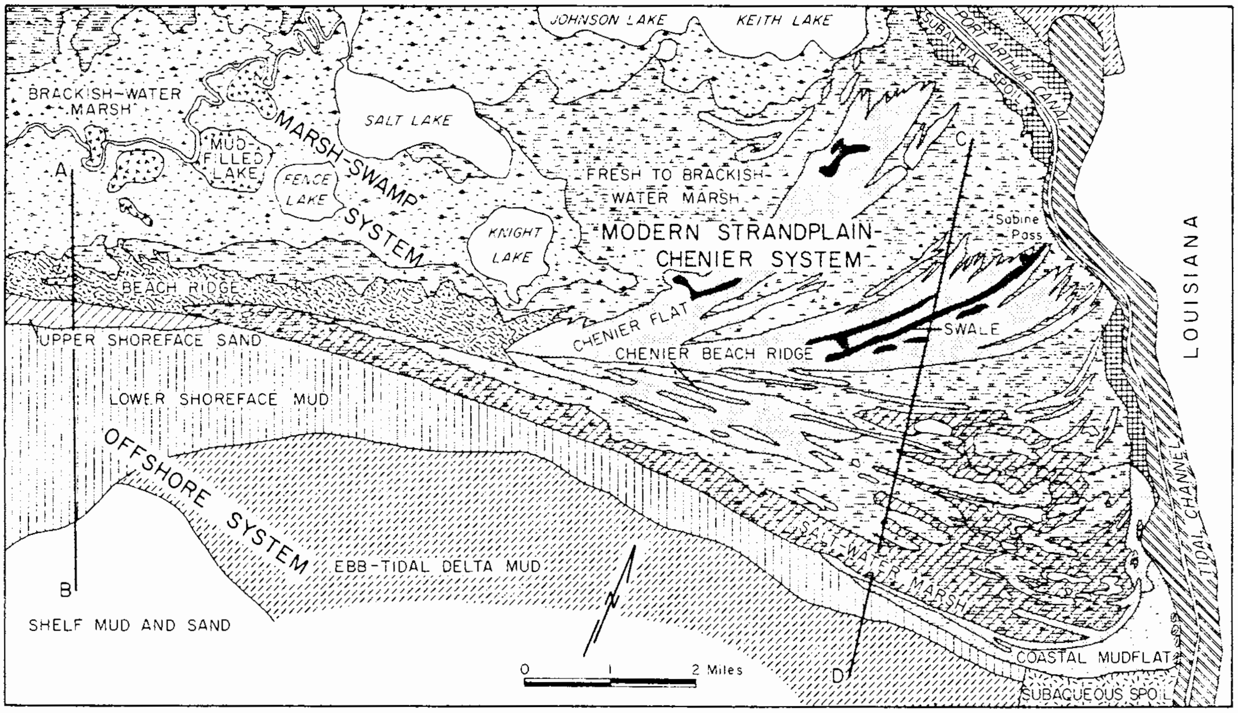
The net result of this sedimentation sequence has been the formation of a series of interfingering lenses of deltaic and marginal marine clays and sands. During periods of westward deposition, the coastline of southeast Texas and southwest Louisiana was mostly mud and prograded seaward very rapidly. When the Mississippi River shifted to an eastern delta lobe, shelly beaches (cheniers) were developed by swash and backwash action. This continual-but-irregular shifting of the Mississippi River from eastern to western delta lakes and visa versa has been correlated by C^{14} dating with alternating slow beach deposition and rapid coastline progradation, respectively. During the last 3000 years, the broad Sabine embayment was progressively separated from the open gulf by several periods of extensive shoreline accretion. This separation resulted in the deposition of chenier plains as much as 10 miles wide. A minute stretch of Gulf shoreline (five miles) west of Sabine Pass is the only portion of the Texas coast accreting; however, it is showing signs of incipient erosion. The shoreline is a broad mudflat being formed in part by the reworking of dredged spoil which was deposited relatively offshore and west of the Sabine Pass jetties. Bernard, et al (1970) have described the growth of Galveston Island. They attribute the growth to the last 5000-6000 year standing sea level stage with growth seaward by beach accretion and southwestward by spit accretion in the direction of longshore drift.

Sediment transport downdrift in the Gulf on westerly currents is causing progradation at several points along the Louisiana coast with substantial development of mudflats in the form reminiscent of cuspate forelands discernible on either side of the Calcasieu River mouth and Sabine Pass. These subaerial deposits are not river deltas, but are largely composed of sediment impounded from longshore currents by hydrodynamic obstacles (including tidal fluxuations). This may be complicated by the presence of stationary jetty obstacles. Hydrodynamic obstacles are responsible for the deposition of sediment on the updrift side and also in a large gyral eddy offshore on the down current side. Fisher, et al (1973) states that tidal currents in Sabine Pass are strong enough to scour the tidal channel and carry a sediment load into the estuary during flood conditions and out of the estuary during ebb conditions. The currents, together with the reworked dredge spoil, are the primary sources of sediment of the Ebb Tidal Delta in the Gulf west of Sabine Pass.

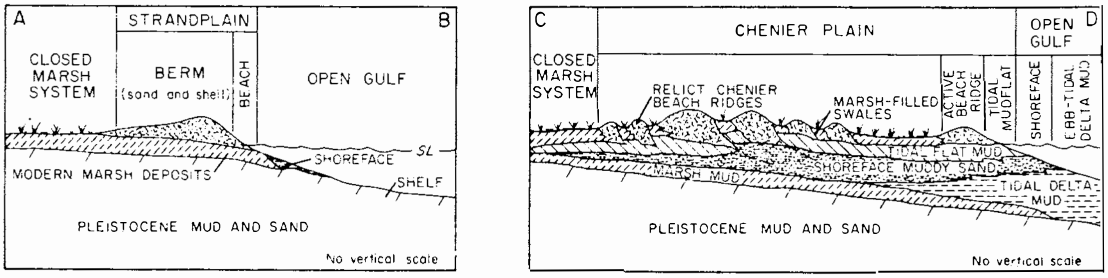
From the present Mississippi position, southwest Louisiana has been essentially isolated from a direct supply of muddy sediments. The sediment has been eroded from the shoreline and inner shelf of Louisiana and extreme southeast Texas, and then transported in the southwest direction. Since the construction of the Sabine Pass jetties, the majority of the sediment load is being trapped behind the north jetty and net seaward accretion is occurring. The jetties have significantly affected the stability of the Gulf shoreline in the area of southeast Texas and the shoreline for twelve miles past Sabine Pass which is beginning to erode.

The open Gulf coastline in southeast Texas exhibits two modes: (1) a strandplain system; and, (2) a chenier and mudflat system. The strandplain system (which is west of Knight Lake) consists of a narrow, partially wave-cut beach and a landward series of beach ridges (Figure P-10). The chenier system (east of Knight Lake consists of chenier ridge and intervening lows and swales with salt and brackish marsh vegetation. Mudflats are extensive on the shoreline along the plain.

The inner continental shelf is predominantly floored by relict Pleistocene sands and muds with extensive biological activity. The shoreface waters extend to approximately 30 feet. In the western part of the Texoma study area (in southeast Texas), the sedimently are fairly thin and are sand dominant. However, to the east, the sediments are chiefly discontinuous, thin mud. Relict Pleistocene deposits are exposed and eroded at various locations. Typical shoreface (upper, middle and lower) designatio are not valid in areas where active deposition is not occurring.



MAP VIEW



CROSS SECTION CROSS SECTION

Figure P-10 Modern strandplain-chenier and offshore systems along Gulf of Mexico, Beaumont-Port Arthur area. Chenier beach edges were deposited along muddy coastline near Sabine Pass; sandy strandplain deposits occur southwestward of cheniers where muds are less abundant. Generalized cross sections contrast strandplains and chenier plains.

(after Fisher, et al., 1973).

Variation in sediment type is significant in the coastal area. Hildebrand (1954) analyzed the bottom sediments off Sabine Pass and states them as follows:

(A) Beach to 8 fathoms - sand, mud and some shell with Sabine Bank being rocky.

(B) 8-18 fathoms - shells, _Murex_ _fulrescens_ and _Strombus alatus_ (prickly conchs).

(C) 18-20 fathoms - mud bottom.

(D) 20 fathoms and out - mud.

Greenman and LeBlanc (1956) observed a wide variation in sediment type coupled with inadequate core-to-core correlation in shelf cores taken from the northwest Gulf (Figure P-11). They conclude that the major zone of the sedimentary facies is normal to the shoreline and is primarily based on water depths. However, a second type of east-west zonation is postulated. The eastern, deep environment of the northeast Gulf is calcareous; whereas, the northwest is one of accumulating clastic deposits. Deposition in the northwest Gulf occurs in five major environments:

(1) To depth of 600 feet - shelf area with a coarse clastic facies.

(2) Rises on the outer edge of the shelf and upper slope--coarse clastic and calcareous biostromal facies. Other deposits between rises are similar to shelf facies.

(3) Upper slope - 600-3,000 feet with a homogeneous clay facies.

(4) Lower slope - 3,000-12,000 feet west Sigsbee Deep with mottled clay facies.

(5) East Sigsbee Deep - foraminiferal ooze; westernmost part of large eastern Gulf is calcareous area.

Greenman and LeBlanc (1956) found that the average thickness of the Holocene deposits of the slope and deep increased toward the shore and from west to east in the deep. Sedimentation rates were calculated at 360, 480, 540 and 1,000 year/inch for the upper slope, lower slope, west and east deep, respectively. Deposition rates 30-60 times greater in recent sediments as compared to Holocene sediments was postulated.

Uchupi and Emery (1968) provide a sediment chart compiled from all available data (Figure P-12). It portrays a terrigenous silt and clay mantle area off the Mississippi Delta, and the continental shelf west of the delta is blanketed by terrigenous sediment that grades from sand near the shore to silt and clay offshore. The

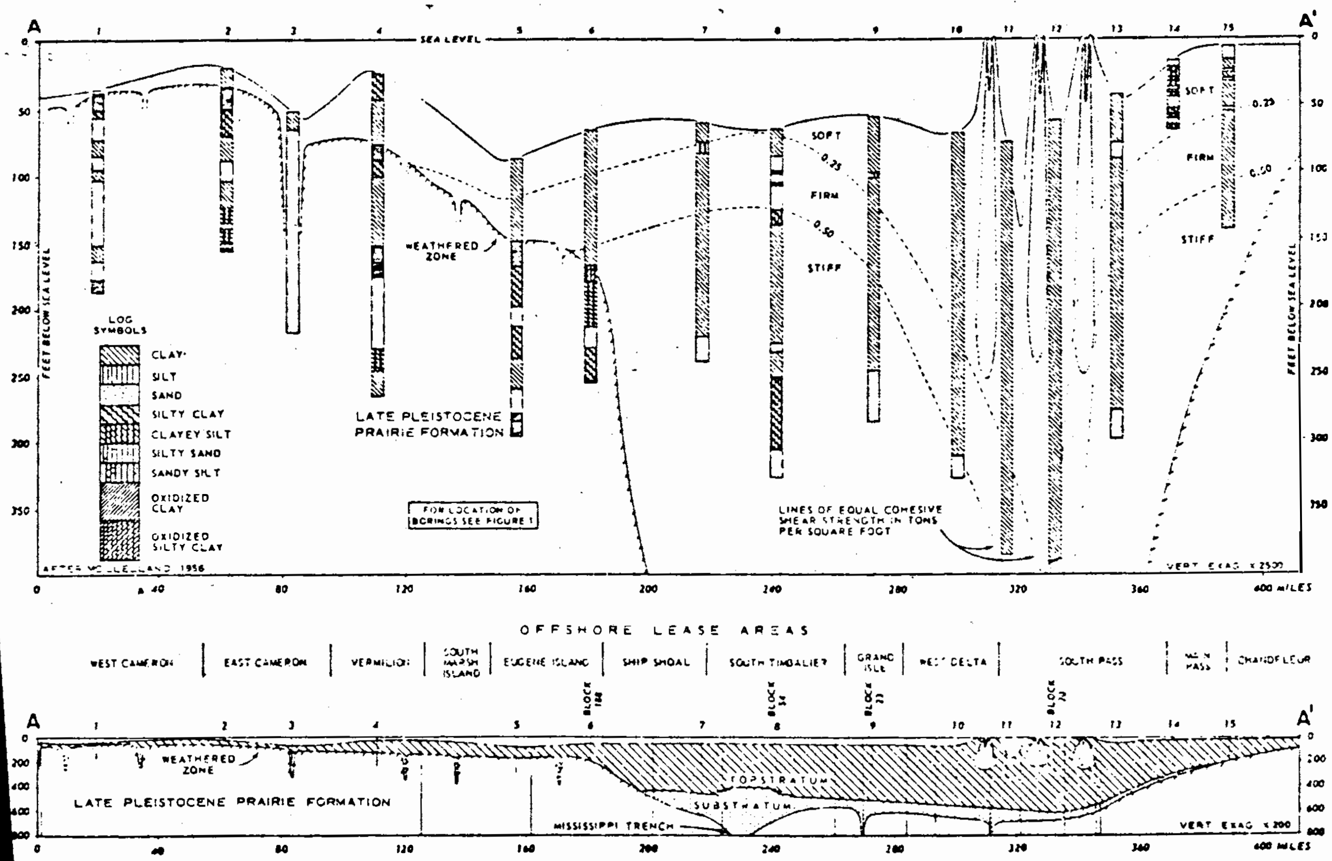


Figure P-11 Cross Section of Near-Surface Shelf Deposits Along Line Approximately Parallel to Louisiana Shore.

(Greenman and LeBlanc, 1956).

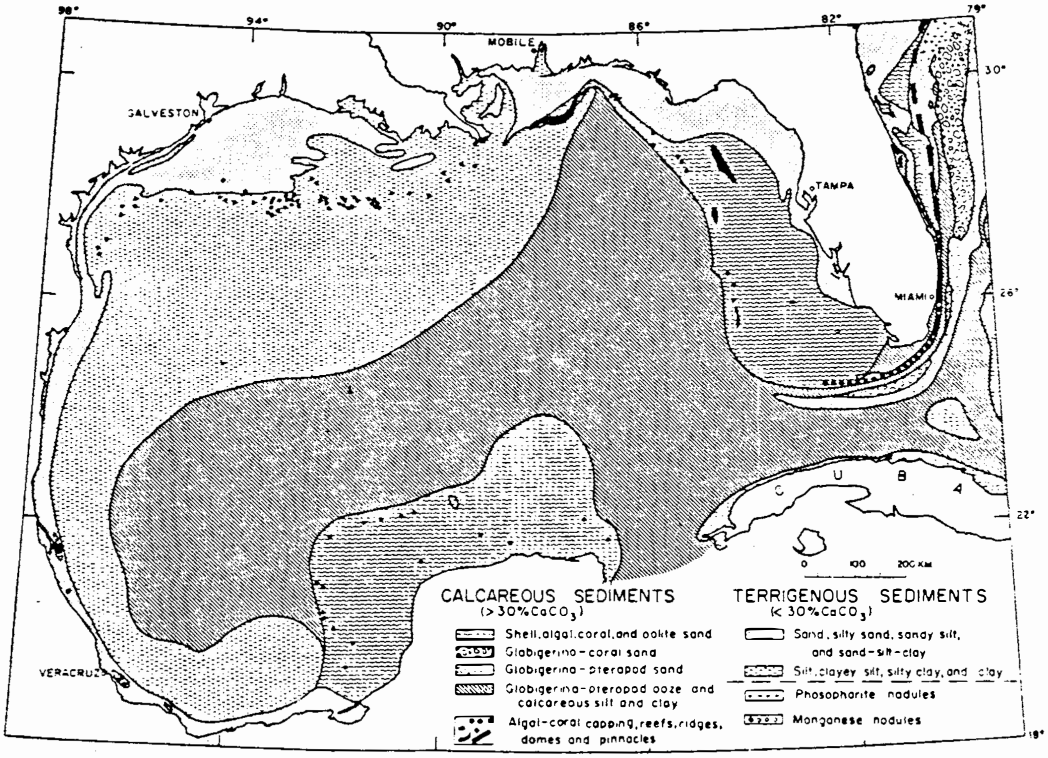


Figure P-12 Sediment map of Gulf of Mexico and vicinity based on data from Stetson (1953), Trask (1953), Gould and Steward (1955), Scruton (1955), Thompson (1955), Ginsburg (1956), Parker and Curray (1956), Ludwick and Walton (1957), M. Ewing et al. (1958), Creager (1958), Shepard (1960), Curray (1960), Harding (1964), Ludwick (1964), Pilkey et al. (1966), Pratt and McFarlin (1966), Lynts (1966), and unpublished material from Woods Hole Oceanographic Institution - U. S. Geological Survey Atlantic Continental Margin Program.

(after Uchupi and Emery, 1968).

later continues seaward beyond the shelf to form a broad belt on the continental slope and rise. It is portrayed that the entire shelf west of the Mississippi Canyon to Mexico is predominately non-carbonates. Bernard and LeBlanc (1965) state that mean grain size of the recent, terrigenous shoreline deposits (between the Mississippi River and the Rio Grande) is fine to very fine sand. This fine texture characteristic is due to the predominance of river borne, deltaic sediments being deposited over deposits derived by coastline erosion of unindurated sediments of older deposits of non-deltaic origin.

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APPENDIX Q

BIOLOGICAL OCEANOGRAPHY OF THE GULF OF MEXICO

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Pulley (1952) recognized the northern Gulf (Mississippi River to Matagorda Island) as a zone of faunal uniformity based on studies of the bivalve molluscs.

Hedgepeth (1954) considered the northern Gulf of Mexico one ecological complex, requiring both estuarine and neritic waters for its integrity, and extending from the inner bays to 15-20 fathoms offshore. The fauna consists primarily of penaeid shrimp and other decapods, sciaenid fishes, polychaete worms, and a secondary oyster biocoenosis and various minor communities, most characteristic of transitional (between temperate and tropic) waters. The number of endemic species is low (10% for most invertebrate groups), and this could be a reflection of varying environmental conditions of the previous millions of years, as recorded in the sedimentary record since the Tertiary (Lowman, 1951). These conditions would favor wide ranging species with broad ecological tolerances rather than a restricted local biota.

Studies of the biota of the Gulf of Mexico are scattered and little site specific information is available except for several areas located near research stations (especially off the Port Aransas area and Galveston). Even with this, the research effort has been heavily skewed in the direction of those species directly involved in the commercial and, to a lesser degree, the sport fisheries. These studies have centered mainly on the structural aspects of ecology, with representative data consisting of various indicators of abundance (e.g., catch per unit effort or seasonal and spatial distribution). The functional aspects of the Gulf ecosystem have been rarely touched. Primary productivity studies have been virtually non-existent, as have studies of nutrient cycling and energy flow. Much research is needed before realistic assessment of ecological impacts can be made.

Riley (1937) studied the distribution of chlorophyll in the Gulf along the Louisiana/Texas coast and found highest values near the mouth of the Mississippi River (See Figure Q-1, but the influence of longshore drift and increased productivity associated with the continental shelf are obvious, as values greater than 7.5 Harvey units/liter were found as far west as Galveston, decreasing in an offshore direction.

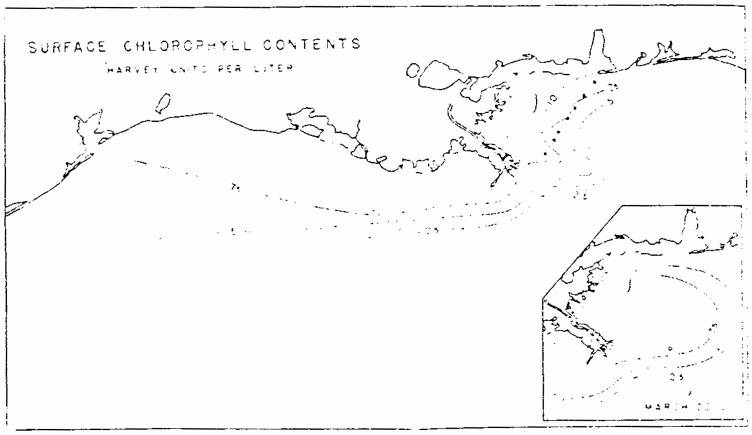

Figure Q-1 Chlorophyll Distribution on the Surface Layer

Diatoms are one of the most important primary producers in open waters in the Gulf of Mexico. Freese, (1952), noted two diatom blooms in his studies in the Rockport Bay area, one in late winter-early spring and the other in early summer. He states that they were so abundant on both occasions as to make the water soupy in appearance. The winter months seemed well suited to diatom growth in the area.

The area offshore of the study area includes a variety of habitats ranging from natural reef communities and sandy beaches to man-made platforms and jetties. The following is a discussion of the habitats encountered (from the first landward line of sand dunes to the open Gulf). It should be noted that the shrimp ground communities are by far the most extensive and will receive the brunt of the brine effects.

Upper beach - above high tide. The ghost crabs (Ocypode albicans) and other fast-moving crustaceans live in burrows on the beach during much of the day, becoming more active at night. When active, they feed at the edge of the tide line, following it in and out. Just above high tide line on the sandy beaches, there are often windrows of algae, especially Sargassum in spring and summer and red algae in winter, which have washed onshore. This vegetation often has associated with it one to several species of beach hoppers (Amphipoda) including Orchestra grillis, O. platensis, and Talorchestia longicornis (Hedgepeth, 1953, 1954).

Intertidal Zone - This includes the lower beach and upper shoreface (down to mean low sea level). The sand beaches afford poor substrate for algal colonization, so in this respect they are quite barren. Also, since the sands are generally fine in texture, little interstitial habitat is available. Thus, the intertidal zone is also generally lacking in microfauna. Several species of the bivalve Donax, the butterfly clam or coguina, along with Emerita portoricensis, which feed on wash detritus and plankton are fairly common, the bivalves occurring in colonies of several thousand to several million. Several species of the small toxoglossid worms, Terebra, prey upon Donas. Worms (polychaetes) are not abundant between the tide marks due possibly to constant redistribution of the sediment, and are only occasionally found under most conditions. The overall sparseness of the interstitial fauna probably reflects lowered temperatures and sea levels during the winter months, which lead to desiccation stress.

The upper shoreface (Fisher et al., 1972) from mean sea level to about 12-foot depth, is the zone of maximum wave intensity and consists of the lower intertidal zone (discussed above) and the area below mean low sea level. Breaker bars (usually three pair) characterize this lower zone in areas where the shoreline is accreting, but along the Texas coast within the study area, the shoreline is erosional and these bars are not well developed.

The longshore troughs between the bars are the habitat for a fairly diverse community including the portunid crabs, *Callinectes* and *Arenaeus*, *Albunea gibbesii* and *Callinissa*, the keyhole urchin, *Mellita quinquesperforata*, holothuroideans, *Thyone briareus* and *Thyonactis sabanallensis* along with the bivalve molluscs *Andara*, *Dinocardium robustum*, *Arca*, *Dosina*, *Pecten*, *Tellina*, *Anatina* and several other genera, and the gastropods *Phlium granulatum*, *Terebra*, *Polinices*, *Busycon*, *Oliva sayana*, *Murax*, *Olivella* and *Luidia*. Also found are *Astropecten* spp. (starfish), and the mudshrimp (*Callianassa*). This fauna is characteristic of the western part of the study area where the sediments are sandy in nature. Proceeding eastward toward the Texas/Louisiana coast and into Louisiana, the upper shoreface becomes muddy, thereby excluding many members, especially the bivalves, large holothuroideans, and filter-feeding lamellibranchs.

The most common larger fish of the Gulf beach are the spot (*L. xanthurus*), the mullet (Mugil cephalus), and the stingaree (*Dasyatis sabina*). The fine sand and mud characteristic of the beaches in the study area offer few large spaces for interstitial fauna such as copepods, tardigrades and small worms, and they are largely absent from the area. Microflora (especially bacteria) are, however quite abundant, especially near the passes where a muddier substrate exists (Zobell, 1946)

Keith and Hulings (1965) reported the results of monthly samples taken in the shallow sublittoral between Sabine Pass and Bolivar Point, Texas. The infauna studied, while not including all infaunal groups, consisted of 17 spp. of crustaceans, 12 spp. of polychaetes and six species of molluscs. Stations A, at Bolivar Point, Station PB, at Pearl Beach, and Station C, at McFadden Beach are characterized by sandy bottoms. Stations D and SD, at McFadden Beach and Sabine Pass respectively, are muddy bottom habitats (Figure Q-2. Seasonal temperature, salinity and oxygen data for each station are presented in Table Q1. The fall 1963 data reflect the effects of Hurricane Cindy on the physico-chemical characteristics of the various habitats. Tables Q-2 and Q-3 present a species breakdown of the organisms sampled and the maximum and optimum depth of penetration of the infauna (in the sediment). In terms of number of individuals, the polychaetes were the most abundant, with little change in maximum depth (1 to 2 inches) seasonally.

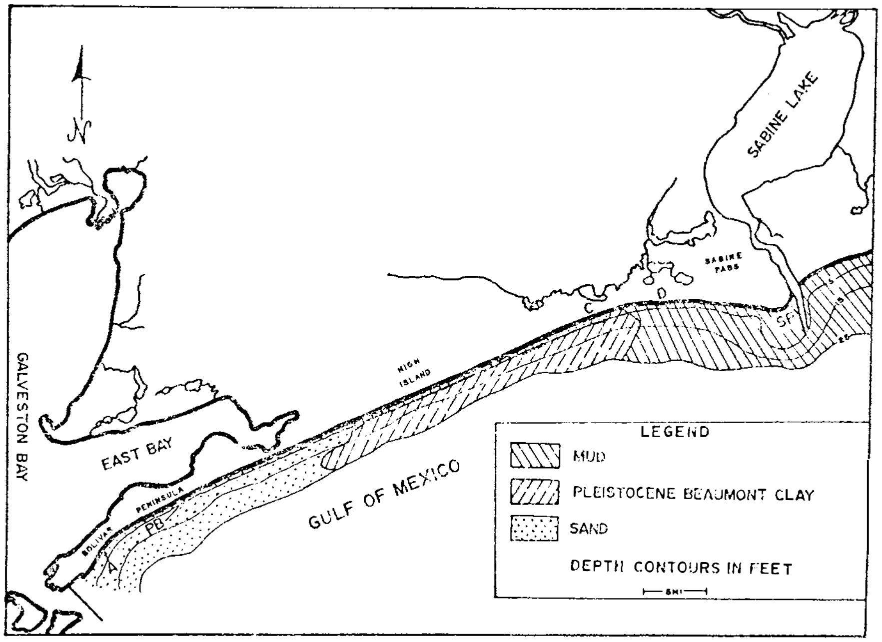

Figure Q-2 Location of stations and distribution of sediments (after Feray, unpubl.).

Figure Q-1 Maximum and optimum depth of penetration (in.) of selected species

	Total No. Specimens	Maximum Depth	Optimum Depth
Polychaeta			
Haploscoloplos fragilis	21	3	1
Lumbrinereis tenuis	6	2	1
Neanthes succinea	15	7	1
Paraonis sp.	24	5	2
Polydora ciliata	3	1	1
Spio setosa	9	3	2
Streblospio benedicti	20	2	1
Crustacea			
Amphithoe sp.	31	4	1
Corophium cylindricum	5	1	1
Haustorius sp.	25	4	2
Mollusca			
Donax variabilis	7	1	1
Petricola pholadiformis (Juvenile)	20	1	1

Table Q-2 Summary of hydrographic data for Stations A, PB, C, D, and SP

	Fall 62			Winter 63			Spring 63			Summer 63			Fall 63		
Sta.	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l
A	33.0	32.0	5.0	10.0	27.7	7.3	29.5	34.4	5.0	30.0	34.8	4.6	27.3	29.6	4.9
PB	32.0	29.9	4.7		28.0		28.0	34.3	5.1	32.1	35.0	4.4	27.5	27.2	4.9
C	33.0	24.7	4.7	9.0	25.3	7.2	27.1	33.5	5.3	33.1	34.4	4.4	27.4	22.1	5.1
D	33.0	24.3	4.8	8.5	25.4	7.2	27.0	33.1	5.2	33.2	34.4	4.3	30.1	22.0	5.8
SP	31.0	24.2	4.5	6.5	28.7	7.3	29.5	28.8	6.4	32.0	34.0	6.9	......	6.9	2.7

Table Q-3 clearly shows that certain species were characteristic of sandy bottoms (*Haploscolopolos fragilis*, *Paranois* sp., *Spio setosa*, *Streblospio bombyx*, *Haustorius* sp., while the mud bottoms were characterized by *Neanthes succinea*, *Amphithoe* sp., *Corophium cylindricum*, and *Petroicola pholadiformis*. Hurricane Cindy had very little effect on the organisms living in sand, but had a drastic effect on those occupying mud bottoms, with salinity decreases, O_2 depletion, turbulence, and suffocation due to mud all probably involved in the decline.

Reid (1955, 1956) studied the fish and fauna on the upper shoreface of Gilchrist Beach just west of High Island. Of the 25 species of fishes caught in 1954 (Table Q-4), 8 species comprised 96.7% of the total number, with the menhaden and anchovy most abundant. Only 5 species caught off the shore were not taken in the adjacent bay (noted in Table Q-4), indicating a close relationship between the two habitats.

Shrimp Ground Community Lower Shoreface and Continental Shelf

The lower shoreface, extending from the two-to-six fathom depth, where the shoreface meets the Continental Shelf, (3-5 miles offshore), is a zone of lesser wave intensity than upper beach, with substrate consisting of sandy mud. The sediments become more muddy on the shelf, because of the small slope. These shallow spawning grounds extend vast distances into the sea, with the 10-fathom depth extending 35-40 miles offshore in the study area.

This area is occupied by an assemblage of sessile, sedentary, and motile invertebrates, and bottom feeding fishes, with various penaeid shrimp as dominant members. The lower shoreface community is similar to that of the upper shoreface troughs, except for the exclusion of certain filter feeding lamellibranchs and larger holothuroideans, in relative proportion to the amount of mud in the substrate. The mud shrimp is common in this area, and burrowing worms become more common.

The inner Continental Shelf fauna is divided into two main communities based primarily on the distribution of the dominant species of penaeid shrimp, *P. setiferus* and *P. aztecus*. The white shrimp (*P. setiferus*) occurs on the inner shelf to depths of about 10 fathoms, where it is largely replaced by *P. aztecus*. Although many bottom forms extend the entire width of the shelf, some depth variations are noted. The sea pansy, *Renilla mulleri*, which occurs in fantastic numbers at certain times, is characteristic of the *P. setiferus* zone, while the small sea star *Astropecten antillensis* and several bivalves, *Pitar cordata* and *Chione lateralis* are more characteristic of *P. aztecus* zone. Living commensally in the sea pansy colonies are the scale worm (*Lepidonolus sublevis*) and the nudibranch (*Arminia tigrina*), which preys on *R. mulleri*. Isolated patches of algae (*Gracilaria* and *Oigeria*) occur on the firmer substrates of the area, but are not extensive.

Total number of individuals of each species at all stations for each sampling period

Species	Station A					Station PB				Station C					Station D					Station SP				
	F 62	W 63	Sp 63	Su 63	F 63	F 62	Sp 63	Su 63	F 63	F 62	W 63	Sp 63	Su 63	F 63	F 62	W 63	Sp 63	Su 63	F 63	F 62	W 63	Sp 63	Su 63	F 63
Polychaeta																								
Cirriformia filigera																							2	
Diopatra cuprea																							2	
Haploscoloplos fragilis	25	104	31	49	30							1		2										
Lumbrinereis tenuis	2	3	3	4	2		2			5	3	23	1	5	2	16	2	11	1				1	
Magelona papillicornis	1		2				2	1				3	5											
Neanthes succinea																4	28	4		4	50	44	14	4
Nepthys picta	1		1					1																
Paraonis sp.	21	24	24	62	34			1		4	15	1	6	21										
Polydora ciliata																3		5		1	1	3	8	
Spio setosa	1				2		1			41	3	5	32	10										
Spiophanes bombyx	2		2	1			1	1				1	3											
Streblospio benedicti	2			147	40																			
Crustacea																								
Actinocythereis subquadrata				1																				
Acuticythereis tuberculata	1																							
Acuticythereis sp.				2																				
Amphithoe sp.															137			1				9	8	
Anomalocera patersoni					2						1	5	10	9										
Corophium cylindricum																3	1					63	2	
Cytherura johnsoni				8																				
Cytherura sp.				1																				
Daistylis polita			1																					
Haustorius sp.	8	11	30	1		2	12	11		18	19	24	53	12										
Lepidopa benedicti								2					1											
Mysis stenolepis				2	2	1			3			2	1	2										
Neopanope texana																		2					1	2
Paracypris sp.			1				1					2												
Unidentified amphipod							4																	
Unidentified cumacean			2									2	1											
Unidentified isopod						1		1				3		1										
Mollusca																								
Anachis obesa																	1	1					3	
Donax variabilis	1				5			3	2				2											
Mulinia lateralis				1																			2	
Natica pusilla			1									1												
Petricola pholadiformis																2	1	184	13	1	1	18	34	
Tellina sp.			11																					

Table Q-3
Total number of individuals of each species at all stations for each sampling period

Species	Number	Frequency	Avg. haul	% of catch
Brevoortia patronus	2664	13	222.00	58.67
Anchoa m. diaphana	601	13	50.10	13.23
Polydactylus octonemus	384	11	32.00	8.45
Galeichthys felis	237	13	19.75	5.22
Chloroscombrus chrysurus	210	8	17.50	4.62
*Trachinotus carolinus**	163	11	13.58	3.59
Caranx hippos	86	9	7.17	1.89
Mugil cephalus	47	9	3.92	1.03
Signalosa petenensis	45	1	3.75	.99
Mugil curema	37	6	3.10	.81
Trichiurus lepturus	21	7	1.75	.46
Cynoscion arenarius	11	3	.92	.24
Stellifer lanceolatus	9	2	.75	.19
*Cynoscion nothus**	8	2	.67	.17
Bairdiella chrysura	5	3	.42	.11
Chaetodipterus faber	2	2	.17	.04
*Larimus fasciatus**	2	2	.17	.04
Sphoeroides nephelus	1	1	.08	.02
Harengula p. pensacolae	1	1	.08	.02
*Menticirrhus sp.**	1	1	.08	.02
*Histrio gibba**	1	1	.08	.02
Carcharhinus limbatus	1	1	.08	.02
Oligoplites saurus	1	1	.08	.02
Membras martinica vagrans	1	1	.08	.02
Cynoscion nebulosus	1	1	.08	.02
Total	4540			

* Species which were not common to both East Bay and the Gulf.

Table Q-4. Species and catch data on Gulf Beach collection.

Other very common forms on these shrimp spawning grounds include the gorgonian, Leptogorgia setacea, and also the tube dwelling Onuphid worms (including Diopatra cuprea), crabs of the genera Hepatus, Calappa and Persephone, the anemone Paranthus raptiformis and certain gastropods, including Busycon, Murex, Dolium and Fasciolaria. The gorgonians also support a small association, including the gastropod Simnia uniplicata and the winged barnacle Balanus galeatus. The large red crab, Petroch kalamensis lives in abandoned shells of these larger gastropods with anemones (especially Calliactus tricolor) usually attached on the outside surface of the shells, and inside, living commensally with the hermit crab, is the porcelain crab, Porcellain sayona. Stomatopods, especially Squilla empressa are also present in irregularly spaced colonies.

Among the other penaeid shrimp are the pink (P. duorarum), the sea bob (Xiphopeneus kroyeri), Trachypeneus similis and two species of hard shell shrimp, Sicyonia dorsalis and S. brevirostris. Other crabs include several Portunus spp. and several Callinectes species, C. danae and C. sapidus. The only sponges that are present to any extent on these bottoms are the predatory boring sponges of the genus Cliona. The sea stars Luidia clathratha and L. alternata are also present. The more motile invertebrates include two species of squid, Lolliguncula brevis and Loligo pealei.

Fish feeding on or near the bottom include the sand trout (Cynoscion nothus), the croaker (Micropogon undulatus), the threadfin (Polydactylus octonemus), the catfish (Galeichthys felis), the moonfish (Vomer setapinnis), the star drum (Stellifer lanceolatus), two flatfishes, (Syacium gunteri and Symphurus plaguisa) and two other sciaenids, the spot (Leiostomus xanthurus) and the whiting (Menticirrhus americanus).

Since most data for these spawning grounds came from trawls, the burrowing forms, including the polychaetes and bivalves, were not adequately represented in this list. Many of the forms mentioned for the intertidal and shoreface area are undoubtedly present.

Hildebrand (1954) reported that only in the area inside 8 fathoms did the white shrimp exceed the brown shrimp in abundance. Greatest numbers of known shrimp were taken during July and August, and least numbers were taken during the spring. From the shore to 10 fathoms, P. setiferus and Xiphopeneus kroyeri were most abundant. Occasional large numbers of young P. aztecus were restricted to offshore. P. aztecus, Trachypeneus similis and Sicyonia dorsalis were the dominant penaeids in the 12-25 fathom depth. The white shrimp is often found out to 25 fathoms off Louisiana, while it is rarely fished in depths greater than 16 fathoms in Texas waters.

Hildebrand concludes that Penaeus aztecus, *Callinectes danae*, *Pitar cordata*, *Busycon contrarium*, *Astropecten antillensis*, *Syacium gunterri*, and *Poronotus triacanthis* were the dominant organisms offshore as compared to *P. setiferus*, *C. donae*, *Renilla mulleri*, *Pitar texasiana*, *Cynoscion nothus*, *Micropogon undulatus*, *Polydactylus octonemus* and *Galeichthys felis* on the inshore grounds.

Hildebrand (1954) presents the results of trawling off Sabine Pass, Texas (Table Q-5) at 6 to 7 fathoms where large numbers of fish were taken compared to other areas of the Gulf. Thirty-six species belonging to 24 families were caught, with 48% Sciaenidae, and together with Polynomidae, Trichiuridae and Otolithidae, the four families comprised 90% of the fishes. This depth zone roughly corresponds to the white shrimp grounds.

Table Q-6 presents a comparison of the results of sampling by Gunter (1945) on white shrimp grounds, and Hildebrand (1954) on the brown shrimp grounds (12-25 fathoms) off Texas, and shows only 2 species, *C. nothus* and *Sycium gunteri* in the first ten most abundant species from both areas.

Hildebrand (1954) presents results of his study and that of Gunter (1945,1950) on the species caught in the white shrimp zone (less than 12 fathoms) and the brown shrimp zone (12-15 fathoms) along the Texas coast (See Tables Q-7 and Q-8). Comparison of the number of species of different taxonomic groups revealed that by far the greatest difference was among fishes, with 81 species captured in shrimp trawls inshore against 122 species in the 12-25 fathom zone.

Moore et al. (1970) report on a series of trawls taken at depths of 7 to 110 meters (4-60 fathoms) off the Texas and Louisiana coasts. Figure Q-3 shows the transects occupied during the study. Transect 5 is off Galveston, while transect 6 is off Cameron, Louisiana. The former transect is at the far western edge of the study area, and the latter passes through the location of the West Hackberry brine disposal area. Table Q-9 indicates the location, depth, and year of sampling for these two transects. Table Q-10 summarizes the catch statistics for these transects. Comparison of yearly catches for each of the more inshore stations which were sampled every year showed no significant differences (See Table Q-11). Catches were generally much larger for the Louisiana transect with the greater differences in shallow water. There were also pronounced seasonal differences (See Figures Q-4 and Q-7) in catches for each area, with both showing maximum catches in the summer, and again the tendency is for the catch to increase offshore. On a yearly basis, (Figure Q-8), the inshore catches are similar for both areas; the main difference being that the larger catches are farther offshore in Louisiana.

Table Q-5

Catch of Fish During June off Sabine, Texas in 6–7 Fathoms*

Micropogon undulatus	58,500	Ogcocephalus cubifrons	23
Polydactylus octonemus	28.800	Pteroplatea micrura	16
Trichiurus lepturus	24.900	Opisthonema oglinum	12
Cynoscion nothus	6.550	Pomatomus saltatrix	12
Cynoscion arenarius	1.550	Anchoa hepsetus	10
Poronotus triacanthus	1,386	Citharichthys spilopterus	10
Centropristes philadelphicus	1,085	Paralichthys lethostigma	6
Galeichthys felis	975	Achirus fasciatus	4
Larimus fasciatus	675	Nautopaedium porosissimum	3
Vomer setapinnis	480	Dasyatis sabina	3
Menticirrhus americanus	430	Brevoortia patronus	2
Chloroscombrus chrysurus	290	Hippocampus hudsonius	2
Anchoa mitchilli diaphana	270	Syngnathus louisianae	2
Prionotus rubio	250	Narcine brasiliensis	2
Chaetodipterus faber	135	Aprionodon isodon	2
Leiostomus xanthurus	75	Ophichthys gomesi	1
Prionotus tribulus	50	Dasyatis sayi	1
Peprilus paru	26	Rhinobatus lentiginosus	1

Table Q-6

The Order of Abundance of the Twenty Fishes Most Often Taken in Trawl Hauls on the White Shrimp Grounds* and Brown Shrimp Grounds in Texas are Given for Comparison†

Gulf

White Shrimp Grounds*	Brown Shrimp Grounds
Cynoscion nothus	Sycium gunteri
Micropogon undulatus	Poronotus triacanthus
Polydactylus octonemus	Cyclopsetta chittendeni
Galeichthys felis	Stenotomus caprinus
Cynoscion arenarius	Cynoscion nothus
Vomer setapinnis	Synodus foetens
Stellifer lanceolatus	Paracentropristes pomospilus
Symphurus plagiusa	Prionotus rubio
Leiostomus xanthurus	Diplectrum arcuarium
Syacium gunteri	Centropristes philadelphicus
Menticirrhus americanus	Cynoscion arenarius
Etropus crossotus	Trichiurus lepturus
Dasyatis sabina	Micropogon undulatus
Orthopristis chrysopterus	Engyophrys sentus
Anchoa mitchilli diaphana	Chaetodipterus faber
Anchoa hepsetus	Citharichthys spilopterus
Chloroscombrus chrysurus	Menticirrhus americanus
Achirus fasciatus	Nautopaedium porosissimum
Bagre marina	Vomer setapinnis
Poronotus triacanthus	Lepophidium brevibarbe

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* From Gunter (1945).

Table Q-7

Lists of Species Caught in Shrimp Trawls in Depths of 12 to 25 Fathoms along the Texas Coast. This compilation is composed of my data

Renilla mulleri
Virgularia mirabilis
Calliactis tricolor
Crepidula plana
Strombus pugilus
Phalium granulatum
Sconsia striata
Distorsio clathrata
Tonna galea
Oocorys sp.
Murex fulvescens
Cantharus sp.
Busycon contrarium
Busycon pyrum
Fasciolaria gigantea
Conus austini
Polystria albida
Pteria colymbus
Atrina serrata
Pecten papyraceus
Ostrea equestris
Echinochama arcinella
Laevicardium laevigatum
Chione clenchi
Pitar cordata
Macoma tageliformis
Lolliguncula brevis
Loligo pealei
Rossia tenera
Squilla empusa
Lysiosquilla scabricauda
Penaeus setiferus
Penaeus aztecus
Penaeus duorarum
Trachypeneus similis
Sicyonia dorsalis
Sicyonia brevirostris
Solenocera vioscai
Scyllarides aequinoctialis
Porcellana sayana
Petrochirus bahamensis
Stenorynchus seticornis
Libinia emarginata
Leiolambrus nitidus
Portunus gibhesi
Portunus spinimanus
Callinectes sapidus
Callinectes danae
Calappa springeri
Hepatus epheliticus
Astropecten antillensis
Luidia alternata
Luidia clathrata
Echinaster echinophorus
Clypeaster ravenelli
Stichopus badionotus
Peprilus paru
Poronotus triacanthus
Seriola dumerili
Trachinotus carolinus
Selar crumenophthalmus
Trachurus lathami
Caranx hippos
Chloroscombrus chrysurus
Vomer setapinnis
Selene vomer
Pomatomus saltatrix
Rachycentron canadus
Garrupa nigrita
Promicrops itaiara
Diplectrum arcuarium
Serraniculus pumilio
Centropristes philadelphicus
Paracentropristes pomospilus
Priacanthus arenatus
Lutianus blackfordi
Lutianus synagris
Pristipomoides andersoni
Rhomboplites aurorubens
Bathystoma a. rimator
Conodon nobilis
Orthopristes chrysopterus
Stenotomus caprinus
Lagodon rhomboides
Eucinostomus gula
Eucinostomus argenteus
Upeneus parvus
Larimus fasciatus
Stellifer lanceolatus
Leiostomus xanthurus
Molpadia cubana
Styela partita
Styela plicata
Mustelus canis
Carcharhinus limbatus
Carcharhinus milberti
Carcharhinus obscurus
Carcharhinus porosus
Sphyrna diplana
Sphyrna tiburo
Sphyrna tudes
Squatina dumerili
Pristis pectinatus
Rhinobatus lentiginosus
Raja texana
Narcine brasiliensis
Dasyatis sayi
Pteroplatea micrura
Harengula pensacolae
Brevoortia patronus
Anchoa hepsetus
Anchoa mitchilli
Congrina flava
Hoplunnis macrurus
Neoconger mucronatus
Uroconger sp.
Gymnothorax nigromarginatus
Mystriophis intertinctus
Bagre marina
Galeichthys felis
Synodus foetens
Synodus poeyi
Saurida brasiliensis
Bregmaceros atlanticus
Urophycis floridanus
Paralichthys albigutta
Paralichthys lethostigma
Ancylopsetta quadrocellata
Syacium gunteri
Citharichthys macrops
Citharichthys spilopterus
Trichopsetta ventralis
Engyophrys sentus
Achirus fasciatus
Gymnachirus texae
Symphurus diomedianus
Symphurus civitatum
Symphurus plagiusa
Syngnathus louisianae
Hippocampus budsonius
Fistularia tabacaria
Sphyraena guachancho
Polydactylus octonemus
Scomber colias
Scomberomorus maculatus
Trichiurus lepturus
Micropogon undulatus
Menticirrhus americanus
Cynoscion arenarius
Cynoscion nothus
Caulolatilus cyanops
Chaetodipterus faber
Scorpaena calcarata
Prionotus ophryas
Prionotus paralatus
Prionotus pectoralis
Prionotus rubio
Prionotus scitulus
Prionotus stearnsi
Prionotus tribulus
Gobionellus gracillimus
Bollmannia communis
Echeneis naucrates
Lonchopisthes lindneri
Kathetostoma albigutta
Brotula barbata
Lepophidium brevibarbe
Nautopaedium porosissimum
Balistes capriscus
Monacanthus hispidus
Alutera schoepfi
Lactophrys tricornis
Lagocephalus laevigatus
Sphoeroides nephelus
Sphoeroides spengleri
Chilomycterus schoepfi
Antennarius scaber
Antennarius radiosus
Ogcocephalus cubifrons
Ogcocephalus sp.
Halieutichthys aculeatus

Table Q-8

List of Species Caught in Shrimp Trawls in Less Than 12 Fathoms Along the Texas Coast. This Compilation is Compiled of My Data and Information from Gunter (1945 and 1950)

Calliactis tricolor
Leptogorgia setacea
Renilla mulleri
Virgularia mirabilis
Zoobotryon pellucidum
Crepidula fornicata
Crepidula plana
Strombus alatus
Polynices duplicata
Phalium granulatum
Busycon contrarium
Busycon pyrum
Murex fulvescens
Thais haemostoma
Tonna galea
Oliva sayana
Arca campechiensis
Noetia ponderosa
Echinochama arcinella
Ostrea cristata
Dinocardium robustum
Chione cancellata
Chione clenchi
Pitar texasiana
Spisula solidissima
Macoma tageliformis
Barnea costata
Lolliguncula brevis
Loligo pealei
Squilla empusa
Penaeus setiferus
Penaeus aztecus
Penaeus duorarum
Trachypeneus similis
Trachypeneus constrictus
Sicyonia brevirostris
Sicyonia dorsalis
Xiphopeneus kroyeri
Porcellana sayana
Petrochirus bahamensis
Libinia emarginata
Leiolambrus nitidus
Portunus gibbesi
Callinectes sapidus
Callinectes danae
Ovalipes ocellatus

Arenaeus cribrarius
Menippe mercenaria
Calappa springeri
Hepatus epheliticus
Persephona crinita
Persephona punctata
Astropecten antillensis
Astropecten articulatus
Astropecten diplicatus
Luidia alternata
Luidia clathrata
Mellita quinquiesperforata
Aprionodon isodon
Carcharhinus leucas
Sphyrna tiburo
Rhinobatus lentiginosus
Raja texana
Narcine brasiliensis
Dasyatis sabina
Dasyatis sayi
Dasyatis americana
Pteroplatea micrura
Harengula pensacolae
Opisthonema oglinum
Brevoortia patronus
Anchoa hepsetus
Anchoa mitchilli
Bagre marina
Galeichthys felis
Urophycis floridanus
Synodus foetens
Paralichthys lethostigma
Paralichthys albigutta
Ancyclopsetta quadrocellata
Syacium gunteri
Cyclopsetta chittendeni
Citharichthys spilopterus
Citharichthys macrops
Etropus crossotus
Achirus lineatus
Achirus fasciatus
Symphurus plagiusa
Symphurus civitatum
Syngnathus louisianae
Hippocampus hudsonius
Sphyraena guachancho
Scomberomorus maculatus
Trichiurus lepturus
Peprilus paru
Poronotus triacanthus
Hemicaranx amblyrhynchus
Caranx hippos
Trachurus lathami
Chloroscombrus chrysurus
Vomer setapinnis
Pomatomus saltatrix
Centropristes philadelphicus
Diplectrum arcuarium
Lutianus blackfordi
Conodon nobilis
Orthopristis chrysopterus
Stenotomus caprinus
Lagodon rhomboides
Eucinostomus gula
Eucinostomus argenteus
Upeneus parvus
Larimus fasciatus
Stellifer lanceolatus
Leiostomus xanthurus
Micropogon undulatus
Menticirrhus americanus
Menticirrhus focaliger
Cynoscion arenarius
Cynoscion nebulosus
Cynoscion nothus
Chaetodipterus faber
Scorpaena ginsburgi
Prionotus rubio
Prionotus tribulus
Prionotus pectoralis
Prionotus scitulus
Astroscopus y-graecum
Rissola marginata
Lepophidium brevibarbe
Otophidium welshi
Nautopaedium porosissimum
Balistes capriscus
Monacanthus hispidus
Lagocephalus laevigatus
Sphoeroides nephelus
Chilomycterus schoepfi
Ogcocephalus cubifrons

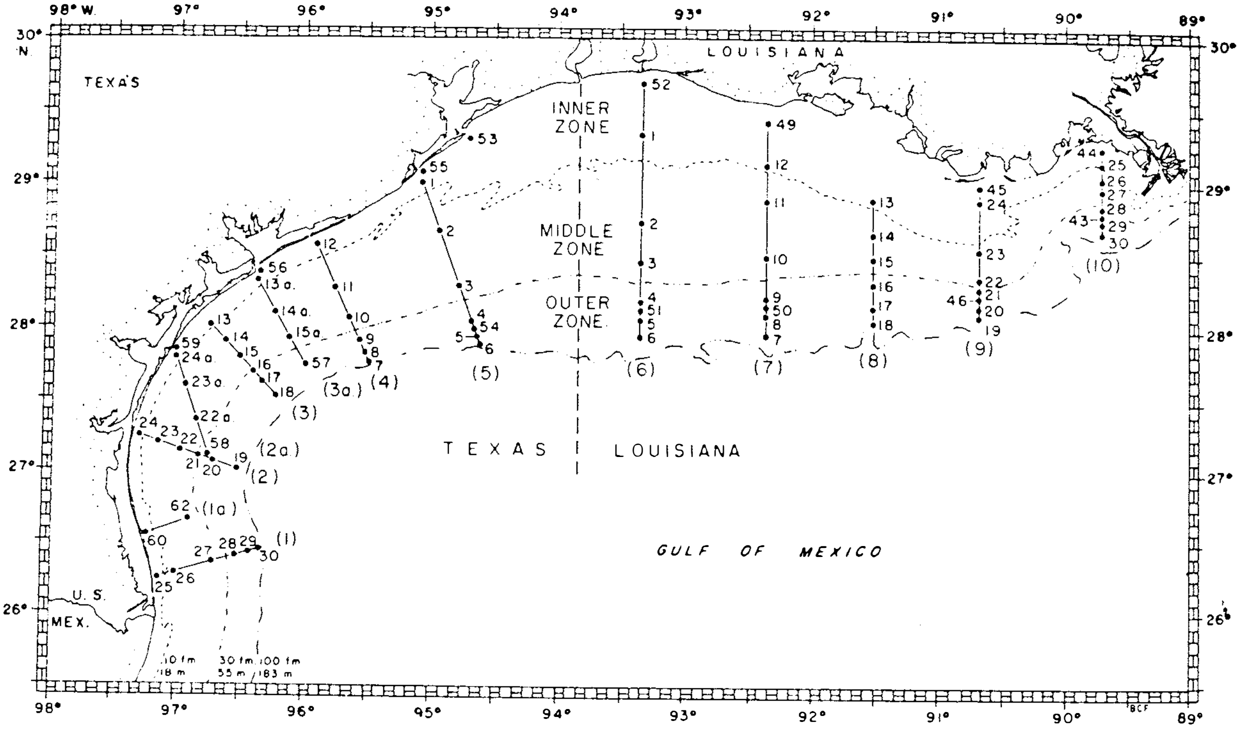


Figure Q-3

Locations of stations at which samples were taken during at least 1 year, 1962-1964 (transect numbers in parentheses)

Table Q-9 Location, depth, and year of sampling at each station off the Texas and Louisiana coast, 1962 through 1964

Station (W.)	Latitude (North)	Longitude (West)	Depth M.	Depth Fm.	Years sampled 1962	1963	1964	Station (E.)	Latitude (North)	Longitude (West)	Depth M.	Depth Fm.	Years sampled 1962	1963	1964
1	29° 01′	95° 05′	14	7.5	X	X	X	1	29° 22′	93° 20′	14	7.5	X	X	X
2	28° 40′	94° 56′	27	15	X	X	X	2	28° 46′	93° 20′	27	15	X	X	X
3	28° 18′	94° 46′	46	25	X	X	X	3	28° 28′	93° 20′	46	25	X	X	X
4	28° 05′	94° 41′	64	35	X	.	.	4	28° 11′	93° 20′	64	35	X	.	.
5	27° 58′	94° 38′	82	45	X	.	.	5	28° 06′	93° 20′	82	45	X	.	.
6	27° 55′	94° 36′	110	60	X	X		6	27° 59′	93° 20′	110	60	X	.	.
53	29° 19′	94° 41′	7	4		X	X	51	28° 09′	93° 20′	73	40	.	X	.
54	28° 00′	94° 38′	73	40		X	X	52	29° 42′	93° 18′	7	4	.	X	X
55	29° 03′	95° 06′	7	4		X	X								

Table Q-10 Catch in pounds' per hour of demersal fishes (species combined) by year, station, depth, transect, and month from Texas and Louisiana, 1962-64

(Night catches are in italics)

Year	Station	Depth M.	Depth Fm.	Transect number	January	February	March	April	May	June	July	August	September	October	November	December
1962	W-1			5	14	3	50	150	80	30	50	*60*	150	*225*	*50*	70
	E-1	14	7.5	6	45	335	*35*	*50*	45	35	60	200	*1.000*	..	..	
	W-2			5	55	*30*	300	*25*	*15*	*30*	..	40	*25*	*35*	*70*	*100*
	E-2	27	15	6	*165*	150	200	*90*	20	*320*	*375*	*350*	*350*	*250*	200	*122*
	W-3			5	*150*	*200*	150	*60*	150	*100*		200	*90*	300	*150*	*300*
	E-3	46	25	6	*220*	225	180	90	150	200	125	*200*	451	650	145	*175*
	W-4			5	*120*	90	*50*	80	*150*	40	165	..	60	300	130	*120*
	E-4	64	35	6	200	*150*	350	55	*100*	500	100	150	75	60	110	110
	W-5			5	*100*	80	*80*	..	*80*	150	50	130	75	200	160	
	E-5	82	45	6	40	200	150	*70*	*85*	120	105	75	*150*	60	*40*	225
	W-6			5	..	150	*155*	65	*20*	50	13	..	120	150	45	
	E-6	110	60	6	.	*100*	*200*	30	*200*	30	85	10	*100*	34	*36*	
	W-55	7	4	5	..	*6*	75	75	35	8	175	25	60	22	25	*30*
	W-53			5a	..	10	50	20	30	12	140	15	60	30	5	25
	E-52	7	4	6	..	32		*50*	*30*	*115*	130	250	150	*45*	*15*	10
	W-1			5	*60*	*10*	50	*120*	110	80	120	50	80	*35*	*12*	*45*
	E-1	14	7.5	6	*26*	*50*	*175*	75	50	180	140	200	100	240	*300*	*30*
	W-2			5	*30*	100	*100*	*15*	*40*	*20*	5	*40*	*100*	*100*	*60*	*75*
	E-2	27	15	6	*135*	300	*225*	10	130	*100*	130	*150*	*300*	175	70	60
	W-3			5	*100*	85	*10*	65	*200*	*150*	*140*	*40*	*30*	*150*	*125*	125
	E-3	46	25	6	*120*	375	*200*	175	70	5	120	*300*	*300*	310	150	80
	W-54			5	*70*	*10*	175	35	175	*80*	45	*85*	50	90	*100*	80
	E-51	73	40	6	*125*	225	100		40		*70*	25	200	*120*	35	[illegible]
	W-6	110	60	5	*30*	2	15	*4*	35	40	55	*100*		60	110	35
964	W-55			5	*18*	6	15	60	40	40	*200*	*85*	*80*	*20*	*50*	*10*
	W-53			5a			25	15	18	150	60	*80*	75	65	100	15
	E-52	7	4	6	5	*20*		60	205	*350*	*150*	*200*	10	55	35	*30*
	W-1			5	*8*	*8*	15	*120*	200	45	*250*	*125*	*60*	*15*	*30*	*12*
	E-1	14	7.5	6	*35*	*8*		40	50	*6*	*550*	*300*	70	*250*	53	*60*
	W-2			5	*25*	175	*20*	*100*	*60*	*30*	25	*100*	*40*	*60*	*155*	*15*
	E-2	27	15	6	*100*	400	850	*175*	*110*	*80*	85	*150*	*250*	*25*	*200*	*15*
	W-3			5	*125*	*125*	*170*	*130*	35	*200*	50	110	*135*	125	*350*	*30*
	E-3	46	25	6	..	*600*		400	125	40	..	300	*150*	75	225	*100*
	W-54	73	40	5	85	.	150	100	65	*20*	30	75		2	85	*60*

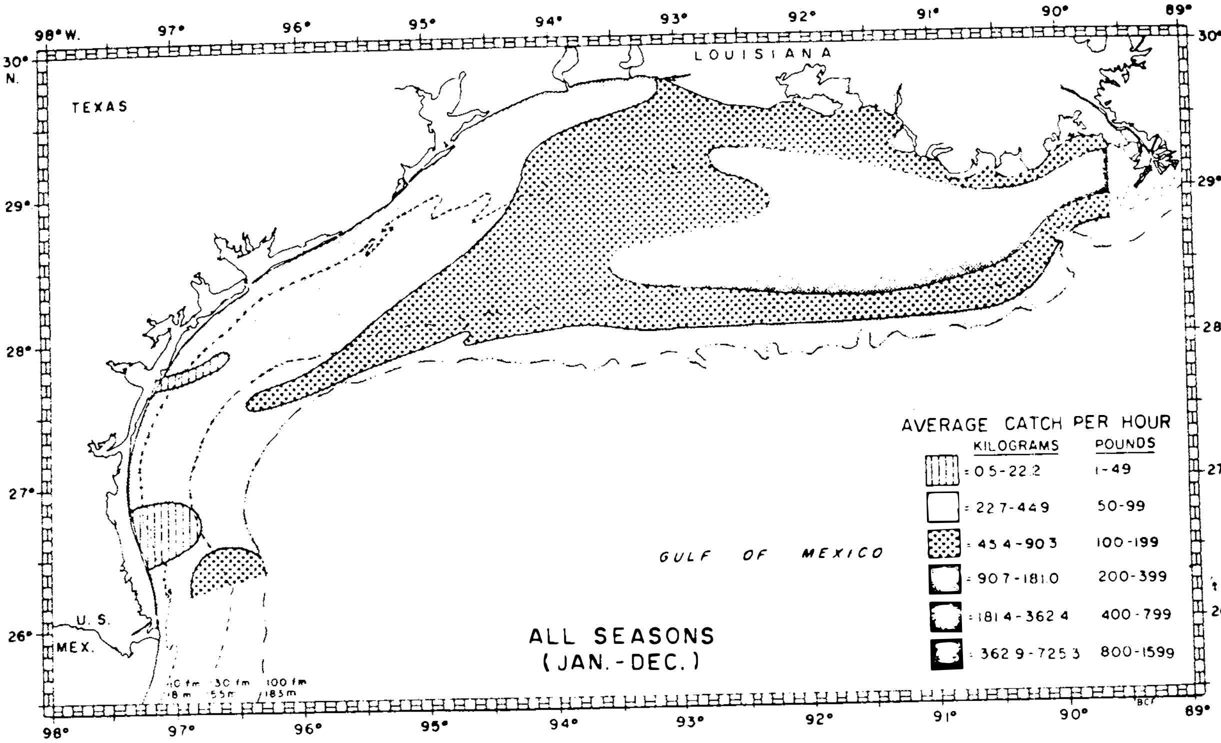


Figure Q-8

Relative abundance (by weight) of demersal fishes from 1962-1964, estimated from the average catch of all fish at each station.

Depth		Coastal region	Station number	Number of the same months in which samples were taken each year	Average catch (pounds/hour)			Test results		
									F value	
M.	Fm.				1962	1963	1964	d.f.	Years	Months
14	7.5	Texas	W 1	12	78	64	74	2, 22	0.18	1.99
		Louisiana	E 1	8	221	103	132	2, 14	0.59	0.94
27	15	Texas	W 2	11	66	62	71	2, 20	0.06	0.91
		Louisiana	E 2	12	216	149	203	2, 22	0.74	1.57
46	25	Texas	W 3	11	168	98	140	2, 20	2.22	0.74
		Louisiana	E 3	9	254	196	224	2, 16	0.33	1.65

Table Q-11

Comparisons of average catch between years by station, 1962-1964.

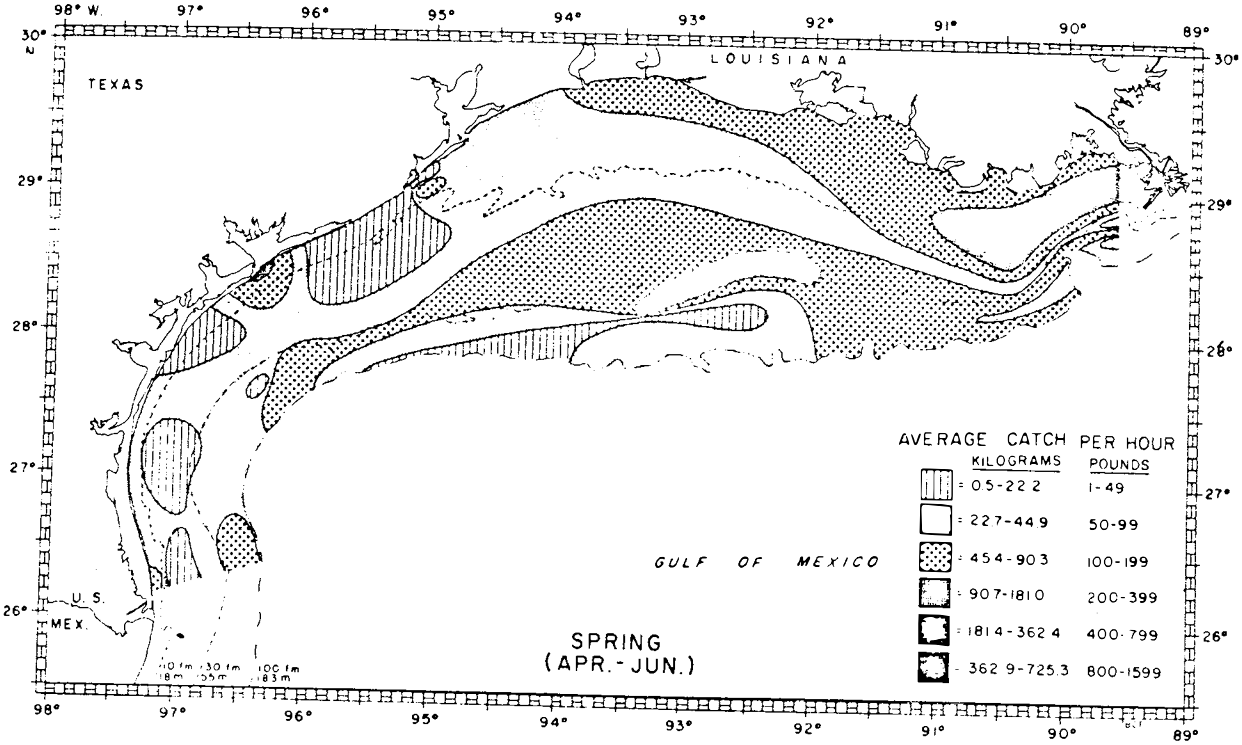


Figure Q-4
Relative abundance (by weight) of demersal fishes in the spring (April-June), estimated from the average catch of all fish at each station, 1962-1964

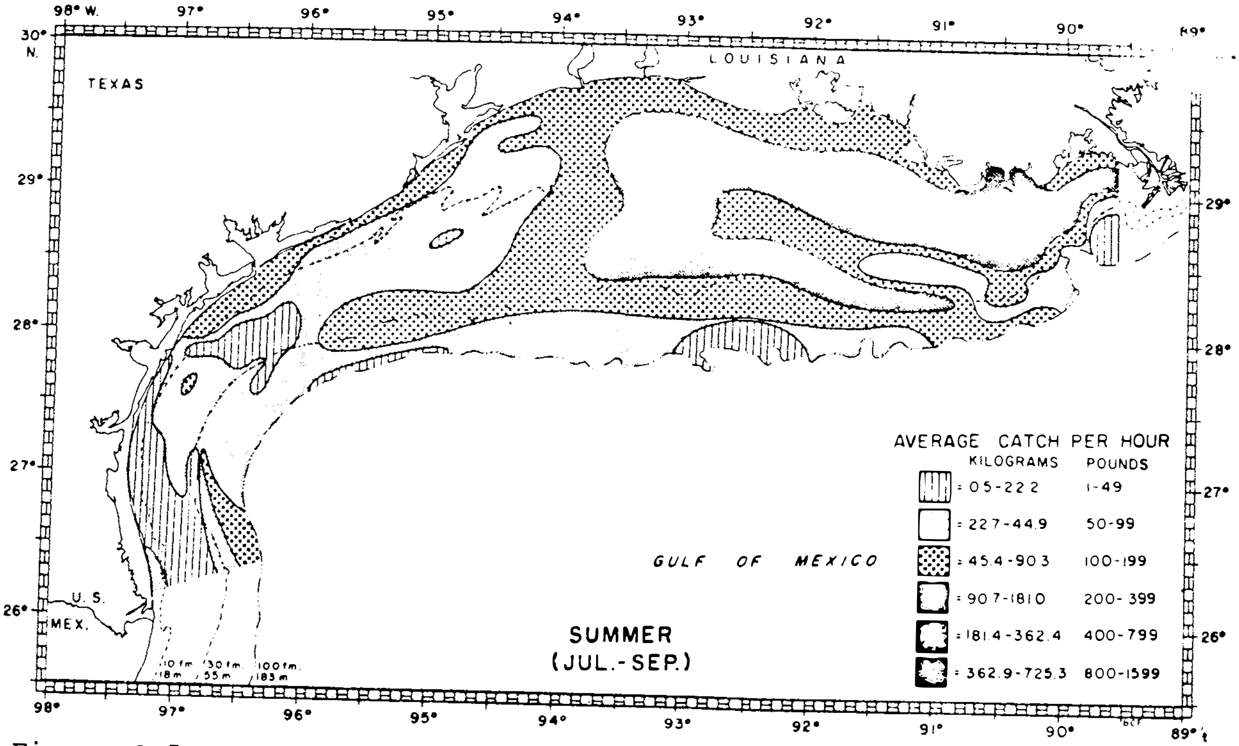


Figure Q-5
Relative abundance (by weight) of demersal fishes in the summer (July-September), estimated from the average catch of all fish at each station, 1962-1964.

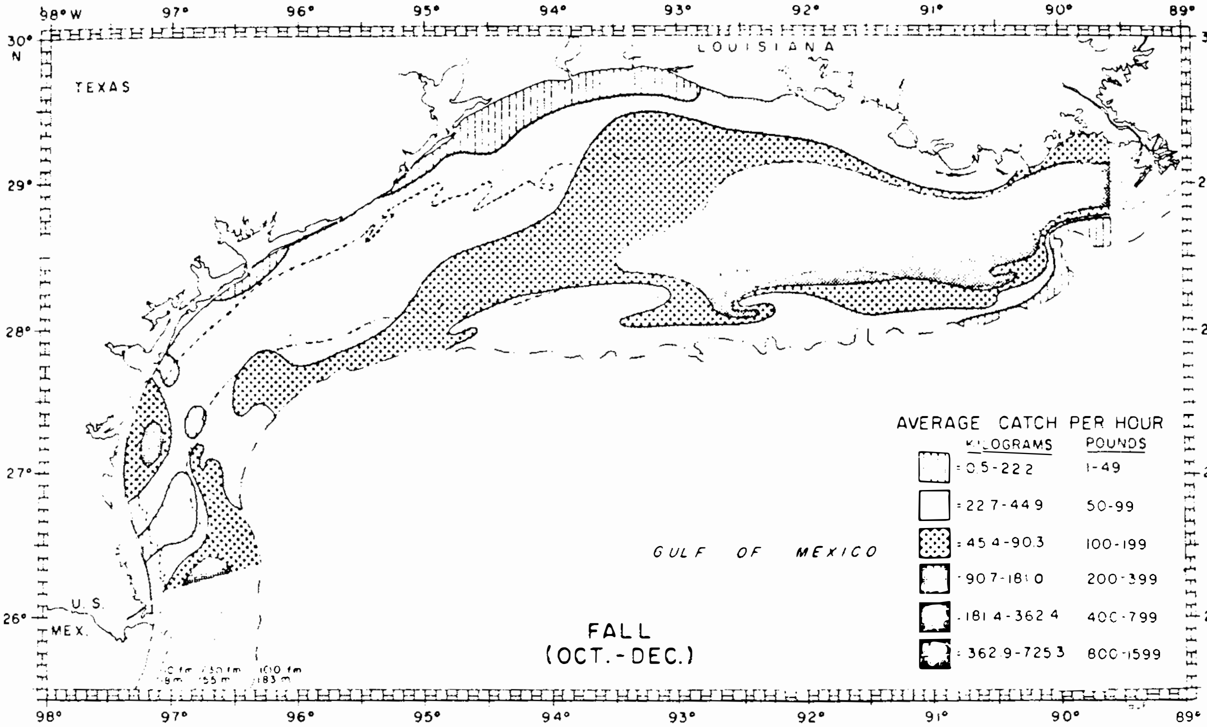


Figure Q-6
Relative abundance (by weight) of demersal fishes in the fall (October-December), estimated from the average catch of fish at each station, 1962-1964.

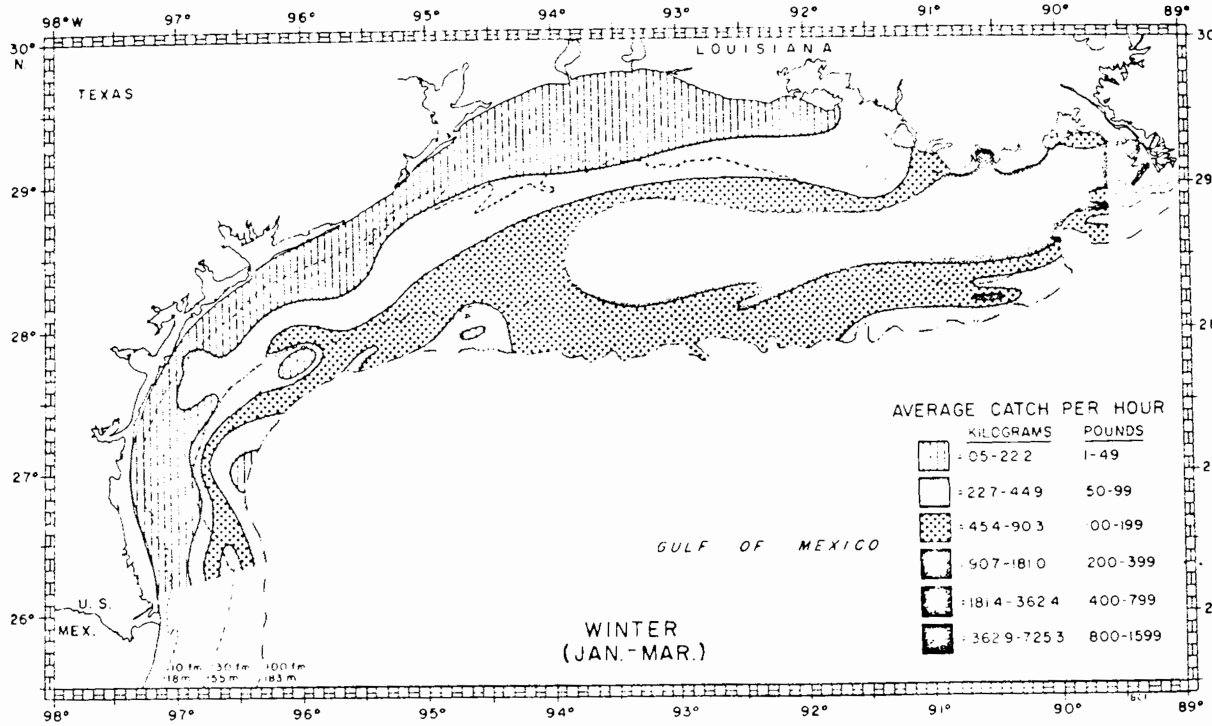


Figure Q-7
Relative abundance (by weight) of demersal fishes in the winter (January-March), estimated from the average catch of all fish at each station, 1962-1964

Table Q-12, which is based on coastwise results, lists the species that constituted one percent or greater of the catch off each area, with the Atlantic croaker by far the most abundant off Louisiana, with only the longspine porgy constituting greater than 10% of the catch. For Texas, the longspine porgy was the only species greater than ten percent of the catch, with the Atlantic croaker and Inshore lizardfish at 9% each. Tables Q-13 and Q-14 give a breakdown of the depth and seasonal distribution of the catch for all species which constituted 5% or greater of the catch. The greater abundance of the longspine porgy in deeper water, and that of the Atlantic croaker in shallow depths, is clearly shown for both states. However, the greatly reduced importance of the croaker in Texas as compared to Louisiana is clearly evident, with the Southern kingfish, which is found in numbers greater than 5% only in winter shallow water off Louisiana, reported as the dominant shallow water species in winter and fall off Texas, where it was recorded during all months as constituting greater than 5% of the catch.

NOAA (1976), in their review of available biological information for BLM concerning the Gulf Continental Shelf, defined two dominant and distinct fish communities in the northern Gulf of Mexico, corresponding to an inner (0-27 m) white shrimp ground fauna. In its report, NOAA also summarized results of various studies concerning the shrimp of this area.

The results of shrimp trawls off Galveston, Texas in statistical area 18 are reported (NOAA 1976). This includes a large part of the brine disposal area. Figures Q-9 and Q-10 show the transects taken off the study area (transects 6 and 17) and Figure Q-11 defines statistical area 18. Table Q-15 delineates the stations for transects 6 and 17, and gives the mean catches over all seasons for each station. Overall largest catches were made from the 13.7-27.5 meter zone. Table Q-16 shows the overall results of the survey. Peak populations occurred in the 13.7 to 45 meter depth, after which they declined precipitously.

Table Q-17 shows that, except for high values for 1961, year year variations are small. Shrimp were present during all months with lowest populations in March through July, and highest populations in September and January-February (See Table Q-18). Table Q-19 shows that the brown shrimp was most abundant, with the white and pink shrimp next in abundance. Tables Q- 19a and Q-20 show that the brown shrimp was most abundant in the 27 .5 and 45.8 meter zones, while the white and pink shrimp were most abundant at the 7.3 and 13.7 meter zones and the 27.5 meter zone respectively.

Table Q-12

Species that constituted one percent or more of the average catch by weight of all demersal fishes caught off Louisiana and Texas, 1962-64

Species	Percent of total catch		
	Louisiana	Texas	Entire coast
Atlantic crocker, *Micropogon undulatus*	35	9	28
Longspine porgy, *Stenotomus caprinus*	18	21	19
Inshore lizardfish, *Synodus foetens*	3	9	5
Sand seatrout, *Cynoscion arenarius*	5	5	5
Sea catfish, *Galeichthys felis*	5	2	4
Silver seatrout, *Cynoscion nothus*	3	7	4
Blackfin searobin, *Prionotus rubio*	4	2	4
Spot, *Leiostomus xanthurus*	4	4	4
Rock sea bass, *Centropristis philadelphicus*	2	4	3
Atlantic cutlassfish, *Trichiurus lepturus*	2	2	2
Southern kingfish, *Menticirrhus americanus*	1	3	2
Gulf butterfish, *Poronotus burti*	1	4	2
Wenchman, *Pristipomoides aquilonaris*	1	5	2
Shoal flounder, *Syacium gunteri*	1	4	2
Mexican searobin, *Prionotus paralatus*	1	4	2
Mexican flounder, *Cyclopsetta chittendeni*	1	2	1
Star drum, *Stellifer lanceolatus*	1	1	1
Red goatfish, *Mullus auratus*		2	1
Bumper, *Chloroscombrus chrysurus*	1	1	1

Table Q-13

Species that constituted five percent or more of the average catch by weight of all demersal fishes caught off Louisiana, 1962-1964
(Listed by season and depth zone)

Depth zone	Season									
	Winter (Jan.-March)		Spring (April-June)		Summer (July-Sept.)		Fall (Oct.-Dec.)		All seasons (Jan.-Dec.)	
	Species	Percent of total catch	Species	Percent of total catch	Species	Percent of total catch	Species	Percent of total catch	Species	Percent total ca
Inner zone 7-14 m. (4-7.5 fm.)	Atlantic croaker	51	Atlantic croaker	49	Atlantic croaker	48	Atlantic croaker	66	Atlantic croaker	52
	Sea catfish	10	Sea catfish	14	Sea catfish	8	Sea catfish	8	Sea catfish	10
	Southern kingfish	7	Sand seatrout	6	Sand seatrout	8			Sand seatrout	6
	Longspine porgy	5	Atlantic cutlassfish	5	Spot	7			Spot	5
			Spot	5	Atlantic cutlassfish	6				
Middle zone 27-46 m. (15-25 fm.)	Atlantic croaker	39	Longspine porgy	27	Longspine porgy	29	Atlantic croaker	40	Atlantic croaker	31
	Longspine porgy	22	Atlantic croaker	20	Atlantic croaker	21	Longspine porgy	20	Longspine porgy	2
			Inshore lizardfish	10	Blackfin searobin	5	Silver seatrout	6	Silver seatrout	
			Atlantic cutlassfish	7			Blackfin searobin	5	Blackfin searobin	
			Blackfin searobin	7			Spot	5		
			Sand seatrout	6						
Outer zone 64-110 m. (35-60 fm.)	Longspine porgy	31	Longspine porgy	38	Longspine porgy	54	Longspine porgy	23	Longspine porgy	3
	Inshore lizardfish	10	Blackfin searobin	11	Mexican flounder	6	Atlantic croaker	12	Blackfin searobin	
	Atlantic croaker	9	Atlantic croaker	9	Rock sea bass	6	Blackfin searobin	9	Atlantic croaker	
	Blackfin searobin	8	Rock sea bass	9	Blackfin searobin	5	Sand seatrout	9	Rock sea bass	
	Rock sea bass	5					Rock sea bass	7	Inshore lizardfish	
							Spot	7		
Entire shelf 7-100 m. (4-60 fm.)	Atlantic croaker	36	Atlantic croaker	28	Atlantic croaker	33	Atlantic croaker	41	Atlantic croaker	
	Longspine porgy	20	Longspine porgy	19	Longspine porgy	17	Longspine porgy	16	Longspine porgy	
			Sea catfish	6	Sand seatrout	6	Blackfin searobin	6	Sand seatrout	
			Sand seatrout	5	Sea catfish	6	Sand seatrout	5	Sea catfish	
			Inshore lizardfish	5	Spot	5				
			Blackfin searobin	5						
			Atlantic cutlassfish	5						

Table Q-14

Species that constituted five percent or more of the average catch by weight of all demersal fishes caught off Texas, 1962-1964

(Listed by season and depth zone)

	Season									
	Winter (Jan.-March)		Spring (April-June)		Summer (July-Sept.)		Fall (Oct.-Dec.)		All seasons (Jan.-Dec.)	
Depth zone	Species	Percent of total catch	Species	Percent of total catch	Species	Percent of total catch	Species	Percent of total catch	Species	Percent of total catch
Inner zone 7-14 m. (4-7.5 fm.)	Southern kingfish	26	Silver seatrout	26	Atlantic croaker	30	Southern kingfish	23	Atlantic croaker	20
	Spot	19	Atlantic croaker	15	Sand seatrout	9	Atlantic croaker	10	Silver seatrout	14
	Sand seatrout	12	Sea catfish	10	Silver seatrout	7	Sand seatrout	9	Southern kingfish	11
	Silver seatrout	7	Spot	7	Seat catfish	6	Silver seatrout	7	Sea catfish	7
			Southern kingfish	5	Southern kingfish	5	Sea catfish	5	Spot	7
			Atlantic cutlassfish	5			Shoal flounder	5	Sand seatrout	5
							Longspine porgy	5		
Middle zone 27-46 m. (15-25 fm.)	Longspine porgy	38	Inshore lizardfish	15	Longspine porgy	25	Longspine porgy	26	Longspine porgy	27
	Sand seatrout	8	Longspine porgy	15	Atlantic croaker	9	Atlantic croaker	12	Inshore lizardfish	9
	Inshore lizardfish	7	Shoal flounder	14	Inshore lizardfish	9	Shoal flounder	8	Shoal flounder	9
	Shoal flounder	7	Gulf butterfish	11	Silver seatrout	9	Spot	8	Atlantic croaker	7
	Rock sea bass	6	Rock sea bass	9	Sand seatrout	7	Inshore lizardfish	7	Sand seatrout	7
	Atlantic croaker	5	Silver seatrout	6	Shoal flounder	5	Silver seatrout	6	Silver seatrout	5
									Rock sea bass	5
Outer zone 64-110 m. (35-60 fm.)	Longspine porgy	29	Longspine porgy	26	Longspine porgy	26	Longspine porgy	27	Longspine porgy	27
	Wenchman	18	Inshore lizardfish	16	Inshore lizardfish	14	Inshore lizardfish	13	Inshore lizardfish	14
	Inshore lizardfish	12	Wenchman	12	Wenchman	12	Wenchman	12	Wenchman	14
	Mexican searobin	9	Rock sea bass	6	Mexican searobin	8	Mexican searobin	8	Mexican searobin	8
			Mexican searobin	6	Rock sea bass	6	Rock sea bass	5	Rock sea bass	5
Entire shelf 7-110 m. (4-60 fm.)	Longspine porgy	28	Silver seatrout	12	Atlantic croaker	17	Longspine porgy	24	Longspine porgy	21
	Inshore lizardfish	9	Longspine porgy	11	Longspine porgy	15	Atlantic croaker	8	Atlantic croaker	9
	Wenchman	8	Inshore lizardfish	9	Inshore lizardfish	7	Inshore lizardfish	8	Inshore lizardfish	9
	Sand seatrout	6	Gulf butterfish	7	Silver seatrout	6	Sand seatrout	6	Silver seatrout	7
	Mexican searobin	5	Atlantic croaker	6			Shoal flounder	5	Wenchman	5
			Shoal flounder	5					Sand seatrout	5
			Rock sea bass	5						

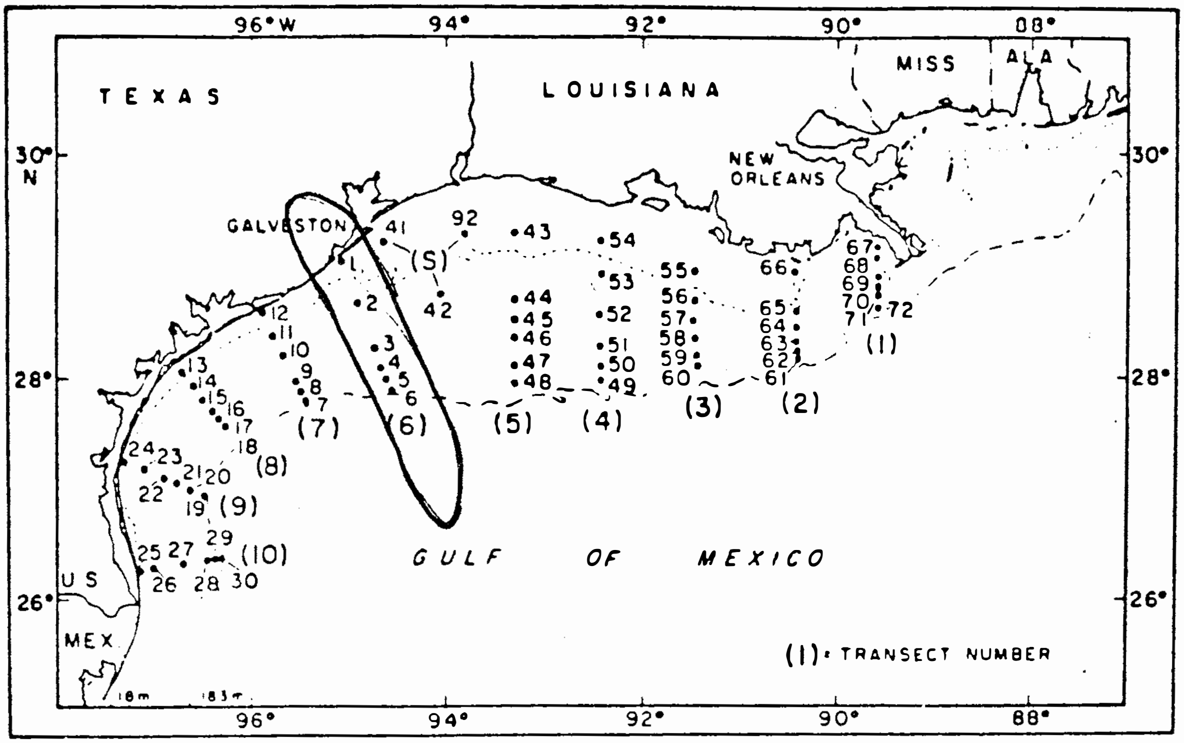


Figure Q-9 Station and transect (numbers) pattern in the northwestern Gulf of Mexico, 1961-62.

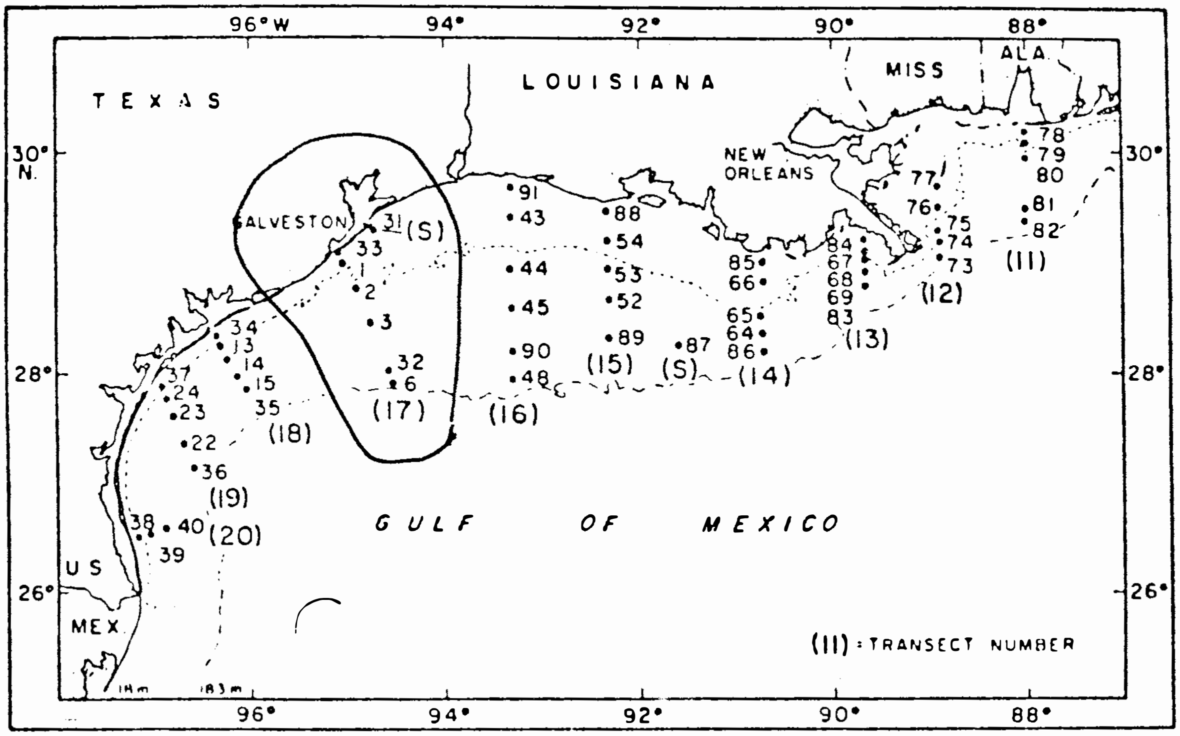


Figure Q-10 Station and transect (numbers) pattern in the northwestern Gulf of Mexico, 1963-65.

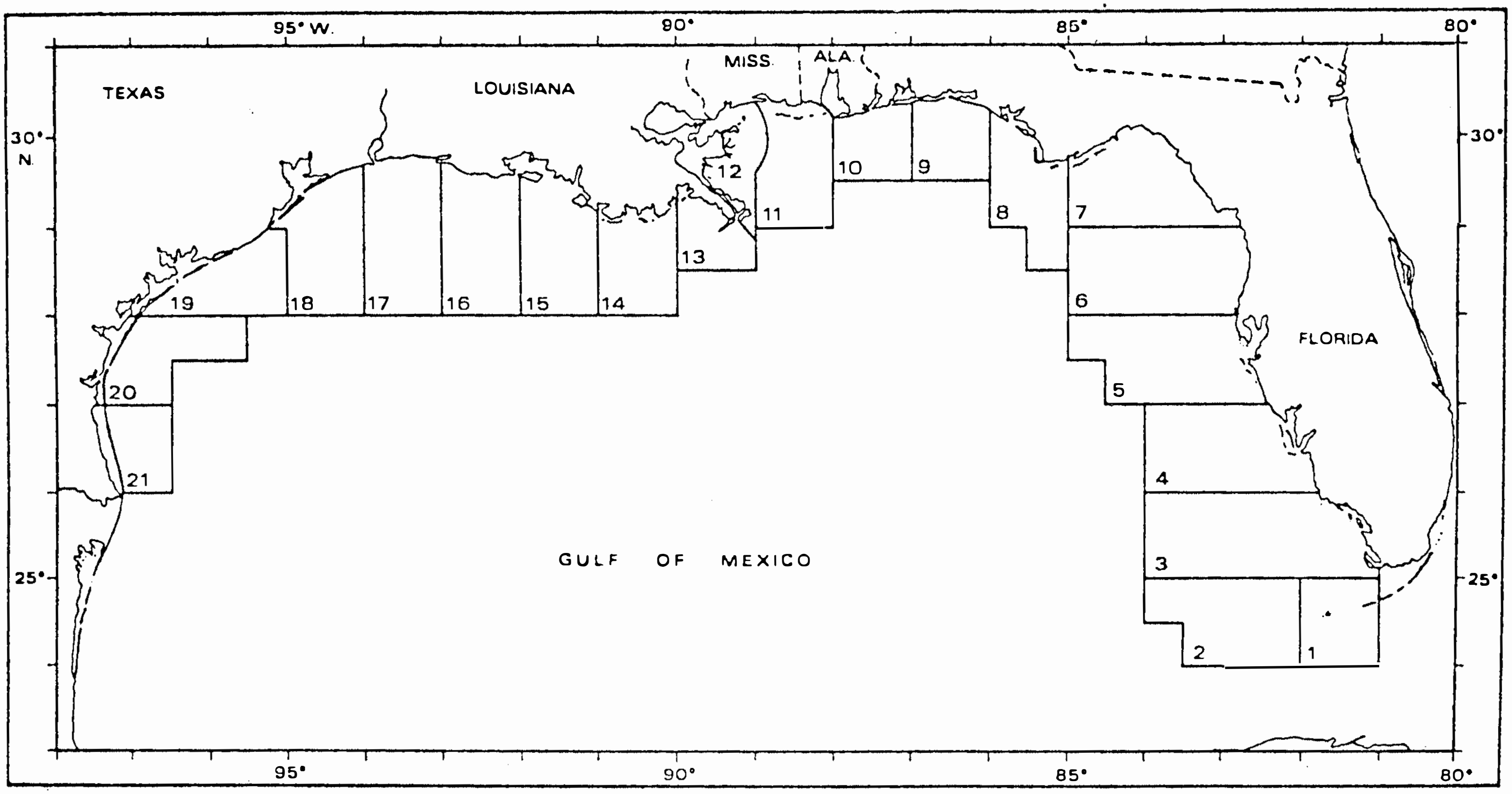


Figure Q-11 Statistical Zones.

Table Q-15

Geometric (G) and arithmetic (A) mean catch (number of individuals) per hour by station number, station code, period, depth zone, coordinate position, and statistical area.

Station Number	Station Code	Period	Depth Zone (Meters)	Latitude	Longitude	Statistical Area	Number of tows	G	A
31	W53	1963-65	7.3	$29^{\circ}19'$	$94^{\circ}41'$	18	28	29.7	78.2
33	W55	1963-65	7.3	$29^{\circ}03'$	$95^{\circ}06'$	18	32	45.3	140.7
1	W01	1961-65	13.7	$29^{\circ}01'$	$95^{\circ}05'$	18	61	102.4	181.6
41	W63	1961-62	13.7	$29^{\circ}12'$	$94^{\circ}45'$	18	17	131.4	181.5
42	W64	1961-62	27.5	$28^{\circ}43'$	$94^{\circ}03'$	18	17	38.3	200.7
2	W02	1961-65	27.5	$28^{\circ}40'$	$94^{\circ}56'$	18	60	169.7	385.2
3	W03	1961-65	45.8	$28^{\circ}18'$	$94^{\circ}46'$	18	59	86.9	272.3
4	W04	1961-62	64.0	$28^{\circ}05'$	$94^{\circ}41'$	18	12	5.5	8.8
32	W54	1963-65	73.2	$28^{\circ}00'$	$94^{\circ}38'$	18	22	67.5	16.7
5	W05	1961-62	82.3	$27^{\circ}58'$	$94^{\circ}38'$	18	23	5.3	13.9
6	W06	1961-65	109.8	$27^{\circ}55'$	$94^{\circ}36'$	18	29	1.9	5.7

Table Q-16

Geometric (G) and arithmetic (A) mean catch (number of individuals) per hour by depth zone.

Depth Zone (Meters)	Number of tows	G	A
7.3	142	29.1	101.7
13.7	189	73.4	178.6
22.9	24	127.7	289.5
27.5	191	141.5	326.5
45.8	193	75.1	218.2
64.0	62	28.2	103.4
73.2	48	8.8	25.6
82.3	72	14.0	44.4
109.8	71	4.5	19.2

Table Q-17

Geometric (G) and arithmetic (A) mean catch (number of individuals) per hour by year

Year	Number of Tows	Statistical Area 18	
		G	A
1961	93	75.3	237.9
1962	72	25.6	152.2
1963	80	30.5	157.3
1964	72	40.1	160.3
1965	43	61.6	167.4

Table Q-18

Geometric (G) and arithmetic (A) mean catch (number of individuals) per hour by month

Month	Number of Tows	Statistical Area 18	
		G	A
January	28	87.3	284.2
February	25	58.5	158.2
March	31	32.9	77.0
April	29	21.6	61.2
May	39	15.1	92.0
June	38	36.9	210.8
July	28	25.7	204.3
August	37	51.1	276.1
September	21	92.2	213.7
October	30	42.9	123.7
November	27	68.5	230.9
December	27	104.3	235.6

Table Q-19

Geometric (G) and arithmetic (A) mean catch (number of individuals) per hour by statistical area and species.

Statistical Area	Number of Tows	*Penaeus aztecus* (Brown Shrimp)		*Penaeus setiferus* (White Shrimp)		*Penaeus duorarum* (Pink Shrimp)		*Xiphopeneus kroyeri* (Seabob)	
		G	A	G	A	G	A	G	A
18	360	9.5	61.8	2.8	32.9	0.4	1.6	0.2	1.2
		Sicyonia brevirostris (Rock Shrimp)		*Sicyonia dorsalis*		*Sicyonia stimpsoni*		*Solenocera vioscai*	
		G	A	G	A	G	A	G	A
18	360	2.7	46.1	0.6	14.3	0.002	0.003	0.04	0.1
		Sicyonia atlantidus		*Trachypeneus similis*		*Trachypeneus constrictus*		*Parapenaeus longirostris*	
		G	A	G	A	G	A	G	A
18	360	0.004	0.01	2.1	20.2	0.01	0.6	0.01	0.03

Table Q-19a

Geometric (G) and arithmetic (A) mean catch (number of individuals) per hour by station number, station code, period, and species.

Station Number	Station Code	Period	Number of tows	*Penaeus aztecus* (Brown Shrimp)		*Penaeus setiferus* (White Shrimp)		*Penaeus duorarum* (Pink Shrimp)	
				G	A	G	A	G	A
1	W01	1961-65	61	7.2	67.5	30.5	80.4	0.4	0.9
2	W02	1961-65	60	74.2	174.3	0.3	3.0	1.8	7.0
3	W03	1961-65	59	30.8	78.7	0.04	0.2	0.1	0.8
4	W04	1961-62	12	1.7	3.6	0.0	0.0	0.0	0.0
5	W05	1961-62	23	4.6	11.1	0.0	0.0	0.0	0.0
6	W06	1961-65	29	1.8	5.2	0.0	0.0	0.0	0.0
31	W53	1963-65	28	1.2	5.1	19.1	68.4	0.2	0.3
32	W54	1963-65	22	4.5	7.5	0.0	0.0	0.0	0.0
33	W55	1963-65	32	2.2	27.8	26.6	99.5	0.4	0.8
41	W63	1961-62	17	8.0	43.1	49.3	96.9	0.2	0.3
42	W64	1961-62	17	8.8	39.1	0.0	0.0	0.7	1.9

ation mber	Station Code	Period	Number of tows	*Xiphopeneus kroyeri* (Seabob)		*Sicyonia brevirostris* (Rock Shrimp)		*Sicyonia dorsalis*	
				G	A	G	A	G	A
1	W01	1961-65	61	0.3	1.1	0.1	0.1	0.1	0.3
2	W02	1961-65	60	0.0	0.0	11.6	45.5	10.0	85.0
3	W03	1961-65	59	0.0	0.0	35.8	184.2	0.2	0.5
4	W04	1961-62	12	0.0	0.0	2.6	5.2	0.0	0.0
5	W05	1961-62	23	0.0	0.0	0.7	2.7	0.0	0.0
6	W06	1961-65	29	0.0	0.0	0.0	0.0	0.0	0.0
1	W53	1963-65	28	0.5	0.9	0.0	0.0	0.0	0.0
2	W54	1963-65	22	0.0	0.0	1.8	9.2	0.0	0.0
3	W55	1963-65	32	0.8	0.6	0.02	0.03	0.1	0.1
1	W63	1961-62	17	0.5	8.9	0.04	0.1	0.3	0.7
2	W64	1961-62	17	0.0	0.0	24.0	156.2	0.0	0.0

Table Q-19a (continued)

Station Number	Station Code	Period	Number of tows	*Sicyonia stimpsoni* G	*Sicyonia stimpsoni* A	*Solenocera vioscai* G	*Solenocera vioscai* A	*Sicyonia atlantidus* G	*Sicyonia atlantidus* A
1	W01	1961-65	61	0.0	0.0	0.0	0.0	0.0	0.0
2	W02	1961-65	60	0.0	0.0	0.01	0.02	0.02	0.1
3	W03	1961-65	59	0.01	0.02	0.1	0.2	0.0	0.0
4	W04	1961-62	12	0.0	0.0	0.0	0.0	0.0	0.0
5	W05	1961-62	23	0.0	0.0	0.1	0.1	0.0	0.0
6	W06	1961-65	29	0.0	0.0	0.2	0.6	0.0	0.0
31	W53	1963-65	28	0.0	0.0	0.0	0.0	0.0	0.0
32	W54	1963-65	22	0.0	0.0	0.0	0.0	0.0	0.0
33	W55	1963-65	32	0.0	0.0	0.1	0.2	0.0	0.0
41	W63	1961-62	17	0.0	0.0	0.0	0.0	0.0	0.0
42	W64	1961-62	17	0.0	0.0	0.0	0.0	0.0	0.0

Station Number	Station Code	Period	Number of tows	*Trachypeneus similis* G	*Trachypeneus similis* A	*Trachypeneus constrictus* G	*Trachypeneus constrictus* A	*Parapenaeus longirostris* G	*Parapenaeus longirostris* A
1	W01	1961-65	61	5.2	30.9	0.1	0.4	0.0	0.0
2	W02	1961-65	60	14.8	67.9	0.1	2.4	0.0	0.0
3	W03	1961-65	59	0.9	7.8	0.1	0.2	0.0	0.0
4	W04	1961-62	12	0.0	0.0	0.0	0.0	0.0	0.0
5	W05	1961-62	23	0.0	0.0	0.0	0.0	0.0	0.0
6	W06	1961-65	29	0.0	0.0	0.0	0.0	0.0	0.0
31	W53	1963-65	28	0.8	2.6	0.3	0.5	0.1	0.4
32	W54	1963-65	22	0.0	0.0	0.0	0.0	0.0	0.0
33	W55	1963-65	32	1.1	5.8	0.3	0.6	0.02	0.03
41	W63	1961-62	17	5.0	31.7	0.0	0.0	0	
42	W64	1961-62	17	1.2	3.5	0.0	0.0		

Table Q-20

Geometric (G) and arithmetic (A) mean catch (number of individuals) per hour by species, statistical area, and depth zone. Data resulted from monthly sampling in 1961-1965.

tatistical area	STATION DEPTHS (Meters)																	
	7.3		13.7		22.9		27.5		45.8		64.0		73.2		82.3		109.8	
	G	A	G	A	G	A	G	A	G	A	G	A	G	A	G	A	G	A
Penaeus aztecus (brown shrimp)																		
18	(60)1/		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	1.7	17.2	7.4	62.2	-	-	47.0	144.5	30.8	78.7	1.7	3.6	4.5	7.5	4.6	11.1	1.8	5.2
Penaeus setiferus (white shrimp)																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	22.8	85.0	33.9	84.0	-	-	0.2	2.3	0.04	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Penaeus duorarum (pink shrimp)																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.3	0.6	0.3	0.7	-	-	1.5	5.9	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xiphopeneus kroyeri (seabob)																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.6	3.6	0.3	2.8	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sicyonia dorsalis																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.03	0.01	0.1	0.3	-	-	5.5	66.2	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sicyonia atlantidus																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.0	0.0	0.0	0.0	-	-	0.02	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solenocera vioscai																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.03	0.1	0.0	0.0	-	-	0.01	0.01	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6

Table Q-20 (cont.)

Statistical area	STATION DEPTHS (Meters) 7.3 G	7.3 A	13.7 G	13.7 A	22.9 G	22.9 A	27.5 G	27.5 A	45.8 G	45.8 A	64.0 G	64.0 A	73.2 G	73.2 A	82.3 G	82.3 A	109.8 G	109.8 A
Sicyonia stimpsoni																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.0	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trachypeneus constrictus																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.3	0.6	0.1	0.3	-	-	0.1	1.8	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sicyonia brevirostris (rock shrimp)																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.01	0.02	0.1	0.1	-	-	13.7	70.0	35.8	184.2	2.6	5.2	1.8	9.2	0.7	0.3	0.0	0.0
Parapenaeus longirostris																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	0.1	0.2	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trachypeneus similis																		
18	(60)		(78)		(0)		(77)		(59)		(12)		(22)		(23)		(29)	
	1.0	4.3	5.2	31.0	-	-	9.2	53.7	1.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1/ number of tows

Table Q-21 shows the commercial catches of shrimp for statistical area 18 for the 1970-1974 years. In all cases, the offshore areas yielded the largest catches, indicating the greater importance of the offshore area for brown shrimp and also for pink shrimp.

NOAA (1976) described the penaeid larvae off the northwest Texas coast (See Figure Q-12 for location of transect 7 and Table Q-22 for precise location of each station on transect 7) and found distinct seasonal trends (See Figure Q-13). In the nearshore zone (7.3-13.7 m) the larval abundance was characterized by two seasonal peaks, one in spring and one in fall, with the larvae generally restricted to April through October in this zone. This time period coincides with the spawning period of the white shrimp (Lindner and Anderson 1956).

The depth zones from 22.9 to 82.3 meters showed similar trends, with spring and fall-early winter peaks and the greatest populations found in the fall. Larvae were present during all seasons, and the fall-winter peak occurred later in the year with increasing depth, probably associated with the movement of brown shrimp offshore with cooling temperature, as most of these larvae are attributed to the brown shrimp spawnings.

Higgins (1937) has previously shown, from tagging experiments, that white shrimp move offshore in the winter in Louisiana.

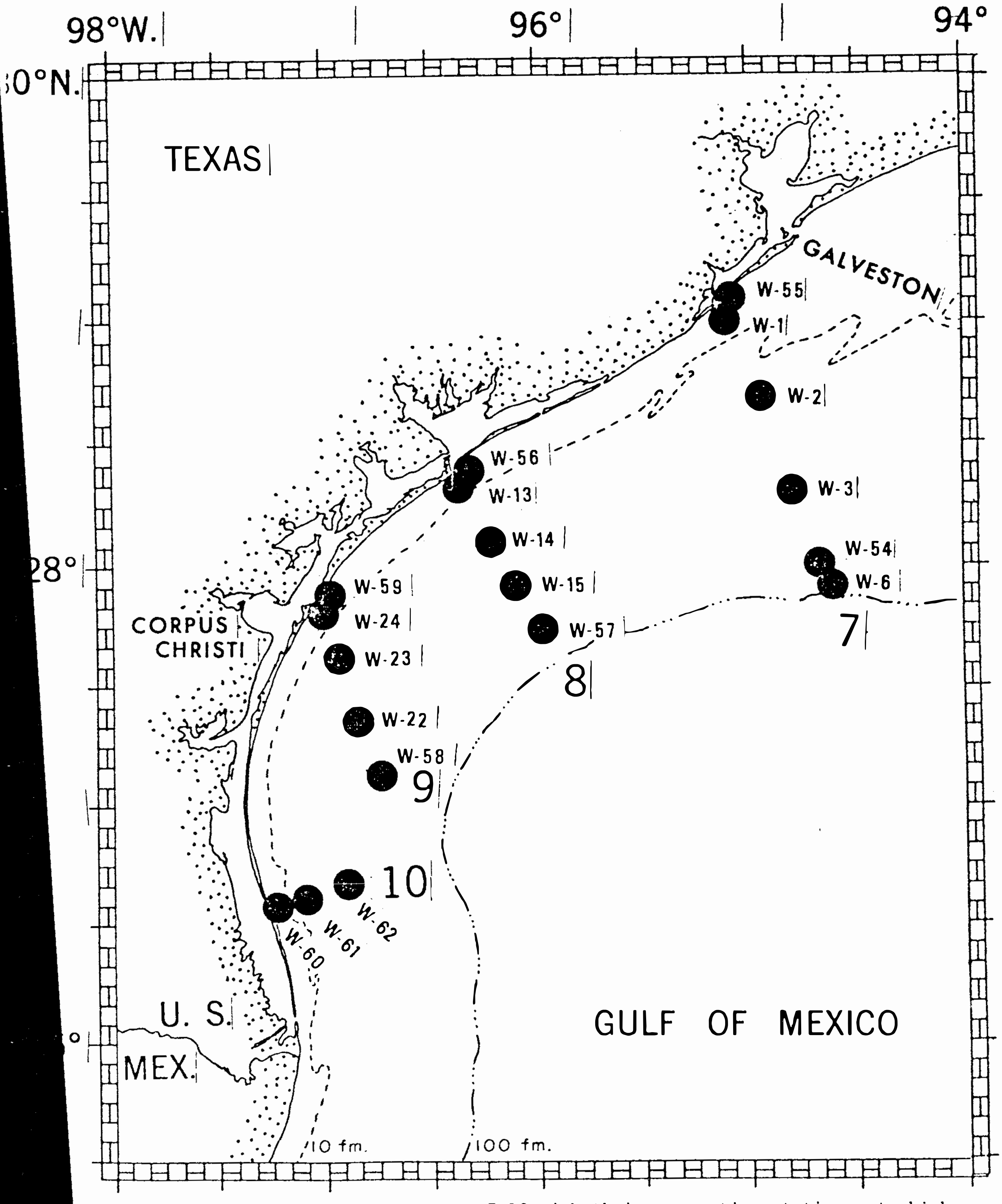
The zone from 82.3 to 109.7 meters showed greatly reduced numbers and probably represents the outer limits of the brown shrimp spawning grounds. Seasonal trends were similar to those of the intermediate zones, but catches were spotty.

Table Q-23 shows that larval populations increased out to 45 meters and then declined further offshore. Figure Q-14 shows the areal distribution and relative abundance of Penaeus spp. larvae for the entire south Texas OCS study area. A further delineation of the data is given in Tables Q-24 and Q-25 for the 1962 and 1963-1965 years respectively for the transects off Galveston. In the 7.3-13.7 meter depth zone, larvae were present from April through August with maximum abundance varying depending on the particular year. In the 22.9-27.5 meter depth, larval populations occurred in late summer with a lesser peak in spring. Winter populations were lowest with no larvae found during many years. Two similar peaks are also seen in the 45.8 meter depth, with the largest populations later in fall than for the previous zone. The zones in the 64-109.7 meter range showed decreasing populations with increasing depth, with only one population peak (fall through early winter). Few larvae were usually present from February to June.

Table Q-21

Commercial shrimp catch (pounds, heads-off) by statistical area, depth zone (offshore vs. inshore), year, and species, and value of catch by year, and statistical area.

Statistical Area	Depth Zone	Penaeus aztecus (Brown Shrimp)	Penaeus setiferus (White Shrimp)	Penaeus duorarum (Pink Shrimp)	1/ Other	$ Value of Catch
			1970			
18	Offshore	2,849,580	2,483,781	2,065	-	4,891,854
	Inshore	966,459	2,351,060	-	-	1,894,112
			1971			
18	Offshore	7,227,439	2,503,552	655	-	11,391,345
	Inshore	1,273,372	1,923,925	-	-	2,054,770
			1972			
18	Offshore	4,230,678	2,088,123	-	-	8,964,462
	Inshore	902,461	2,070,394	-	-	2,749,743
			1973			
18	Offshore	1,854,800	2,643,913	1,105	14,120	8,575,49
	Inshore	593,411	2,647,870	-	-	3,342,48
			1974			
18	Offshore	8,086,470	3,280,142	-	46,882	15,244,5
	Inshore	883,640	1,553,479	-	80	1,811,3



igure Q-12 The location of transects 7-10 with their respective stations at which monthly sampling was conducted between January 1963 and December 1965.

Table Q-22

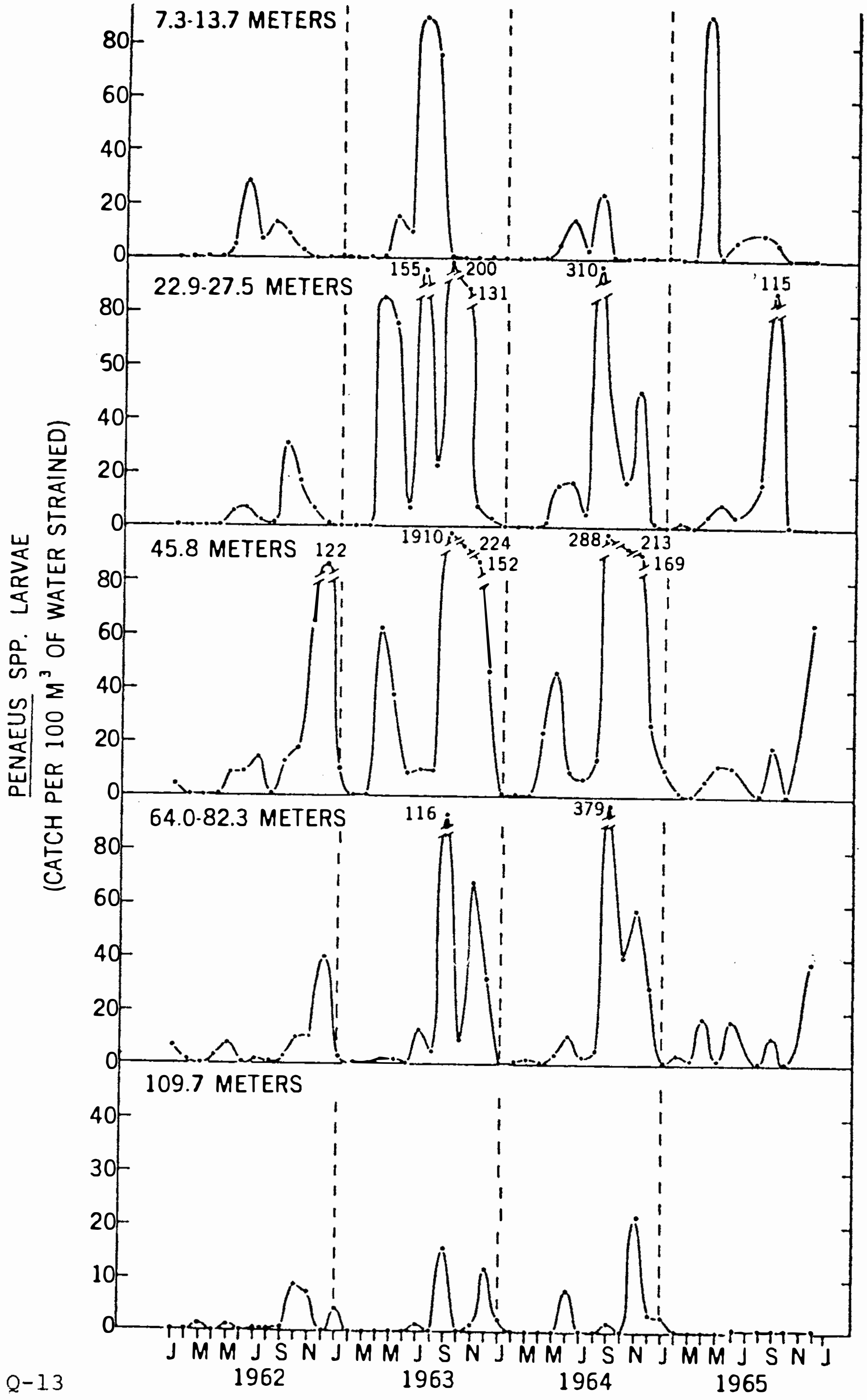
Stations at which 20-minute plankton hauls were made monthly in 1962 and 1963-1965.

1962				1963-1965			
Stations	Depth (m)	Location		Stations	Depth (m)	Location	
		Latitude	Longitude			Latitude	Longitude
W- 1	13.7	29°01'	95°05'	W-55	7.3	29°03'	95°06'
W- 2	27.5	28°40'	94°56'	W-53	7.3	29°19'	94°41'
W- 3	45.8	28°18'	94°46'	W- 1	13.7	29°01'	95°05'
W- 4	64.0	28°05'	94°41'	W- 2	27.5	28°40'	94°56'
W- 5	82.3	27°58'	94°38'	W- 3	45.8	28°18'	94°46'
W- 6	109.8	27°55'	94°36'	W-54	73.2	28°00'	94°38'
				W- 6	109.8	27°55'	94°36'

Table Q-23

Average yearly catch (#/100 m^3) of *Penaeus* spp. larvae by depth zones over a 4-year period, 1962-1965

Depth Zones (Meters)	1962	1963	1964	1965	4-year Average
7.3-13.7	5.0	15.5	4.1	8.9	8.3
22.9-27.5	6.9	57.6	48.3	14.8	31.9
45.8	25.0	218.0	71.4	14.4	82.2
64.0-82.3	7.6	24.7	54.6	10.4	24.3
109.7	2.1	3.6	3.6	0.3	2.4



ure Q-13

Abundance trends of Penaeus spp. larvae by depth zones, 1962-1965.

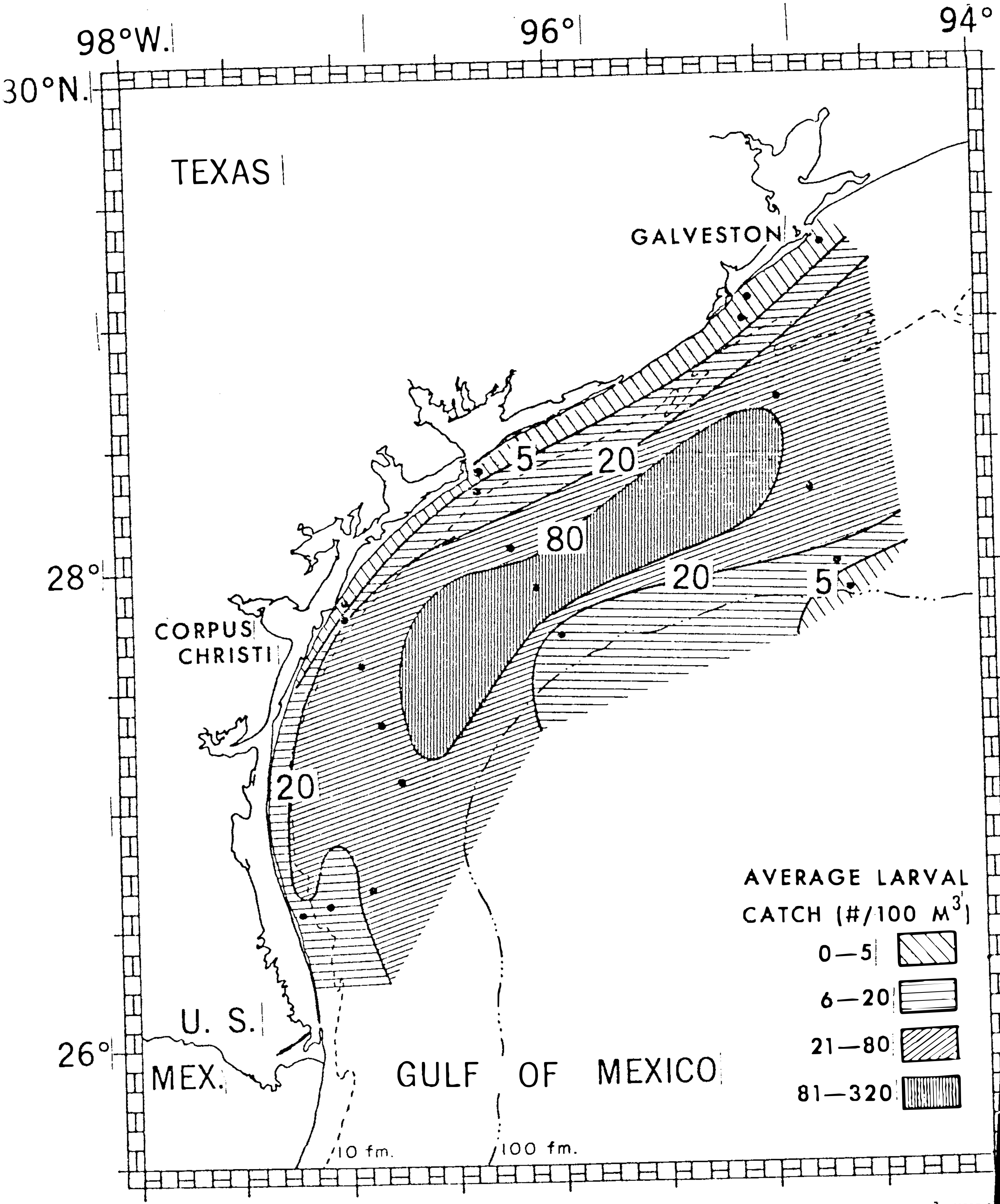


Figure Q-14 Average areal distribution and relative abundance of Penaeus spp. larvae over the south Texas OCS study area. Data are derived from monthly catches over a 3-year period, 1963-1965.

Table Q-24. Average monthly catch (#/100 m^3) of *Penaeus* spp. larvae by stations (1962).

	DEPTH					
	13.7m	27.5m	45m	64.0-109.7m		
	STATIONS					
Month-Year	W-1	W-2	W-3	W-4	W-5	W-6
01-62	0.0	0.0	0.0	34.1	0.0	0.0
02-62	0.0	0.0	0.0	20.0	0.0	0.0
03-62	0.0	0.0	0.0	0.0	0.0	0.0
04-62	0.0	0.0	0.0	0.0	0.0	0.0
05-62	14.7	8.3	13.7	0.0	0.8	0.0
06-62	0.0	0.0	1.9	-	0.0	0.0
07-62	1.6	1.3	17.3	0.0	0.0	0.0
08-62	39.8	2.7	0.0	0.0	0.0	0.7
09-62	0.0	46.8	2.7	-	-	2.9
10-62	3.2	8.1	0.0	3.0	6.5	0.8
11-62	0.0	0.0	12.0	31.0	3.6	0.0
12-62	0.0	0.0	34.7	280.6	-	-

— No sample taken.

Table Q-25. Average monthly catch (#/100m^3) of Penaeus spp. larvae by stations (1963-1965)

	DEPTH						
	7.3-13.7m			22.9-27.5	45m	64.0-109.7m	
Month-Year	STATIONS						
	W-53	W-55	W-1	W-2	W-3	W-54	W-6
01-63	1/	-	0.0	0.0	20.0	3.9	1.4
02-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03-63	0.0	0.0	4.0	0.0	0.0	0.0	0.0
04-63	0.0	0.0	0.0	3.1	40.8	0.0	0.0
05-63	0.0	0.0	0.0	228.8	93.2	0.0	0.0
06-63	16.0	40.0	10.5	10.0	20.0	0.0	0.0
07-63	0.0	0.0	35.2	10.2	14.8	28.8	1.3
08-63	0.0	0.0	0.0	-	-	-	-
09-63	0.0	0.0	0.0	976.0	1244.4	152.6	15.8
10-63	0.0	0.0	0.0	13.0	181.3	1.6	0.0
11-63	0.0	0.0	0.0	11.2	173.6	42.4	1.3
12-63	0.0	0.0	0.0	7.4	70.1	20.3	12.0
01-64	0.0	0.0	0.0	0.0	0.0	0.0	2.3
02-64	-	0.0	0.0	0.0	0.0	0.0	0.0
03-64	0.0	0.0	0.0	0.0	0.0	0.0	0.0
04-64	0.0	0.0	0.0	0.0	38.0	0.0	0.0
05-64	0.0	0.0	5.9	27.9	25.4	0.0	0.0
06-64	0.0	20.8	0.0	43.2	31.8	33.3	7.7
07-64	5.6	0.0	5.2	2.1	12.0	1.4	0.0
08-64	3.8	0.0	0.0	912.7	14.4	5.1	0.0
09-64	0.0	0.0	0.0	91.4	22.5	13.9	1.7
10-64	0.0	0.0	0.0	6.0	115.8	4.1	0.0
11-64	-	0.0	-	34.7	250.6	94.6	21.4
12-64	0.0	0.0	0.0	1.7	28.4	16.6	3.3
01-65	0.0	0.0	0.0	0.0	-	0.0	2.9
02-65	0.0	0.0	0.0	4.6	3.3	4.3	0.0
03-65	0.0	0.0	0.0	0.0	0.0	0.0	0.0
04-65	0.0	13.8	14.0	0.0	0.0	0.0	0.0
05-65	0.0	0.0	3.9	29.0	3.6	4.6	0.0
06-65	32.0	0.0	0.0	21.0	0.0	0.0	0.0
07-65	-	-	-	-	0.0	-	-
08-65	0.0	0.0	0.0	18.6	0.0	0.0	0.0
09-65	0.0	0.0	0.0	10.3	14.3	-	-
10-65	-	-	-	-	0.0	-	-
11-65	-	-	-	-	0.0	-	-
12-65	0.0	0.0	0.0	0.0	88.1	16.1	0.0

1/ No samples taken.

Diurnal vertical migrations of planktonic crustacea are well known, consisting of an evening ascent, a midnight sinking, a dawn rise to near optimum light conditions and a subsequent decrease to daytime depth (Cushing (1950).

Temple and Fischer (1965) reported on the distribution of penaeid meroplankton at the 36.5 meter depth contours approximately fifty miles south of Galveston. Samples were taken at four hour intervals at each of three depths (2, 18 and 34 meters from surface). They state that brown shrimp spawn in the open Gulf as far as 110 miles offshore (up to 110 meter **contour**). The eggs are slightly more dense than sea water and are deposited on the bottom. After hatching, young planktonic shrimp go through 3 larval (nauplii, protozeal and mysis) and several post-larval stages and enter the bays as advanced postlarvae, where they grow to subadult size and migrate offshore. The authors state that the water currents of the northwest Gulf may be of considerable importance in the survival of the planktonic stages, because the currents vary with depth. Figure Q-15 shows the vertical distribution at each date for all stages combined. The abundance varied with date but depth distribution was similar over all dates. The data for all stages combined showed that immature penaeids were two to four times as abundant at the 18-34 meter depths than at 2 meters. The protozeal and mysis stages were frequently found in deeper portions of the water column while the postlarvae occurred most frequently in the upper portion. The vertical distribution of the protozea and mysis stages found here agrees well with the observations of Russell (1925)and Heegaard (1953), the latter reporting on the larval stages of P. setiferus. Thus, the vertical distribution of the larvae reversed with age. During November, when no stratification of the water column existed, larvae of all stages were equally distributed throughout the water column due to vertical mixing of the water column. All three summer collections showed the presence of a thermocline and vertical differences for each planktonic stage.

Distribution (Figure Q-16) showed no change diurnally for November due to mixing of the water column, while on all other dates all stages extended their distribution into the surface layer at darkness, with mysis and postlarval stages appearing to migrate at an earlier hour, and to remain in the surface layer longer than did the protozeal stages. Again the results agree with those of Russell (1925) who reported that decapod larvae in general extended their range into the surface layer with darkness. Of the four dates, larval abundance was lowest in September, and, except for November, night catches exceeded day catches, being twice as great during June and July.

Figure Q-15 Depth distribution of immature (planktonic) penaeids.

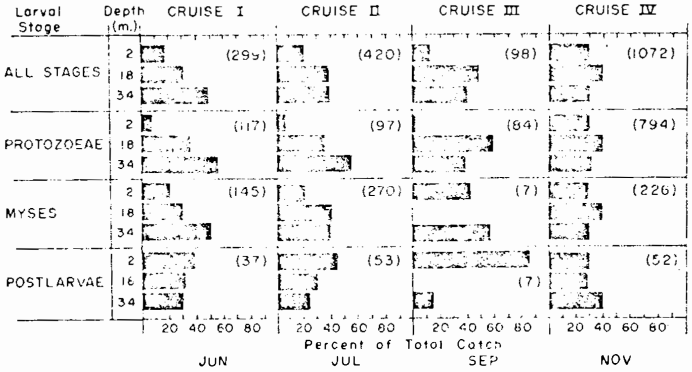
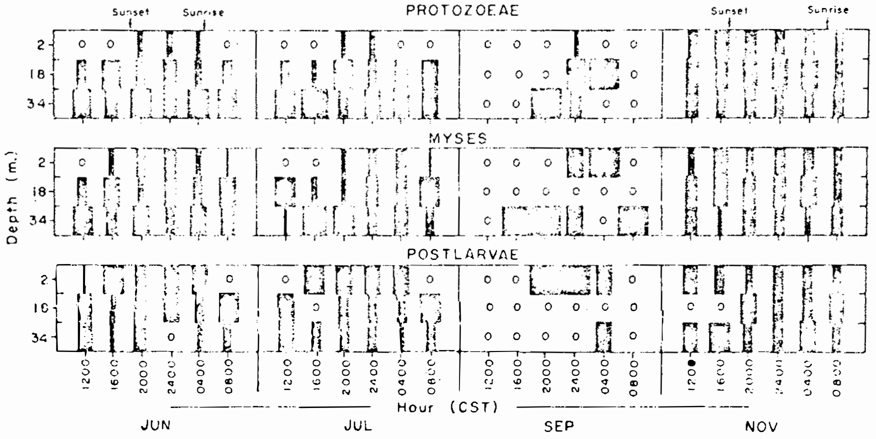


Figure Q-16 Variations in the vertical distribution of immature (planktonic) penaeids over a 24-hour period.



As is clearly shown by Gunter (1967), the species that dominate the fisheries of the Gulf of Mexico are dependent on the estuarine system for support during at least some part of their life cycle. Commercially important species include one or two species of menhaden (*Brevoortia patronus* and *B. gunteri*), two species of croaker (*Micropogon undulatus* and *Leiostomus xanthurus*), three species of shrimp (*Penaeus setiferus*, *P. aztecus*, and *P. duorarum*), the blue crab (*Callinectes sapidus*), and the oyster (*Crassostrea virginica*). Except for the oyster, all these species utilize open Gulf waters at certain times of the year either to spawn or to avoid environmental (especially temperature) stresses. Although there are large temporal differences in migration patterns between species, the general trend is for movement to the Gulf in fall and return to the bays from mid-winter to April. The mature mullet, however, returns to the coast from offshore immediately after spawing in early fall. As will be seen below, year to year differences are often large, especially in relation to period of maximum abundance, indicating that spawning seasons vary over a considerable period of time. However, in addition to using the offshore for spawning, many organisms also utilize it for refuge from adverse environmental conditions. Thus, the open Gulf and estuaries are both important in these life histories, and should be viewed as one continuous system.

Gunter et al. (1964) state that it is widely known that fauna in estuaries change seasonally as the isohaline lines move in and out with wet and dry seasons, and the influx of high salinity organisms into the northern Gulf coast bays reaches a peak in the fall during a time when temperatures are beginning to drop. As temperatures continue to drop, many of these motile forms leave the bays for the open Gulf. This may account for the different seasonal patterns of abundance reported for certain Gulf species by different authors.

Temperature also seems responsible for the seasonal appearance of migrant species of fishes such as the spanish mackeral, bluefish, and jack, which generally appear in the late spring and depart from coastal waters in fall.

Members of the croaker family (including the sea trout, drum, and Atlantic croaker) are the most numerous fishes collected in Texas coastal waters. Two species, the common croaker *Micropogon undulatus* and the spot *Leiostomus xanthurus* make up 75% of the catch of "industrial fishes". These species move into the saline waters of the Gulf from October through December (Figure Q-17). Most fishes then return to the bays from February to April (Gunter, 1967). In the Sabine District, approximately 5,000 pounds of croaker-type fish were caught for the period January - August 1976. The dollar value of this catch exceeds $100,000 (NOAA, 1976)

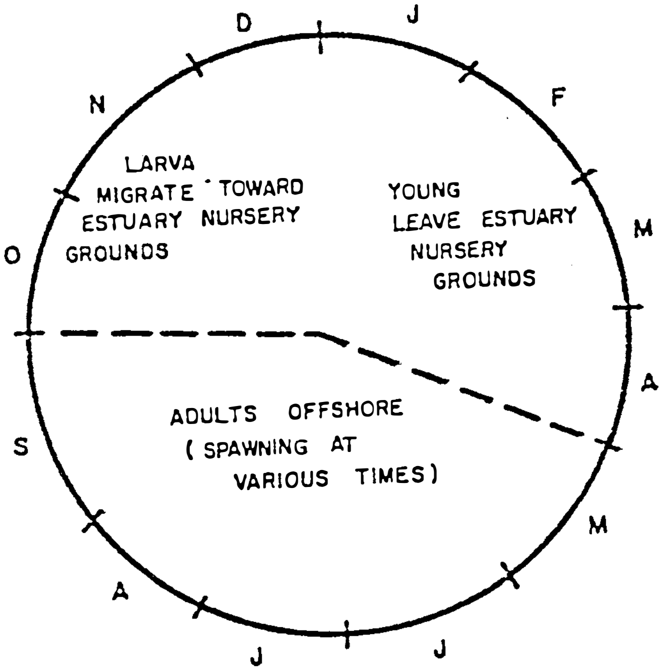


Figure Q-17 Idealized Life Cycle Diagram of Typical Gulf Fishes

SOURCE: Smith, A.L., 1971 Autecological Study of the Marsh Grass (Scolochloa festucacea), Willie Link, Ph.D. Dissertation, Department Range Science, Texas A&M University, College Station, Texas

Gunter (1945) found the croaker to be most abundant in summer and least in winter in Texas Gulf coast bays and shallow waters. Hildebrand (1954) did not find croakers abundant on the offshore brown shrimp grounds, although, like the spot, they were found in deeper water in the winter. Croakers were found to be extremely abundant off Sabine in June. Polychaete worms seemed to be the preferred food. Data presented earlier, (Moore et al., 1970) seem to confirm the greater abundance of this species in the shallow waters, especially off Louisiana.

Other important commercial fishes whose seasonal migrations bring the young into estuarine waters include: the mullet (*Mugil cephalus*) and the menhaden (*Brevoortia patronus* and *B. gunteri*).

Roe mullet are found around the estuary or lagoon mouths during late October to mid-November, and are reported to spawn during late fall. Arnold (1958) found spawning mullet 40-50 miles off the coast, so it appears that they range widely over the coast. Post-larvae appear by mid December, and drift into the estuaries. They return to the estuaries soon after spawning. Mullet are detritivores, feeding on the surface of the muddy bottoms.

Menhaden use the estuaries for more than half of their first year (Reintjes and Pacheco, 1966). They spawn in the Gulf, and after hatching, the larvae,which feed selectively on zooplankton, move into the estuaries. They are filter feeders as postlarvae, feeding predominantly on planktonic diatoms and dinoflagellates. They range out to 25 miles offshore, but are predominantly near the shore (Christmas and Gunter, 1960). Seventy percent of the 2 billion pounds of menhaden caught in the Gulf were taken in 5-24 $^{o}/00$ salinity, but *B. patronas* has been found in salinities up to 60 ppt salinity in the Laguna Madre.

Reintjes (1970) presents the results of a study of menhaden spawning grounds (See Figures Q-18 and Q-19. The area of the brine disposal is seen as the area of maximum density of menhaden eggs, and Figure Q-19 shows that peak egg abundance occurred in December, with eggs present from October through March. This temporal pattern is similar to that observed on the South Atlantic coast (Reintjes, 1961), Higham and Nicholson (1964), while further north spawning takes place from May through October off New England and New York (Perlmutter 1939, Whentland 1956, Richards 1959, Herman 1963, Bigelow and Schroeder 1953, Marak and Colton 1961). Larvae enter estuaries from May to October in the New England states and October to June in the mid-Atlantic states (Hildebrand and Schroeder 1928, Pearson 1941) and December to May in the South Atlantic states (Deubler 1958, Tagatz and Dudley 1961), with the latter probably the situation in the Gulf coast.

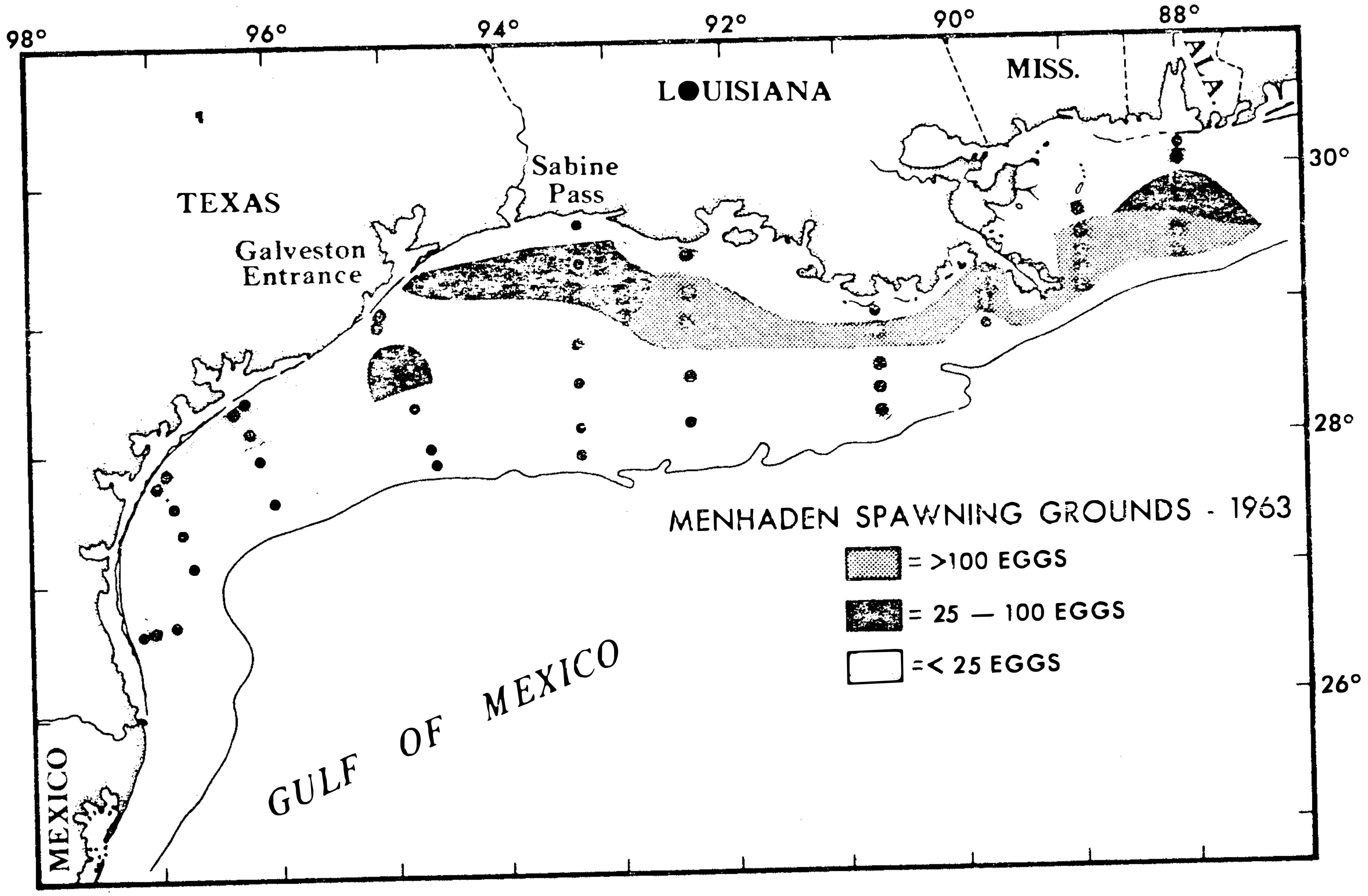


Figure Q-13 The winter spawning grounds of the Gulf menhaden (adapted from Reintjes, 1970).

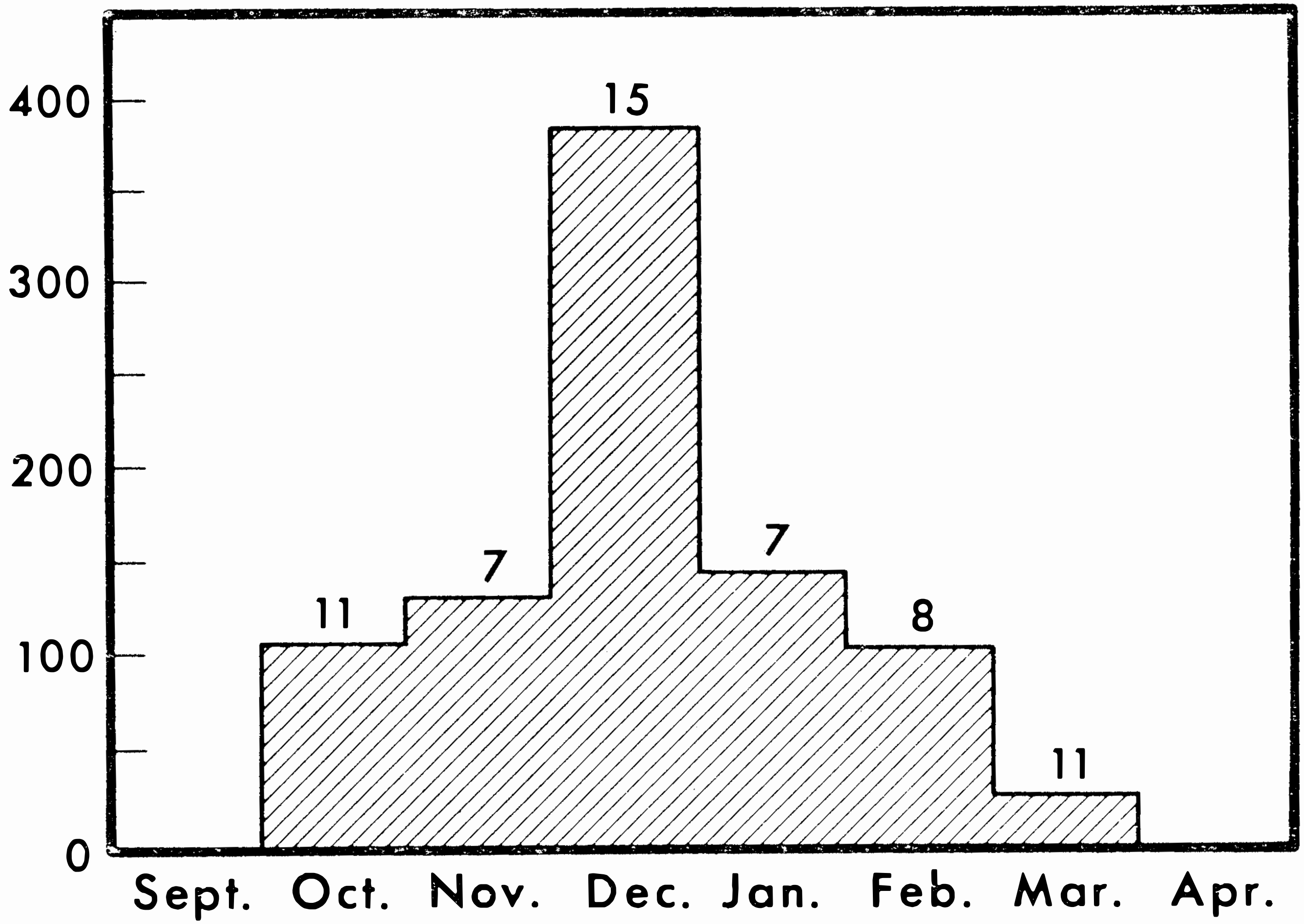


Figure Q-19 Distribution of menhaden eggs in the northern and western Gulf of Mexico, 1963. The numbers represent the number of collections containing eggs (adapted from Reintjes, 1970).

Young and adult menhaden can tolerate a wide range of salinities, from fresh water to high salinity lagoons (Hildebrand 1948, Gunter 1956). Darnell (1958) found juvenile Gulf menhaden feeding on phytoplankton, small crustaceans, and detritus and grazing directly on Anabaena (blue-green algae). Peck (1894) and Anderson, Jones, and Odum (1958) found menhaden with stomach contents indicative of bottom feeding (detritus, sand, mud, clay, and benthic diatoms). It appears that menhaden form the food base of a number of marine carnivores (Ellison 1951, Bigelow and Schroeder 1953).

Although many species of crabs are present in Texas coastal waters, the blue crab (Callinectes sapidus) is the only crab extensively exploited by man. In contrast to the shrimp, adult blue crab populations are harvested in near shore bays as well as on the inner shelf of open Gulf waters. Distribution of total crab catch in Texas in 1971, is shown in Figure Q-20 . Sabine Lake and similar bay systems are responsible for 70% of the total Gulf blue crab catch. The Sabine District alone was responsible for approximately 360 thousand pounds of blue crabs, valued at 2.1 million dollars for the period January-August 1976 (NOAA, 1976).

Darnell (1959), Dougherty (1952), Gunter (1950), and Hildebrand (1954) are primarily responsible for investigating and documenting the life history of the blue crab on the Texas coast. Generally, the life span varies from two to three years. Females may spawn more than once, producing from one to three million eggs per spawning. Fertilization of the eggs takes place in the passes and estuaries. After mating, the female carries the eggs to deeper, more saline Gulf waters for deposition. Adult males remain in the landward waters, where they may mate with maturing females. During exceptionally dry years, many of the fertilized females may remain in the more saline estuaries and lagoons. The eggs develop and hatch in about 15 days in the Gulf waters. After hatching, larval crabs called "zoeae" migrate via the currents through the coastal passes to the estuaries and lagoons, where they feed and grow to maturity. During the second summer, at the age of 12 to 14 months, the crabs mature and mate. Critical survival periods occur during the inland migration of the larva in the fall and spring.

The mating apparently takes place in warmer months, with the females noticeably absent from the estuaries in February and March, 2 - 3 months before the appearance of the spring young, and again in August and September before fall recruitment. The females are relatively scarce in the estuaries in the winter. and may overwinter offshore. During the long spawning season successive waves of different instars may appear in the estuary.

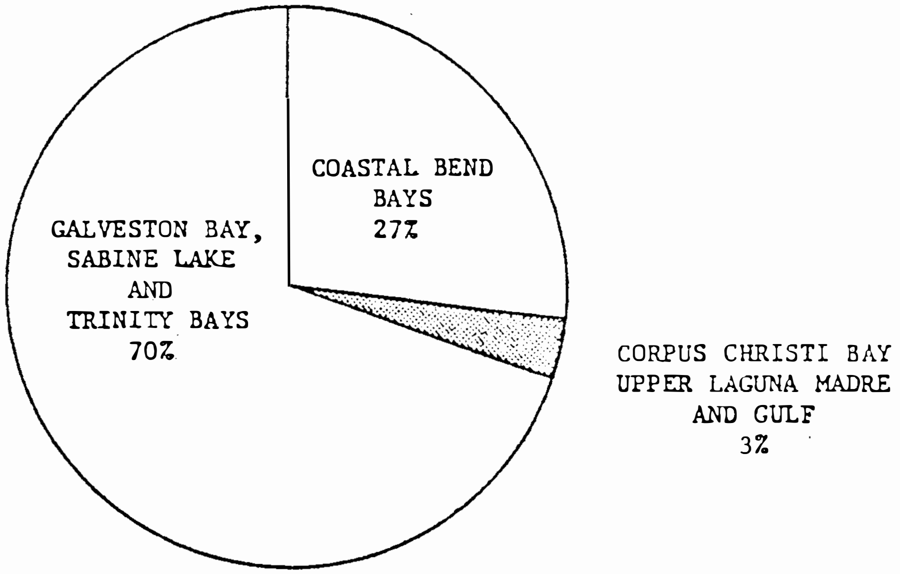


Figure Q-20 Distribution of Total Crab Catches in Texas, 1971 (Boykin, 1972).

Daugherty (1952) states that in mild years, spawning can take place all year, but during most years it is spread over the warmer months with 2 peaks, one in the spring and the other in fall, either of which can be larger.

Food habits of the blue crab have been summarized by Van Ensel (1958) and Darnell (1958). Zoea larvae have been found to grow successfully only when fed yellow dinoflagellates. The megalops are omnivorous, as are the postlarvae. The blue crab is cannibalistic. Darnell (1959) concluded that in Lake Pontchartrain the species is a detritivore, bottom predator, and general scavenger.

Darnell (1959) found some indication of a diurnal pattern of activity in the blue crabs, with maximum individuals taken during dark periods.

Both Gunter (1950) and Hildebrand (1954) found blue crabs very abundant in the white and brown shrimp zones.

The American oyster (Crassostrea virginica) occurs in estuaries with salinities ranging from 10 to 30 ppt. The commercial harvest distribution is centered in Galveston Bay, Sabine Lake, and Trinity Bays (See Figure Q-21). Oyster catches have declined over the past three years from 4.6 million pounds to less than 4.0 million in 1972.

Maturation of gonads in the oyster occurs in the early spring, usually February and March. As the gonads enlarge and develop, the oyster assumes a "milky" appearance. As the water temperatures reach 24°C (75°F), usually from April to October, spawning is triggered. Spawning by one oyster stimulates others to spawn. Therefore, the majority of oysters in an area may be spawning at the same time.

The sperm and eggs are expelled out into the water, where fertilization occurs. After fertilization, the eggs undergo division and many-celled embryos, capable of free swimming, are formed. A "shell" begins forming and the miniature oyster larva, known as a "spat," settles to the bottom in search of a clean, firm substrate on which to cement itself. Unless a suitable attachment site is found, the spat will die. Once attached it remains for life. As adults, oysters get fat in the winter and lean in the summer and fall after they have spawned. It appears that the fatness of the oysters corresponds to the peak bloom of plankton organisms, which occurs during the winter and spring (Gunter, 1967). Two critical periods exist for oysters: (1) the winter-spring, when highest quality is attained from plankton blooms, and (2) immediately after spawning, when the larvae may exhibit vertical migration in the water column before settling as spat.

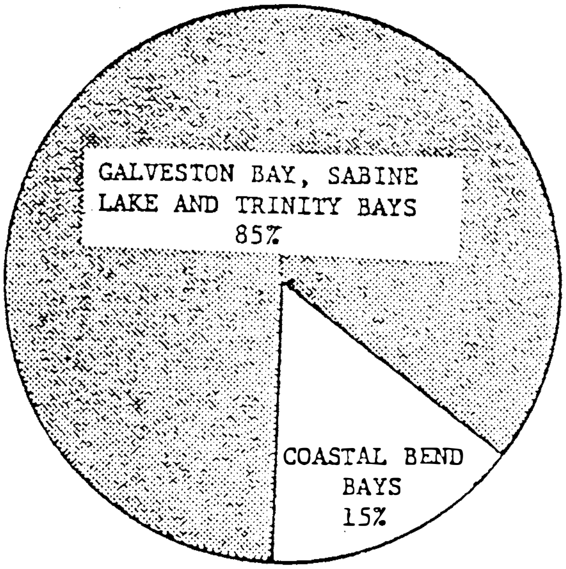


Figure Q-21 Distribution of Total Oyster Harvest in Texas, 1971 (Boykin, 1972).

During late spring and early summer, migrant species arrive along the Gulf coast shores and depart in the fall in response to cooling waters. Included in this group are Spanish mackeral, bluefish, jack, and cobia.

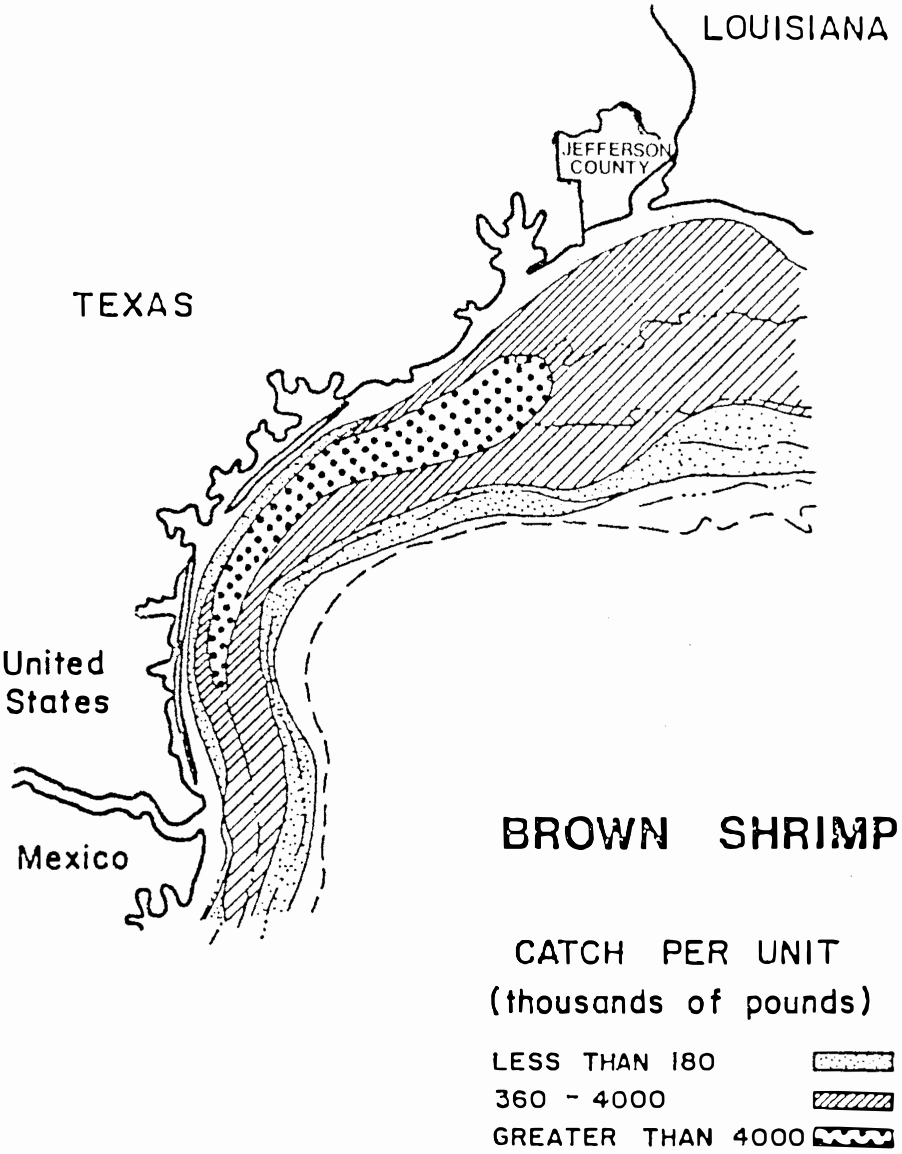
Shrimp are the single most valuable marine product in Texas. Shrimp landings in the state amounted to 92 percent of the total dollar value of finfish and shellfish in 1970 and 1971 (Boykin, 1972). From 1966 to 1971, Texas landings have accounted for 37 percent of the Gulf state shrimp catches. Brown shrimp are the most abundant shrimp in Texas waters and tend to be concentrated in the intermediate zone from Galveston to Rio Grande (see Figure Q-22). White shrimp are relatively more abundant in the coastal area of Jefferson County (see Figure Q-23). Pink shrimp are also caught commercially in this region. In the Sabine District, the total shrimp catch was over 1.1 million pounds for the period January-August 1976. White shrimp made up approximately 80 percent of the catch (NOAA, 1976).

Hedgepeth (1954) felt that the distribution of closely related species of penaeid shrimp was due to salinity preferences at various juvenile stages.

Gunter and Hildebrand (1954) noted a marked decline in production of white shrimp during a drought in the Gulf area in 1947-57. Gunter (1962) reported increased production once the drought was broken (1958),with catches increasing 331 percent. Gunter et al. (1964) concluded that the commercial catch of white shrimp is limited by rainfall.

Gunter et al. (1964) state that the kind of shrimp species in coastal waters will vary seasonally and from year to year with the rainfall (and hence salinity). Lower salinity levels at which white, brown, and pink shrimp were found were .42, .80, and 2.5 ppt in the northern Gulf. Young white shrimp have been shown from several studies to be most abundant in salinities less than 10 ppt, brown shrimp 10-20 ppt, and pink shrimp 18 ppt and above. This agrees with commercial catches which show greatest abundance of white shrimp in the low salinity waters of southeastern Louisiana, while the greatest catches of brown shrimp are from saltier Texas waters. Pink shrimp prefer areas of oceanic salinity. Pink shrimp have been taken in waters of salinity 65 ppt, while the other species have not been taken above 45 ppt.

Williams (1960) found from laboratory experiments that the three principle species of shrimp in the Gulf, the brown, white, and pink, had different substrate preferences. P. duorarum was found most frequently on shell sand, while P. aztecus and P. setiferus were found most frequently on softer muddier substrates, including sandy mud and muddy sand. This corresponds well to the distributions found in the Gulf of



Source: Osborn, K. W., B. W. Maghan, and Shelby B. Drummond, 1969. Gulf of Mexico Shrimp Atlas. Bureau of Commercial Fisheries, Dept. of Commerce.

Figure Q-22 Location of Brown Shrimp Grounds off the Texas Coast

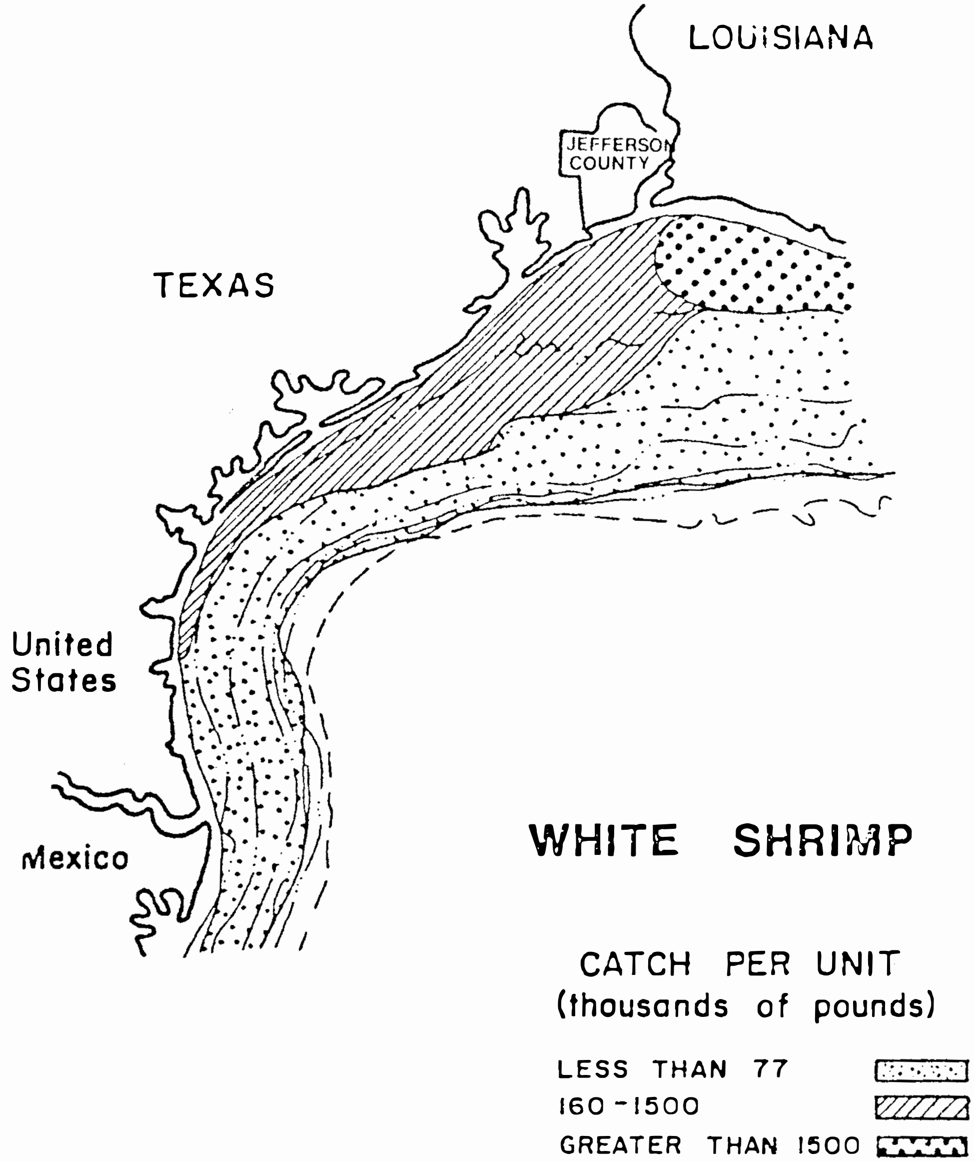


Figure Q-23 Osborn, K. W., B. W. Maghan, and Shelby B. Drummond, 1969. Gulf of Mexico Shrimp Atlas. Bureau of Commercial Fisheries, Dept. of Commerce.

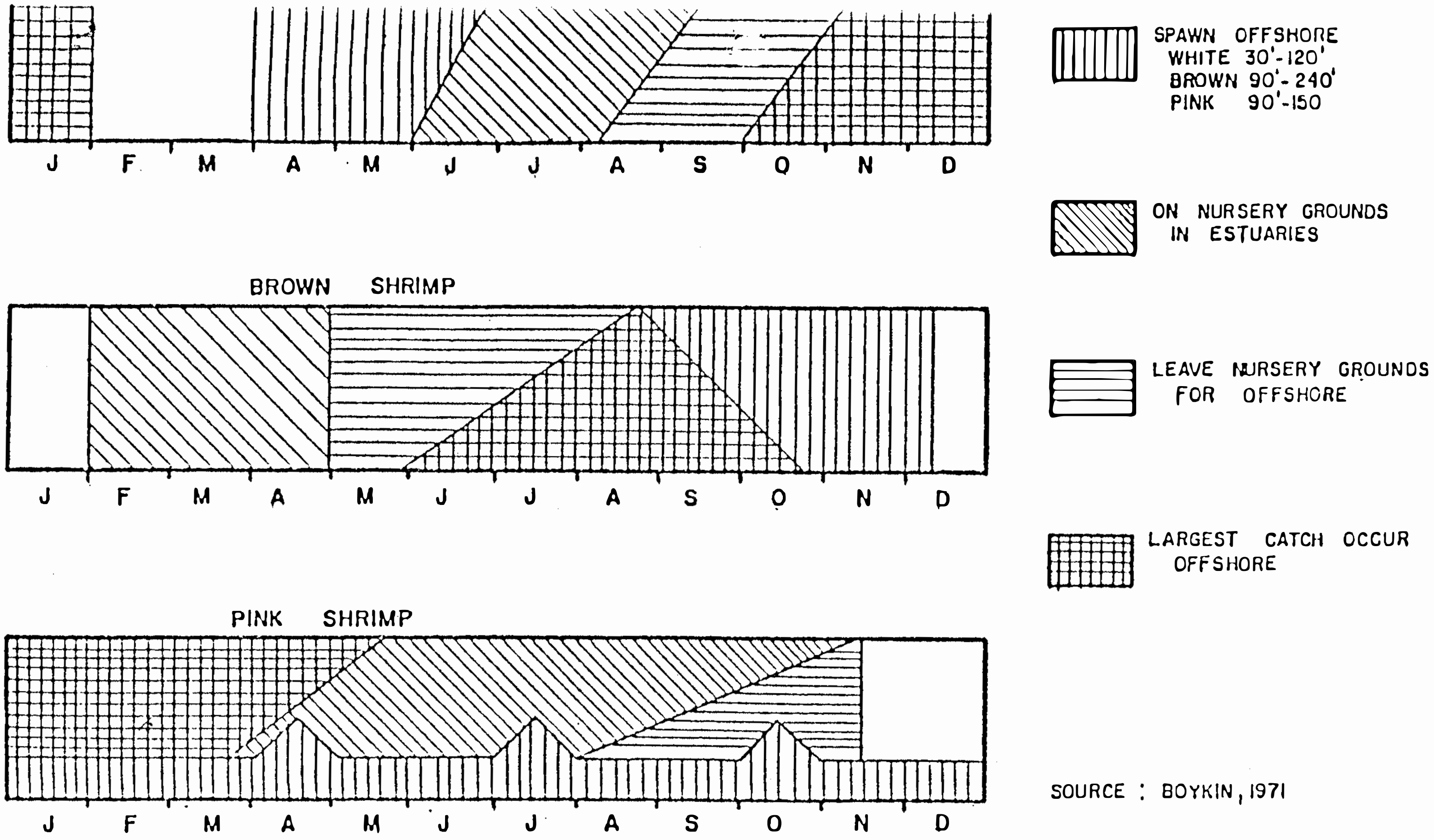
Location of White Shrimp Grounds
off the Texas Coast

Mexico (Hildebrand, 1954, 1955) where the pink shrimp is found principally over calcareous mud and sand or mixtures of shell and sand, while P. setiferus and P. aztecus were found in greater densities over bottoms of terrigenous salt. Williams (1960) noted the ability of P. duorarum to burrow into coarse substrates, with the animals generally remaining buried during the day, with most activity at night. Older P. aztecus burrowed into mud substrates, but the younger were often found on sandier substrates where they did not burrow. Activity was generally restricted to the night, although a few could always be found on the surface. The pink shrimp showed a different burrowing aspect, with the long antennae of this species laid on the surface of the substrate.

Wickham and Minkler (1975) found activity patterns of the three commercial shrimp species to be very similar to those reported by Williams (1958). The pink shrimp were active during the night, with all individuals inactive or burrowed during the day. The brown shrimp were also active during the night, and remained quiescent on the surface or burrowed during much of the day, with a few individuals active on the surface throughout the day. White shrimp showed the greatest activity, and were not seen to burrow. They were most active at night, but were exposed on the substrate or swimming off the bottom day and night. They were the least responsive of the 3 species to alterations of the light-dim cycle, while the pink were the most responsive. This sensitivity to changes in the light-dim cycle may be related to the water clarity in their preferred habitats.

Numerous instances of food preferences have been reported. Williams (1955) found that his experimental organisms contained detritus, plant fragments and sand. Laboratory cultures have demonstrated that P. setiferus larvae can live on algae, copepods, and ground fish, and the adults on groundfish or shrimp (Johnson and Fielding 1956, Pearson 1939). Flint (1956) reported P. setiferus larvae eat blue-green algae, and larger sizes are omnivcrous, consuming among other things, filamentous blue-green algae, lithophytic algae and diatoms. Foster (1953) has shown that daudean shrimp are coprophagous. Woodbum et al. (1957) found P. duorarum to be omnivorous, and it is expected that the same is true of P. aztecus and P. setiferus. A change of diet is apparent between larval and postlarval stages.

Figure Q-24 depicts the life cycles of all three shrimp in Texas waters. As with the finfishes, spawning occurs offshore, and the larvae must migrate through the passes into the estuarine nursery grounds. Again, the time at which migration occurs is important.



SOURCE : BOYKIN, 1971

SOURCE: Boykin, R. E., 1972. Texas and the Gulf of Mexico. Department of Marine Resources Information, Center for Marine Resources, Texas A&M University, College Station, Texas, September.

Figure Q-24 The Life Cycles of Three Panaeid Shrimp in Texas Gulf Waters

Coastline Adjacent to Inlets

This area contains several communities, including those of the tidal mudflats (which replace the upper shoreface sands of the non-depository coast), the lower shoreface mud (already discussed), the ebb tidal delta mud, and the subaqueous spoil deposited on the downcast side of the jetty.

The coastal mudflats contain no macroscopic vegetation, being subject to moderate tidal activity. Animal species common to this area belong to the following genera: *Petricola* (clam), *Anachis* (snail), *Neanthes*, *Polydora* and *Lumbrinereis* (polychaete worms), and the crustaceans *Corophium* and Amphithoe. Infauna dominate the assemblage (Fisher et al., 1973).

The ebb tidal delta, which extends to depths of approximately 30 feet, contains a diverse epifauna including gastropods (*Littorina*, *Neritina*, *Bulla*, *Polinices*, *Busycon* and *Thais*), crabs (*Uca*, fiddler crabs and *Pagurus*, hermit crab), sea urchins (*Mellita*) and occasionally the oyster (*Crassostrea virginica*).

The biota of the subaqueous spoil depends on a number of factors, including sediment characteristics, age of spoil, and depth.

Jetty Community

General descriptions of the jetty macrobiota (exclusive of fishes) was given by Hedgepeth (1953, 1954). The community which develop on this atypically rocky habitat can be subdivided into vertical zones, just as in other oceans of the world. Figure Q-25, from Hedgepeth, shows the general zonation characteristics of the community. This community is apparently limited to hardy forms capable of withstanding the occasional low winter temperatures, wave shock, sudden variations in temperature, and exposure during abnormally low tides accompanying north winds. The three floral zones include: the upper Ulva zone, an intermediate red algae zone (especially *Gracilaria* and *Gelidium*), and a lower brown algae zone (dominated by *Padina*). Seasonally, there is a green algae growth above the *Ulva* zone. This dies off in winter during periods of lowered tides. Below the *Padina* zone, occur the subtidal bryozoa, sponges and hydroids with some encrusting sponges. Superimposed on this flora are the animals, the common, less motile of which are shown in Figure Q-25 (for Port Aransas jetty). In addition, several motile arthropods *Pachygrapsus transversus* and *Ligia exotica* move up and down the assemblage with changes in water level. Port Aransas jetty is similar to the jetties further east (in the study area) except for the absence of *Brachidontes recurvus* and other mussels at Port Aransas. Most of these jetties, including those at Calcasieu Pass, Sabine Pass and Galveston,

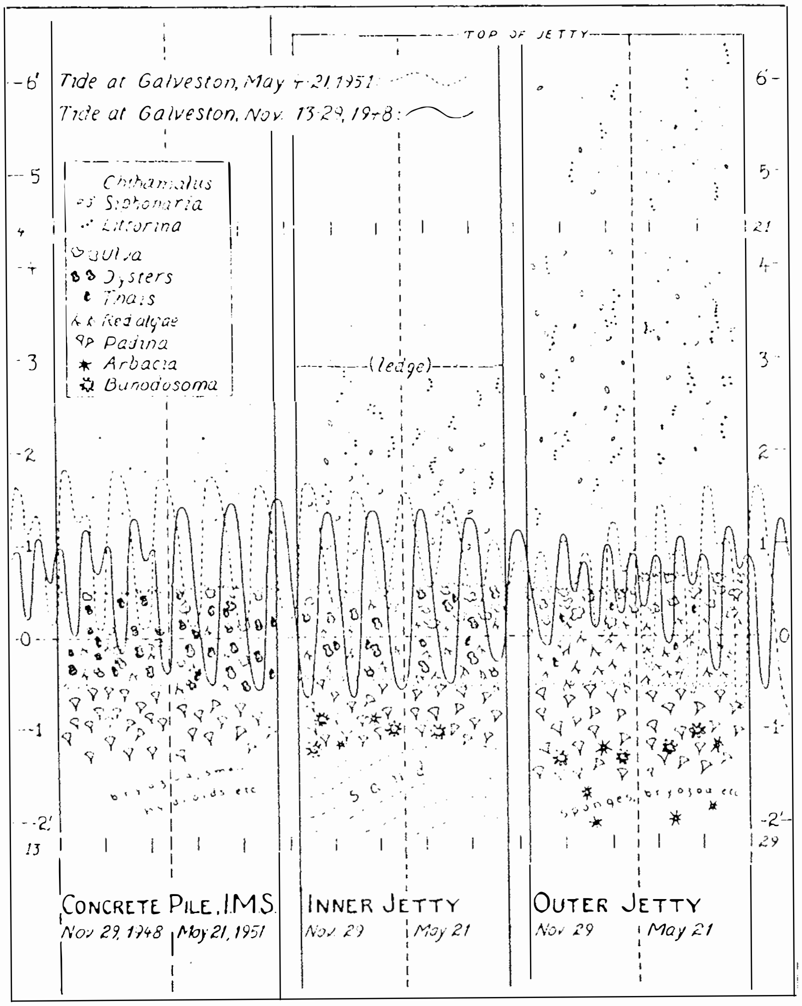


Figure Q-25

Diagram representing zonation on concrete piling and jetties at Port Ar ansas as observed on November 29, 1948 and May 21, 1951, with the predicted tide curves for the two-week period preceding observations superimposed.

are less than 100 years old, and the community includes some species found nowhere else in the northern Gulf, due to the lack of suitable natural substrate. Members have southern affinities. Kapraun (1974) presented the results of sampling benthic algae from the Louisiana coast, including monthly collections from the east jetty at Calcasieu River during 1968. Tables Q-26 and Q-27 show the temperature and salinity regime, the 18 species encountered, and the seasonal distribution of species collected at the jetty. For the algae frequently collected, two groups could be recognized on the basis of their seasonal distribution. One group, with greatest growth in summer, had distinct tropical affinities. Most species developed maximum growth in winter or early spring, probably due to the relatively mild winter, which allowed growth of temperate and subtropical forms in colder months. Of the 18 species found at Calcasieu jetty, 10 were restricted to the jetty, and most of these were probably relatively stenohaline. Vertical zonation trends were apparent, with some correlation between species composition and exposure to wave action. The vertical extent of the algae was 1.5 meters in winter, and 1.0 meters in summer.

Platforms

Sonnier et al. (1976) report that one is within sight of oil platforms virtually anywhere within 140 km of the Louisiana coast, with greater than 3,000 having been erected off Louisiana. There platforms provide substrates with a vertical profile unsuitable in any natural occuring environment in the Gulf of Mexico. The authors reported on visual observations of platform-associated fishes in water depths of 18-55 m between 90°W and 93° W. The results are shown in Tables Q-28 and Q-29. Of special interest is the fact that many platforms showed species common to the reefs (Table Q-28) and, therefore, of tropical affinity. The lower species diversity of the platforms was related to the lower niche (due to lesser epifaunal growth) and the fact that most platforms were located north of the most offshore and tropical-related reef. Very few nektonic fish were associated with the platforms.

Gunter and Geyer (1955) examined the epibiota of several oil platforms located in ten fathoms of water (maximum depth) off Freeport, Texas, and the resulting distribution determinations are schematically shown in Figure Q-26. Small barnacles, the horse oyster (_Ostrea equestis_), and a bryozoan dominated the fouling organisms on the lower 25 feet. These organisms became much less abundant on the upper half of the structure and near the surface a few commercial oysters (_C. virginica_) were present. Hydroids (in masses) were the dominant sessile organisms at the mudline. Arc shells (_Arca transversa_) and filamentous green algae were found at the upper levels. Serpuled worm tubes and the coral _Astrangia_

Table Q-26

Monthly average water temperature and surface salinity for three Louisiana stations

Month	Grand Terre (1969)		Calcasieu Pass (1968)		Vermilion Bay (1968)	
	Salinity	Temp. C.	Salinity	Temp. C.	Salinity	Temp. C.
January	26.7	12.9	17.6	8.9	1.0	7.9
February	25.4	14.8	14.8	11.3	4.9	7.7
March	22.1	15.0	21.1	15.3	5.3	11.6
April	20.4	22.3	17.2	22.8	10.5	21.7
May	14.2	25.3	14.5	25.8	3.0	26.8
June	18.1	29.4	16.7	31.4	1.9	29.6
July	22.1	30.5	19.1	34.3	2.7	33.1
August	20.3	29.6	17.9	31.0	. .	34.9
September	23.4	28.4	13.5	25.5	0.0	24.0
October	28.3	23.9	18.8	24.1	3.8	25.9
November	30.6	18.1	25.1	14.7	. .	. .
December	28.9	16.4	24.5	13.0	3.7	6.1

Table Q-27

Seasonal periodicity of benthic marine algae along the Louisiana coast

Chlorophyta	J	F	M	A	M	J	J	A	S	O	N	D
Blidingia marginata	.	C	C	C	. .	. .	R	. .	. .	. .	. .	. .
B. minima	C	C	. .	. .	C	. .	. .	. .	. .	. .	. .	. .
Chaetomorpha linum		R	. .	C	. .	. .	. .	. .	. .	. .		R
Cladophora dalmatica	C	C	C	M	M	C	C	C	C	R	C	C
Enteromorpha clathrata	C	M	M	C	. .	C	. .	C	C	. .	. .	C
E. linza	M	M	M	M	C	C	C	R	C	. .	C	C
E. prolifera	C	C	C	. .	. .	. .	. .	. .	. .	. .	. .	. .
Entocladia testarum	C	C	. .	. .	.	. .	.	.	.	C	.	.
Pseudendoclonium submarinum	C	C	C	C	C	C	C	C	C	C	C	C
Rhodophyta												
Bangia atropurpurea	M	M	C	C	C	. .	. .	R	R	. .	C	C
Bostrychia radicans	C	C	M	C	C	. .	C	C	. .	C	C	C
Erythrocladia subintegra	R	R	. .			R	C	R	. .	. .	. .	. .
Erythrotrichia carnea	. .	. .	. .	. .	R	. .	. .	. .	. .	. .	. .	. .
P. subtilissima	.	R	. .	C	. .	C	C	C	. .	C	. .	. .
Phaeophyta												
E. siliculosus	R	.	. .	. .	. .	. .	. .	. .	. .	R	R	C
Giffordia mitchelliae	R	. .	. .	. .	. .	. .	. .	. .	. .	R	R	R

Legend:
M = Maximum vegetative development
C = Common
R = Rare

Table Q-28

Species Occurring at both Platform and Reef Areas. C = common; O = occasional; R = rare; *specimens available.

Species	Area A	Area B	Area C	Platforms
Dasyatis americana	C	C	C	R
*Epinephelus adscensionis**	C	C	C	O
*E. itajara**	R			C
*Mycteroperca phenax**	C	C	C	C
Apogon maculatus	C	C	C	O
*Rachycentron canadum**	O			C
*Caranx hippos**	C	C	C	C
*C. latus**	C	C	C	C
Elagatis bipinnulata		O	C	R
*Selene vomer**	C	O		C
*Seriola dumerili**	C	C	C	C
*Lutjanus campechanus**	C	C		C
L. cyanopterus	R			R
L. griseus	C	O		C
*Rhomboplites aurorubens**	O	C	C	O
*Haemulon aurolineatum**	C			O
*Archosargus probatocephalus**	R			C
*Equetus umbrosus**	R			R
Kyphosus sectatrix	C	C		C
Chaetodon ocellatus	O	O	O	O
Holacanthus bermudensis	C	C	C	C
H. ciliaris	O	O	O	O
H. tricolor		O	O	R
Pomacanthus paru	C	C	C	C
Pomacentrus variabilis	C	C	C	C
Amblycirrhitus pinos		O	O	R
Bodianus pulchellus			O	O
*B. rufus**	C	C	C	R
Thalassoma bifasciatum	C	C	C	O
Sphyraena baracuda	C	C	C	C
Scomberomorus cavalla	C			C
*Aluterus scriptus**			R	R
*Balistes capriscus**	C	C	C	C
B. vetula		R	O	R
Cantherines pullus		R		O
Canthidermis sufflamen	O	C	C	C
Canthigaster rostrata	O	O	O	O
Totals	30	28	[illegible]	37

Table Q-29

Species Associated Primarily with Platforms. C = common; O = occasional; R = rare; *specimens available.

Species	
Epinephelus nigritus	C
*Rypticus maculatus**	C
*Caranx crysos**	C
*Chloroscombrus chrysurus**	R
*Vomer setapinnis**	R
*Ocyurus chrysurus**	O
*Chaetodipterus faber**	C
Pomacanthus arcuatus	R
*Hypleurochilus geminatus**	C
Acanthurus coeruleus	R
*Aluterus schoepfi**	R
*Monacanthus hispidus**	C

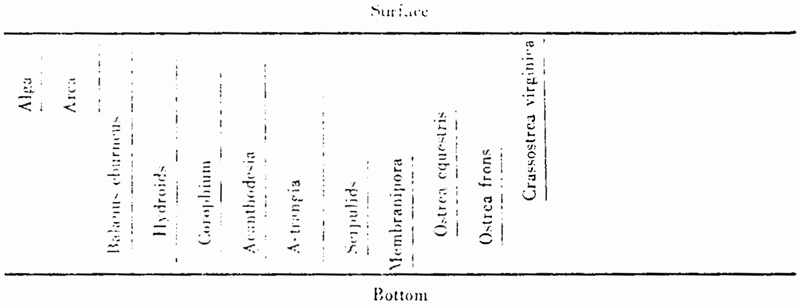


FIGURE II. A schematized distribution of the fouling organisms along the two Louisiana oil-well platforms described in the text. The greatest depth was fifty feet.

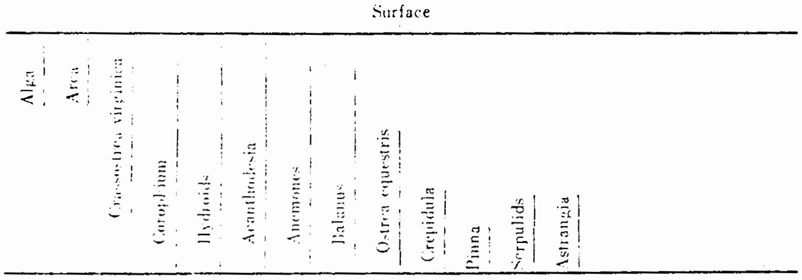


Figure Q-26

A generalized graphic distribution of the common fouling organism along the two Texas oil-well platforms described in the text. Th greatest depth was sixty feet. Except for the alga, organisms were not found right at the surface or right at the mudline. Relative abundance at depths are shown very roughly by thickness of the lines.

were found at lower levels only. Hydroids, Corophium (mud-depositing amphipod) and Acanthodesia (encrusting bryozoa) were present at all levels.

In general, the top to bottom distribution of sessile animals represented a summary of horizontal benthic distribution from estuarine waters to sea water (over a distance of many miles) with the salinophilous organisms found at lower levels and more estuarine organisms taken near the surface.

Offshore Reefs

Along the outer edge of the continental shelf, in areas of 90-100 fathom depths, are small patches of reef located on topographic rises (10-25 fathoms of surface), which have recently been confirmed as being expressions of intrusive structures (salt domes). These reefs along the Texas and Louisiana coasts, the largest being the Flower Gardens, were found to contain tropical, stenohaline communities representing northern frangments of Carribean (West Indian) reefs. The presence of these reefs is correlated with the 18° C isotherm of minimum temperature, which is the lower limit for the formation of significant reef deposits. Parker and Curray (1956) discuss the results of dredge sampling on several of these banks, and include a comparison and reevaluation of their findings with those of Stetson (1953), who also sampled some of these areas. Data from both studies are presented in Table Q-30 and include the molluscs, a large Ophiruid echinoderm (brittle star, Ophioderma rubicundum) and corals. Stetson reported five corals present, but Parker and Curray, who reexamined the material, concluded that only one species, Madracis mirabilis was alive at the time of collection. This coral is an encrusting species, not a reef builder. It appears that the corals were living on these rises during a time when sea levels were lower, since the depths of these rises are below the normal depth of reef formation. The majority of the calcareous substrate has been contributed by the abundant living lithothamnoid algae and bryozoans, such as Smittina, Schizoprella and Mamillopora.

A total of 137 species of molluscs, living and dead, were collected in the two studies from the banks. Practically all the living and dead species of these and the other organisms collected are of tropical affinity with only 52 of the species of molluscs being previously reported north of the central Florida coast. The majority are also characteristic of shallow waters, with many living in bays and intertidal waters in the West Indies. These shallow water forms were morphologically distinct (subspecific level) from their tropical counterparts.

Table Q-30

FAUNA FROM CALCAREOUS BANKS OFF TEXAS AND LOUISIANA

Species	*Baker Bank (31 fms.)*	*Big Southern (30 fms.)*	*West Flower Garden (24 fms.)*	*East Flower Garden (30 fms.)*	*Other Occurrences (Depth)*
MOLLUSKS					
Abra lioica Dall 1881		D			North Carolina to West Indies—3-6 fms.
Acmaea pustulata Heilbling 1779			D		Florida Keys to W. I.—Shallow water.
Acteon, new species		D			
Aequipecten muscosus Wood 1828	D				North Carolina to W.I.—Shallow water.
Anachis translirata Ravenel 1861	D	D			Mass. to N.E. Florida—Shallow water.
Anachis, new species	D				
Anomia simplex Orbigny 1842	D				New York to West Indies—Shallow water.
Antigona strigillina Dall 1902	D	D	D		SE. Florida to W. I.—20 to 70 fms.
Arca umbonata Lamarck 1819	D				North Carolina to W. I.—Shallow water.
Arca zebra Swainson 1833	A	D			North Carolina to W. I.—Shallow water.
Arcopsis adamsi E. A. Smith 1888	A	D	A		North Carolina to Brazil—Shallow water.
Arcopsis a. conradiana Dall 1886	D	D			North Carolina to Florida—25 fms.
Arene gemma Toumey and Holmes 1856	D		D		North Carolina to Brazil—12-22 fms.
Astraea caelata Gmelin 1780			A		SE. Florida to W. I.—Shallow water.
Barbatia cancellaria Lamarck 1819	D		A	A*	S. Florida to W. I.—Shallow water.
Barbatia candida Gmelin 1790	D	D			North Carolina to Brazil—Shallow water.
Barbatia domingensis Lamarck 1819	D	D	A*	A*	N. C. to West Indies—Rocks at low tide.
Barbatia tenera C. B. Adams 1845	D		D		Florida to West Indies—Shallow water.
Botula fusca Gmelin 1792			A*	A*	S. C. to West Indies—Shallow on rocks.
Bulla eburnea Dall 1881?	D				N. Carolina to W. I.—103-337 fms.
Calliostoma jujubinum rawsoni Dall 1889	D		D		Lower Keys to W. I.—1 to 10 fms.
Calyptraea centralis Conrad 1841		D			North Carolina to W. I.—Shallow water.
Cerithiopsis exile C. B. Adams 1850		D			Jamaica—Littoral Zone (1-5 fms.).
Cerithiopsis flavum C. B. Adams 1850			A		Jamaica—Littoral Zone (1-5 fms.).
Cerithiopsis greeni C. B. Adams 1839		D			Mass. to West Indies—3 to 10 fms.
Cerithiopsis latum C. B. Adams 1850			A		Jamaica—Shallow water.
Cerithiopsis subulatum Montagu 1808	A	A	A		West Indies—2 to 15 fms.
Cerithium literatum Born 1780			A	A	S. Florida to W. I.—Shallow water.
Cerodrillia thea Dall 1883		D			S. Florida—Sand bars in inside waters.
Chama congregata Conrad 1833	A	D	A		North Carolina to W.I.—1 to 7 fms.
Chama macerophylla Gmelin 1792	D	D	D		Florida to W. I.—Shallow, protected.
Chione grus Holmes 1858	D				North Carolina to Yucatan—12 to 63 fms.
Chlamys benedicti Verrill and Bush 1897	D	D			West Indies—25 to 72 fms.
Conus stearnsi Conrad 1869	D		D		Florida to Yucatan—4 to 6 fms.
Corbula aequivalvis Philippi 1836		D			Porto Rico—Shallow water.
Corbula cymella Dall 1881	D	A			Florida Keys—Shallow water.
Corbula dietziana C. B. Adams 1852			D		North Carolina to W. I.—2 to 18 fms.
Corbula swiftiana C. B. Adams 1852	D				North Carolina to W. I.—6 to 100 fms.
Crassinella martinicensis Orbigny 1842	D	D			Mass. to West Indies—Shallow water.
Crenella divaricata Orbigny 1842				A	North Carolina to W. I.—20 to 50 fms.
Crepidula plana Say 1822			D		Canada to Texas—1 to 3 fms.
Cuspidaria ornatissima Orbigny 1842	D				North Carolina to W. I.—2 to 100 fms.
Cuspidaria perrostrata Dall 1881		D			Mass. to West Indies—58 to 500 fms.
Cyclocardia armilla Dall 1903		D			NW. Florida to Texas—24 to 169 fms.
Cyclostrema amabilis Dall 1889			A		Cuba, West Indies—Shore to 150 fms.
Cythara bartletti Dall 1889	D				Key West to W. I.—16 to 150 fms.
Dentalium laqueatum Verrill 1885		D			North Carolina to W. I.—10 to 193 fms.
Dentalium, species		D			
Diodora cayenensis Lamarck 1822	D	D			Maryland to Brazil—½ to 3 fms.
Distorsio clathrata Lamarch 1816	D	D			N. C. to Colombia, S. A.—22 to 124 fms.
Drillia acestra Dall 1889?	D				Florida Straits, W. I.—Over 400 fms.
Drillia detecta Dall 1881?	D	D			Gulf of Mexico—339 fms.
Drupa didyma Schwengel 1943	D		A		SE. Florida—5 to 35 fms.
Emarginula phrixodes Dall, 1927	D		D		North Carolina to W. I.—20 to 129 fms.
Emarginula sicula Gray 1825	D				Mediterranean, West Indies—8 to 250 fms.
Erato maugeriae Gray 1832	D				Florida to West Indies—2 fms.
Glyphostoma gratula Dall 1881		D			Florida to W. I.—227 to 247 fms.
Gouldia cerina C. B. Adams 1845	A	A			Florida to W. I.—Shallow water.
Haminoea succinea Conrad 1846?		D			Florida—Shores to 2 fms.
Hiatella arctica Linné 1767	D	D			Greenland to W. I.—1 to 100 fms.
Lemintina decussata Gmelin 1791	D	D			S. Florida to W. I.—Low tide to 3 fms.
Lima pellucida C. B. Adams 1846	A	A			N. C. to West Indies—Shallow water.
Lima tenera Sowerby 1846	D	D	D		S. Florida to W. I.—Shallow at low tide.
Liotia bairdi Dall 1889	D	A			N. C., Fla. Keys, Yucatan—15 to 127 fms.
Liotia, new species			A		Taken only off Texas
Lithophaga aristata Dillwyn 1817			A*		S. Florida to West Indies, La Jolla to Peru in coral in shallow water.
Lithophaga bisulcata Orbigny 1842				A*	N. C. to West Indies—Shallow water.
Litiopa melanostoma Rang 1829		D			Pelagic in warm seas.
Lucapina sowerbii Sowerby 1835			A		Florida Keys to Brazil—Under rocks at low tide.
Macoma extenuata Dall 1900	D	D			Gulf of Mexico in 32 fms.
Mangelia psila Bush 1885?	D	D			North Carolina to W. I.—16 fms.
Mangelia, species	D				Taken only off Texas
Mathilda scitula Dall 1889	D	D			North Carolina to W. I.—49 to 294 fms.
Melanella arcuata C. B. Adams 1850	D				North Carolina to W. I.—Shallow water.
Melanella bilineata Alder 1848			[illegible]		North Carolina to W. I.—No depth given.
Melanella patula Dall & Simpson 1900		D			Georgia to Porto Rico—Shallow water.

Table Q-30 (cont.)

Species	*Baker Bank (31 fms.)*	*Big Southern (30 fms.)*	*West Flower Garden (24 fms.)*	*East Flower Garden (30 fms.)*	*Other Occurrences (Depth)*
Microcardium transversum Rehder & Abbott 1951	D	D	A		Gulf of Mexico—20 to 60 fms.
Mitra nodulosa Gmelin 1790	D	D	A		N. C. to West Indies—Low tide, under rocks.
Mitrella lunata, new subspecies	D	D			*M. lunata* is a bay form.
Murex, juvenile	D		D		Taken only off Texas.
Musculus coralliophagus Gmelin 1790			A•		Florida to W. I.—2 to 7 fms.
Musculus opifex Say 1822	A	D			North Carolina to Brazil—Shallow water.
Nassarina glypta Bush 1885	D	D			N.C. to Florida Keys—14 to 63 fms.
Nassarius ambiguus Pultney 1794	D	D			N.C. to West Indies—Low tide line to 6 fms.
Natica canrena Linné 1758	D	D			N.C. to West Indies—Low tide line.
Nucula crenulata A. Adams 1856	D				N.C. to West Indies—30 to 250 fms.
Nuculana jamaicensis Orbigny 1842	D				N.C. to West Indies—54 to 640 fms.
Odostomia seminuda C. B. Adams 1839	D				Nova Scotia to Fla.—Shore to 12 fms.
Papyridea soleniformis Bruguiere 1784		D			S. Florida to Brazil—Low tide to 2 fms.
Pecten papyraceus Gabb 1873	D	D			Gulf of Mexico to W. I.—30 to 60 fms.
Peristichia toreta Dall 1889	D	D			N. C. to Florida—2 to 22 fms.
Peristichia, species		D			Taken only off Texas.
Pitar fulminata Menke 1830	D	D			N. C. to Brazil—1 to 6 fms.
Plicatula gibbosa Lamarck 1801	D	D		A•	N. C. to West Indies—Intertidal—20 fms.
Pododesmus rudis Broderip 1834	D				Florida to W.I.—Intertidal to 3 fms.
Polinices, species	D				Taken only off Texas.
Prunum, species			D		Taken only off Texas.
Pteria colymbus Röding 1798	D				N. C. to W. I.—Intertidal to 4 fms.
Pycnodonta hyotis Linné 1758		D			Florida to W. I.—20 to 50 fms.
Pyramidella crenulata Holmes 1859			D		S. Carolina to W. I.—1 to 6 fms.
Pyramidella, species	D				Taken only off Texas.
Pyrunculus caelatus Bush 1885	D	D			North Carolina to Florida—15 to 53 fms.
Rhizorus acutus Orbigny 1841	D	D			North Carolina to W. I.—15 to 124 fms.
Rimula aequisculpta Dall 1927		D			S. Florida to W. I.—1 to 25 fms.
Ringicula semistriata Orbigny 1842	D				North Carolina to W. I.—31 to 107 fms.
Rissoina browniana Orbigny 1842			D		North Carolina to W. I.—Grassy bottom in littoral zone.
Rissoina cancellata Philippi 1847	D	D	D		Florida to W. I.—Eel grass, 1-2 fms.
Rissoina chesneli Michaud 1832	D	D			North Carolina to W. I.—Shallow intertidal.
Rissoina elegantissima Orbigny 1842			D		Cuba to West Indies—Shallow water.
Rissoina multicostata C. B. Adams 1850		D			Florida to West Indies—Intertidal.
Rocellaria hians Gmelin 1790	D	D			N. C. to W. I.—Coral in shallow water.
Scaphander watsoni Dall 1881	D				N. C. to Cuba—63 to 324 fms.
Seila adamsi H. C. Lea 1845	D	D			Mass. to West Indies—1 to 6 fms.
Spondylus americanus Herman 1781				A•	Florida to W. I.—5 to 24 fms.
Teinostoma, new species		D			Taken only off Texas
Teinostoma, new species			A		Genus found S. Fla. to W. I.—Shallow water under rocks.
Trinostoma, new species			D		
Tellina promera Dall 1900	D				Fla. to Trinidad—Shallow, intertidal.
Tellina radiata Linné 1758		D			S. Carolina to W. I.—Shallow sandy.
Tellina versicolor Dekay 1843	D				Rhode Island to W. I.—1 to 10 fms.
Tenagodus squamatus Blainville 1827		D			Florida to W. I.—20 to 160 fms.
Thyasira trisinuata Orbigny 1842	D				Nova Scotia to W. I.—15 to 90 fms.
Trachycardium magnum Linné 1758		D		A•	Lower Keys to W. I.—Shallow water.
Triphora intermedia C. B. Adams 1850	D	D	A		Jamaica—Shallow water.
Triphora melanura C. B. Adams 1850	D		A		N. C. to West Indies—Shallow water.
Triphora pulchella C. B. Adams 1850	D		D		Florida to W. I.—1 to 40 fms.
Triphora turristhomae Orbigny 1842			A		N. C. to West Indies—Shallow water.
Triphora, species	D		A		Taken only off Texas.
Trivia suffusa Gray 1832	D				S. Florida to W. I.—1 to 14 fms.
Turbonilla incisa Bush 1849		D			SW. Florida—No depth given.
Turritella exoleta Linné 1758	D	A			S. Florida to W. I.—5 to 7 fms.
Varicorbula operculata Philippi 1848	D	A			N. C. to West Indies—5 to 250 fms.
Vermicularia spirata Philippi 1836	D	D	A		S. Florida to W. I.—1 to 14 fms.
Vitrinella multistriata Verrill 1884	D				N. C. to West Indies—3 to 142 fms.
Williamia krebsi Mörch 1877	D		A		Fla. Keys to W. I.—10 to 30 fms.
Yoldia solenoides Dall 1881	D	D			Gulf of Mexico—20 to 118 fms.
Zeidora biglowei Farfante 1947			D		S. Cuba—175 to 225 fms. (dead) only taken once.
ECHINODERM					
Ophioderma rubicundum Lütken 1856			A		Cape Florida, Bahamas and W. I.—9-12 fms.
CORALS					
Madracis mirabilis Duchassaing and Michelotti, 1861			D•	A•	Florida Keys to West Indies—0-400 fms.
Porites astroeoides Lamarck 1816			D•		Bermuda, S. Florida, W. I. to Brazil—0-20 fms.
Montastrea annularis Ellis and Solander, 1786			D•		Florida to West Indies, C. America—Outer edges of reefs.
Manicina gyrosa Ellis and Solander 1786			D•		Florida and Caribbean—0-10 fms.
Diploria strigosa Dana 1846			D•		Bermuda, Florida, West Indies—Massive reef builder.

D—Indicates dead occurrences.
A—Indicates taken alive.
• —Taken by Stetson, Feb. to March, 1947.

There is an equally striking parallel for the fish fauna of these banks. Sonnier et al. (1976) who surveyed the ichthyofauna visually, confirmed earlier observations (Casey 1969, Moseley 1966, Walls 1973, Hildebrand et al. 1964, and Pulley, 1963) that tropical elements prevailed. The results of this study are shown in Table Q-31. They noted a clear reduction in species diversity from offshore to inshore, with the most characteristic tropical components being replaced by more temperate species. Very few nektonic fishes were associated with the reefs, and those that were did not use them for feeding. They noted a striking similarity between this list for the Flower Gardens and that published by Smith and Taylor (1973) from a tropical Bahamian reef. They noted parallels in other groups also, among these, the presence of substantial numbers of Florida rock lobster (*Panulirus argus*), arrow crab (*Stenorhynchus seticornis*), and cleaner shrimp (*Stenopus hispidus*).

Kapraun (1974) reported on benthic algae from the Flower Garden area, listing 10 species (see Table Q-32), six of which were previously unreported from the state. The study seemed to indicate that the benthic offshore flora continues along the northern arc of the Gulf, where water temperature and light penetration permit. See also Table Q-33 for spatial distribution of benthic marine algae along the Louisiana coast.

Table Q-31

Species Primarily Associated with Reefs. C- common; O -occasional; R- rare; *specimens available.

Species	Area A	Area B	Area C
Carcharhinus leucas	R		
*Galeocerdo cuvieri**	R		
Ginglymostoma cirratum	O	O	O
Aetobatis narinari	O		
Gymnothorax moringa	C	C	C
Synodus synodus		R	
Holocentrus ascensionis	C	C	C
H. rufus			R
Myripristis jacobus		C	C
Aulostomus maculatus			O
*Epinephelus cruentatum**		C	C
*E. guttatus**			R
E. inermis			O
Mycteroperca rubra	R		
M. venenosa			R
Paranthias furcifer	C	C	C
*Priacanthus arenatus**	R		
Apogon pseudomaculatus	R		
Alectis crinitus		R	R
Caranx bartholomaei			R
C. lugubris			R
Lutjanus jocu			R
Haemulon melanurum		R	
Calamus nodosus		R	
*Equetus punctatus**		O	O
Mulloidicthys martinicus		O	O
Pseudupeneus maculatus		O	O
Kyphosus incisor		R	
Centropyge argi		R	R
Chaetodon capistratus			R
C. sedentarius			O
C. striatus		O	O
Prognathodes aculeatus			R
Chromis cyaneus	O	C	C
C. enchrysurus	R		
*C. multilineatus**		O	O
*Microspathodon chrysurus**			R
Pomacentrus partitus	O	O	C
Clepticus parrai		O	O
Halichoeres caudalis		O	O
H. garnoti			R
Lachnolaimus maximus		R	
Scarus croicensis			R
S. taeniopterus			R
Sparisoma aurofrenatum			R
S. viride			R
Gobiosoma oceanops		R	R
Acanthurus bahianus	O	O	C
A. chirurgus	O	O	C
Euthynnus alletteratus		O	O
*Scorpaena plumieri**	R	R	
*Cantherines macrocerus**			O
Melichthys niger			O
Lactophrys quadricornis		R	
L. triqueter	C	C	C
Diodon holocanthus			R
Totals	17	29	42

Table Q-32

List of benthic marine algae from coastal and off-shore Louisiana

Chlorophyta	1	2	3	4	5	6
Blidingia marginata				x		
B. minima				x		
Bryopsis plumosa						x
Caulerpa prolifera			x			
Chaetomorpha linum				x	x	
Cladophora dalmatica (=C. fascicularis)		x			x	
C. repens				x		
Cladophoropsis membranacea		x		x		
Enteromorpha clathrata		x	x	x	x	
E. flexuosa		x		x	x	
E. lingulata		x				
E. linza				x	x	
E. prolifera				x		
E. ramulosa				x		
Entocladia testarum				x		
Phaeophila dendroides			x			
Pseudendoclonium submarinum				x		
Rhizoclonium hookeri					x	
R. kochianum			x	x	x	
R. riparium		x				
Ulothrix flacca				x	x	
Ulva lactuca		x		x		
Ulvella lens			x			
Phaeophyta	**1**	**2**	**3**	**4**	**5**	**6**
Bachelotia antillarum				x		
C. zosterae (= Eudesme zosterae)			x			
Dictyota dichotoma	x	x	x			x
D. bartayresii						x
Ectocarpus dasycarpus	x	x				
E. intermedius	x					
E. siliculosus (= E. confervoides)	x	x		x	x	
Giffordia mitchelliae (= Ectocarpus mitchelliae)	x	x		x		
G. rallsiae (= Ectocarpus rallsiae)	x		x	x		
Lobophora variegata (= Pocockiella variegata)						x
Padina vickersiae	x	x	x			
P. sanctae-crucis						x
Rosenvingea intricata						x
Sargassum acinarium	x					
S. filipendula	x	x			x	x
S. fluitans	x			x*		
S. natans	x	x				
Sphacelaria furcigera	x		x			
S. tribuloides	x					
Streblonema oligosporum				x		
Turbinaria tricostata				x*		

Rhodophyta	1	2	3	4	5	6
Acrochaetium crassipes		x				
A. flexuosum			x	x		
Bangia autropurpurea				x		
Bostrychia radicans				x	x	
Caloglossa leprieurii				x		
Ceramium byssoideum			x			
C. fastigiatum						x
Chondria dasyphylla					x	
C. collinsiana					x	
C. tenuissima					x	
Dasya baillouviana (= D. pedicellata)		x				
Dermatolithon pustulatum					x	
Digenia simplex		x	x			
Erythrocladia subintegra				x		
Erythrotrichia carnea		x		x		
Gracilaria caudata			x			
G. foliifera		x	x	x	x	
Griffithsia tenuis			x			
Heteroderma lejolisii (= Fosliella lejolisii)		x	x		x	
Hypnea musciformis		x	x		x	x
H. cornuta					x	
H. pannosa			x			
Jania capillacea				x*	x	
Laurencia gemmifera		x				
L. poitei			x		x	
Lophosiphonia sacchoriza			x			
Polysiphonia denudata (= P. variegata)		x	x			
P. echinata			x		x	
P. havanensis			x	x		
P. ramentacea		x				
P. subtilissima				x		x
Solieria tenera (= Agardhiella tenera)		x	x			
Spyridia filamentosa		x	x		x	
Wrightiella tumanowicz			x			

* Unattached.

Legend
1 Earle 1969
2 [illegible] 1959
3 Humm and Darnell 1959
4 Coastal periodic collections }
5 North Chandeleur Island } Kapraun
6 [illegible] Gardens area }

Table Q-33

Spatial distribution of benthic marine algae along the Louisiana coast

Chlorophyta	1	2	3	4
Blidingia marginata	x	x	x	
B. minima	x			
Chaetomorpha linum	x	x	x	x
Cladophora dalmatica	x		x	
C. repens		x		x
Enteromorpha clathrata	x	x	x	x
E. flexuosa	x	x	x	x
E. linza	x	x	x	x
E. prolifera	x	x	x	x
E. ramulosa		x	x	x
Entocladia testarum	x			x
Pseudendoclonium submarinum	x	x	x	x
Rhizoclonium kochianum		x		x
Ulothrix flacca		x		x
Ulva lactuca			x	x
Rhodophyta				
Acrochaetium flexuosum			x	
Bangia atropurpurea	x		x	
Bostrychia radicans	x	x	x	x
Caloglossa leprieurii		x		
Erythrocladia subintegra	x		x	
Erythrotrichia carnea	x			
Gracilaria foliifera				x
Polysiphonia havanensis		x	x	
P. subtilissima	x	x		x
Phaeophyta				
Bachelotia antillarum			x	
Ectocarpus intermedius	x		x	x
E. siliculosus	x	x	x	
Giffordia mitchelliae	x		x	
G. rallsiae			x	
Streblonema oligosporum			x	

Legend
1. Calcasieu River jetty
2. Vermilion Bay: Redfish Point, Southwest Pass on Marsh Island
3. Grand Isle jetty, Fort Livingston on Grand Terre
4. Caminada Bay, Caminada Pass

Salt in the Marine Environment

A decade ago, Copeland (1967) foresaw the problems associated with increased utilization of the resources of the Gulf Coast, especially in relation to water availability. He noted that increasing needs for fresh water along with diminishing supplies of usable ground water would lead inevitably to desalinization of sea-water, which would be accompanied by disposal of excess brine into the Gulf of Mexico.

Among the potential effects of brine disposal on marine organisms, one can include osmotic effects, ion imbalance, lower dissolved oxygen concentrations, adverse pH, strange buffer systems and large potential temperature fluctuations. Secondary effects such as induced density stratification are also possible.

Kalle (1971) present data (Figure Q-27) showing the relationships between various properties of sea water (density, light refraction, electrical conductivity and speed of sound) and temperature and salinity. He states that these changes in physical properties can cause a whole series of important biological and climatological consequences and significantly influence the large scale mixing processes in the oceans.

Salt content modifies the density, osmotic pressure and vapor pressure, and consequently the freezing and boiling points as well as density maximum. Increasing salinity causes density and osmotic pressure to increase, and vapor pressure to decrease. For example, temperature of maximum density of water of ppt salinity is 4C, while at 35.5 ppt salinity, it is lowered to -3.8C. Freezing point declines less rapidly with a freezing point depression at 35.5 ppt of 1.96C.

Copeland (1967) decribes the differential precipitation of salts when sea water evaporates (Figure Q-28). Ferric oxide and calcium carbonate begin to separate out in the area of 70 ppt salinity, borates at approximately 120 ppt calcium sulfate at 150 ppt, sodium chloride, magnesium sulfate and magnesium chloride all precipitating at 290 ppt, and sodium bromide and potassium chloride forming the majority of the dissolved solids at 300 ppt. These ionic changes are responsible for a number of other changes in chemical properties of waters of increasing salinities. As pH approaches 9 (as it does in going from 40-70 ppt as $CaCo_3$ reaches saturation) the acid-base imbalance may have a toxic effect on some marine

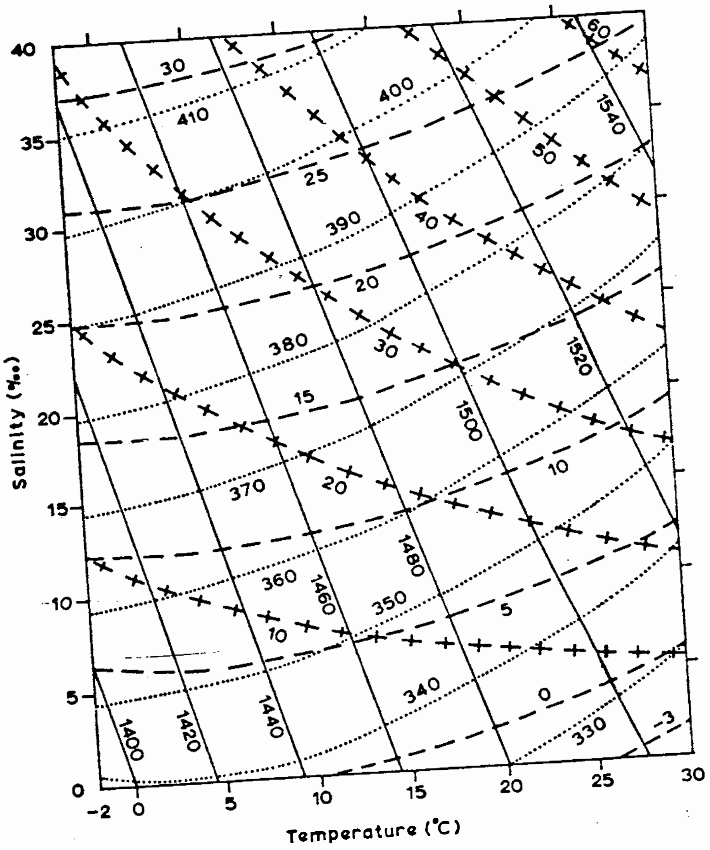


Figure Q-27

Some important properties of sea water as a function of salinity and temperature. Density - - -; light refraction... (place 1.3 before the numbers given); electrical conductivity (reciprocal ohms times 1000) + + +; and speed of sound (m/sec)   From Kalle (1971).

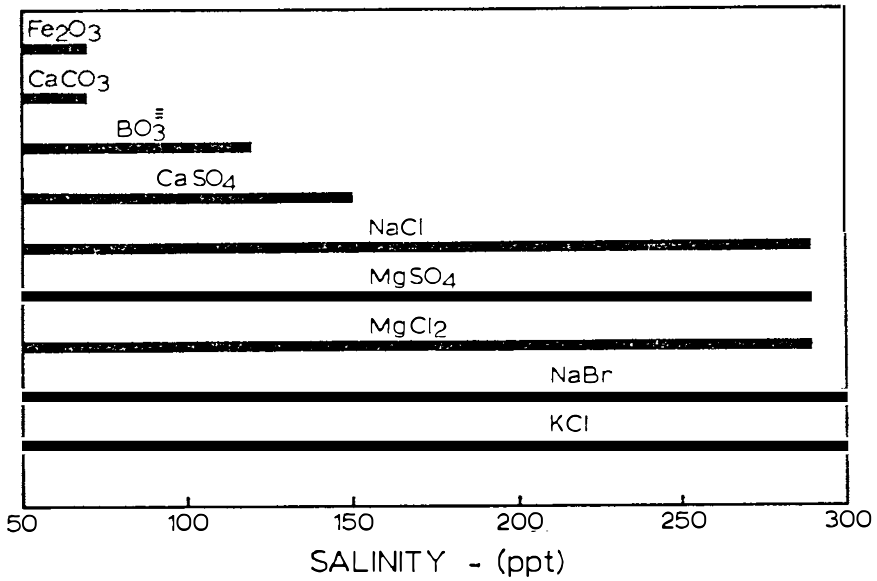


Figure Q-28

Precipitation of salts during evaporation of seawater (modified from Thompson and Robinson 1932). The end of the bar indicates the salinity at which precipitation first occurred.

organisms that are adapted to lower and more stable pH, and this may be especially true of the larval stages. Photosynthesis by algae unable to utilize bicarbonates is possible since the CO_2 content of sea water at pH 9 is about zero.

Kinne (1967) states that significant changes in the ionic composition of surrounding water may modify lethal limits and salinity preferences as well as the capacities for growth reproduction and competition; hence may affect the abundance and distribution of estuarine species.

Carpelan (1957), places an upper limit on the hypersaline realm at 70 ppt which corresponds to the first major upset in the ionic ration of sea water (precipitation of $CaCo_3$). It is at this point (70 ppt salinity) that the euryhaline marine fauna falls out, and its occurrence may be linked to the ionic imbalance (predomination by sodium, potassium and magnesium halides).

Blinks (1951) found that Laminaria (marine plant) may be killed in pure NaCl or $CaCl_2$ solutions, although it can live in a mixture of the two.

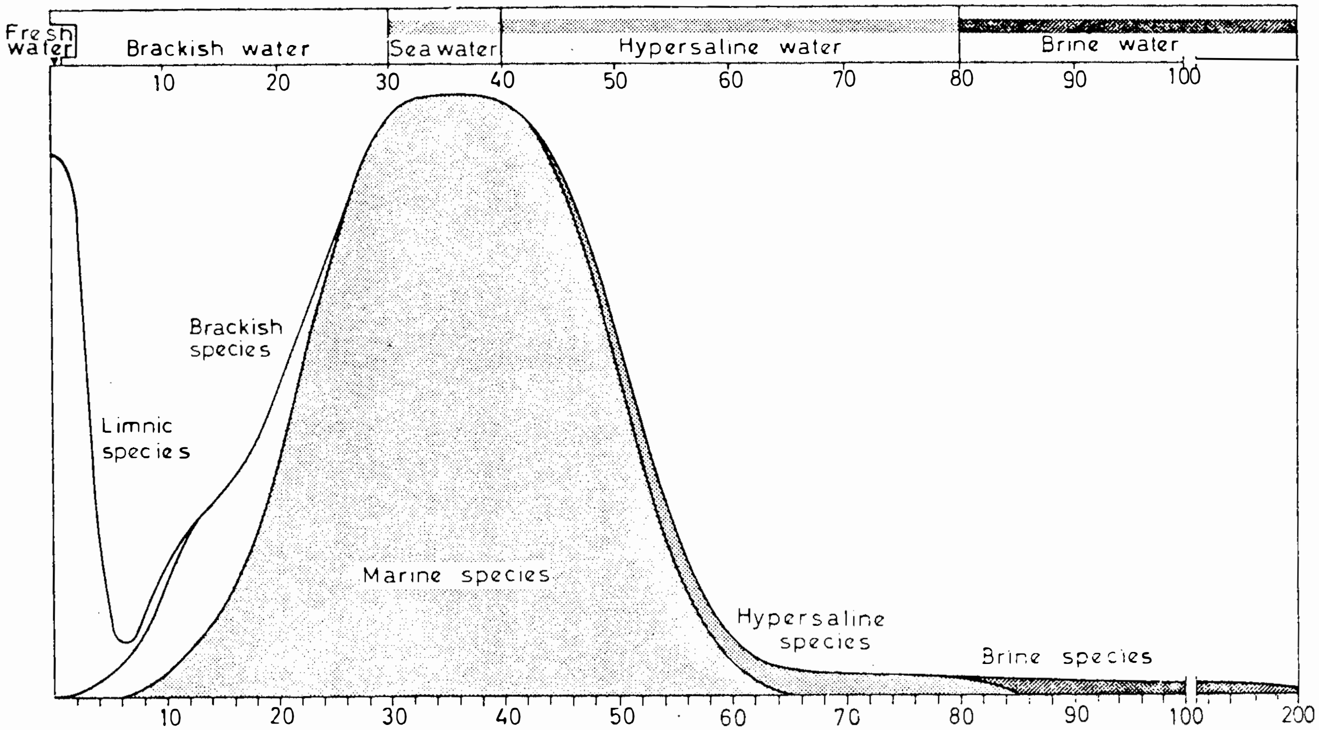
Kinne (1971) presents data (Figure Q-29) showing the relative numbers of aquatic invertebrates species along the salinity gradient from fresh water to 200 ppt. It can be seen that the estuarine assemblage is quite depauperate compared to the marine fauna and is predominantly marine in origin, being derived from the most euryhaline components of this group which are, by and large, intolerant of salinity change.

Dahl (1956), in attempting to establish ecological salinity boundaries, states that curves of number of species versus salinity show a great decrease from 34-30 ppt leaving only those euryhaline marine forms below about 28 ppt.

Pearse and Gunter (1967) state that most marine invertebrates have body fluids isotonic with their medium and have no osmotic problems in sea water. However, they have a very limited range of salinities in which they can survive. Thus, it can be stated that most marine forms are stenohaline, with only a small percentage of their members adapted to conditions of lowered salinity. In a similar respect, most marine forms have been shown to be intolerant of increases in salinity.

Figure Q-29

From Kinne 1971



Quantitative relations between aquatic invertebrate species occupying fresh, brackish, sea, hypersaline or brine waters. For each salinity (0‰-200‰), the relative number of species is indicated by the vertical extension of the respective areas. Rough estimations, based on REMANE (1934), HEDGPETH (1959) and own data. (Original.)

Day (1951) and Hedgepeth (1951) found that the marine fauna as a whole does not penetrate beyond salinities of 40 ppt and Dahl (1956) also feels that this probably represents an ecological transition zone, separating the marine stenohaline from the marine euryhaline forms.

It is generally agreed that there is no characteristic endemic fauna of the hypersaline realm (40-80 ppt salinity) with most elements being drawn from the estuarine realm (Day 1951, Hedgepeth 1957, Carpelan 1957, Emery et al. 1957). Simmons (1957) presents a list of fishes taken in the Lagune Madre at hypersaline (60-70 ppt) conditions, and all ten are also found in salinities from 25 ppt up and are found on Gunter's (1956) list of euryhaline fishes of the U. S. This indicates that fish required to osmoregulate in waters of varying salinity are better able to cope with hypersaline waters than those species living in more stable environments of the open ocean. Copeland (1967) presents a graph (Figure Q-30) showing the inverse relationship between salinity and the numbers of species of fishes in a hypersaline lagoon on the Gulf Coast of Mexico. In February 1964, after salinities had varied from 110 and 120 ppt for almost one year, only two fishes, *Cyprinodon variegatus* and *Menidia beryllina* remained, and they disappeared at 140 ppt. After 150 ppt only *Artemia salina* was present in December 1964, when salinity reached 295 ppt, even in the brine shrimp had disappeared.

Thus, the number of marine species declines as the salinity varies from the optimum (full sea water), with the majority of marine forms having relatively narrow ranges of salt tolerances. In consequence, the food chains are relatively simple and the competition mainly intraspecific in these hypo- and hypersaline habitats.

An area of major concern with relation to salinity impacts is the benthic community. First, the benthic infauna and much of the eipfauna are relatively sedimentary and, as such, have little ability to avoid the brine discharge. The response of the infauna to an increase in interstitial salinities would be to burrow deeper into the sediments. They are, however, limited as to maximum depth of penetration by such vertical gradients as redox, pH, and oxygen content. Second, Kinne (1971) and others have stated that the interstitial habitat is more stable (lesser degree of fluctuation of environmental variables) than the overlying water column. As a result, the infauna is less adapted to salinity changes than the organisms in the water column, and should represent one of

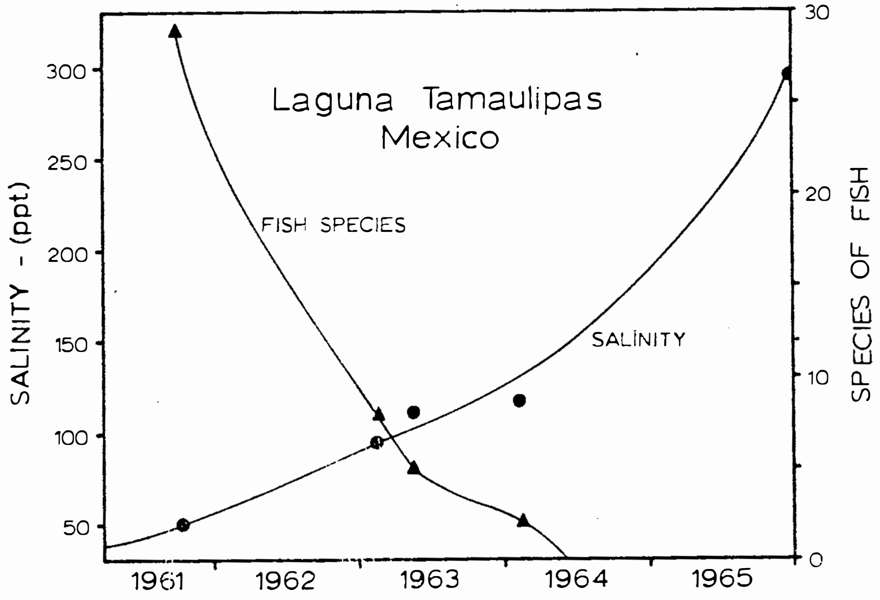


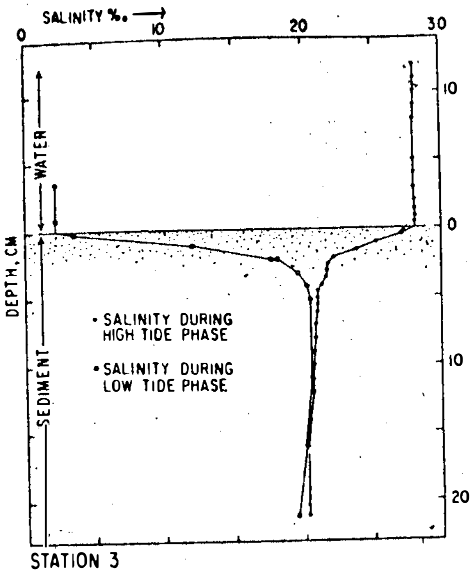
Figure Q-30

Salinity in parts per thousand and number of fish species in the Tamaulipas, Mexico, during 1961 through 1965.

the most stenohaline components of the aquatic system. Sanders et al. (1967) studied the relationships between various water quality parameters of the overlying waters and interstitial water at a number of stations along a salinity gradient in a Massachusetts estuary (fluctuating type). In contrast to the marked fluctuations in the salinity of bottom waters (of the water column) the interstitial water was stable and relatively constant (Tables Q-34 and Q-35, and Figure Q-31) with the magnitude and rate of change of salinity in the sediments an order of magnitude lower than for the water. The ratio of epifauna to infauna for these soft, mud substrates was much less than 1, indicating a less rigorous environment for the relatively stenohaline infauna. They found for Station 3 (mid-estuary) that tidal salinity differences at the sediment surface were 26 ppt, while at 2 cm below the surface there was less than 5 ppt change and at 7 cm, less than 0.1 ppt change. They also found that the rate of penetration of salt depended on the nature of the sediment, with loose, coarse, porous sands showing greater rates of penetration by salt water, followed by soft muds, with least penetration of stiff, hard packed muds. They also showed that integrated salinity deficit of the bottom water at low tide compared to mud is 1.6 times as great as the integrated salinity excesses at high tide, indicating that high salinity water is more than half again as effective in determining the sediment salinity than is low salinity water. This is in accord with the results of Laevastu and Fleming (1959) who found that replacement of fresh intertidal water with salt water in an estuary was rapid, but the reverse process was much slower, and the overall rate of change being dependent on sediment type (see also Kinne 1967 and Hicks 1973).

Nelson (1959, 1962) who stated the intertidal water chemistry in Chesapeake Bay found that sodium replaced calcium as the dominant exchange cation as the salinity increased, with concentrations of magnesium and potassium also increasing. The pH changed from slightly acid in fresh water to moderately alkaline as a result of saturation of the sediment exchange complex with basic cations. Thus, the situation is directly analagous to soils, except that in the latter, natural drainage processes cause removal of chloride and consequent disruption of the physical structure of the soil mass. Since chloride would always be present in the marine sediments, this problem is not anticipated. Since salinity increase are known to decrease oxygen holding capacity of the water and increase temperature fluctuation due to decrease in specific heat, secondary effects are possible. Salinity stress could cause

Figure Q-33



Salinity profiles at high and low tide of the sediment and the immediately overlying water at Station 3.

Table Q-34

Station	Magnitude of salinity change during tidal cycle	Max rate of salinity change/hr
1	almost 28‰	17
2	25	18.5
3	27	15.3
4	26	11
5	ca. 15	12(?)
6	20	12
7	10	9

Magnitude and rate of salinity change in the sediment at the seven Pocasset River stations

Table Q-35

Station	Mean salinity (‰)	Magnitude of salinity change during tidal cycle	Max rate of salinity change/hr
1	7	9.5	5.5
2	17	3	0.8
3	20.7	1.4	0.7
4	22.9	1.8	0.8
5	26.5	0.5	0.2
6		freshwater spring	
7	29.8	0.7	0.6

Magnitude and rate of salinity change of the bottom water at the seven Pocasset River stations higher metabolic rates in infauna, leading to higher O_2 requirements during periods when O_2 capacity is lower. Depletion of oxygen, in addition to causing asphyxiation of the benthic community could cause major changes in the intertidal water - water column element exchange balance. Mortimer (1942) noted that an exchange ions between lake sediments and water began to occur as soon as dissolved oxygen concentrations fell below 2 ppm. However, this accelerated exchange can occur independently of induced oxygen relationships. Feick et al (1972) who were aware of the problem of salt additions to surface waters, investigated the role of NaCl in determining the ratio of mercury in water to mercury in sediment. In laboratory experiments, they found that the equilibrium for sandy soils was higher than that for organic soils indicating that the organic soils held the mercury more tightly than the sandy soils. This in turn was due to greater cation exchange capacity in the former. Additions of NaCl (35 g/liter) increased the ratio several orders of magnitude. They felt that this was due to the chloride complexing with the mercury of the sediments, and the replacement of mercury on the exchange sites of the soil by sodium. The effect tended to increase as the mercury burden of the sediments increased.

To this must be added the interactive effects of salinity, temperature and other environmental factors (such as concentrations of toxins). Temperature-salinity interactions are well documented (see Kinne 1967) and both factors are related to the relative toxicity of certain contaminants (e.g. heavy metals and hydrocarbons) to the biota. Dorgelo (1976) concludes that the effect of temperature on salt tolerance can be beneficial or harmful depending on the species. Ritchie (1957) who studied temperature-salinity relations in _Phoma_, a marine fungus, found optimum salt concentrations increasing with increasing temperature within the limits of tolerance of the organisms. However, this relationship was not seen in all species tested. McLeese (1956) has shown the interactive effect of temperature and salinity on the survival of the American lobster. Williams (1960) has shown a temperature-salinity interaction in juvenile brown shrimp and adult pink shrimp but found that temperature had a far greater effect on survival than salinity.

Lewis (1966) and Lewis and Helter (1968) found that the acclimation history and rate of change in environmental variables (temperature and salinity) were most important in determining tolerance in the Atlantic manhaden, but temperature was far more important than salinity, with high temperatures (greater than 35C) causing extensive mortality. They state that since the temperature in the nursery areas can exceed 33°C, the rate of change will be a determining factor. They also reported that yearlings were more sensitive to higher salinities than younger fishes. Simmons (1957) noted that the dissolved oxygen decreases with both high temperatures and increasing salinity, and fish kills in the Laguna Madre might be a combination of reduced oxygen content of the water at times of maximum physiological stress, combined with the greater metabolic needs of organisms for osmoregulation.

Lockwood (1962) states than ionic regulation is thermally influenced and multiple environmental factors, each at a sublethal level, can interact synergistically to cause death.

Jones et al (1976) found that both high and low salinities increased the toxicity of copper to the polychaete, *Nereis diversicolor* (an estuarine form) and they suggested that synergistic effects of these factors rather than the amount of copper per se may be the important lethal factor.

Vernberg and Vernberg (1972) found that the gill tissues of the fiddler crab, *Uca pugilator* were the main site of mercury concentration, with significant concentrations also in the green gland and hepatopancreas. A concentration of mercury, sublethal under optimum condition of temperature and salinity, greatly reduced survival under temperature or salinity stress.

Vernberg and O'Hara (1972), O'Hara (1973), Jones (1973, 1975) and Thurberg et al (1973) have all indicated that increased toxicity of metals was due to loss of osmoregulatory functionin the latter being due to the presence of the metals.

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APPENDIX R

EFFECTS ON FISHERIES OF USING BLACK LAKE AS A LEACHING/DISPLACEMENT WATER SOURCE

APPENDIX R

EFFECTS ON FISHERIES OF USING BLACK LAKE AS A LEACHING/DISPLACEMENT WATER SOURCE

Since physicochemical changes induced in Black Lake and in associated water bodies by withdrawal of water from the lake would be relatively slight as analyzed with the MIT WATER QUALITY NETWORK model, no significant long-term changes in the capacity of this system to support fisheries species are foreseen. A long-term change is one that persists for more than a year after the end of a period of water withdrawal. Fisheries species would certainly be depleted over the short-term, but their reproductive powers would enable them to recover rapidly.

The emphasis of this analysis is, therefore, upon the magnitude of losses which could be sustained during and after water withdrawals. The losses of shrimp will be considered first. Two species are equally important in the region, with respect to inshore harvests.

Both species, the white and brown shrimp, use Black Lake and its adjacent waterways as staging areas prior to their return to the Gulf of Mexico, where they spawn. The shrimp are harvested in these inshore staging areas and offshore in the Gulf. Marsh areas adjacent to staging areas serve as nursery areas within which much of the growth of the shrimp occurs. Nursery areas have been proposed to be managed as sanctuaries by researchers in the Louisiana Wildlife and Fisheries Commission (White and Boudreaux, 1977).

Near Black Lake on the west, northwest, and southwest are impoundment and partial impoundment areas which also presently function as nurseries (White and Boudreaux, 1977; Lowery, 1977). These impoundments are thought to be responsible for an upsurge in brown shrimp production. Prior to these impoundments functioning as significant nursery areas, most brown shrimp harvested in the area were thought to have developed elsewhere. Circumstantial evidence indicated Rockefeller Refuge might have been the location. They apparently then migrated into the Calcasieu Basin and used it as a staging area (Gaidry and White, 1973).

In proportion to its size, the Black Lake area is regarded as highly productive of certain commercial species, and is not simply an extension of Calcasieu Lake (Lowery, 1977). Several million dollars per year of income probably result from Black Lake area shrimp catches (Lowery, 1977). However, this cannot be verified from official records. Only the catch sold to commercial dealers is reported on these records, and catch locations are not identified specifically enough to single out the Black Lake area. Most of the shrimp catch is not reported (White and Boudreaux, 1977). Perhaps 95 per cent of the shrimp obtained from the Black Lake complex is for home consumption or marketed without going to a dealer (Andy's Seafood Shop, 1977). An estimate of a typical brown shrimp catch in Alkali Ditch of about 20,000 lbs/night (Shaugnessy, 1977) during the spring season, combined with a period of good catches extending over about two months (White and Boudreaux, 1977), gives a seasonal harvest of 1,200,000 lbs. from this source. This estimate assumes an average of 20 boats per night and an average catch of 1,000 lbs per vessel per night for 60 nights. There are also 10 or 15 boats which fish Black Lake itself with trawls, usually with 16-foot nets and occasionally 24- or 30-foot nets (Andy's Seafood Shop, 1977). Their catch would add another few hundred thousand pounds. Some shrimp are also captured with stationary nets as they move into the southern, breached impoundment located on the western side of Black Lake. An estimated 30,000 lbs were caught in this manner in 1976 between June 1 and July 1 by one small shrimping group. Approximately 3,000 lbs could be caught in 2 hours from a 4-foot wide channel and with a water flow of 1.5 fps (Lowery, 1977).

The values given above do not consider the fraction of the offshore brown shrimp harvest which is dependent on the nursery and staging areas in the Black Lake area. Commercial catches from offshore of Cameron Parish, reported by the National Marine Fisheries Service, are on the order of 2 to 5 times the reported commercial inshore catch for 1973 and 1974, respectively. Most of the offshore harvest is probably reported. The offshore catch for 1973 was approximately 1.2 million pounds. The offshore catch for 1974 was approximately 1.7 million pounds. The Calcasieu Estuary lakes, including the Black Lake complex, are the main staging location in this part of Louisiana, and much of the offshore harvest is dependent in some way upon it.

White shrimp offshore commercial harvest data have been higher than for brown shrimp. A breakdown for 1972, 1973, and 1974 gives 3,625,000 lbs offshore, 700,000 lbs inshore; 4,250,000 lbs. offshore, 900,000 lbs inshore; and 4,000,000 lbs offshore, 100,000 lbs inshore; respectively. Once again, the inshore values are underestimated because much of the catch is not reported. If a significant fraction of the white shrimp harvest is dependent on the Black Lake area, as is evidently true for brown shrimp, the overall shrimp harvest directly attributable to the Black Lake system seems to stand at a lower limit of between 1 and 2 million pounds.

Based on body proportions, shrimp longer than about 45 mm long would not be susceptible to entrainment through the smallest intake screen mesh size (about 9.5 mm on a side). The bar screen in front of this screen on the lake side would have a mesh with openings 12.7 mm on a side and would not admit shrimp longer than about 60 mm. Shrimp too large to pass through the 9.5 mm screen but large enough to pass the 12.7 mm screen could potentially be trapped in the space between them. Although the 9.5 mm screen would be a traveling, mechanically cleaned screen and should not clog, the 12.7 mm screen may be susceptible to clogging. If this occurs, the intake velocity would increase and impingement could become more significant.

There is a difference of opinion among shrimp researchers as to whether shrimp too large to be entrained could be impinged at the projected intake velocity of 0.5 fps Charles White (1977) indicated that subadults (emigrating juveniles) would be able to resist this velocity. Cities Service Refinery intake screens sometimes become clogged with shrimp at about 1.5 fps (White, 1977). Dr. Kirk Strawn of Texas A&M University (1977) thought that even emigrating juveniles would be unable to avoid an 0.5 cfs velocity and could be impinged. It seems clear that postlarvae and the smallest juveniles which come into the influence of the intake would be entrained. The emigrating juveniles usually leave on the outgoing tide and at night. The currents get strong enough in Black Lake Bayou so that boats involved in shrimping have to be tied off to keep them from drifting (Andy's Seafood Shop, 1977) and the currents in the other outlets presumably also reach similar strengths. It is near these outlets that the shrimp are observed in the greatest numbers (Shaugnessy, 1977). They are apparently concentrated in these locations by the prevailing current patterns.

Under natural conditions, postlarval density is not a good indicator of later population density. It indicates only potential recruitment*. Hydrological conditions in the estuary largely determine the sizes attained by juvenile shrimp populations (White and Boudreaux, 1977). Mortality is very high from the larval stage throughout the rest of the life cycle (White and Boudreaux, 1977). The adult females produce tremendous numbers of eggs (500,000 to 1,000,000 per female) (Moffett, 1970). According to White and Boudreaux (1977), Gunter felt that the weekly mortality of shrimp in the bays could be under 40 percent a week, but that egg and larval mortality was higher. A mortality level of 40 percent per week was considered low enough to permit a continuing increase in the total weight of growing shrimp. However, Kuhn found natural mortality to be so high in every case in field observations that a continuing decline in total weight would occur if the shrimp were not harvested as soon as they were of legal size.

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*Recruitment is the increase in population numbers resulting from immigration.

For purposes of estimating brown shrimp entrainment it is assumed that all postlarvae in the intake water would be lost. Postlarval numbers are estimated based on two sample stations, one in Calcasieu Pass and one in a nearby channel to the east. An influx of postlarvae at a density of 8/100 m^3 for each of 11 weeks and a density peak of 540/100 m^3 for 1 week, for an average of approximately 50/100 m^3 over 13 weeks, is assumed. This converts to 81,812.5 postlarvae entrained per day during leaching and 116,923.7 postlarvae per day during displacement for 13 weeks of each year involved or totals per year of approximately 7.4 x 10^6 and approximately 1.06 x 10^7, respectively. These losses would not be significant in terms of harvestable shrimp. As discussed below for white shrimp, these losses would amount to roughly 1000 lbs. of harvestable brown shrimp lost.

Juvenile brown shrimp less than 45 mm long would also be expected to be lost. It is estimated that this loss would occur over about 9 to 10 weeks. This time duration and the estimate of juvenile density below are based on composite values for weekly samples for Calcasieu Lake, including the ship channel vicinity near the ICW. Juvenile shrimp are good predictors, and are used in setting the opening dates of the inshore shrimping seasons. The up-to-45-mm brown shrimp juveniles are estimated to have an average density of 2/100 m^3. This converts to a loss of 3,272.5 juveniles per day during leaching or about 2.2 x 10^5 for the 66 days of each year involved. During displacement, the estimate of juvenile brown shrimp entrainment is approximately 4,677 per day, or approximately 3.1 x 10^5 over a 66 day period. Brown shrimp in the less-than-45-mm-long size range, are approximately a month or more away from harvestable size. Given high shrimp natural mortality rates, most of them would have died without ever reaching such a size. Assuming high survivorship of 13 percent per month in juveniles and about a month to reach smallest harvestable size, less than 1,000 lbs of brown shrimp would be lost in a year in which there was either leaching or displacement. Predators on shrimp would be affected by the reduction in a food source.

White shrimp postlarvae enter the estuary in greatest abundance from June through September. Juveniles under 50 mm long are present from July through September, sometimes occurring as early as June. By late summer and early fall, most of the white shrimp juveniles are between 50 mm and 100 mm long. Nearly all of the white shrimp less than 45 mm long are found in the nursery areas and not in the staging areas such as Black Lake. Most of the potential interference with the white shrimp harvest resulting from entrainment losses would involve entrainment of postlarvae. White and Boudreaux (1977) state that the Calcasieu Basin does not usually have a strong influx of postlarvae. However, numbers of juveniles are high in both the nursery and staging areas. This indicates a high survivorship. The order of magnitude of postlarval densities can be estimated by reference to density values for two other coastal zones which are characterized by similarly low postlarval immigration. The estimated average density of postlarvae is approximately $2.5/100^3$. Assuming this is an average for June through mid-October, or 18 weeks, approximately 5.2 x 10^5 postlarvae would be lost during each year of leaching and about 7.4 x 10^5 postlarvae would be lost for every year that displacement overlapped with immigration. The average fall density of juvenile white shrimp in the Calcasieu system is estimated at approximately 1.1/100 m^3, so that at least 44 percent of the postlarvae immigrating in fall generally survive to be fall juveniles. A certain proportion of these would develop to harvest size and a certain fraction of these survivors would be taken by shrimpers. As with brown shrimp, the fraction of entrained white shrimp juveniles which would otherwise have survived to harvestable size is estimated to be very small, the equivalent of less than 1,000 lbs. per year of leaching or displacement. The monitoring program which provided information for analyses of shrimp entrainment losses was carried out by the Louisiana Wildlife and Fisheries Commission (White and Boudreaux, 1977).

Other fisheries species reported in the Black Lake area are menhaden and blue crabs (Lowery, 1977). Some 25,000 lbs of blue crabs were harvested in an impoundment to the west of Black Lake in 1966 (Lowery, 1977). Such crabs have planktonic early stages, a small fraction of which would be entrained by use of Black Lake water for leaching and displacement.

Menhaden eggs and larvae are known to enter the Barataria Bay estuarine system from September to April and this appears fairly typical for the estuaries along the entire coastline of Louisiana (Dunham, 1972). They appear to be susceptible to entrainment up to a length of about 34 mm and to be able to pass through the bar screen of the intake up to a size of approximately 39 mm. The great majority of the menhaden in the estuary are juveniles too large to be entrained, if Barataria Bay data are indeed typical.

The susceptibility to impingement of young menhaden, shrimp, and crabs larger than those which could be entrained is an unanswered question. Such information will probably require original research.

In summary, since the physical and chemical changes induced in Black Lake and associated water bodies would be slight, the habitat of commercially important species would not experience any irreversible changes. Thus, no permanent changes in the capacity to support fisheries species are predicted. Fisheries species, such as brown shrimp, would experience some degree of entrainment during susceptible stages of their life cycle. The influence of this mortality on population dynamics is not straightforward and cannot be stated with absolute certainty. However, it is known that shrimp populations are adapted to heavy mortality, especially in the younger life stages. An adult female can produce 500,000 to 1 million eggs during her life. Obviously only a few of these offspring reach maturity and reproduce. By virtue of the tremendous reproductive capacity and migratory behavior of shrimp annually into Black Lake, we can conclude that regardless of the direct effect on shrimp during a given time period, populations would recover the year following cessation of water withdrawal.

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APPENDIX S

OIL IN BRINE MODEL STUDY

APPENDIX S

OIL IN BRINE MODEL STUDY

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PART I - GENERAL DISCUSSION AND USE OF EXISTING CAVERNS

S.1 INTRODUCTION

The storage of crude oil in the Strategic Petroleum Reserve Program will entail the contact of oil with brine solutions. This contact would result in the dissolving and entrainment of small concentrations of hydrocarbons in the brine through a number of physical phenomena. In order to assess the magnitude of oil concentrations discharged into the brine surface control facilities, a study was performed to determine the mechanisms of interactions between the oil and brine within a typical underground oil storage cavern. This appendix discusses the results of that study.

The primary cavern interactions which would distribute the oil into the brine are dissolution and dispersive reactions. Dispersive reactions require a physical energy input to the system to agitate the micro oil particles into the underlying brine. Dissolution occurs on the molecular level where the hydrocarbon solute dissolves into the brine solvent system. Although both of these reactions occur simultaneously during certain operational phases, the study indicates that principally dissolved components would be discharged to the surface brine control facilities.

Results of the study indicate that under a worst-case situation, the brine discharge would contain an estimated maximum 32 parts per million (ppm) of oil. However, this condition is not expected to occur. A more reasonable estimate of the dissolved oil-in-brine concentration discharged from a typical cavern during initial fill is approximately 16 ppm, during approximately the later 10% of an individual cavern discharge and 6 ppm during the entire individual cavern discharge period for subsequent refills.

The sections which follow describe the oil/brine interactions within a storage cavern (Section S.2), dissolving reactions (Section S.3), dispersive reactions (Section S.4), expected concentration of oil-in-brine discharged to the surface brine control facilities (Section S.5), and conclusions (Section S.6).

S.2 OIL/BRINE INTERACTIONS IN A SALT SOLUTION-MINED STORAGE CAVERN

The following sections briefly describe the major interactions that occur between the oil, brine, and raw water within a salt dome storage cavern. The interactions which occur during the operational phases of the storage program are illustrated schematically in Figure S-1 and are described herein as:

The initial oil fill and discharge of brine;
The long-term storage of oil in a quiescent state;
Raw water injection to displace oil;
Storage cavern conditions after oil is displaced; and
The second and subsequent refills.

S.2.1 Initial Oil Fill

The salt dome cavern, prior to the initial oil fill, is filled with brine. As crude oil injection begins, jetting (approximately 8 feet per second) causes turbulence at the oil-brine interface which produces an emulsion of oil and brine and affects solution of various hydrocarbons into the brine. Turbulence would be confined to approximately the upper 50 feet of the cavern. As cavern filling continues, interface turbulence would decrease as the interface descends. At a depth of approximately 50 jet diameters, the oil jet momentum would be one-tenth of its initial value and interface turbulence would have ceased (American Petroleum Institute, 1969).

The lighter, more soluble hydrocarbons diffuse across the oil-brine interface, while the heavier, less soluble components slowly begin to form a relatively dense and viscous refractory layer between the oil and brine. Thus, the major oil contamination of the brine occurs during the initial period of the filling phase while turbulence is high.

Dissolved and dispersed oil is expected to remain within the uppermost 100 feet of the brine column during initial fill due to a low rate of vertical diffusion. Consequently, during the early stages of fill the oil concentration of the discharged brine would be near zero. As the oil/brine interface approaches the bottom of the brine displacement tubing, oil concentration of the discharged brine would increase and average 16 ppm during the final stages of fill (Section S.5).

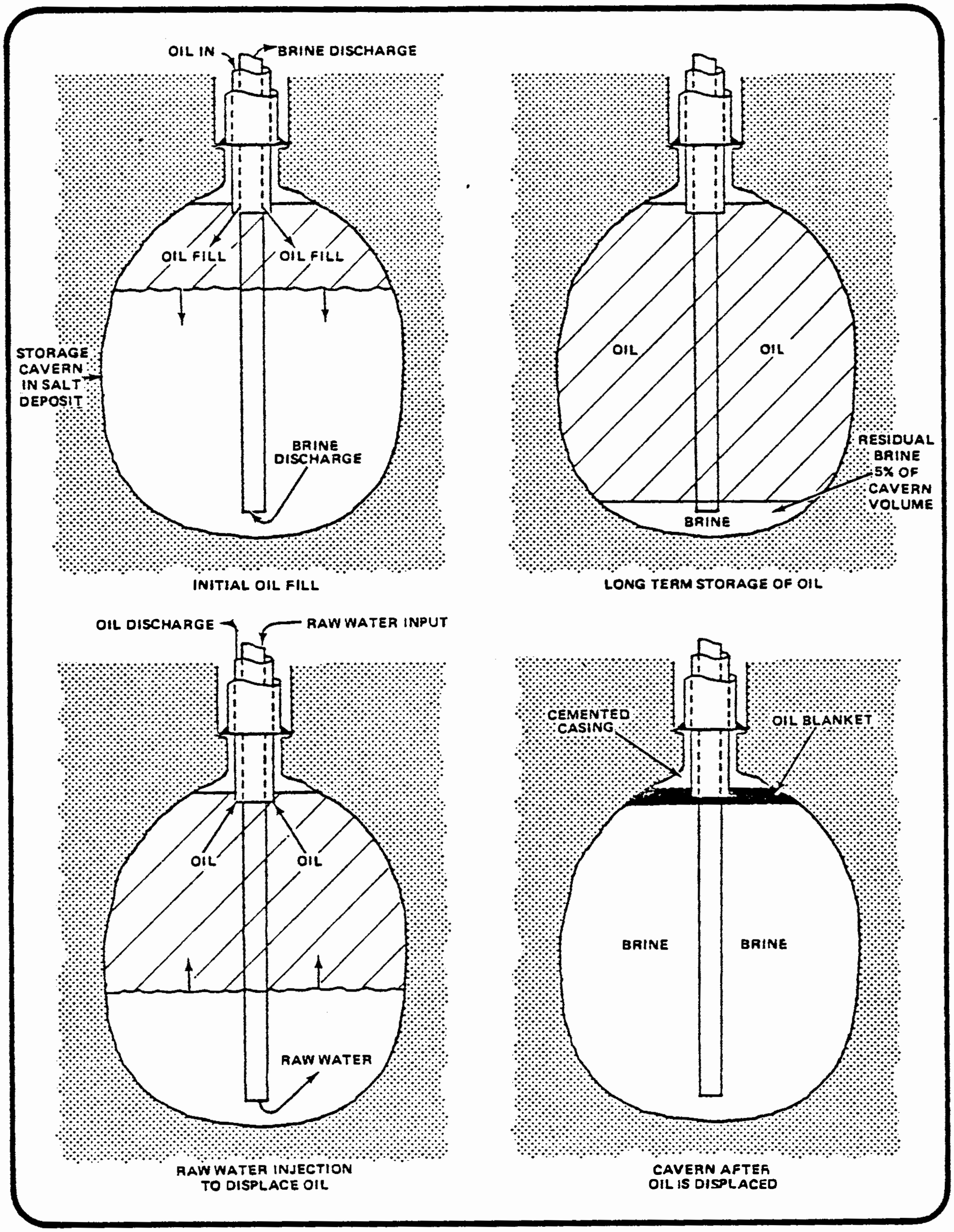


FIGURE S-1 Operational phases of oil storage program

S.2.2 Long-Term Oil Storage

During long-term oil storage, a brine layer is maintained at the bottom of the solution cavern and would amount to approximately 5 percent of the total cavern volume. The oil concentration within this brine is assumed to reach equilibrium during long-term storage. A refractory layer would form at the oil brine interface because of the loss of soluble hydrocarbons into the underlying brine and a consequent enrichment of heavier, relatively insoluble hydrocarbons. Any remaining small fraction of dispersed oil in brine would be expected to rise to the oil-brine interface contributing to the refractory layer or be absorbed by suspended particles and in turn settle to the bottom. The long-term storage is the only phase of the program where time allows the hydrocarbons to dissolve and establish equilibrium conditions with respect to the brine.

S.2.3 Injection of Raw Water and Displacement of Oil

The oil is displaced from the cavern by injection of raw water into the lower level, causing the upward displacement of oil. The raw water would dilute the residual brine solution in the bottom of the cavern and may resuspend settled particles. The resultant dilution of both the brine and dissolved oil concentration would allow further dissolution of oil into brine. Initially, there would be turbulence at the oil-brine interface which may disperse some of the oil. The refractory layer at the oil-brine interface would effectively limit diffusion and dispersion. When the crude oil is displaced from the storage cavern, an oil film would remain on the cavern walls. This oil film would, in time, partly dissolve into the brine and partly rise to the oil-brine interface as solution of the underlying salt progresses. For calculation purposes, in this report, this oil film was assumed to be totally dissolved, adding approximately 1.6 ppm to the oil-in-brine concentration.

The raw water being injected into the cavern would rise toward the surface due to its lower density and induce a circulation within the brine. This may result in an increase in the diffusion of oil into the now non-equilibrium system. As the interface rises within the cavern, the circulation would decrease in the upper brine column due to the rapid dilution of the raw water. The brine temperature within the cavern will eventually rise to approximately 150°F and an increase in salinity will occur as the dissolution of the cavern walls proceeds. The net effect is a decrease in oil solubility because the salinity factor has a greater influence than that of temperature (Section S.3). The dissolved oil concentration in the brine at the end of this operation is therefore the result of:

(1) the twentyfold dilution of the residual brine which had reached equilibrium oil concentrations at the bottom of the cavern,

(2) some dissolution of the oil layer on the cavern walls, and

(3) some small additional dissolution at the oil-brine interface during displacement.

S.2.4 Storage Cavern Conditions After Oil is Displaced

After the cavern is filled with water and the crude oil removed, a small amount of the crude oil would be retained as a blanket on top of the brine column. The oil blanket acts as a barrier between the solution cavern ceiling and the brine, thereby minimizing salt dissolution around the cemented casing. The oil at the oil-brine interface will be composed of a relatively dense, viscous layer and would only allow slow diffusion of the soluble hydrocarbon components. The additional oil concentration dissolved into the brine during this operation is judged to be minimal.

S.2.5 Second and Subsequent Oil Refill Phase

The oil-brine interface would now have had sufficient time for a dense refractory layer to form. This layer would reduce the diffusion and dissolution during subsequent refills. Throughout subsequent oil refills approximately 6 ppm of oil in brine (as calculated in Section S.5) will be discharged to the surface brine control facilities, providing the dense refractory layer continues to act as a barrier. In the event that the refractory layer is penetrated by the input jet of oil, reactions similar to those of the initial fill cycle would occur.

S.3 DISSOLUTION REACTIONS DURING CAVERN OPERATIONS

The solubilities of various hydrocarbons in water and in brine have been studied by a number of workers. The data illustrated in Figure S-2 indicate that for each homologous series of hydrocarbons, the logarithm of solubility in water is a linear function of hydrocarbon molar volume. The solubility of hydrocarbons as illustrated in Figure S-2 and listed in Table S-1 increase with a decrease in molar volume and molecular weight and an increase in branching and degree of unsaturation. The most soluble hydrocarbons are the low molecular weight aromatics (Price, 1973; McAuliffe, 1976).

Review of studies which were conducted to determine the saturation concentrations for oil in seawater and in freshwater, indicate that as the hydrocarbons dissolve, solubility rates decrease before equilibrium conditions are established (Price, 1973).

Equilibrium concentrations at standard temperature and pressure for four different crudes are listed in Table S-2. Equilibrium concentrations found by other researchers for crude oil in both freshwater and saltwater, range from 7 to 40 ppm with the preponderance of data ranging from 20-30 ppm (McAuliffe, 1976; Frankenfeld, 1975; Candle, 1977; Anderson, 1974).

Selected data for the La Rosa and Murban crudes, presented in Table S-3, reveals the variations in equilibrium concentrations which can be expected. This data indicates that the hydrocarbon composition of a particular stored crude would effect the concentration of dissolved oil being discharged with the brine. For the purpose of calculating estimated oil concentrations in a brine discharge, the Middle East Murban crude was considered as a possible crude to be stored in the Strategic Oil Reserve Program.

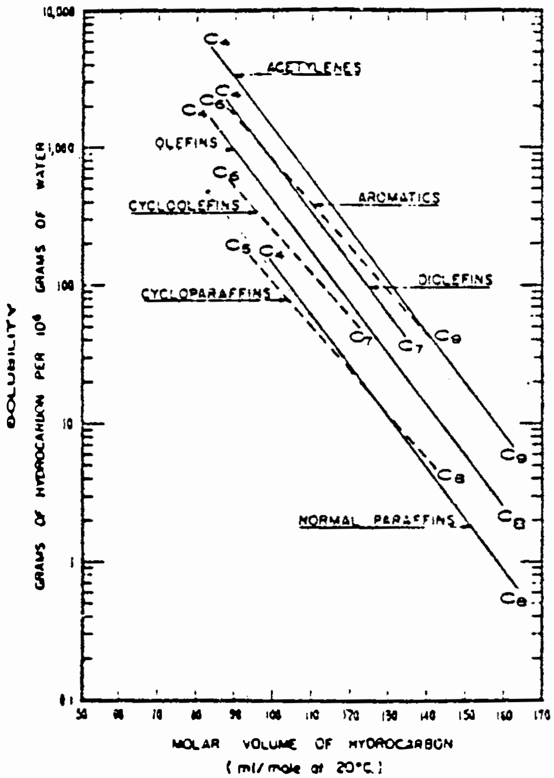
The equilibrium concentration of Murban crude in seawater with a salinity of 36 ppt is 27.9 ppm at standard temperature and pressure as shown in Table S-2.

As temperature and pressure change within the storage cavern, the resultant equilibrium concentrations can be expected to change. General hydrocarbon solubility studies indicate that as temperature and pressure increase, solubility and equilibrium concentrations increase. Increasing

TABLE S-1 Aqueous solubility values of individual compounds at 25°C (ppm).

COMPOUND	PRICE	MCAULIFFE
PENTANE	39.5	38.5
HEXANE	9.47	9.5
HEPTANE	2.24	2.93
OCTANE	0.431	0.66
NONANE	0.122	0.22
ISO PARAFFINS		
2,3 – DIMETHYLBUTANE	19.1	
2,2 – DIMETHYLBUTANE	21.2	
2 – METHYLPENTANE	13.0	
3 – METHYLPENTANE	13.1	
2,4 - DIMETHYLPENTANE	4.41	
2,2 – DIMETHYLPENTANE	4.40	
2,3 – DIMETHYLPENTANE	5.25	
3,3 – DIMETHYLPENTANE	5.94	
2,2,4 – TRIMETHYLPENTANE	1.14	
2,3,4 – TRIMETHYLPENTANE	1.36	
ISOPENTANE	48.0	
2 – METHYLHEXANE	2.54	
3 – METHYLHEXANE	2.65	
3 – METHYLHEPTANE	0.792	
4 – METHYLOCTANE	0.115	
BICYCLOPARAFFIN		
(4.4.0) BICYCLODECANE	.889	
NAPTHO–AROMATIC	88.9	
CYCLOPARAFFINS		
CYCLOPENTANE	160	156
METHYLCYCLOPENTANE	41.8	42
PROPYLCYCLOPENTANE	2.04	
PENTYLCYCLOPENTANE	0.115	
1,1,3 – TRIMETHYLCYCLOPENTANE	3.73	
CYCLOHEXANE	66.5	55.2
METHYLCYCLOHEXANE	16.0	14.0
1,4 – TRANSDIMETHYLCYCLOHEXANE	3.84	
1,1,3 – TRIMETHYLCYCLOHEXANE	1.77	
AROMATICS		
BENZENE	1740	1780
TOLUENE	554	515
M – XYLENE	134	
O – XYLENE	167	175
P – XYLENE	157	
1,2,4 – TRIMETHYLBENZENE	51.9	57
1,2,4,5 – TETRAMETHYLBENZENE	3.48	
ETHYLBENZENE	131.1	152
ISOPROPYLBENZENE	48.3	50
ISOBUTYLBENZENE	10.1	

SOURCE: PRICE, 1973.
McAULIFFE, 1969



SOURCE: McAuliffe, 1969

FIGURE S-2 Comparison of the solubilities in water at 25°C of various types of hydrocarbons, as functions of their molar volumes

TABLE S-2 Hydrocarbons dissolved in sea water* equilibrated with oil samples.

COMPOUND	SOUTH LOUISIANA CRUDE (1) ppm	KUWAIT CRUDE (1) ppm	VENEZUELA LA ROSA CRUDE (2) ppm	MIDDLE EAST MURBAN CRUDE (2) ppm
ALKANES				
ETHANE	.54	.23	2.011	.23
PROPANE	3.01	3.30	3.63	2.150
n BUTANE	2.36	3.66	1.88	2.880
ISOBUTANE	1.69	.90	.76	.800
n PENTANE	.49	1.31	.60	1.340
ISOPENTANE	.70	.98		1.030
CYCLOPENTANE + 2 METHYLPENTANE	.38	.59		
METHYLCYCLOPENTANE	.23	.190	.275	.355
HEXANE	.09	.290	.65	1.35
CYCLOHEXANE			.190	.410
METHYLCYCLOHEXANE	.22	.080	.160	.235
n HEPTANE	.06	.090	.100	.330
C_{16} n PARAFFIN	.012	.0006		
C_{17} n PARAFFIN	.009	.0008		
TOTAL $C_{12} - C_{24}$ n PARAFFINS	.089	.004		
AROMATICS				
BENZENE	6.75	3.36	3.30	6.080
TOLUENE	4.13	3.62	2.80	6.160
ETHYLBENZENE	1.56	1.58	.275	.825
M – P – XYLENE			.840	1.940
O – XYLENE	.40	.67	.350	1.010
TRIMETHYLBENZENE	.76	.73	.300	.750
NAPHTHALENE	.12	.02		
1 METHYLNAPHTHALENE	.06	.02		
2 METHYLNAPHTHALENE	.05	.008		
DIMETHYLNAPHTHALENE	.06	.02		
OTHER AROMATICS	.021	.013		
TOTAL SATURATES	9.86	11.62	11.200	11.100
TOTAL AROMATICS	13.90	10.03	7.860	16.800
TOTAL DISSOLVED HYDROCARBONS	23.76	21.63	19.000	27.900

*Seawater (36 PPT) at Standard Temperature and Pressure

SOURCE: 1 ANDERSON, et. al., (1974)
2 MCAULIFFE (1976)

TABLE S-3 Relative aromatic components of crude and their effect on equilibrium concentrations*.

	MURBAN CRUDE (ABU DHABI)		LA ROSA CRUDE (VENEZUELA)	
	EQUILIBRIUM CONCENTRATIONS ppb	PERCENT COMPOSITION IN CRUDE	EQUILIBRIUM CONCENTRATIONS ppb	PERCENT COMPOSITION IN CRUDE
BENZENE	6,080	.13	3,300	.07
TOLUENE	6,160	.49	2,800	.22
TRIMETHYLBENZENE	750	.74	300	.30
TOTAL	12,990	1.36%	6,400	.59%

*In Seawater at Standard Temperature and Pressure

REF. MCAULIFFE, 1976

the salinity of the solvent yields a decrease in the hydrocarbon solubility and a reduction of the equilibrium concentrations. The following sections summarize the anticipated changes in cavern equilibrium concentrations of the oil in brine as a result of a temperature increase to 150°F, an increase in pressure to approximately 1500 psi and an increase in salinity to 310 parts per thousand.

S.3.1 Increased Temperature Effects on Equilibrium Concentrations

As illustrated in Figures S-3 and S-4 the temperature/solubility relationship is non-linear and until temperatures in excess of 257°F are reached significant increases in solubilities do not occur. The operating temperature for the caverns will be approximately 150°F. Published data indicate that for an increase of from 70°F to 150°F an equilibrium concentration increase of 1.5 is the maximum that can be reasonably expected (Price, 1973; Griswold, 1942). For model calculation purposes, a temperature multiplier of 1.5 has been utilized.

S.3.2 Increased Salinity Effects on Equilibrium Concentrations

The aqueous solubility of hydrocarbons is an inverse function of salinity (Price, 1973; Candle, 1977). Within the salt dome caverns brine concentrations will be in excess of 310 parts per thousand (ppt) (McAuliffe, 1969). The results of solubility experiments on discrete hydrocarbons listed in Table S-4 indicate that large reductions in hydrocarbons solubility can be expected with increases in salinity. Recent studies on a number of domestic crude oils (Table S-5) exhibit similar decreases in hydrocarbon solubility when compared over the smaller range of salinity. Based on these studies a salinity multiplier of 0.15 is reasonable and perhaps even conservative.

S.3.3 Increased Pressure Effects on Equilibrium Concentrations

The effect of increasing pressure on the solubility of hydrocarbons is to increase their solubility. As illustrated in Figure S-5, this effect is most significant for the lighter or lower molecular weight hydrocarbons such as methane and butane. Similar effects for larger hydrocarbon molecules could not be identified. The data as listed in

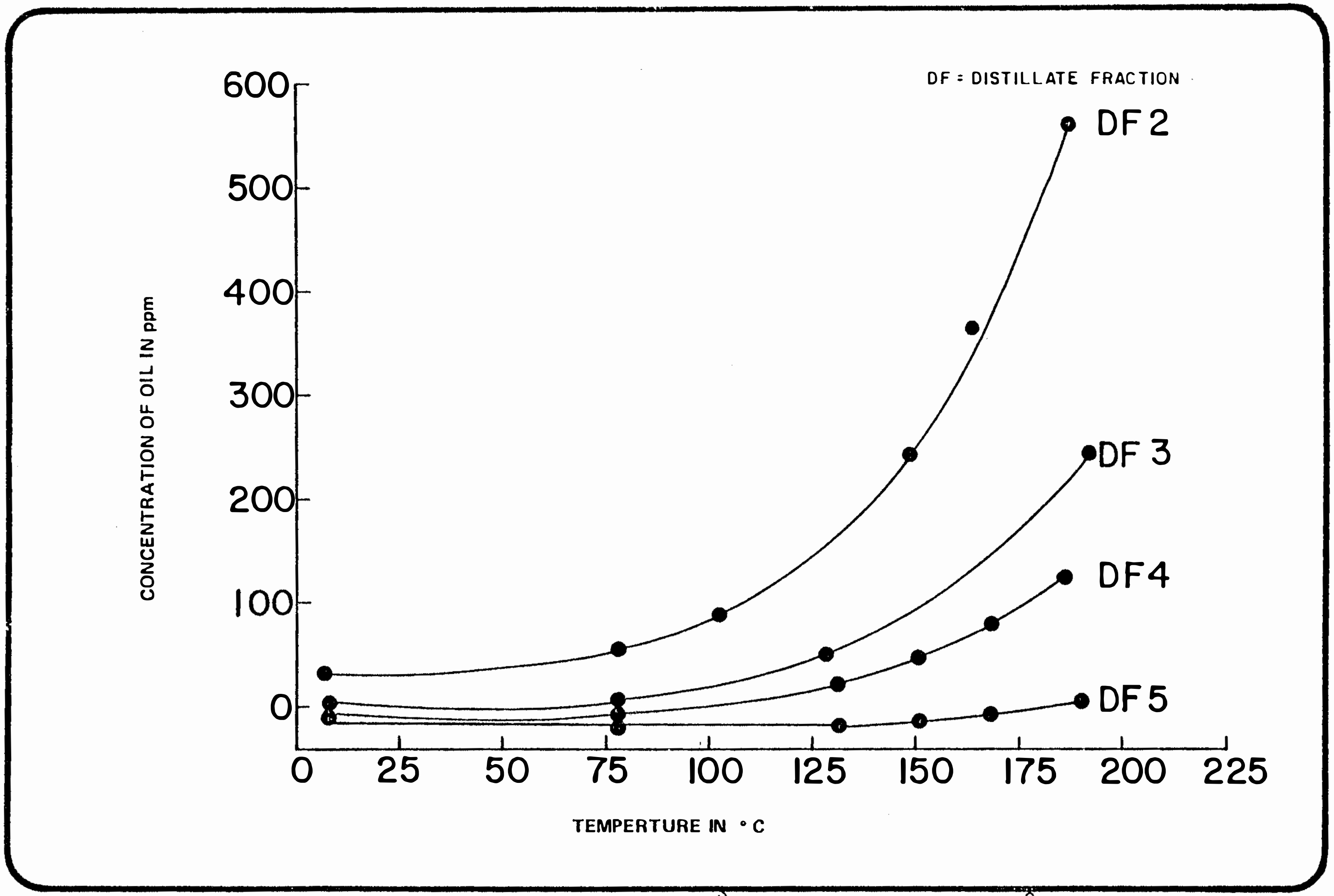
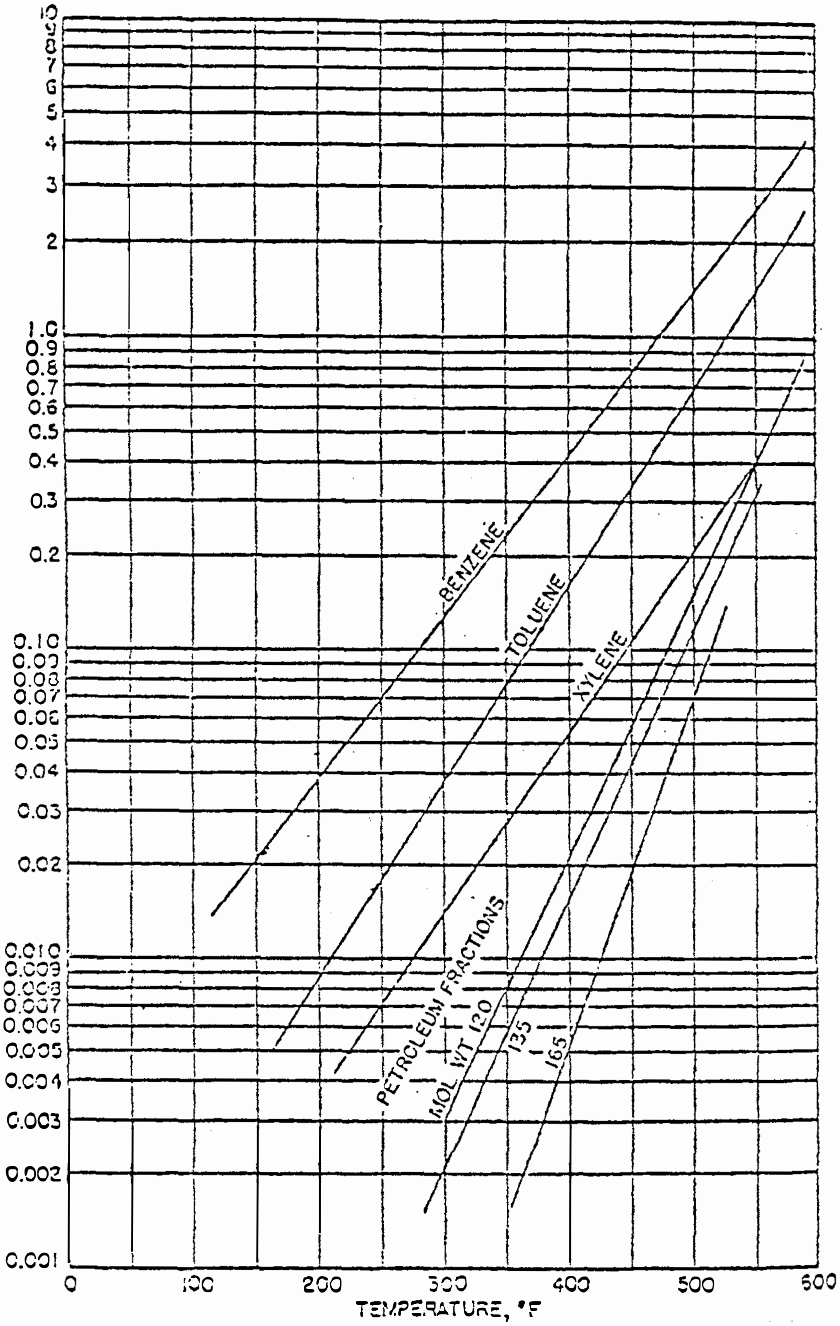


FIGURE S-3 The solubilities of the second (DF 2, 132-193°C), third (DF 3, 193-232°C), fourth (DF 4, 232-316°C) and fifth (DF 5, 316-371°C) distillation fractions of the Ghawar Arabian crude oil in water as a function of temperature at systems' pressure



SOURCE: Griswold, 1942

FIGURE S-4 Solubilities of hydrocarbons and petroleum fractions in water at total system pressure

TABLE S-4 Solubility of individual hydrocarbons in aqueous solutions at 25°C as a function of NaCl concentration.

NaCl CONCENTRATION IN PPM	SOLUBILITY OF HYDROCARBON IN PPM			
	PENTANE	BENZENE	TOLUENE	METHYLCYCLOPENTANE
0	39.5	1740	544	41.8
1,002	36.8	1718	526	38.0
10,000	34.5	1628	490	36.3
SEA WATER * 34,472	27.6	1391	402	29.2
50,030	22.6	1194	359	27.0
125,100	10.9	593	182	12.7
199,900	5.91	388	106	5.72
279,800	2.64	214	53.8	3.36
358,700 **	2.01	134	37.2	1.89

* ARTIFICIAL SOLUTION

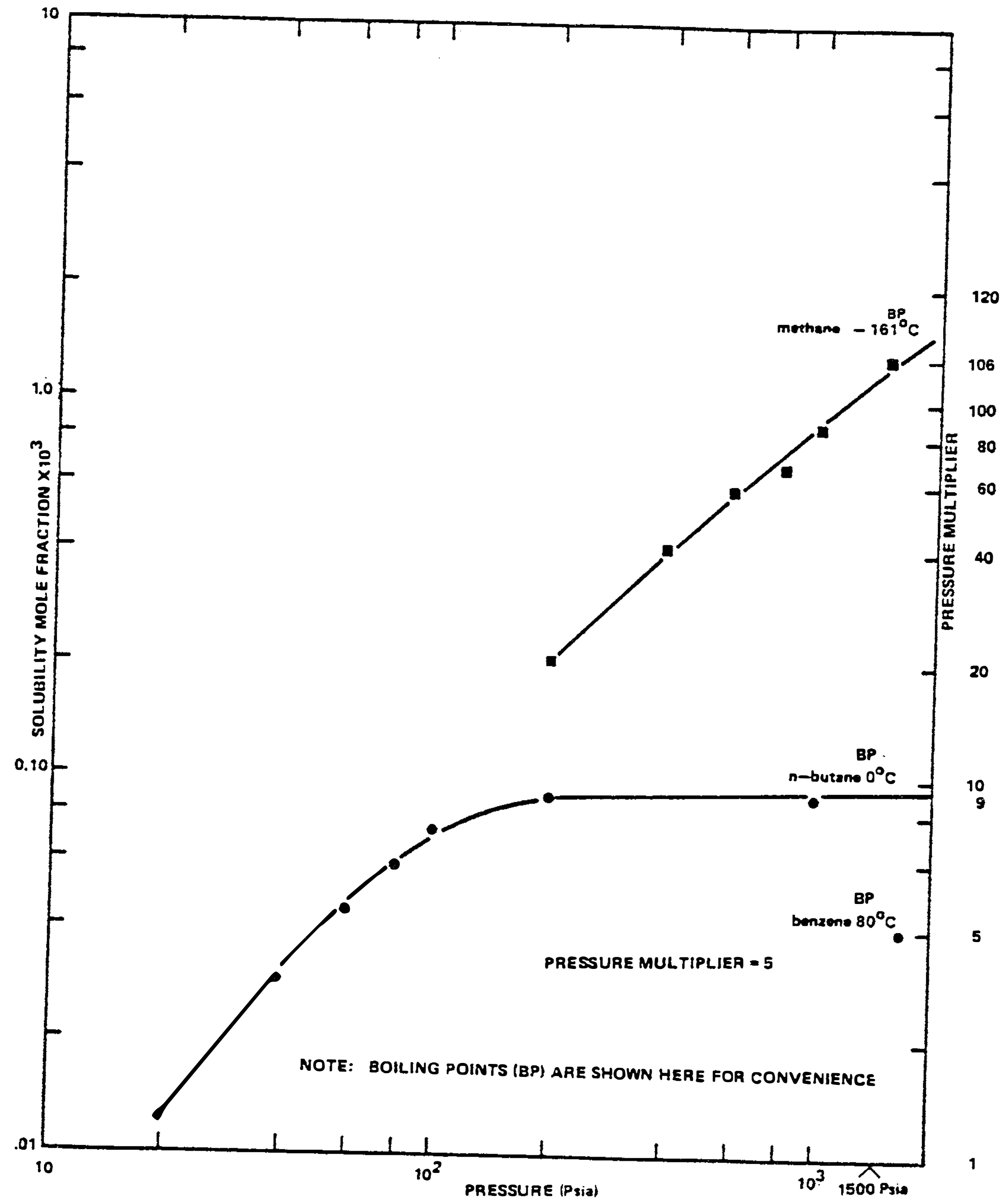
** SATURATED NaCl SOLUTION

SOURCE: Price, 1973

TABLE S-5 Dissolved oil content of brines equilibrated with various oils.

	BRINE ppt	GRAVIMETRIC mg/l
GULF COAST TEXAS CONDENSATE	1 30 100	9.64 5.83 2.45
GULF COAST TEXAS HIGH GRAVITY CRUDE	1 30 100	6.87 4.03 2.15
LOUISIANA MEDIUM GRAVITY CRUDE	1 30 100	6.16 5.53 3.68
EAST TEXAS MEDIUM GRAVITY CRUDE	1 30 100	11.49 6.96 3.11
EAST TEXAS LOW GRAVITY CRUDE	1 30 100	5.02 3.96 2.41
CALIFORNIA LOW GRAVITY CRUDE	1 30 100	0.40 0.31 0.60
CALIFORNIA MEDIUM GRAVITY CRUDE	1 30 100	9.64 4.58 3.87
ALASKA CRUDE	1 30 100	9.56 7.83 5.04
FLORIDA CRUDE	1 30 100	10.51 7.51 4.15

SOURCE: Caudle, 1977



SOURCE: Reference Petroleum Production Handbook

FIGURE S-5 Pressure effect on solubility

Table S-6 and shown in Figure S-5, taken at a temperature of 160°F to approximate cavern conditions, indicates a corresponding increase in solubility with pressure in addition to the importance of the hydrocarbons molecular size and boiling point. This data suggests that pressure has a diminishing effect on the solubility of the hydrocarbons as their molecular weights and boiling points increase (Price, 1973; McKelta and Wehe, 1962). For convenience, the boiling points of the hydrocarbons are also listed on Figure S-5. Since no data was located for pressure/ solubility relationships for the higher boiling point hydrocarbons, a pressure multiplier of 5 was used for calculation purposes. The pressure multiplier of 5 is plotted on Figure S-5 in relation to the boiling point of benzene. The pressure multiplier factor of 5 appears to be a reasonable worst case assumption and only operating data or precise experimentation would provide closer approximations.

S.3.4 Calculations of Dissolved Oil Concentrations

Based on the preceding discussion, expected cavern equilibrium concentration for Murban crude can be computed as follows:

Seawater Equilibrium		Temperature Multiplier		Salinity Multiplier		Pressure Multiplier		
(27.9 ppm)	X	(1.5)	X	(0.15)	X	(5)	=	(31.4 ppm)

Allowing the cavern brine to reach equilibrium conditions, the concentrations of hydrocarbons will be roughly equivalent to that of seawater concentrations as determined by McAuliffe. Personal communications with McAuliffe on this subject reveals that 25-30 ppm would be a reasonable equilibrium concentration.

The equilibrium concentration would occur only during the long oil storage period. However, this concentration would ultimately be diluted by a factor of 20 by raw water during displacement of the oil (see Section 2 and 3). This dilution would lead to non-equilibrium conditions and a resumption of dissolution. During the relatively short periods between cessation of oil withdrawal and completion of cavern refill the entire volume of brine should not attain an equilibrium concentration of dissolved oil. Solution would be retarded by the refractory layer at the

TABLE S-6 Pressure effect on solubility.

SMOOTHED VALUES FOR THE SOLUBILITY OF
METHANE IN WATER IN THE VAPOR–LIQUID REGION

PRESSURE, psia	MOLE FRACTION $CH_4 \times 10^3$ 160° F*
200	0.203
400	0.407
600	0.599
800	0.780
1,000	0.945
1,250	1.133
1,500	1.308
2,000	1.608
2,500	1.861
3,000	2.094
3,500	2.309
4,000	2.516
5,000	2.888
6,000	3.221
7,000	3.519
8,000	3.782
9,000	4.007
10,000	4.211

*Temperature of the System

SOURCE: McKetta and Wehe (1962)

TABLE S-6 continued.

SOLUBILITY OF n–BUTANE IN WATER	
PRESSURE psia	MOLE FRACTION OF n–BUTANE X 10^3 160° F*
20	0.012
40	0.029
60	0.044
80	0.058
100	0.071
200	0.088
300	0.088
400	0.088
500	0.089
600	0.089
800	0.089
1,000	0.090
5,000	0.098
10,000	0.103

*Temperature of the System

SOURCE: McKetta and Wehe (1962)

brine/oil interface and downward diffusion of dissolved oil will proceed very slowly.

The dissolved oil concentrations contributed from the cavern wall (based on the dimentions of cavern number 4 at Bryan Mound) will be 1.6 ppm. This calculation was based on an estimated 50 micron oil film remaining on the wall during oil displacement and subsequent dissolution into the brine as the underlying salt is dissolved away. The oil film adhering to the cavern wall would be thick for heavy, viscous crudes but relatively thinner for the lighter more fluid crudes. An effective film thickness was calculated by considering the largest (in molecular volume) hydrocarbon which has a measurable solubility. Under cavern operating conditions, the largest normal paraffin which would dissolve in appreciable amounts is C_{10} (decane) which has a typical layer thickness of 50 microns. A molecular layer was estimated to remain on the cavern wall.

An analysis of the wall oil layer component to the brine (based on cavern number 4) indicates that for a millimeter wall layer, the oil in brine concentration would increase to 28.6 ppm. The latter concentration is roughly equivalent to the equilibrium concentration for the entire volume.

The amount of hydrocarbons which would dissolve from the oil-brine interface during oil fill and withdrawal and during non-oil storage periods is difficult to estimate due to the lack of experimental data. The rates of solubility as determined by Price (1973) were based on studies of hydrocarbons and brine solutions in test tubes. Under these conditions, Price observed that it required 2-4 days to achieve equilibrium conditions. Under these relatively slow rates and given the infinitely larger volumes of the cavern, it is reasonable to assume that only the brine close to the oil-brine interface would be affected by dissolved oil during oil filling and withdrawal phases. The dissolution of hydrocarbons during the oil withdrawal and refill phases should be reduced with the existence of the refractory layer at the oil-brine interface. This layer will develop as a result of lighter, more soluble hydrocarbons dissolving into the underlying brine leaving the heavier, relatively insoluble hydrocarbons at the interface. The resistance of this layer to dissolution would increase with time until practically all diffusion across the interface ceases.

The hydrocarbon concentration due to dissolution occurring during the period of non-equilibrium conditioned between oil withdrawal and cavern refill will be 3 ppm. This value is based on the assumption that the time between cessation of drawdown and completion of refill will be of such short duration so that only the volume of the uppermost 50 feet of brine will approach equilibrium. Assuming a 500 foot cavern height, a ten-fold dilution of the equilibrium concentration would occur; resulting in 3 ppm of oil dispersed within the brine column. This average value would change as a function of the cavern geometry and phase within the brine discharge cycle. The addition of this component to the total hydrocarbon concentration being discharged would be minor during first quarter of a cavern's discharge cycle and increase as the oil brine interface descends toward the bottom of the brine pipe. The near equilibrium concentration close to the oil brine interface would not be discharged due to cavern enlargement and diffusion during oil withdrawal and refill phases.

The total dissolved hydrocarbon concentration expected to be discharged is derived as follows:

(1)	Long-Term Storage Equilibrium Component	= 1.6 ppm	Assumes the residual 5% volume of brine attains equilibrium of 31.4 ppm and is diluted 20 times during oil withdrawal.
(2)	Wall Oil Component	= 1.6 ppm	The solution of the 50 micron oil film from the cavern wall's surface. (cavern geometry dependent)
(3)	Oil Withdrawal, Non-Storage Period and Refill, Non-Equilibrium Component	= 3.1 ppm	Assumes the upper most fifty feet of the cavern volume attains equilibrium concentrations and is diluted by the remaining brine volume. (cavern geometry dependent)
	Total dissolved hydrocarbon concentrations	= 6.1 ppm or 6 ppm	

S.4 DISPERSION REACTIONS

Whereas dissolution occurs on a molecular level, dispersive reactions occur on a particle level. This reaction requires a breakup of the oil into particles and dispersing them into the underlying brine. The energy for this reaction is produced during the initial oil injection where oil is jetted at a velocity of approximately 8 feet per second into the brine and micro particles dispersed into the upper area of brine. This agitation would diminish and eventually cease as the downward oil-jet momentum is balanced by the buffering force of the oil thereby limiting the depth of the turbulent zone.

Studies of the dispersion of oil in seawater under oil slick conditions indicate that the greatest amount of oil is dispersed in a particle size of 40 microns or less in diameter (Price, 1973). For illustrative purposes data for Bunker C, listed in Table S-7, show the distribution of particle sizes ranges from 10 to 80 microns.

The suspension time for oil particles in the brine would be very short because of the large density differential of the oil (sp.gr.approx. .85) versus the brine (sp.gr. 1.19). Studies of crude dispersions, Table S-8, in seawater illustrates the rate of floatation. With the greater density differential, as in saturated brine, the dispersed oil within the caverns would be expected to show even faster floatation rates.

Within the cavern, even under the most rapid fill rates, the dispersed particles would have several weeks in which to rise and coalesce at the oil/brine interface. This is believed to be sufficient time for the dispersed oil concentrations to decrease to values of less than 1 ppm. For calculation of oil in brine, a value of 1 ppm of dispersed oil is assumed to be discharged to the brine surface control facilities.

TABLE S-7 Distribution of particle size beneath an oil spill*.

	NO. AND VOL. OF PARTICLES IN 10-MICRON RANGE CENTERED AT							
	10u	20u	30u	40u	50u	60u	70u	80u
NUMBER	323	147	57	19	4	3	3	1
VOLUME	0.45	0.96	1.42	1.35	0.40	0.66	1.12	0.60

* BUNKER C OIL

SOURCE: The Fate of Oil Spilt at Sea

TABLE S-8 Settling time and dispersed oil particles*.

TIME OF SETTLING DAYS	OIL CONTENT PPM
0.01	31
0.02	10
0.04	4.5
0.33	2.5
1.0	4.6 **
1.1	1.5
2.2	2.7 **
147	0.6

SOURCE: THE FATE OF OIL SPILT AT SEA.

* TYPE OF CRUDE OIL NOT STATED
** REASONS FOR OIL CONTENT INCREASE NOT GIVEN

S.5 DISCHARGE OF THE OILY BRINE TO THE SURFACE CONTROL FACILITY

The discharge of brine containing hydrocarbons, as schematically illustrated in Figure S-6, will involve different scenarios dependent upon whether it is during initital fill or subsequent refills.

For initial fill, an assumption was made that the top 50 feet of brine became saturated with hydrocarbons (31.4 ppm) and this was diluted into the uppermost 100 feet yielding approximately 16 ppm (see Section S.2.1). This initially high hydrocarbon concentration would result from the fresh unweathered crude not having sufficient time to form a refractory layer before fill is completed. In subsequent fills the refractory layer will be present. The 16 ppm would exhibit a concentration gradient (0 to 31 ppm) when discharged; however, its average over the discharge period is expected to be about 16 ppm.

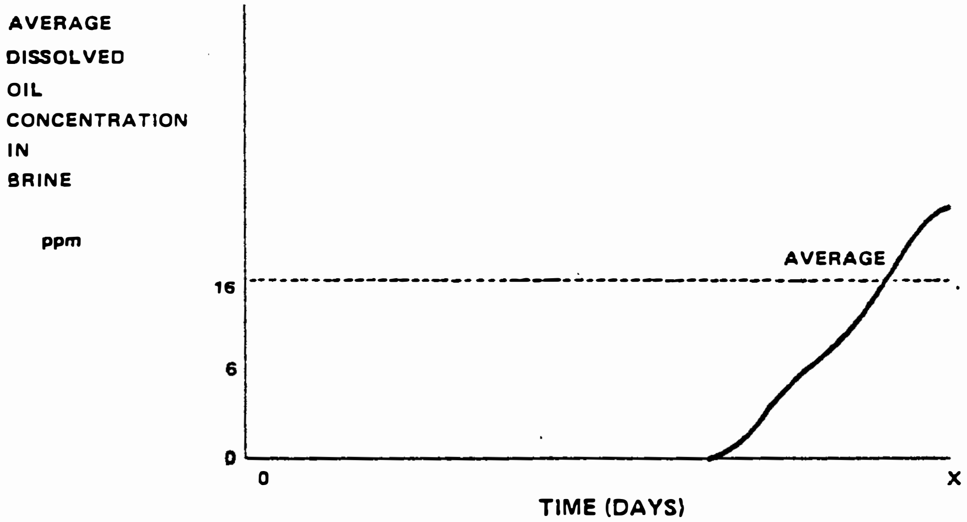
It is expected that low levels of oil averaging approximately 6 ppm would be discharged continuously during subsequent refills. Contingent upon differing cavern geometries, the oil concentration would vary from 4 to 15 ppm.

The only available data from similar operations are from the German oil storage facility at Etzel, Germany and the French oil storage facility at Manosque, France.

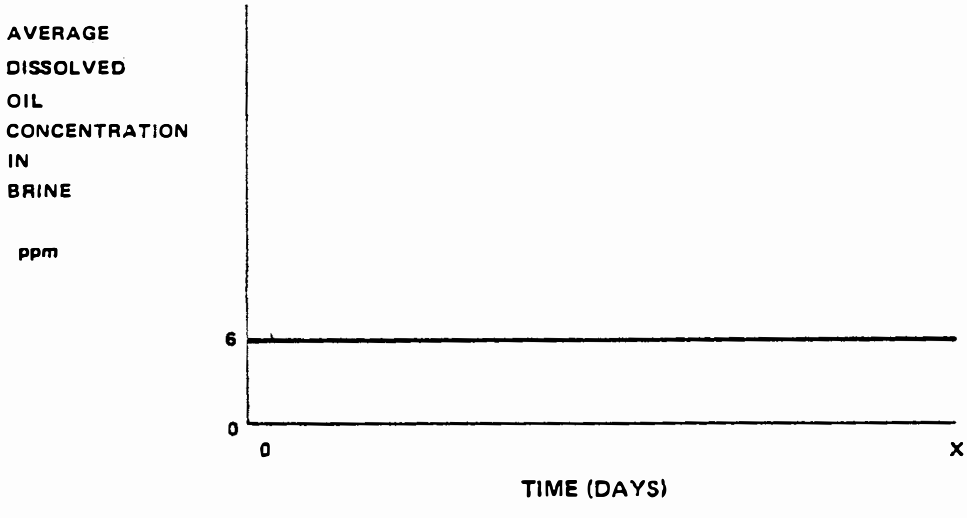
The Etzel data (Kavernen Bau - und Betriebs - BmbH, n.d.) indicate that the oil concentration of brine discharged from the brine control surface facility is less than 1 ppm.

The Manosque data (LOOP, Inc., 1975) indicate an oil concentration of 17 ppm in the brine discharged from the cavern to the surface facilities. Neither the duration of storage or type of crude were identified.

These data from the two operating oil storage facilities clearly indicate that with an expected eighty percent reduction of the oil concentration due to vaporization of light hydrocarbons such as butane, pentane and benzene (McAuliffe, 1969) and an additional reduction by oil skimming, the estimated oil concentration in the discharged brine of approximately 6 ppm appears reasonable for the proposed U.S. facilities.



INITIAL OIL FILL



SUBSEQUENT OIL FILL

FIGURE S-6 Schematic representation of oil in brine concentrations discharged from a typical cavern

S.6 CONCLUSIONS OF THE OIL BRINE STUDY

The major conclusion of this study is that there is insufficient time, turbulence and circulation within the cavern during oil fill and withdrawal phases, to allow the dissolved oil to reach equilibrium. Equilibrium concentrations for the thirteen crudes studied will not exceed approximately 31 ppm under the cavern operating conditions. Thus, during the time when the cavern is principally filled with non-equilibrium oil-brine concentrations of less than 31 ppm, dissolution and diffusion reactions will occur in the upper brine column.

The results of the study indicate that the dissolved oil in the brine discharged to the brine surface control facility is expected to average 16 ppm for the later stages of the initial oil fill of each cavern and average approximately 6 ppm for subsequent oil refills from a cavern of specific geometry. Differing cavern geometry effects the duration of the initial oil discharge and the concentration of the dissolved oil in subsequent discharges. The oil concentration in the brine will be principally composed of dissolved hydrocarbons rather than dispersed oil as is commonly found beneath oil slicks at sea. The dispersed oil component which is created during initial turbulent oil injection is quickly and naturally removed from the brine column due to its high buoyancy and less than 1 ppm would be expected in the brine discharge.

Studies of the effects on hydrocarbon solubility as a function of increasing the temperature of 150^{o}F, pressure to 1500 psi and salinity to 310 ppt indicate that solubility changes of: 1.5 times would occur due to temperature increase, 5.0 times for pressure and 0.15 times for salinity. The net effect of these would be an increase in solubility of only 1.125 times in comparison to seawater equilibrium concentrations. Thus, cavern oil equilibrium concentrations will be very similar to values measured for the various crudes in seawater at standard conditions of temperature and pressure.

The oil film remaining on the cavern wall is not expected to appreciably affect the net oil concentrations of the brine due to the large dilution effect within the cavern and the estimated 50 micron thickness of the wall film.

At the start of filling operations the oil jet velocities should be controlled to limit the amount of turbulence during initial fill and the possible disruption of the refractory layer during the subsequent refills.

A refractory layer is expected to form at the oil brine interface which will reduce dissolution and to a degree dispersion reactions.

S.7 REFERENCES

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PART II - SOLUTION MINING AND USE OF NEW CAVERNS

S.1 Oil-In-Brine, Cavern Construction and Operation Effects

S.1.1 Cavern Construction and Initial Fill

The caverns at the proposed SPR storage sites are to be constructed by utilizing the leach-then-fill and/or leach/fill methods. Leach-then-fill is the primary method. It requires that the cavern to leached to its design capacity before crude oil storage begins. This method has the advantage of less potential for oil-brine interactions than leach/fill does, but the disadvantage that the lengthy (2 year) leaching process must precede oil fill. The leach/fill method may be utilized to reduce the time required for initial oil storage. Leach/fill allows for storage of crude oil concurrently with all but the initial months of cavern leaching, but has a potential for higher hydrocarbon (HC) concentrations in the brine displaced from the caverns than the leach-then-fill method does. These higher HC concentrations would have a negative impact on air quality and on the brine disposal area.

S.1.1.1 Leach-Then-Fill Method

When the leach-then-fill method is utilized, caverns would be leached to their design capacity in a continuous operation. The resulting caverns would be approximately cylindrical in shape and have a maximum diameter of about 300 feet. Blanket oil (to restrict upward growth of the cavern roof) would be installed early in the leaching process and would remain in place for the duration of leaching operations.

At the conclusion of leaching of a cavern, oil fill would be initiated, displacing brine from the cavern. Initially, the displaced brine would have negligible HC concentrations. Brine with low HC concentrations would then be displaced for about two-thirds of the oil fill period. Finally, brine (near the oil-brine interface) with higher HC concentrations would be displaced. During the final stages of oil fill, HC concentrations are anticipated to average 16 ppm.

Brine displaced to the surface control facility (brine pond) would be retained for settling of insoluble material. A four hour retention time is planned, during which 50 to 100 percent of the hydrocarbons in in the brine would evaporate. The remaining hydrocarbons would be transported with the brine to the disposal area. Monitoring of HC concentrations in the brine is planned, both at the cavern wellheads and at the output of the surface control facility. Filling operations would be adjusted to maintain effluent HC concentrations below state standards (at a level of about 10 ppm). Filling would be curtailed if concentrations exceeded state standards.

S.1.1.2 Leach/Fill Method

The leach/fill procedure would permit crude oil to be stored after about 1 MMB of available capacity is reached in a given cavity. With the designed cavern diameter, 1 MMB would occupy the upper 100 feet of the cavern. As with the leach-then-fill concept, the oil-in-brine would remain within the upper 100 feet of the brine column. Therefore, after a fill of 1 MMB of oil, the oil-in-brine would extend 200 feet below the top of the cavern. Additional fill would be added as space is leached.

With the leach/fill procedure the leach casings and zones of active leaching would precede oil fill by only a short vertical distance. Oil levels would be adjusted for optimum leaching configuration. The volume of brine in the cavern would be smaller than with leach-then-fill and the total elapsed time in which oil-brine activity could occur would be longer. Hence, total hydrocarbons dissolved in brine are likely to be higher for this method than leach-then-fill. Depending on casing depths and oil fill increments utilized, high concentrations of oil in brine could be released earlier using this method than for leach-then-fill. Continual monitoring of the hydrocarbon concentrations would be required to determine the appropriate criteria for leach and fill rates and schedules, to maintain concentrations below state standards.

S.1.2 Second and Subsequent Oil Refills/Withdrawals

Following displacement of stored oil during the first withdrawal, HC concentrations would be similar whether leach-then-fill or leach/fill procedures were used for cavern construction. The principal effects of subsequent fill/withdrawal cycles on the quantity of oil dissolved in brine would be 1) cavern enlargement during withdrawal, 2) the dilution of residual brine during refill, and 3) the dissolution of oil remaining on the cavern walls during withdrawal.

Assuming an initial cylindrical cavern of 10 MMB capacity, 1000 feet in height and 270 feet (average) in diameter, cavern enlargement would be experienced approximately as shown in Table D-9. Using fresh water as the displacement source, the cavern would grow from its initial 10 MMB capacity to about 18.6 MMB in size over the 5 cycles. As only 10 MMB of crude oil is planned to be stored during each fill, about 3/4 as much brine as oil would be contained in the cavern after the fifth oil fill. The cavern diameter could enlarge by as much as 50 feet and the area of the brine-oil interface would increase by 40 percent over 5 cycles. The refractory layer would then be spread over the larger area, and additional oil would be expected to enter the layer.

Cycling the cavern with 10 MMB of crude oil during each fill and withdrawal would have the effect of moving the brine-oil interface higher in the cavern with each cycle. Because brine is removed from the bottom of the cavern during oil fill, the high HC concentrations in brine (near the top of the brine) would be farther from the brine exit with each additional cycle.

Long-term storage of crude oil between withdrawals would cause increasing volumes of brine to reach equilibrium HC concentrations (31.4 ppm) prior to dilution during withdrawal. Accounting for dilution by displacement water, concentrations would increase 10-fold for 5 cycles.

Short-term dissolution would also occur in the interim between the initiation of a withdrawal and the completion of a refill; mostly occurring during the period of no activity prior to refill. Assuming the upper 50 feet of the brine reaches equilibrium HC concentration, the average HC concentration shown in Table D-9 would result. Average HC concentrations would increase in later cycles as the volume of the 50 foot thick layer becomes a greater portion of the cavern volume utilized for a 10 MMB refill.

Oil in brine resulting from residual oil on cavern walls entering solution during withdrawals is only slightly affected by cavern enlargement. As cavern volume increases, the surface area increases at a smaller rate, and the resulting average HC in brine concentrations would be less for later cycles. These concentrations are greatly affected by the thickness of the residual oil film and clingage thicker than the 50 microns assumed would greatly increase concentrations.

S.2 Summary

In summary, hydrocarbon concentrations of displaced brine during oil fill would be relatively high (due to turbulence and mixing early in the fill) during the latter stages of the initial fill. Following the initial fill, a dense refractory layer would form, lessening those effects during later fills. The later fills/withdrawals would be affected by the rate of cavern enlargement and the increasing distance from the brine withdrawal pipe to the refractory layer. The second fill would displace the least hydrocarbons due to the formation of the refractory layer and the small percentage of cavern enlargement. During subsequent fills, the effects of cavern enlargement would become more pronounced with HC concentrations approaching equilibrium conditions.

TABLE S-9 Fill/withdrawal cycle vs. cavern size relationship.

TABLE D-9. Fill/Withdrawal Cycle vs. Cavern Size Relationship

Fill Cycle	Withdrawal Cycle	Active Cavern Volume, MMB	Total Cavern Volume,[1] MMB	Residual Brine After 10 MMB Fill, MMB	Brine Dilution During Withdrawal	Long-Term Storage Equilibrium Concentration,[2] ppm	Oil Clingage on Cavern Walls,[3] bbl	Clingage Oil Concentration in Brine, ppm	Short-term Oil Dissolution[4] Ratio	ppm	Total Dissolved HC Concentration ppm
1	0	10.0	10.5	0.5	-	-	-	-	-	-	-
2	1	11.7	12.2	2.2	1:20	1.6	27	2.6	1:20	1.6	5.8
3	2	13.4	13.9	3.9	1:4.5	7.0	30	2.5	1:16.0	2.0	11.5
4	3	15.1	15.6	5.6	1:2.6	12.1	32	2.3	1:13.9	2.3	16.7
5	4	16.8	17.3	7.3	1:1.8	17.4	34	2.2	1:12.2	2.6	22.2
-	5	18.6	19.1	-	1:1.4	22.4	36	2.1	1:10.9	2.9	27.4

1) Including 0.5 MMB sump

2) Equilibrium concentration ÷ dilution

3) Assuming 50 micron thickness

4) Assuming only upper 50' of cavern reaches equilibrium concentration of 31.4 PPM

PART III - HISTORICAL EXPERIENCE

S.1 Introduction

The following testimony was given by Mr. Gerard Fedida of GEOSTOCK at the May 2, 1978 public meeting jointly convened by the U.S. Army Corp of Engineers, Galveston District and the U. S. Environmental Protection Agency (EPA) in Freeport, Texas. The purpose of the public meeting was to consider application of the Department of Energy for Department of the Army permit to construct a 30 inch brine outlet pipeline and brine outlet diffuser in the Gulf of Mexico and an EPA National Pollutant Discharge Elimination System permit to discharge brine into the Gulf via this structure. Mr. Fedida appeared as a technical witness for the Department of Energy. His testimony provided a perspective on actual oil storage operations being conducted in France.

S.2 Comments of Gerard Fedida Concerning Studies of the Oil Content of Brines Discharged from Salt Caverns at Manosque, France

I am Gerard Fedida, Manager of Projects at GEOSTOCK (Societe Francaise DE Stockage Geologique) at the time of this study and the coordinator of the group which wrote the reports on the content of oil in brines discharged from salt caverns at Manosque, France.

My professional training in engineering was obtained at the Ecole Polytechnique and Ecole Nationale Superieure des Techniques Avancees in Paris, France. I have been associated with GEOSTOCK since 1973, and was formerly associated with C. G. DORIS, a French offshore engineering firm.

GEOSTOCK is a subsidiary of four oil companies in France, and has specialized in performing design and management services in the implementation of the French strategic petroleum reserve and other underground hydrocarbon storage facilities. GEOSTOCK presently is the operator for approximately 90 million barrels of a variety of hydrocarbons, including LPG, gasoline, naphtha and crude oil.

In November 1977, the Department of Energy (DOE) entered into a contract with Geostorage Inc., the American subsidiary of GEOSTOCK, for the following four studies related to the storage of crude oil in salt-solution caverns at Manosque, France:

1. A compilation of selected historical data and measurements of the oil content of brines taken during several years of facility operation;

2. Sampling and measurement of the oil content of brines from caverns which had contained crude oil for prolonged periods;

3. Sampling and measurement of the oil content of brines displaced from caverns during normal fill operations; and

4. A compilation of selected historical temperature profiles made within certain caverns. This latter study has no direct bearing on my testimony and will not be discussed further.

(TRANSPARENCY NO. 1) The Manosque storage complex is located in the south of France, 55 miles northeast of Marseille.

Between 1968 and 1973, 18 cavities were leached in a massive salt formation. In a second phase of development currently underway, 18 new cavities are being created. The volume of these cavities ranges from 700,000 to 2.5 million barrels.

The facilities include two brine surge ponds for 1.2 million barrels capacity at Manosque, two 20" pipelines linking the site to brine lakes and refineries and VLCC facilities on the Mediterranean coast near Marseille, and the necessary pumping equipment and controls. Brine samples are periodically taken at the Rognac station here. The description of this complex is analogous to the general system description of the DOE complex appearing in the Bryan Mound final Environmental Impact Statement.

The two 20" pipelines mentioned above serve to carry excess brine and petroleum between Manosque and the petrochemical industries near Marseille. One of these pipelines is dedicated to brine and the other to petroleum; they are not used interchangeably.

(TRANSPARENCY NO. 2) Each cavity is equipped with two concentric pipes. Hydrocarbons are pumped into a cavity through the annulus and brine is displaced through the suspended tubing (TRANSPARENCY NO. 3) to the surface brine ponds, where most dissolved and dispersed hydrocarbons separate out. This method is virtually identical to the one in which DOE will operate its facilities. Any excess brine is pumped through 20" pipeline, mentioned earlier, to the brine lakes near Marseille. During drawdown cycles, the procedure is simply reserved.

Since inception of the project at Manosque, frequent samples of the brine in the 20" pipeline have been collected in order to monitor corrosion and oil content. For Part 1 of our study, a total of 40 analyses were compiled for the period January 4, 1972 - through November 25, 1976. These analyses represent both leaching under a hydrocarbon blanket and actual storage operations.

As noted earlier, the brine displaced from the various caverns initially flows into one of two 600,000 barrel capacity surface ponds which act as surge pits. Any film which forms on the ponds is periodically skimmed and disposed of.

(TRANSPARENCY NO. 4) Each of the 40 samples, selected for this compilation, was withdrawn from the 20" pipeline at the Rognac pump station, which you will recall is located near Marseille.

All samples were analyzed using an infared spectrometric method similar to the one recommended by Michael Gruenfeld, Environmental Protection Agency, Edison, New Jersey. This method involves a liquid-liquid extract of the brine with a suitable solvent such as Freon-113 or carbon tetrachloride, followed by a measurement of the infrared absorbance of the solution. Using this method the practical limit of detection is 0.5 parts per million (PPM).

Residence time of the brine in the ponds varied from one day to more than 3 weeks depending on the scale and type of operation at the time. Differences in residence time of brine in the ponds appear to have an insignificant effect on its oil content since most hydrocarbons either volatilize, or come out of solution and form a surface film, within a short time after the brine reaches the surface, due to the decrease in pressure.

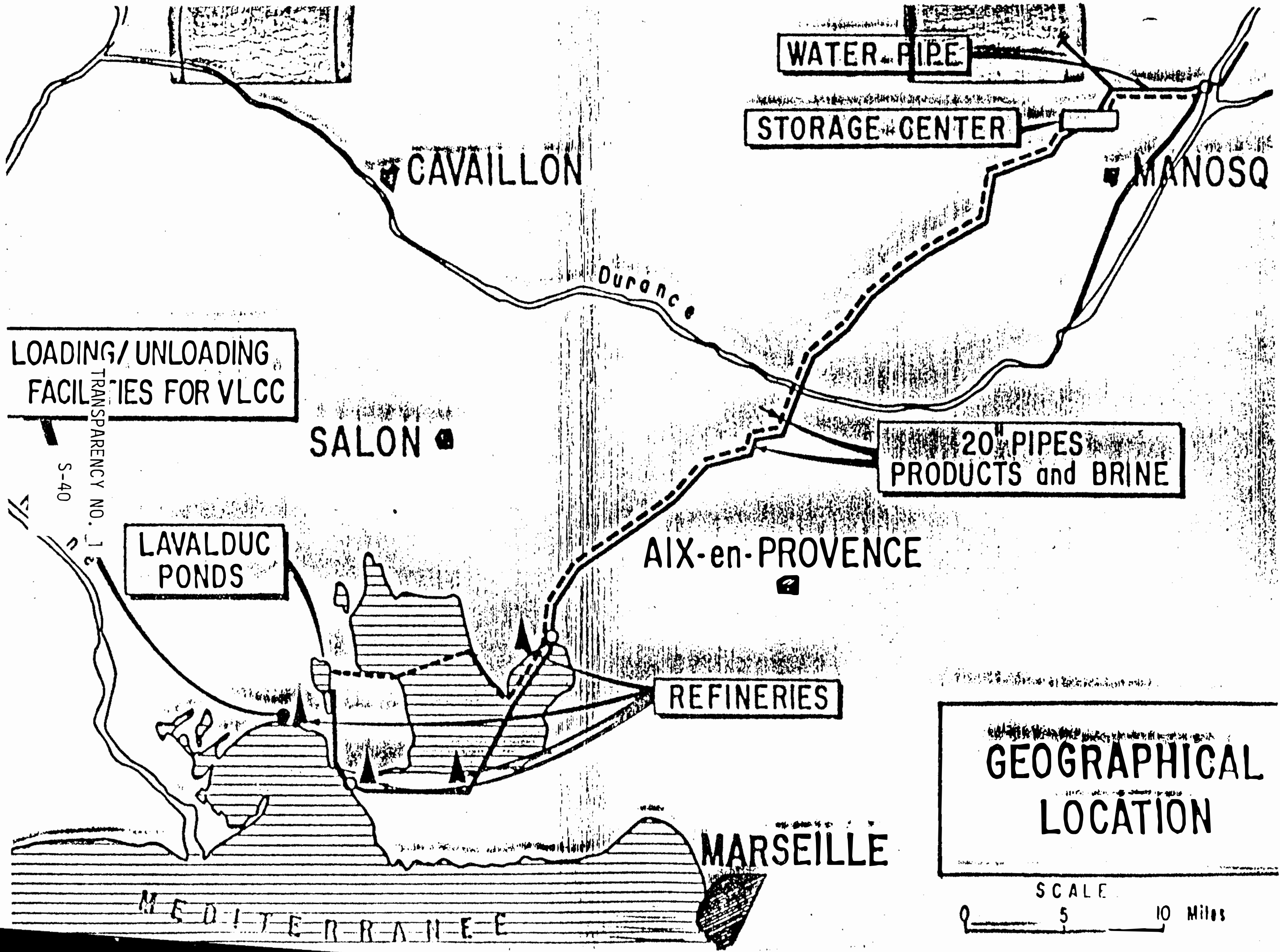
Other parameters of simultaneous movements in the caverns were also compiled, such as brine temperature and density, distances between the oil/brine interface and the shoe of the brine displacement casing, and the spacing between the shoes of the oil injection and brine displacement casings. No relationship was established between these parameters and the concentration of oil in the brine samples, the distribution of which appears in transparency no. 4.

The second part of our study required the collection and analysis of brine samples from caverns which had contained crude oil in quiescent storage for prolonged periods. The purpose of this task was to obtain data on the oil content of brines which approached equilibrium with the stored oil before the smaples had undergone the separation effects of the surge ponds.

We selected four cavities which we felt were appropriate for this study. Two samples were collected at the wellhead of each cavern. The first sample was collected after the volume of brine standing in the tubing had been displaced to the surface. The second sample was collected after an additional few thousand barrels had been displaced. The results of the analysis of these samples is presented in the next transparency (No. 5). As you will note, brine from cavity ET, which had contained crude oil for 13 months, contained only 12.7 parts per million oil. You will recall that these samples were collected before any settling of the brine had taken place in the ponds. All samples exhibited a strong odor of hydrocarbons and degassing when they were collected. This is consistent with what is known about the solubility of hydrocarbons in brine, namely, that the light hydrocarbons, expecially those like butane and propane are the more soluble, and solubility is pressure dependent. Therefore, when brine from beneath stored crude oil is produced to the surface, the reduction in pressure will cause dissolved hydrocarbons to volatilize.

Our final study regarding oil-in-brine, called for the sampling and analysis of brines displaced from cavities during normal fill cycles. A total of 24 samples were collected from the wellheads of five cavities for the purposes of this task. The results of the analyses of these samples is presented in the next Transparency (No. 6). As can be seen, the maximum oil content was only 9.4 ppm, before any settling in the surge ponds, which is within the range reported earlier for historical data of operational cavities. All of the samples exhibited a hydrocarbon odor and most were obviously degassing.

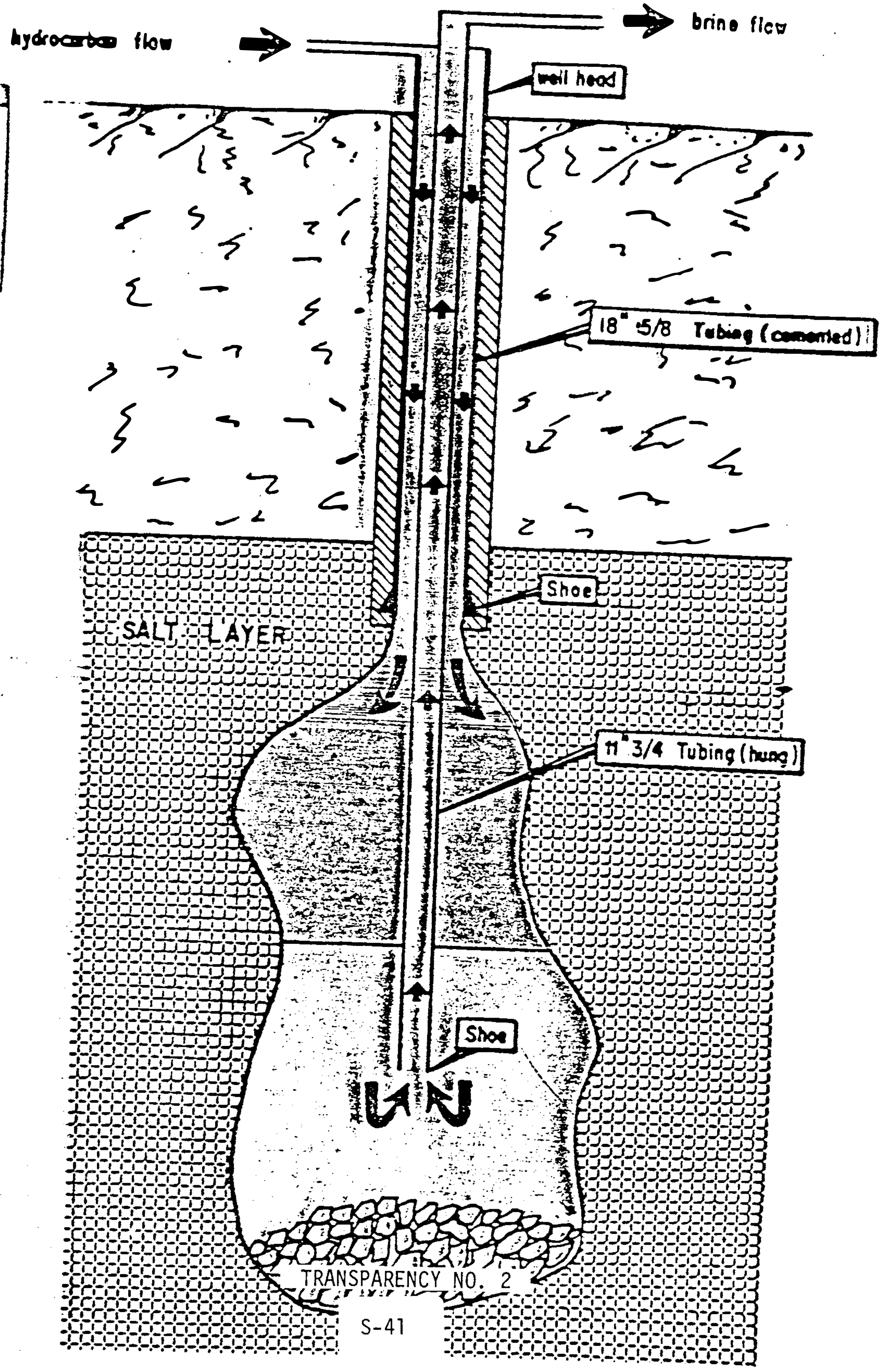
All of the oil-in-brine analyses reported were made on samples obtained from a hydrocarbon storage facility which has been in operation for ten years. The samples were obtained from origins as different as the wellheads of static storage, the wellheads of operating storage and the effluent of a brine settling pond. These analyses show that the oil concentration is below 15 parts per million even in the worst case and averages four to five ppm.



GEOGRAPHICAL LOCATION

TRANSPARENCY NO. 12
S-40

(for destorage, reverse the flow)



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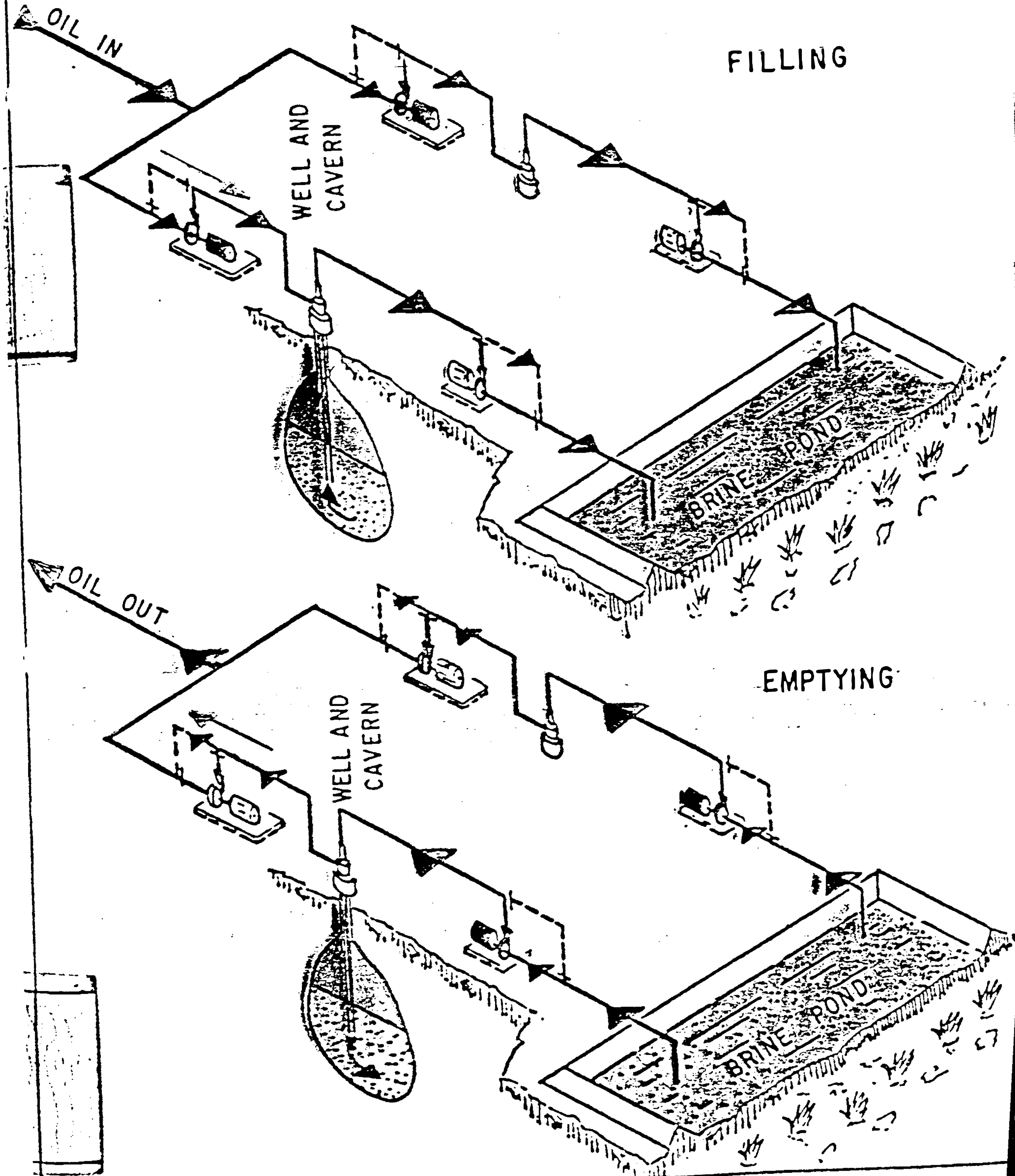


UNDERGROUND STORAGE FOR PETROLEUM PRODUCTS IN LEACHED CAVERN

OPERATION PROCESS

TRANSPARENCY NO. 3

CONTENT OF OIL IN BRINES DISPLACED FROM CAVERNS AT MANOSQUE, FRANCE

OIL CONTENT (PPM)

OPERATIONAL CAVERNS (18 SAMPLES)		LEACHING OF NEW CAVERNS (22 SAMPLES)
0.0-13.8	RANGE	0-10
2.8	MEDIAN	2.6
4.6	AVERAGE	3.3

TRANSPARENCY NO. 4

Oil Content of Brine Samples From Cavities Containing Crude Oil For Prolonged Periods

(All samples collected at the wellhead)

Cavity	Minimum Storage Time	Total Oil Content (ppm)	
		First Sample	Second Sample
ET	13 months	12.7	9.3
A	3 weeks	9.4	3.8
D	3 weeks	6.1	1.7
F	3 weeks	2.2	1.6

TRANSPARENCY NO. 5

OIL CONTENT OF BRINE DISPLACED FROM CAVITIES DURING NORMAL FILL OPERATIONS

(ALL SAMPLES COLLECTED AT THE WELLHEAD)

CAVITY	TOTAL OIL CONTENT (PPM)		
	START OF CAVERN FILL	END OF CAVERN FILL	RANGE
A	9.4	0.7	0.7-9.4
D	6.1	1.4	0.8-6.1
W	0.7	0.7	0.7-3
E	3	0.7	0.7-3
G	0.7	1.4	0.7-1.4

TRANSPARENCY NO. 6

APPENDIX T

SELECTED CHARACTERISTICS OF THE AQUATIC ENVIRONMENT NEAR THE PROPOSED WATER INTAKE ON THE INTRACOASTAL WATERWAY

Introduction

DOE's Strategic Petroleum Reserve Office (SPRO) has selected the Intracoastal Waterway (ICW) west of its intersection with Alkali Ditch as a proposed water source for leaching and oil displacement at the West Hackberry expansion oil storage facility. This selection was made after a review of potential water sources by SPRO and with consideration given to recommendations from other agencies.

SPRO authorized a field study of the aquatic environment in the ICW to verify that no extraordinary conditions existed which would limit or preclude use of the waterway as a water source. This appendix presents the findings of that field study.

Conditions at the ICW are discussed at several other places in this document. Sections in Volume I summarize the physical and chemical quality of the water itself (3.3.1.2), the organisms which are present and their significance (3.3.1.5), and how water withdrawal would affect the aquatic environment (4.3.2 and 4.3.5). The same subjects are treated in more depth in Appendices B, C and D. Corps of Engineers water quality data for the ICW are presented in Appendix D.6, Tables D.6-2 and D.6-3. The computer modeling results of water withdrawal effects on depths, salinity, and current velocity are presented in Appendix D.27.

Field Study Objectives

Objectives of the field study included the measurement of physical and chemical variables; a survey of biological species--especially economically important ones; and the measurement of depth near the proposed ICW water intake location. These data were employed in assessing biological losses, determining effects on brine chemical quality, and estimating the potential for induced salinity intrusion.

Materials and Methods

Sampling was carried out on June 8, and June 9, 1978. Eleven water samples were collected for chemical analysis and nine samples for biological determinations. In addition, measurements of conductivity, pH, temperature and dissolved oxygen were carried out 5 separate times and at different locations and depths.

Laboratory chemical analyses were largely carried out according to Standard Methods for the Examination of Water and Wastewater. However, a special extraction and analysis was used with the heavy metals to minimize interference from materials in seawater.

The special extraction method is more costly than the other analyses and detection is improved by increasing the sample volume. For these reasons and because water concentrations of heavy metals were not expected to vary greatly during the sampling period, composite samples were used to determine these metals, other cations, and oil and grease. Two composites were analyzed. Each was formed by mixing three 1-liter samples. The three samples comprising each composite sample were taken at the same sampling point. One sample in each composite was taken in the morning, one in the afternoon, and one in the morning of the second day of sampling. The two sampling points corresponding to the two composite samples were identical to the starting point for plankton tows and the end point for trawling in the vicinity of the proposed water intake.

Each time a heavy metals sample was taken, a sample to be used for analyses of main nutrients, chloride, and sulfate was also taken. One additional nutrient sample was obtained each time the other samples were obtained. The additional sample point was located halfway between the other points--at the end point for plankton tows in the intake vicinity. Table T-1 shows the sampling scheme for the samples chemically analyzed in the lab. Figure T-1 displays the locations of the sampling points.

The following variables were analyzed in all of the 9 uncomposited samples: nitrate, nitrite, silica (reactive), orthophosphate, sulfate, and chloride. In addition, other variables determined from the two composite samples (metals) include: iron, copper, cadmium, nickel, zinc, lead, manganese, magnesium, calcium, potassium, sodium, and oil and grease.

The nine uncomposited samples provided a good measure of precision and were indicators of mixing during the period of the study. Each was an approximately 100 ml aliquot. Water samples were obtained from a depth of 5 ± 1.5 feet using a 2 liter Van Dorn type closing bottle with a horizontal holder suspended by a nylon-coated cable. Samples used in analysis of metals levels were fixed in the field with HNO_3, nitric acid; other samples to determine chemistry were frozen. Depth profiles of conductivity, pH, temperature, and dissolved oxygen were obtained at the same stations used for the lab chemistry and biological samples except that only one location was studied at a particular time of day. Such profiles were also obtained at a station near the Gum Cove Ferry, about

Table T-1

Times and Locations at Which Water Samples Were obtained for Chemical Analysis

Time/Date	Location		
	P	N	T
10:30--12:00 noon June 8	X^c	X	X^c
2:50--3:00 pm June 8	X^c	X	X^c
9:10--9:30 am June 9	X^c	X	X^c

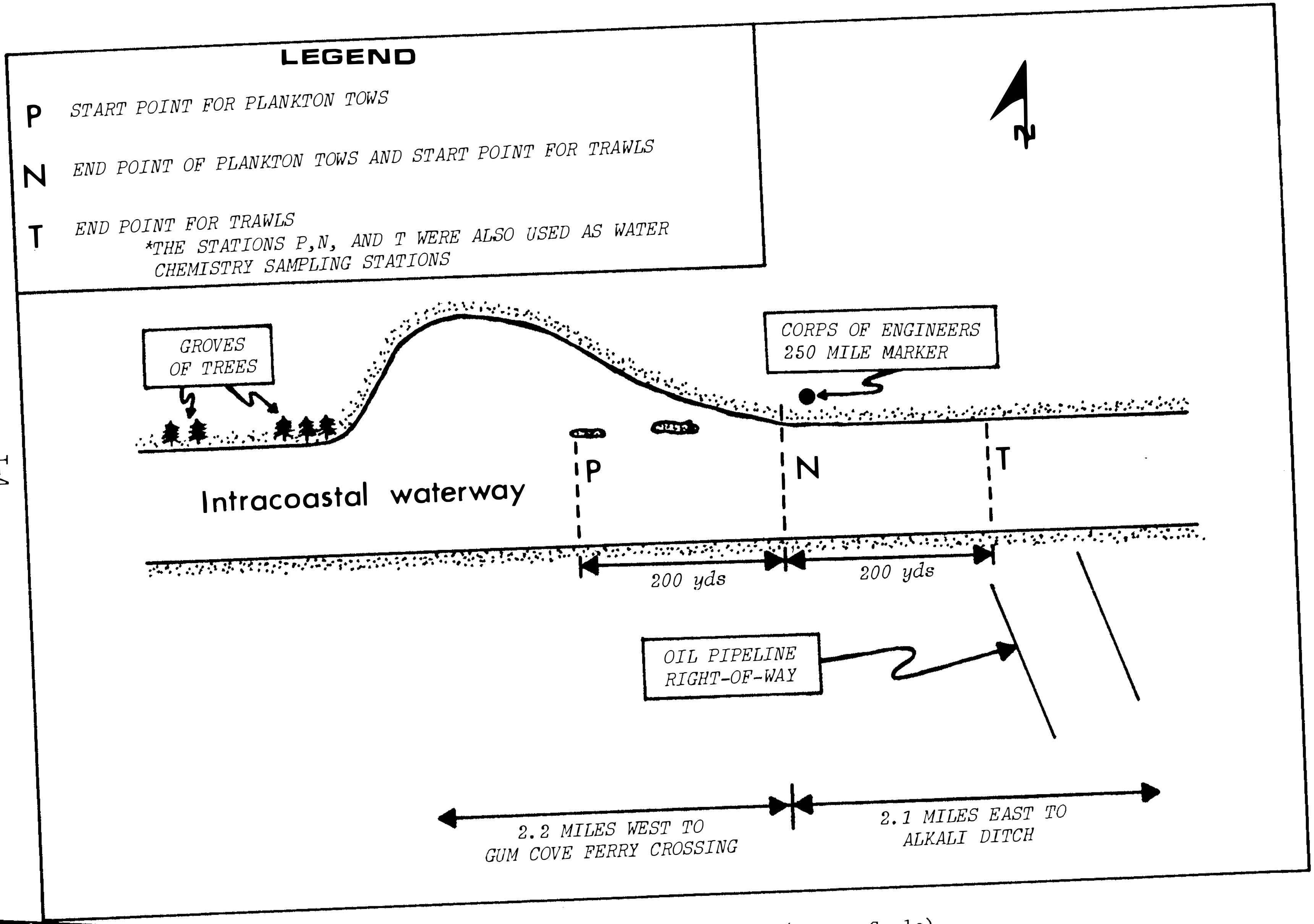
X = One sample.

X^c = Two samples, one of which was used in the composite sample for the station.

P = Point from which plankton tows were begun.

N = Point at which plankton tows were ended and trawls begun.

T = Point at which trawls were ended.



tions Near Proposed Intake (Not to Scale).

2.2 miles west of the other locations. Construction of the profiles resulted in a depth determination in addition to the other factors. A portable Hydrolab Surveyor system was used to construct the profiles. The line by which the sensors were suspended was marked at 1 meter intervals, enabling direct determinations of the distance from the surface at which the sensors were located. The depth readout on the Hydrolab Surveyor malfunctioned and only the depth data from soundings were used. The following profiles were constructed: Station P, 10:30 pm, June 8; Station T, 11:55 am, June 8; Gum Cove Ferry Station, 1:50 pm, June 8; Station N, 3:05 pm, June 8; and Station P, 8:45 am, June 9.

Biological sampling was performed using a 30-foot otter trawl to collect demersal fish and epibenthic fauna, and a large plankton net was used to sample the water column proper. Both trawls and plankton tows were made using a 20-foot flat-bottomed workboat with a 115 horsepower outboard motor to pull the sampling apparatus at a slow speed. All trawls and plankton tows were made in a downcurrent (easterly) direction.

The otter trawl used had the minimum legal commercial mesh size of 3/4-inch on a side, 1½-inch maximum aperature stretched, and a vertical dimension at the mouth of approximately 3 feet. During operation, the trawl probably only opened to about 28 feet. Trawls were made four times and at two locations, near the proposed intake and near Gum Cove Ferry Crossing. The three trawls near the proposed intake all traversed the same segment of the ICW channel (Station N to Station T). The trawls were timed and were pulled over a sight-estimated distance of 200 yards. The accuracy of this distance probably is within ± 50 yards. Trawls were made at different times of the day on June 8.

A one-meter diameter, #6 (243 microns on a side), nylon plankton net fitted to a collecting bucket with a #6 wire mesh window was used to sample the water column. This net was towed five different times and at two locations, near the proposed intake and near Gum Cove Ferry Crossing. The four tows near the proposed intake all traversed the same segment of the ICW channel (Station P to Station N) at approximately middepth. To avoid the excessive turning encountered in the first tow, subsequent plankton tows were made off the bow of the boat with the motor in reverse. The last tow was made on the second day of work, June 9. Plankton tows were timed, as with the trawls. Similarly, they were made over a sight estimated distance of 200 yards ± 50.

The relative locations of the sampling stations near the proposed intake are shown in Figure T-1. The sampling zone is about 2.1 miles west of the intersection of the ICW and

Alkali Ditch. Samples were taken in a coordinated way. The work in this zone was started at Station P at each sampling time. All other sampling (e.g., metals, nutrients, Hydrolab) was completed, then the plankton tow was made. Any work scheduled for N was then completed, and a trawl was made if scheduled. At the end of the trawl (Station T), any additional sampling scheduled for T was performed.

A series of samples were obtained east of Gum Cove Ferry Crossing at about 2:00 pm, June 8. These included a plankton tow, a trawl, and Hydrolab Surveyor data. The plankton tow and trawl were back-to-back, and each an estimated 200 yards long as at the sampling zone near the proposed intake. The plankton tow was started on line with the sign for the ferry immediately east of the actual crossing. This study was made to support evaluation of conditions in a fresher part of the Waterway.

Results

Results are presented in tabular form with summations in the accompanying text. These appear in the order: chemical analyses, Hydrolab Surveyor measurements, and biological results.

Table T-2 presents heavy metals levels measured in the two composite samples from Stations P and T. The values have been compared to the water quality advisory levels presented in Appendices D.3 and interpreted in relation to brine discharge by reference to Appendix D.15.

Nutrients, chloride, and sulfate are presented in Table T-3. These values have been compared against standards and with respect to their contribution to brine discharge levels, as with heavy metals. Compared to high levels of various elements and compounds previously noted on p. C.3-6, present analysis indicates good quality. Only iron was high, and this probably includes suspended iron and is therefore misleading. The day-to-day changes in values in Table T-3 were slight, as were the differences between sampling locations. In situ measurements profiles obtained with the Hydrolab Surveyor are presented below in Table T-4. Conductivity has been converted to salinity, and dissolved oxygen adjusted to conductivity/salinity in the table. Depths at the bottom and corresponding in situ measurements are presented in Table T-5.

Comparison of in situ measurements with state standards and EPA advisory levels does not disclose any cases of extreme low quality, although pH and dissolved oxygen may occasionally have been marginal by some of the EPA advisory levels. It is interesting to note the day-to-day change in salinity

Table T-2

Results From Composite Samples

Material	P Composite	T Composite
Calcium	68.8 mg/l	68.4 mg/l
Magnesium	0.1 g/l	0.11 g/l
Sodium	1.86 g/l	1.85 g/l
Potassium	0.1 g/l	0.11 g/l
Manganese	8.4 µg/l	9.4 µg/l
Zinc	2.2 µg/l	2.4 µg/l
Lead	<2.0 µg/l	<2.0 µg/l
Iron	0.38 g/l	0.38 g/l
Copper	<2.0 µg/l	<2.0 µg/l
Cadmium	0.2 µg/l	0.1 µg/l
Nickel	<1.0 µg/l	<1.0 µg/l
Oil and Grease	1.0 mg/l	2.0 mg/l

Table T-3 Macronutrients, Chloride, and Sulfate

Material and Time			Station P	Station N	Station T
Nitrate mg/l	morning	6/8	0.024	0.021	0.029
	afternoon	6/8	0.026	0.026	0.036
	morning	6/9	0.024	0.036	0.041
Nitrate mg/l	morning	6/8	0.13	0.11	0.18
	afternoon	6/8	0.21	0.08	0.21
	morning	6/9	0.22	0.18	0.20
Orthophosphate mg/l	morning	6/8	0.043	0.070	0.051
	afternoon	6/8	0.060	0.049	0.058
	morning	6/9	0.087	0.072	0.078
Reactive Silicate mg/l	morning	6/8	0.70	0.99	1.67
	afternoon	6/8	0.41	1.38	1.14
	morning	6/9	0.70	2.35	0.41
Chloride g/l	morning	6/8	2.16	2.77	2.87
	afternoon	6/8	2.64	1.80	2.64
	morning	6/9	1.51	1.52	1.58
Sulfate g/l	morning	6/8	0.32	0.38	0.38
	afternoon	6/8	0.36	0.37	0.38
	morning	6/9	0.23	0.22	0.26

Table T-4 Temperature, Salinity, Dissolved Oxygen, and pH Depth Profiles

Depth	Profile	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH
Surface	1	26.0	4.8	6.1	6.7
	2	27.0	5.0	6.1	6.6
	3	26.0	1.1	5.5	6.4
	4	27.6	4.6	6.1	6.8
	5	26.0	2.5	5.1	7.9
1 M	1	26.0	5.0	5.6	6.7
	2	27.0	5.1	6.0	6.6
	3	25.5	1.4	5.3	6.3
	4	27.5	4.6	5.8	6.7
	5	26.0	2.6	4.9	7.9
2 M	1	26.0	5.0	5.4	6.7
	2	26.8	5.2	5.9	6.6
	3	25.3	1.4	5.1	6.3
	4	27.3	4.7	5.5	6.7
	5	26.0	2.7	4.5	7.9
3 M	1	-	-	-	-
	2	26.0	5.3	5.8	6.6
	3	25.3	1.5	5.0	6.2
	4	27.2	4.7	5.6	6.7
	5	26.0	2.7	4.8	7.9
4 M	1	-	-	-	-
	2	25.5	5.4	5.7	6.6
	3	25.2	1.5	5.0	6.2
	4	27.0	4.8	5.2	6.6
	5	26.0	2.7	4.5	7.9
5 M	1	-	-	-	-
	2	-	-	-	-
	3	25.1	1.6	5.0	6.2
	4	-	-	-	-
	5	-	-	-	-

Profile Key

1 = Station P, 10:30 am, June 8
2 = Station T, 11:55 am, June 8
3 = Gum Cove Ferry Station, 1:50 pm, June 8
4 = Station N, 3:05 pm, June 8
5 = Station P, 8:45 am, June 9

Table T-5 Bottom Depths of Profiles and Corresponding Temperature, Salinity, Dissolved Oxygen, and pH

Profile	Bottom Depth M	Temp. (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH
1	2.5	26.0	5.0	5.6	6.7
2	4.5	26.0	5.5	5.8	6.6
3	5.0	25.1	1.6	5.0	6.2
4	4.75	27.0	5.0	4.8	6.6
5	4.2	26.0	2.7	4.5	7.9

*The key to profiles is in Table T-4.

and pH. A comparison is available for Station P which was studied both on the morning of June 8 and the morning of June 9. Over this period, salinity fell by nearly half and pH went up by more than a unit. This may be explained by the fact that heavy rains occurred on June 6 and 7. Runoff from this precipitation may have flushed the canal, removing both dissolved solids and humic materials. The current was observed to be to the east--Gulfward--at each sampling time. A period of general drought preceded the rain. The data indicate mixing within the water column under high freshwater runoff conditions rather than stratification.

Trawl and plankton net catches were transported to the laboratory to be processed. Total counts by species were made of economically important animals and other forms obtained in the trawl catches. In the plankton samples, large forms were counted in toto; small forms were estimated by subsample counts. Economically important forms were identified as fully as possible, others were only generally noted. Approximate volumes of water filtered were calculated to apply to the number of animals in the corresponding samples. This gave rude estimates of average density. In a trawl, an estimated 1,411.2 m^3 were intersected by the trawl. In a plankton tow, an estimated 144.48 m^3 were intersected

The trawls caught such economically important forms as brown shrimp juveniles, blue crabs, sand seatrout, and Atlantic croaker. Shrimp were also collected in plankton tows near the proposed intake. Shrimp were most prevalent in plankton in the morning and late afternoon tows--when their numbers in the trawls were relatively lower. This was interpreted as a reflection of the shrimp lifting off the bottom and moving with the current in midwater.

Species or other groupings caught in trawls are listed in Table T-6 along with their abundances. Of the species in this table, only the bay whiff and the southern flounder were not also reported in June catches in 1968 in the same estuarine area according to the report in the Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana. Numbers per catch are also on the same order of magnitude in the present and in the 1968 studies.

The largest fish from the trawl samples were the two foot-long flounders taken in the last two tows. Shrimp ranged between 45 and 110 mm in length with the greatest number at around 65 mm. Sand Seatrout ranged between 40 and 120 mm long, with a mode near 90 to 95 mm. Atlantic croaker ranged between 50 and 240 mm, with the greatest number at about 75 mm.

Table T-6 Abundances in Trawl Samples

Species	Trawl 1 Abundance (No. /100 M^3)	Trawl 2 Abundance (No. /100 M^3)	Trawl 3 Abundance (No. /100 M^3)	Trawl 4 Abundance (No. /100 M^3)
Fish				
Anchoa mitchilli Bay Anchovy	.1			
Brevoortia patronus Largescale Menhaden	.07	.14		.07
Citharichthys spilopterus Bay Whiff	.07	.14	.07	.07
Cynoscion arenarius Sand seatrout	2.0	1.2	.57	.5
Leiostomus xanthurus Spot		.07	.07	
Micropogan undulatus Atlantic croaker	7.65	5.2	10.42	3.7
Paralichthys lethostigma Southern Flounder	.07	.07	.07	.07
Polydactylus octonemus Atlantic Threadfin	.07			
Trinectes maculatus Hog Choker			.14	
Nonfish				
Callinectes sapidus* Blue Crab	At least 2.7	At least 2.1	At least 2.1	At least .7
Penaeus aztecus Brown Shrimp	16.1	22.9	1.56	9.0
Rangia cuneata Marsh Clam				.07

*Density includes estimate of at least 10 large blue crabs discarded after each trawl.

Species or other groupings in the plankton tows are listed in Table T-7 along with their abundances in the samples. The species list is dissimilar to that in the Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana, in that a number of small fish species, mysids, ostracods, mayflies, and barnacle larvae were present. This is partly attributable to the more inland location of sampling in the present study. Large proportions of the *Acartia* copepods collected were covered with stalked ciliates to varying degrees. This indicates a high concentration of small food particles. Detritus was very abundant in the water and quickly clogged the screening in the collecting bucket, causing backwashing. This means that the densities observed in samples were low. These overlapped in order of magnitude with those observed in the cooperative inventory. There was much more of a range at the ICW, perhaps somewhat reflecting the greater number of species collected.

Sizes of fish and shrimp in the plankton were relatively small. The maximum size was about 100 mm, which was attained by the speckled worm eel. Shrimp and anchovies ranged between about 20 and 75 mm long. Seatrout and menhaden were in the 60 to 80 bracket. The clown goby ranged between 20 and 25 mm long.

Discussion/Conclusions

Since there was a period of drouth before the sampling period although heavy rains occurred the two days just before field studies were conducted, marsh and estuarine animals probably penetrated farther inland than they normally do. The ICW has been regarded as unproductive by informed local observers. On the basis of the present work it certainly does not appear exceptionally rich in fisheries species compared to other parts of the estuary. If local observations are correct, it must be a rare occasion on which one could obtain the high catches which were seen.

One can certainly see the effect of runoff from the recent precipitation in the data. Salinities go down during the first day (later in the day) and into the next. The chloride levels falls first in station N, indicating that current differences may be developed during heavy runoff. On the return from Black Bayou an area of silt-laden water was observed to be advancing along the shore. Its edge was quite discrete. This also seems to indicate the development of discrete currents.

The ICW is a relatively good quality water source according to the data observed in the present study. The present data support the conclusion that the potential for harm to biota from using ICW water from the study area compared to other potential sources is probably relatively low.

Table T-7

Abundances in Zooplankton Catches

Species or Other Group	Tow 1 Abundance (no/100m^3)	Tow 2 Abundance (no/100m^3)	Tow 3 Abundance (no/100m^3)	Tow 4 Abundance (no/100m^3)	Tow 5 Abundance (no/100m^3)
Acartia Calanoid Copepod	293	288	420	288	555
Anchoa mitchelli Bay Anchovy	7	13	2	3	12
Aurelia aurita Jelly Fish	14	21		6	
Balanus nauplii Barnacle Larvae	2	2		3	
Brachuyuran zoeae Crab Larvae	14	3	15		36
Brevoortia patronus Large scale Menhaden					1
Callinectes sapiclus Blue Crab		1			1
Cirolana Isopod	1	1		1	
Cynoscion arenarius Sand Seatrout			2		
Ephemeropteran Mayfly Larvae			14		
Labidocera Calanoid Copepod			1		
Mysid Shrimp-like Crustacean	1	1	22	6	6
Microgobius gulosus Clown Goby	7	17		3	
Myrophis punctatus Speckled Worm Eel					1

Table T-7 (Continued)
Abundance in Zooplankton Catches

Species or Other Group	Tow 1 Abundance (no/100m^3)	Tow 2 Abundance (no/100m^3)	Tow 3 Abundance (no/100m^3)	Tow 4 Abundance (no/100m^3)	Tow 5 Abundance (no/100m^3)
Ostracod no. 1				1	
Pagurid zoeae Hermit Crab Larvae				1	1
Penaeus aztecus Brown Shrimp	10	4	3	9	18
Penaeus setiferus post larvae Very young stage white shrimp				50	
Penilia Ostracod			10		
Temora Calanoid Copepod			5		