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Salinity Calibration using 1987 Data

To achieve a satisfactory salinity calibration, many simulation runs were initiated, each requiring a long CPU time. To run a two-year simulation required about 60 CPU hours on a Sun SPARKstation 20.

Unlike results of hydrodynamic calibrations, we have to accept that agreement between simulated and observed salinities may not be as good as we would like. There are a few reasons for valid disagreement between observed and simulated salinities in a properly working model. For instance, the depth at which salinity measurements are made in the field may be important. Salinity measured near the surface may be different than measurements made near the bottom. Fixed salinity recording meters, such as DataSondes, an important source of data for this study, may record values in only one of a multi-layered water mass. The model, on the other hand, is a depth-averaged model and may not compute salinities strictly comparable to the observed. The major parameter for salinity calibration is the diffusion (or dispersion) coefficient. The value of this parameter is adjusted so that the simulated data fit the observed data. However, adjustments can create a diffusion parameter which can be orders of magnitude larger than what is considered to be a realistic value for the physical parameter, as experienced by Brandes and Masch (1971). In line with our expectations of how the system works, different diffusion coefficients were used from node to node.

Another difficulty in salinity calibration arises from the lack of salinity data at the Gulf tidal boundary. There are no consistent observed salinity data to represent the near-shore Gulf of Mexico. For modeling, a constant value of 34‰ was set along the tidal boundary. Generally this works well, but for extreme cases, such as during very wet or very dry climatic conditions, simulations with a constant boundary value may produce results which deviate from the observed values. Given this and the above problems, the most productive approach to salinity calibration is to produce results which follow the overall pattern of observed salinity changes.

In 1987, TWDB initiated a water quality data collection program using HydroLab DataSondes, continuously recording automated instruments. In this data set, a large flood event of the Nueces River, 12000 cfs at peak, is captured. For the 1987 simulation, a separate model was run to determine the boundary salinity values at the northern end of the CCBNEP grid. This simulated salinity was set at the GIWW near the Aransas National Wildlife Refuge and Ayres Dugout. This was important for 1987, because a major flood of the Guadalupe River freshened the bays to the north of the study area and moved lower salinity water through the GIWW and Ayres Dugout, influencing salinity in Aransas Bay. Figures III.14(a) through III.14(d) are the salinity calibration plots. There are disagreements between the observed and simulated salinities, but overall trends are traced well by the simulation.

Salinity Calibration by 1988-1989 Data

Model verification is generally defined as a simulation run with a set of calibrated parameters but using an independent data set. For instance, the 1988-1989 simulation can be considered a verification run using the calibrated parameter set obtained in the salinity calibration with 1987 data. However, new calibration runs were preferred over strict verification. Because different years have different data sets, different data locations, and different data set lengths, it is not possible to set up a verification run for some locations. Since the purpose of model calibration (and verification) is to find a reliable set of parameters, we felt the additional 1988-1989 data set should be used to increase the quality of the model parameters.

The second purpose of the 1988-1989 simulation was to see how the model simulates a dry year, such as occurred in 1989. (A minor purpose was to see how a multiple year simulation worked; this was TWDB's first exercise in running a two year dynamic simulation.) The dry condition is most evident in the Laguna Madre in the summer of 1989, as exhibited in Figure III.15(a) at Baffin Bay where recorded salinity reached 60‰ and near the JFK Causeway with salinity over 50‰.

Calibration comparisons are shown in Figures III.15(a) through III.15(f). In the Baffin Bay comparison, associated point data indicate that the period of low observed salinities is likely anomalous, indicating probe fouling, and can be discounted (Figure III.15(a)). However, the period of high salinities near the end of 1989 is likely representative of conditions at the location. The simulation seems to underestimate the observed salinity at the higher end, but it does show the correct trend. A similar observation can be made for the JFK Causeway site, with model underestimation of sparse observed data (Figure III.15(b)). Figure III.15(c) compares salinities at mid Nueces Bay and Figure III.15(d) compares salinities at mid Corpus Christi Bay. Simulated salinities do not fluctuate as much as observed salinities but they trace the observed salinities reasonably well. Observed salinities in Mid-Aransas Bay are tracked well by the model (Figure III.15(e)). Model and observed salinities at the Copano Causeway site track acceptably for most of the first year, then diverge (Figure III.15(f)). Lower simulated salinities may be caused by over-estimation of rainfall runoff in ungaged basins or be a result of the constant 34‰ set at the tidal boundary.

Salinity Calibration using 1991-1992 Data

A third data set was prepared with 1991 and 1992 salinity data for model calibration targeting the Laguna Madre part of the model. This data set is particularly valuable because salinities in Baffin Bay dropped significantly from high levels, roughly 40‰ near the end of 1991, to lower salinities, about 25‰ early 1992, and then recovered over a period of time to almost 35‰ in the late summer of 1992. Similar changes in salinity were recorded at the JFK Causeway site. As exhibited in Figures III.16(a) and III.16(b), simulation traces the overall changes well at both sites.

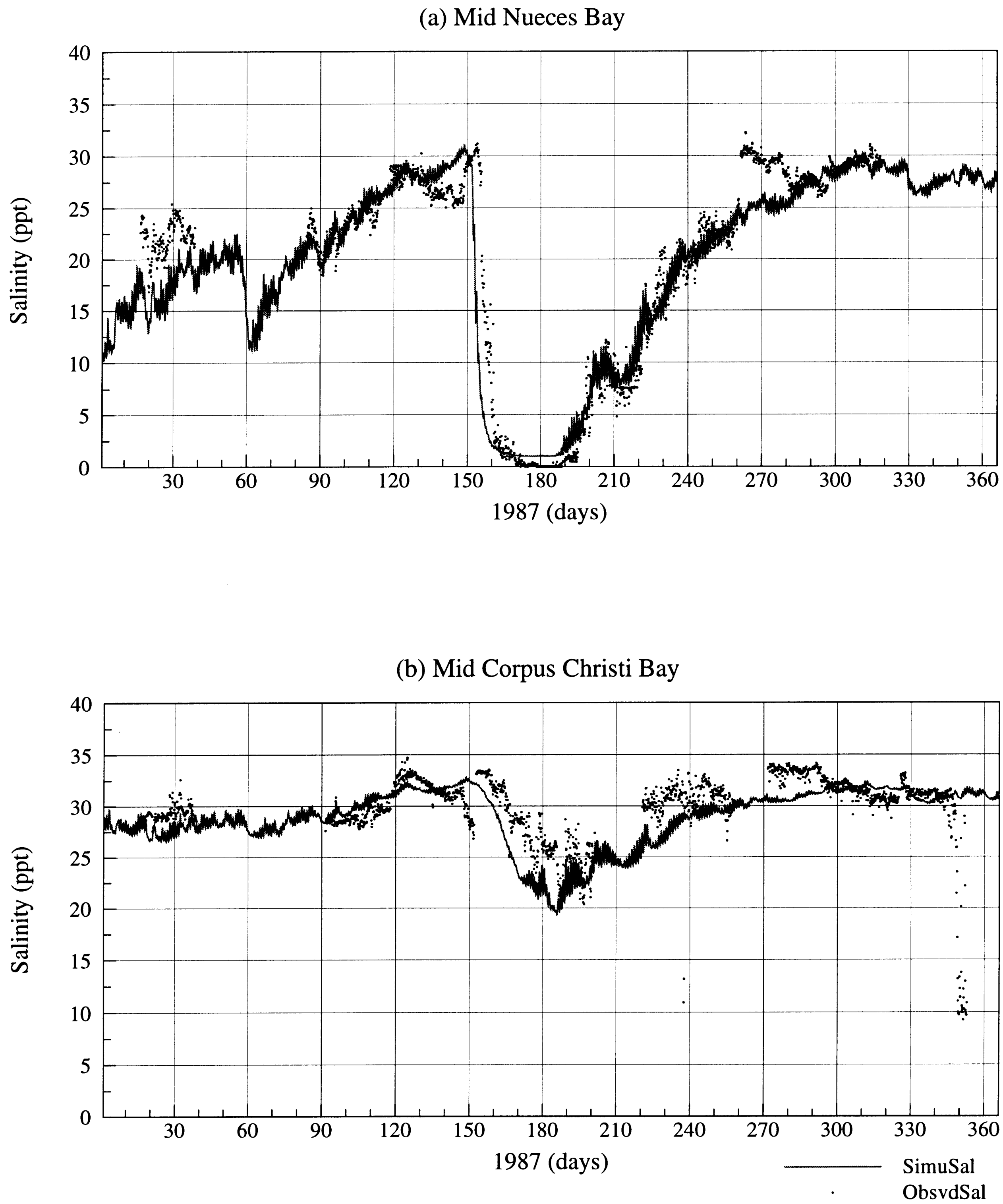
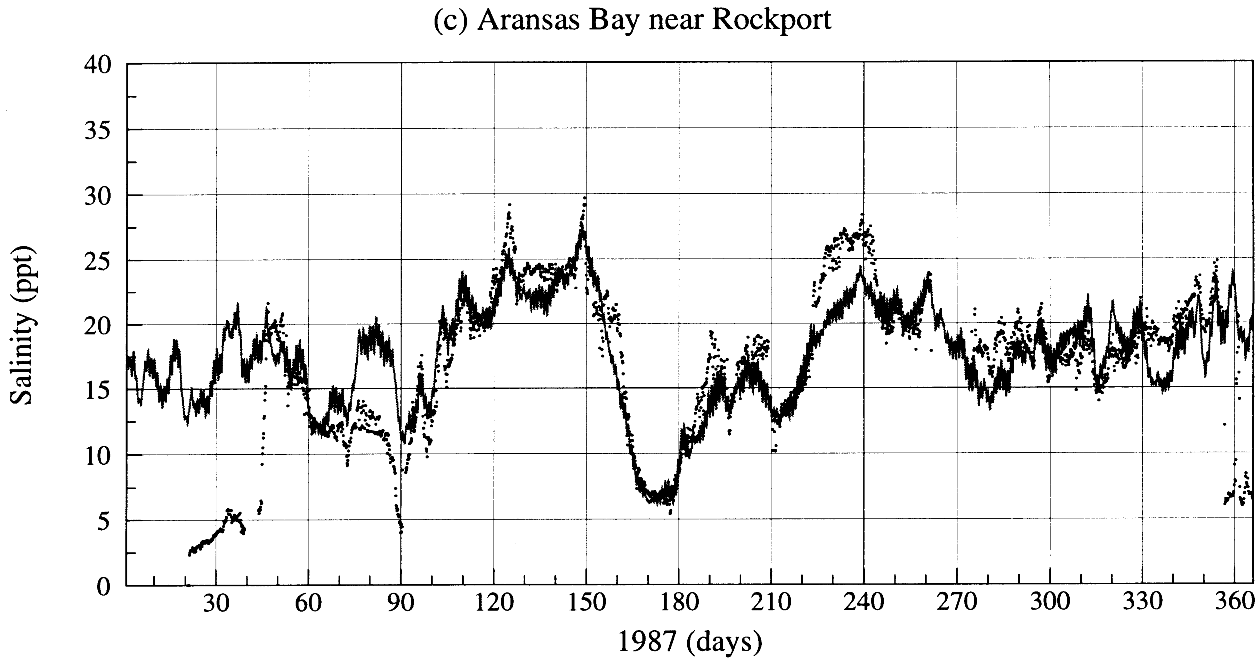


Figure III.14 Simulated and observed salinities in 1987



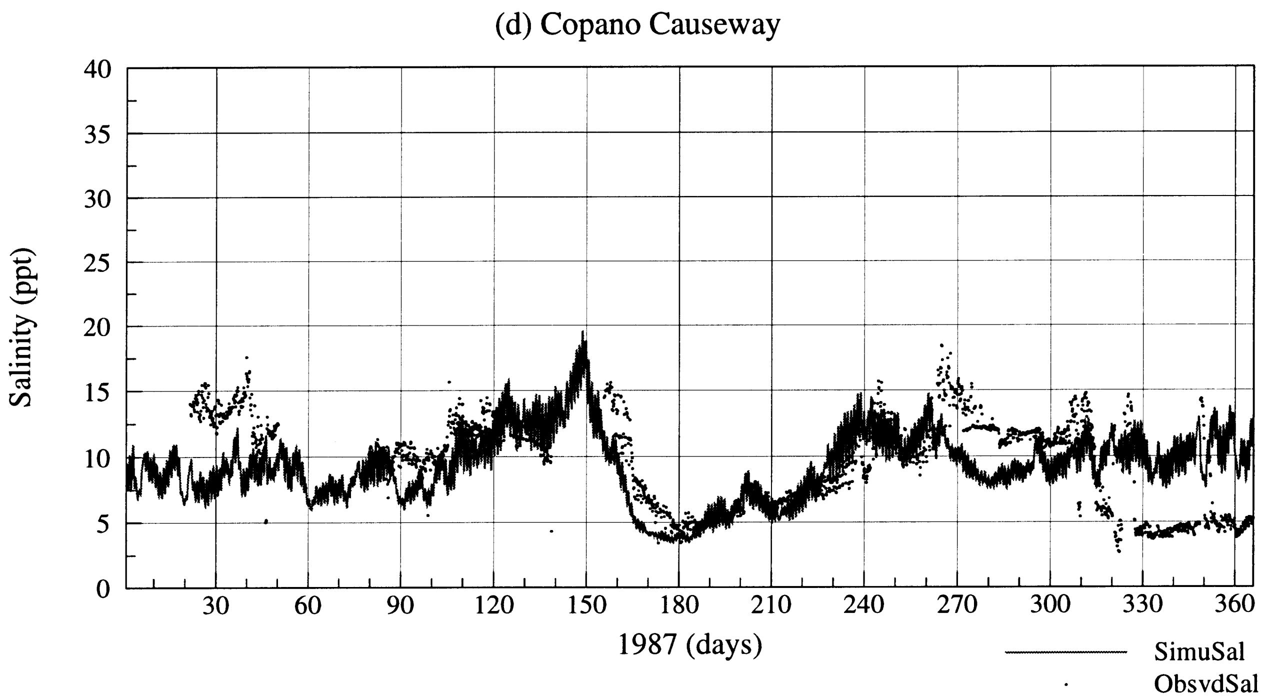


Figure III.14 Simulated and observed salinities in 1987

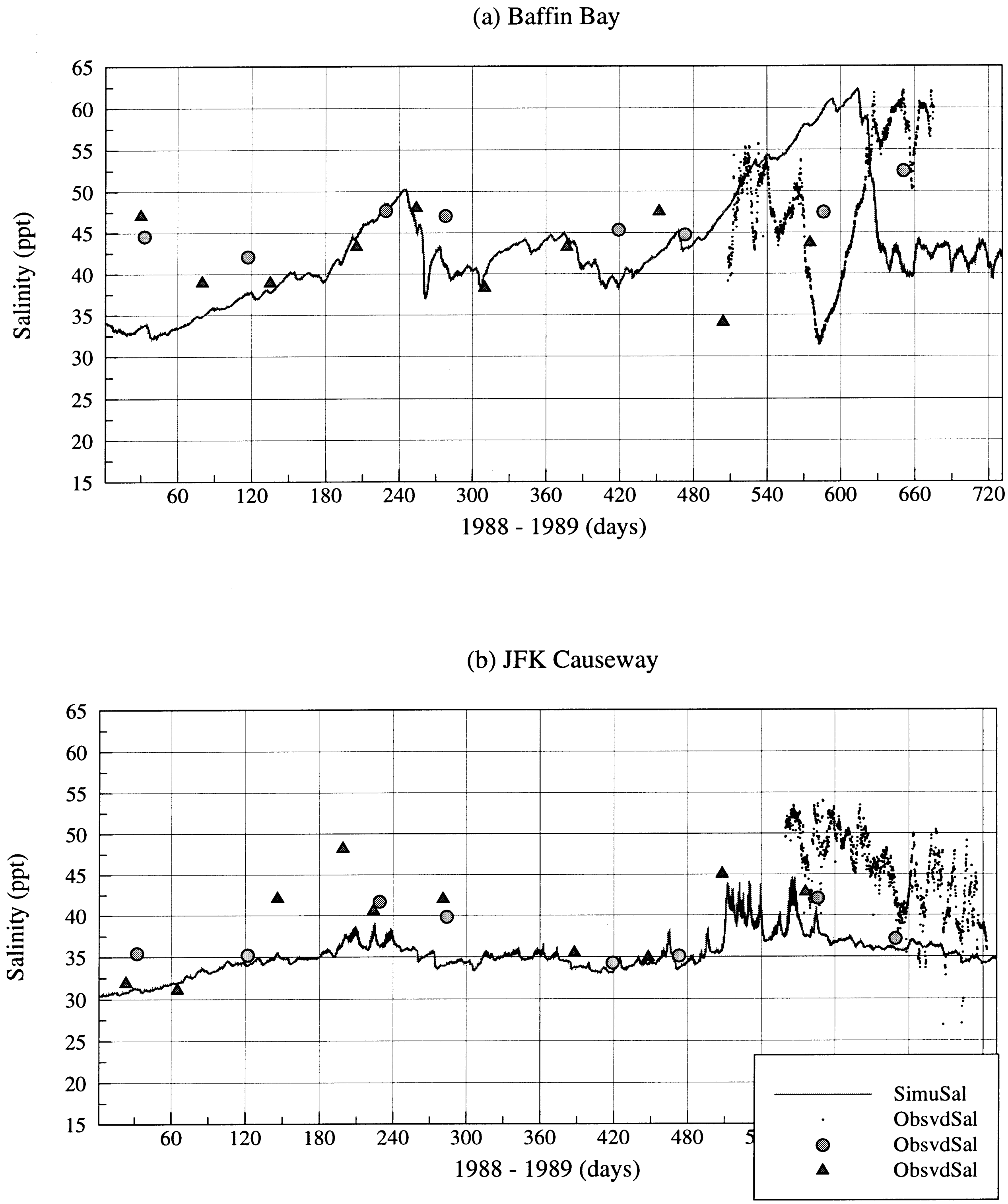
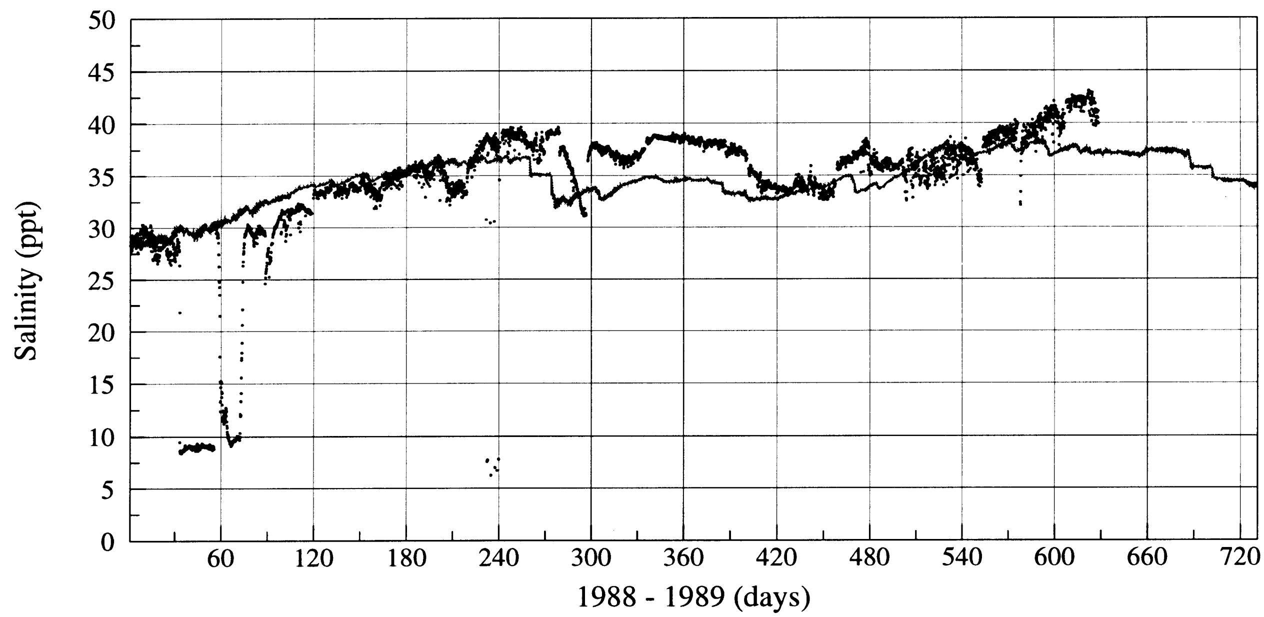


Figure III.15 Simulated and observed salinities in 1988-1989. Observed Datasonde data are shown by dots, CDS data by triangles, and SMN data by circles.

(c) Mid Nueces Bay



(d) Mid Corpus Christi Bay

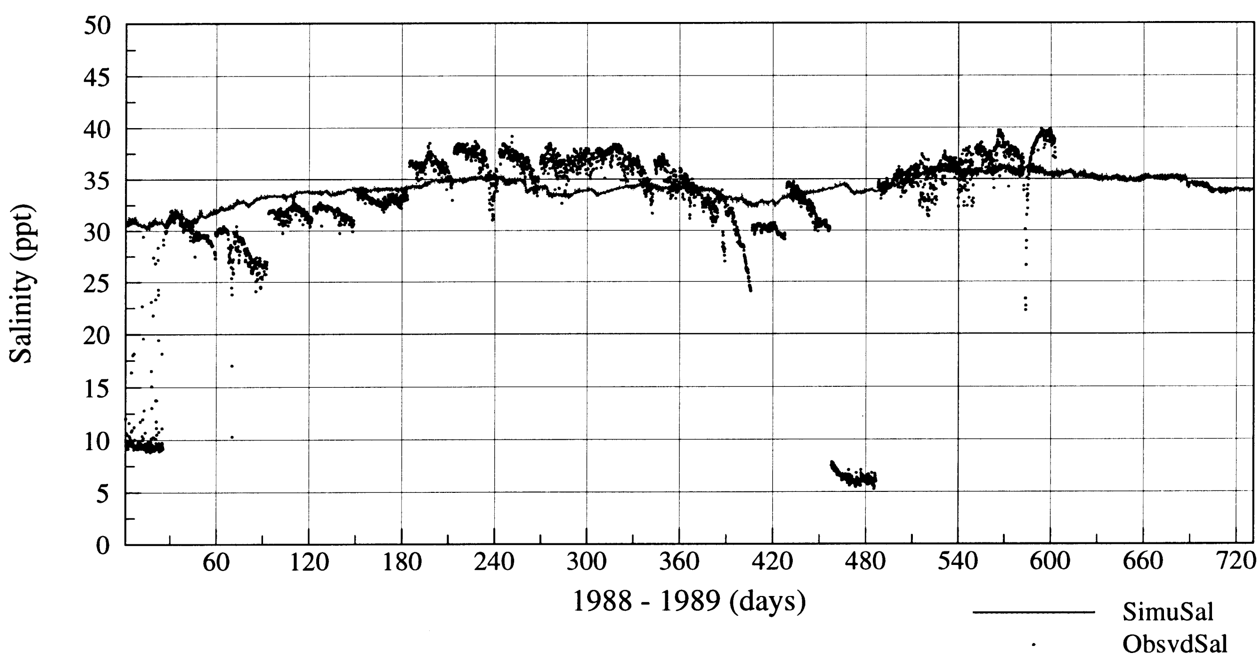
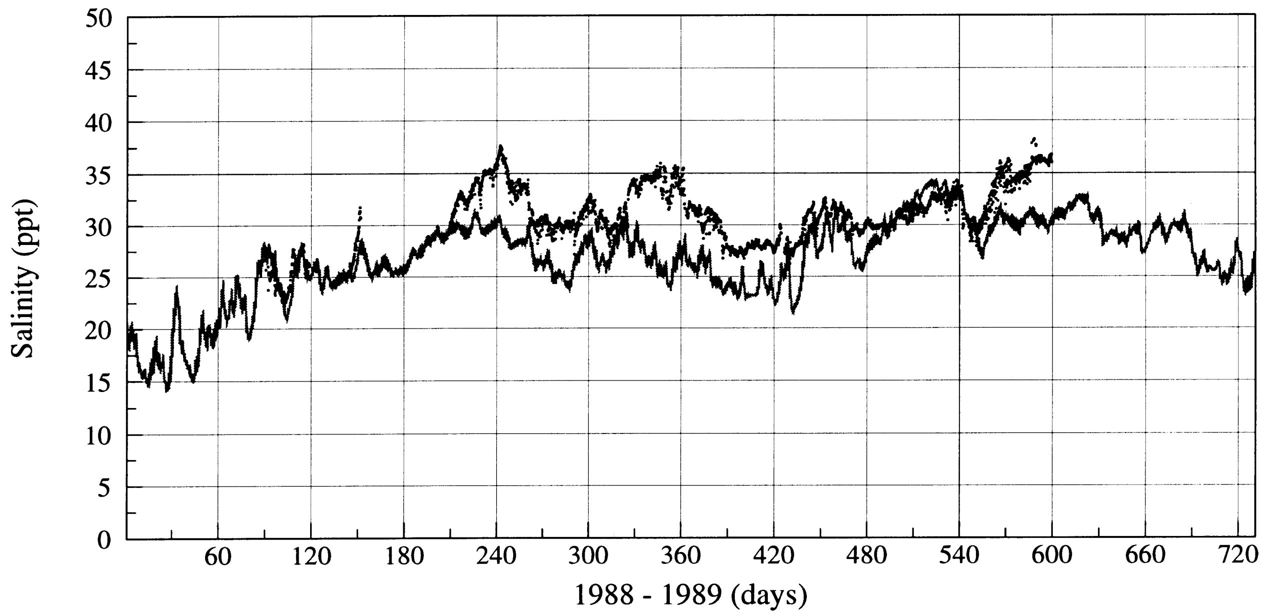


Figure III.15 Simulated and observed salinities in 1988-1989

(e) Aransas Bay near Rockport



(f) Copano Causeway

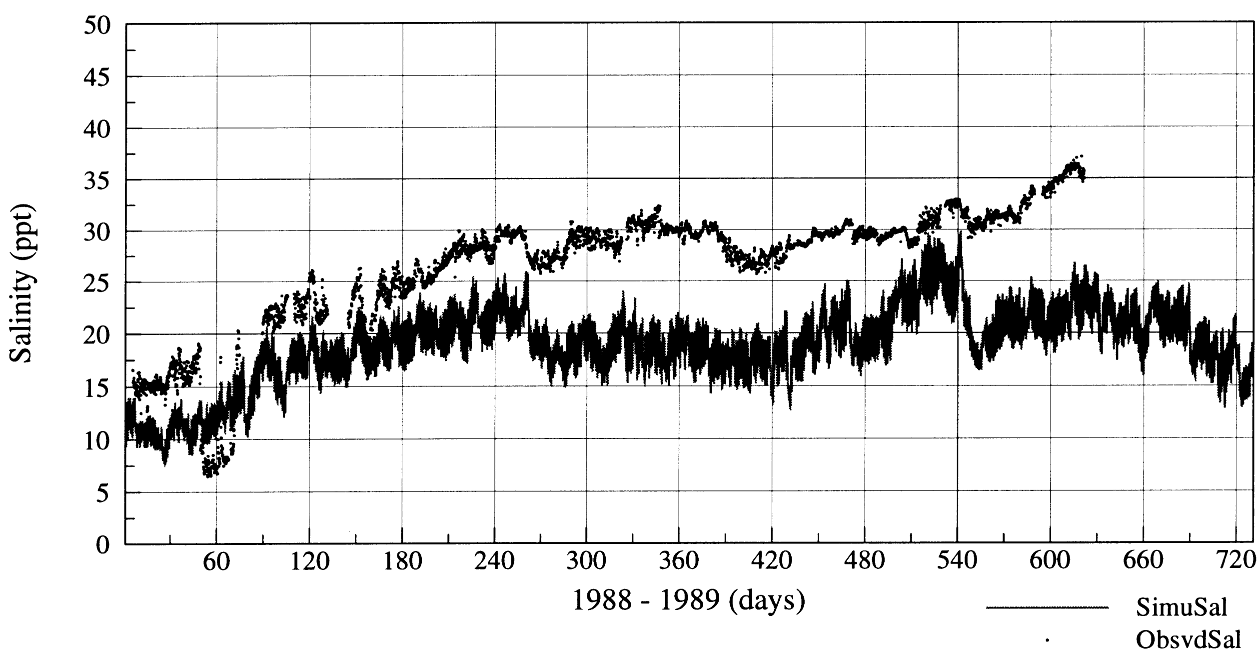


Figure III.15 Simulated and observed salinities in 1988-1989

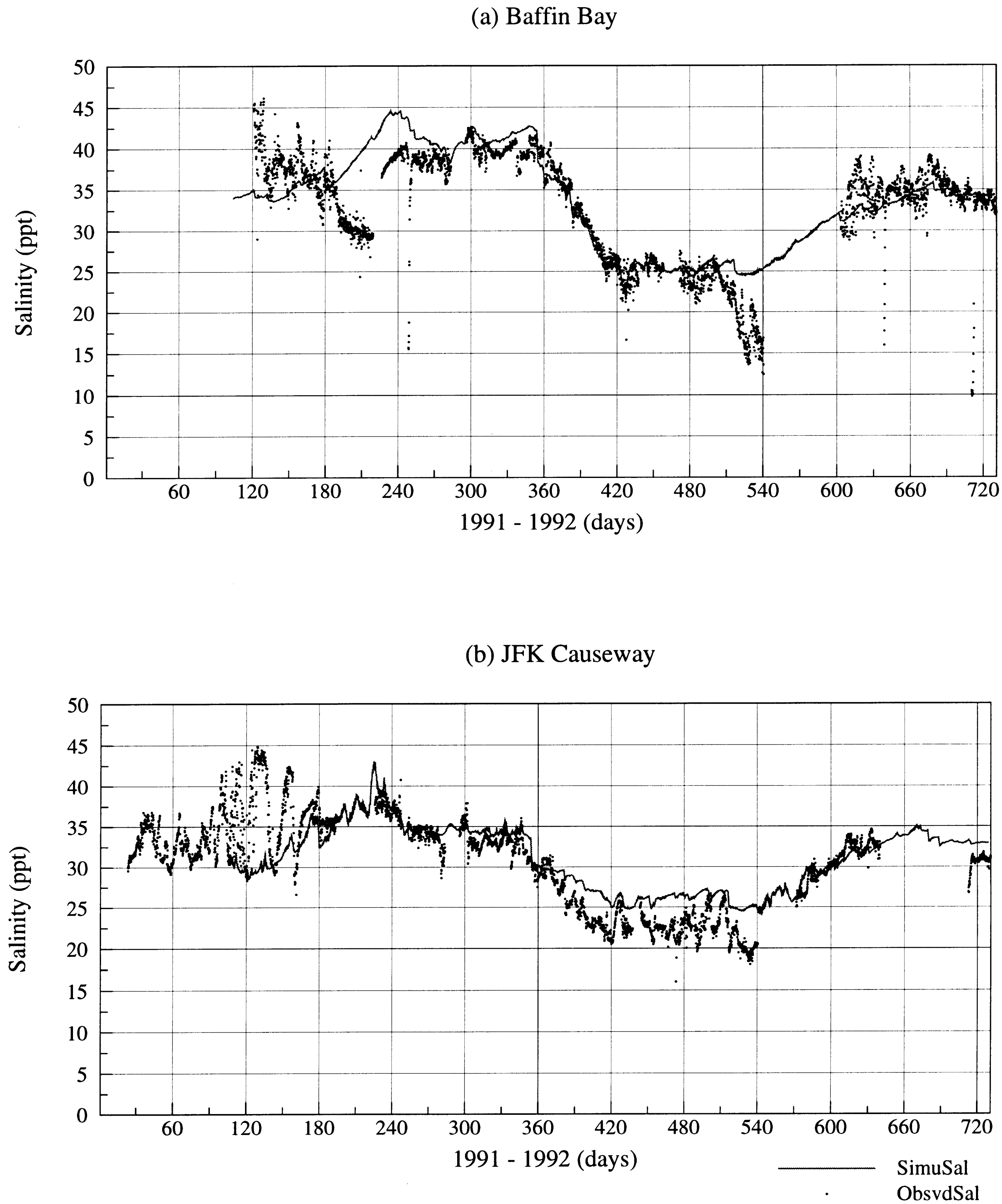


Figure III.16 Simulated and observed salinities in 1991-1992

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IV. CASE STUDIES

Five case studies are conducted for the CCBNEP project. The purpose of the case studies is to examine differences in circulation and salinity patterns between the existing condition and earlier conditions where the structures or practices are removed from the model.

Existing Condition

The existing condition is used as a bench mark for comparison. Two structures are examined in the case studies: the JFK Causeway linking the northern end of Padre Island to the mainland, and the Corpus Christi Ship Channel, a deep-dredged channel leading from the Gulf of Mexico to the harbor in Corpus Christi. Although there is some question concerning the effect of the Nueces Causeway on circulation between Nueces and Corpus Christi bays, this structure is not included in this analysis since the causeway is elevated and water can move under it.

Three practices are examined in the case studies. The first is withdrawal of Laguna Madre water for use as cooling water by the Barney Davis Power Plant. After use, the water is returned to Oso Bay. The second practice is similar in operation but involves the Nueces Bay Power Plant: water is drawn from the Corpus Christi Ship Channel in the harbor and discharged into Nueces Bay. The third practice is the diversion of freshwater from the Nueces River above Nueces Bay. Water is removed from the river, treated, and delivered to municipal and industrial users. Treated wastewater is returned to Nueces and Corpus Christi bays at several points.

The existing condition includes both structures and all practices. In the first four scenarios, one structure or one or more practices are removed from the existing condition, allowing differences in circulation and salinity patterns to be examined. In the final scenario, all structures and practices are removed from the model and a comparison is made between the existing circulation and salinity patterns and those that may have existed before the structures and practices were constructed or begun.

Withdrawal by the Barney Davis Power Plant

The Barney Davis Power Plant withdraws water from Laguna Madre near Pita Island for cooling and releases it into Oso Bay. The monthly return flows in ac-ft over the five-year period from 1988 to 1992 are listed in Table IV.1. The average monthly return flow is 39,554 ac-ft (1,301 ac-ft/day or 656 cfs).

Withdrawal by the Nueces Bay Power Plant

The Nueces Bay Power Plant withdraws water from the Corpus Christi Ship Channel for cooling and discharges it into Nueces Bay. The monthly return flows in ac-ft over the five-year period from 1988 to 1992 are listed in Table IV.2. The average monthly return flow is 29,763 ac-ft (979 ac-ft/day or 494 cfs).

Table IV.1 Monthly return flows (ac-ft) by Barney Davis Power Plant

Month\Year	1988	1989	1990	1991	1992
Jan	48405	33002	36618	49946	36798
Feb	23673	30522	25426	33280	27945
Mar	25458	34458	36475	40452	50555
Apr	32941	37232	36283	48694	44459
May	42326	42183	43629	49889	30205
Jun	47773	42894	45131	48878	42802
Jul	38682	47444	49879	49547	38054
Aug	42725	50079	49851	49080	48129
Sep	42737	35961	48712	47930	46779
Oct	27066	30186	26800	48567	46930
Nov	32499	27003	23993	24628	44615
Dec	33326	30186	36903	36465	50127

Table IV.2 Monthly return flows (ac-ft) by Nueces Bay Power Plant

Month\Year	1988	1989	1990	1991	1992
Jan	35561	30809	28085	35122	32276
Feb	31796	30231	18406	28950	28870
Mar	30826	33646	32372	32549	13512
Apr	16376	12459	33375	15474	30051
May	24859	11864	41327	38328	30468
Jun	29343	15188	36721	36230	24466
Jul	39908	37764	38171	31006	14270
Aug	38153	40217	40527	42797	14261
Sep	30657	33774	31275	32787	13820
Oct	36874	40273	39998	30747	14291
Nov	35691	28769	41093	34088	13761
Dec	28091	35488	38280	35496	13923

Salinity under the Existing Condition

Figure III.3 shows the location of several nodes on the computational grid that are used for salinity comparisons in the rest of this chapter. It is difficult to determine a salinity value that represents the bay as a whole, particularly when salinities may vary spatially within a bay. Therefore, consistent presentation of tables and plots of salinity through time at selected nodal points will provide a good comparison of the effects of the five scenarios.

The average monthly salinities in ‰ for 1988-1989 simulation and 1991-1992 simulation are listed in Table IV.3. These salinities are used to compute the differences between the existing condition and each scenario. Figure IV.1 is a plot of the simulated monthly average salinities for August 1989. It clearly shows the very high salinity conditions in Baffin Bay and Laguna Madre. The steep salinity gradients exhibited in the figure at inflow points to the bays are due to the input of water with a constant salinity near 0‰ that is specified for these points in the model.

Figure IV.2 shows the monthly average salinities for May 1992 for the existing condition. Copano Bay is very fresh, Aransas Bay shows a steep gradient, upper Nueces Bay is very fresh, lower Nueces Bay is a transition zone, Corpus Christi Bay is rather low in salinity for the bay, in the 20's (in ‰), Laguna Madre is uniformly in the 20's also, Baffin Bay shows a steep gradient from fresh to moderate salinities in the 20's.

Table IV.3 Simulated monthly average salinities (‰) for existing condition

Year	Month	Aransas Bay	Nueces Bay	Corpus Bay	Naval Air Sta.	GIWW JFK	GIWW Pita	Baffin Bay
1988	1	16.96	29.29	30.74	30.63	30.73	30.82	33.26
1988	2	18.70	30.39	31.43	31.27	31.31	31.34	32.99
1988	3	23.04	32.02	32.67	32.56	32.73	33.05	34.77
1988	4	25.11	33.59	33.53	33.76	33.97	34.37	36.73
1988	5	25.30	34.39	33.76	34.32	34.64	35.28	38.44
1988	6	25.94	34.84	33.96	34.48	34.74	35.35	39.81
1988	7	28.47	35.59	34.57	35.64	36.49	38.31	43.34
1988	8	29.90	35.93	34.98	35.97	36.74	40.03	48.20
1988	9	27.75	35.40	34.39	35.17	35.41	35.87	44.07
1988	10	26.33	33.07	33.58	33.89	34.12	34.70	40.41
1988	11	27.94	34.00	34.01	34.38	34.75	35.79	41.99
1988	12	26.29	34.55	34.14	34.72	35.14	36.41	43.78
1989	1	24.99	33.91	33.59	34.10	34.31	35.06	43.08
1989	2	23.92	32.86	32.70	33.21	33.48	33.92	39.67
1989	3	26.89	33.57	33.49	33.74	34.08	35.10	41.45
1989	4	28.27	34.11	33.96	34.37	34.74	36.10	44.03
1989	5	31.12	35.16	34.59	35.85	37.09	40.37	47.22
1989	6	32.93	37.19	35.81	37.75	39.46	47.14	53.30
1989	7	29.71	37.13	35.75	37.51	39.13	45.83	56.44
1989	8	30.65	37.13	35.61	36.76	37.36	40.89	60.41
1989	9	30.98	36.65	35.19	35.94	36.23	37.23	52.26
1989	10	29.02	36.35	34.93	35.67	36.05	36.69	41.79
1989	11	28.42	35.81	34.73	35.43	35.72	36.45	42.52
1989	12	25.56	34.04	33.80	34.19	34.44	35.00	41.90
1991	4	19.35	18.03	29.46	29.39	30.38	32.84	34.39
1991	5	21.92	24.58	30.99	29.94	30.06	31.29	34.13
1991	6	23.68	28.51	32.64	32.98	33.67	34.98	36.25
1991	7	25.51	30.28	33.19	34.30	35.67	37.59	37.45
1991	8	31.34	35.73	35.39	37.14	38.59	42.03	42.77
1991	9	27.20	33.12	33.87	34.26	34.31	35.35	41.72
1991	10	25.70	32.44	33.80	34.24	34.59	35.30	40.39
1991	11	21.21	32.34	33.23	33.85	34.38	35.28	41.11
1991	12	20.60	29.64	32.44	32.64	32.72	33.91	40.59
1992	1	14.53	20.72	29.49	29.10	29.10	28.92	33.69
1992	2	12.82	7.75	26.15	26.08	26.53	26.74	26.62
1992	3	18.20	12.29	26.99	25.49	25.65	26.34	25.46
1992	4	13.81	11.55	27.55	26.45	26.31	25.54	25.17
1992	5	16.68	9.55	27.88	26.82	26.73	26.29	25.91
1992	6	12.54	5.48	23.60	24.01	24.87	25.21	24.98
1992	7	25.68	18.78	26.59	25.71	26.70	27.95	27.74
1992	8	28.19	26.61	30.83	29.64	29.83	30.32	31.01
1992	9	28.51	30.25	32.49	31.83	31.79	31.87	32.55
1992	10	26.25	31.96	33.42	33.48	33.69	33.90	33.98
1992	11	23.73	31.72	33.26	33.50	33.60	33.86	34.80

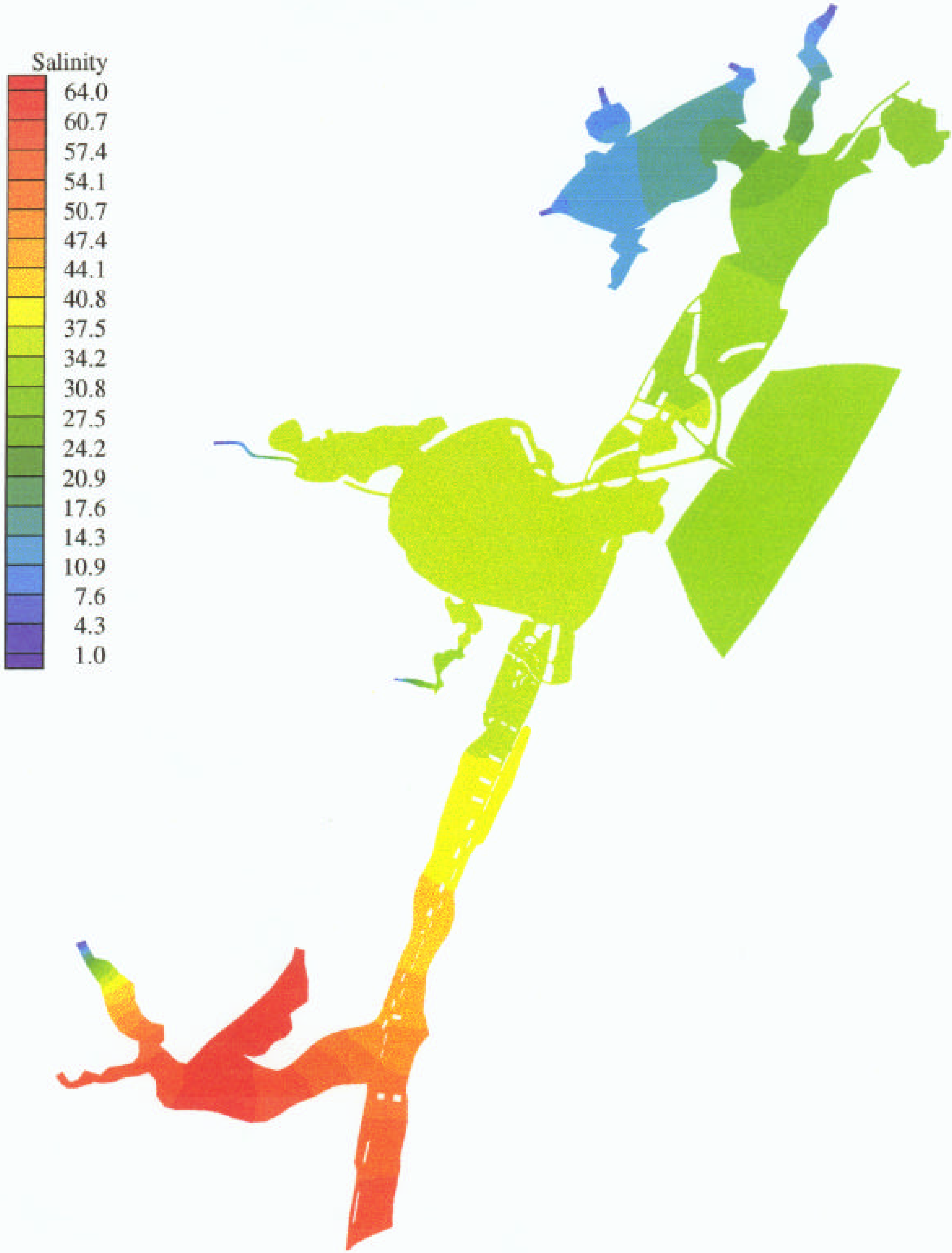


Figure IV.1 Simulated monthly average salinity (ppt) in August 1989 for the existing condition

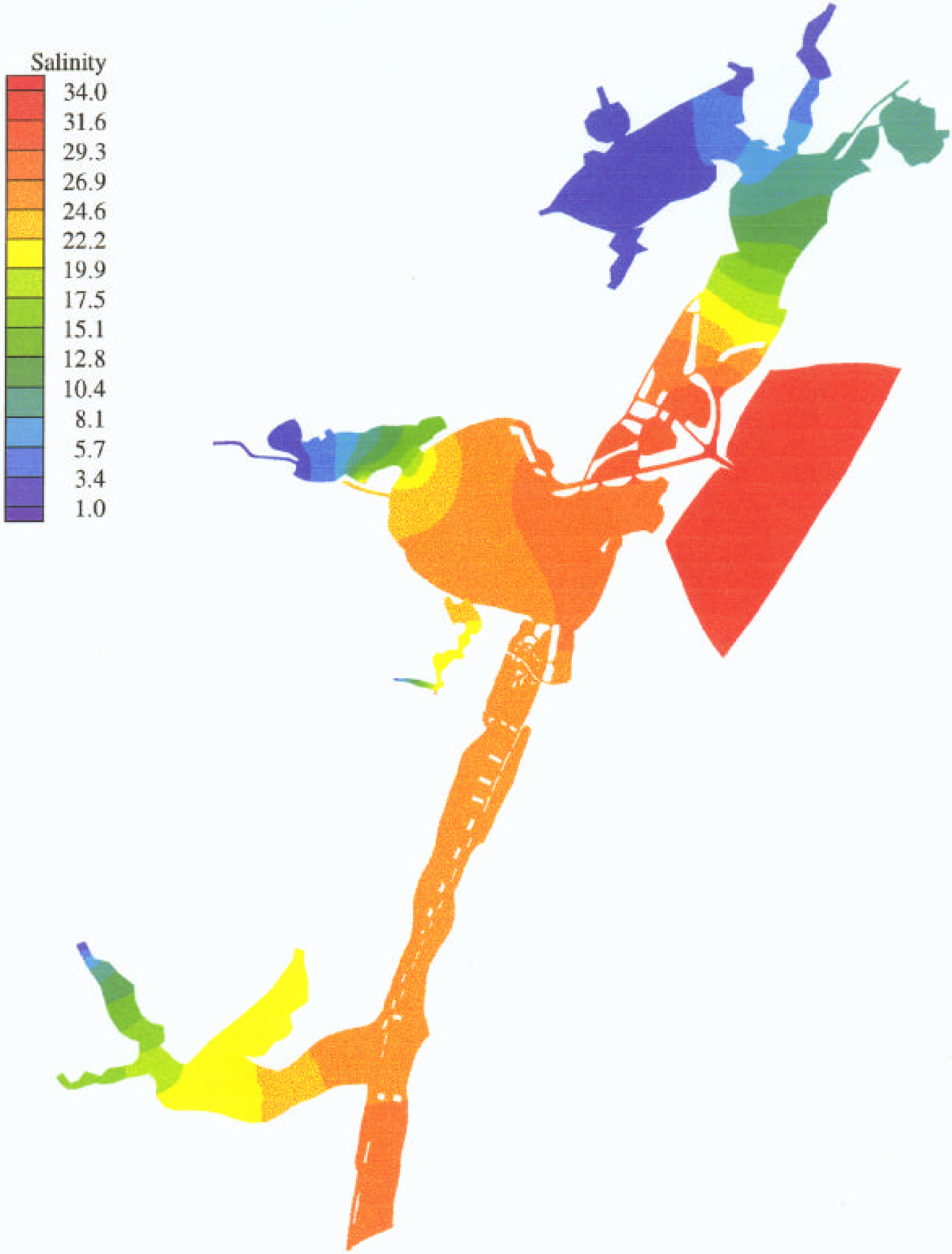


Figure IV.2 Simulated monthly average salinity (ppt) in May 1992 for the existing condition

Scenario 1: Effect of Withdrawal of Seawater by Power Plants

The purpose of this scenario is to examine the effects of withdrawal of seawater for cooling by power plants and the return of this water to different water bodies. To simulate the no-withdrawal case, the model was operated with no removal of water for cooling from Laguna Madre into Oso Bay for the Barney Davis Power Plant, and no removal of water for cooling from the Corpus Christi Ship Channel into Nueces Bay for the Nueces Bay Power Plant.

Table IV.4 lists the monthly average salinity differences between the existing condition and the scenario for the 1988-1989 and 1991-1992 simulations. Difference is computed by subtracting the scnerario salinity from the existing salinity; the difference is positive if the existing salinity is higher than the scenario salinity. Figures IV.3(a) through IV.3(f) for 1988-1989 and Figures IV.4(a) through IV.4(f) for 1991-1992 show the time histories of scenario salinities at selected locations compared with the existing condition. Figure IV.5 is a plot of salinity differences for August 1989 and Figure IV.6 for May 1992.

The effect of power plant operation is to equalize salinities in the bay near the intake area and discharge areas. When Nueces Bay is fresh because of flooding by the Nueces River, the cooling water withdrawn from the Ship Channel and discharged into the Nueces Bay raises the salinity of Nueces Bay water. This occurs because the salinity in the Ship Channel is much higher than the salinity of Nueces Bay, as seen in Table IV.3 from February through June of 1992. At the calculation node in Nueces Bay, the salinity is as much as 6‰ lower under the no-cooling water withdrawal scenario when Nueces Bay salinity is much lower than Corpus Christi Bay salinity (Figure IV.4(a)).

If Nueces Bay becomes hypersaline, the salinity in the Ship Channel is lower than the salinity in Nueces Bay and the discharge lowers the salinity in the Nueces Bay. This can be seen during the latter part of 1989 (Figure IV.3(a)) although the difference is small, less than 1‰ (Table IV.4). When salinities are not extremely low but are less than normal marine conditions (35‰) in Nueces Bay, the effect of the cooling water diversion is to slightly raise salinity at the calculation point in Nueces Bay since ship channel water is usually more saline than Nueces Bay water. Note that the largest salinity differences in Nueces Bay are limited to the area immediately adjacent to the discharge point at the southern shore; salinity differences are not noticeable throughout most of the rest of the bay (Figure IV.5).

At the mid Corpus Christi Bay calculation site during periods of lower salinity (less than 25‰), the effect of the cooling water diversion is to raise the salinity by less than 3‰ (Figure IV.4(b) and Table IV.4). The effect diminishes as the salinity level increases to 35‰. Under hypersaline conditions, the effect of the cooling water diversion is to slightly lower the salinity at the Corpus Christi Bay calculation node. The difference of 0.1‰ in the simulations is negligible, but as Nueces Bay salinity increases, the difference may become 1-2‰ as in the case of lower salinity.

Table IV.4 Salinity differences between the existing condition and no power plant operation. The difference is positive if the existing salinity is higher than the simulated salinity.

Year	Month	Aransas Bay	Nueces Bay	Corpus Bay	Naval Air Sta.	GIWW JFK	GIWW Pita	Baffin Bay
1988	1	0.00	0.45	-0.01	-0.05	-0.04	0.00	0.10
1988	2	0.02	0.52	0.03	0.03	0.00	-0.02	0.14
1988	3	0.01	0.41	0.08	0.04	-0.01	-0.03	0.20
1988	4	0.02	0.20	0.05	0.03	0.00	-0.03	0.22
1988	5	0.01	-0.08	0.00	-0.07	-0.13	-0.12	0.24
1988	6	0.02	-0.29	-0.03	-0.09	-0.14	-0.22	0.26
1988	7	0.01	-0.59	-0.06	-0.43	-0.64	-0.29	0.39
1988	8	0.01	-0.49	-0.08	-0.53	-1.02	-0.92	0.62
1988	9	0.01	-0.42	-0.05	-0.14	-0.21	-0.30	-0.07
1988	10	0.01	0.14	0.04	0.06	-0.03	-0.15	-0.11
1988	11	0.02	0.27	0.11	0.04	-0.10	-0.18	0.07
1988	12	0.01	0.14	0.08	0.01	-0.18	-0.22	0.27
1989	1	0.01	0.12	0.04	0.02	-0.06	-0.18	0.36
1989	2	0.01	0.15	0.02	-0.01	-0.05	-0.07	0.28
1989	3	0.01	0.04	0.05	-0.04	-0.16	-0.18	0.42
1989	4	0.01	0.04	0.04	-0.12	-0.28	-0.22	0.60
1989	5	0.01	-0.07	0.02	-0.48	-0.66	-0.13	0.69
1989	6	-0.01	-0.16	-0.05	-1.24	-2.41	-0.91	0.77
1989	7	-0.01	-0.22	-0.07	-1.21	-2.43	-2.03	0.80
1989	8	-0.01	-0.37	-0.10	-0.53	-1.14	-2.04	0.85
1989	9	-0.01	-0.61	-0.09	-0.17	-0.29	-0.57	0.05
1989	10	-0.01	-0.79	-0.09	-0.13	-0.18	-0.22	-0.19
1989	11	0.01	-0.72	-0.06	-0.10	-0.17	-0.27	-0.04
1989	12	0.00	-0.32	-0.04	-0.06	-0.13	-0.17	0.07
1991	5	0.03	3.76	0.21	-0.10	-0.37	-0.41	0.00
1991	6	0.06	3.73	0.29	-0.23	-0.42	-0.17	0.02
1991	7	0.06	3.39	0.32	-0.71	-0.96	-0.12	-0.01
1991	8	0.04	1.86	0.15	-0.80	-1.40	-0.75	-0.07
1991	9	0.03	1.07	0.02	-0.08	-0.31	-0.74	-0.12
1991	10	0.03	1.26	0.08	0.00	-0.09	-0.16	-0.28
1991	11	0.05	1.12	0.14	0.06	-0.09	-0.17	-0.06
1991	12	0.06	1.40	0.19	0.17	-0.04	-0.20	0.10
1992	1	0.06	3.55	0.38	0.47	0.41	0.28	0.23
1992	2	0.09	3.93	1.18	1.03	0.76	0.49	0.17
1992	3	0.18	5.43	1.48	1.44	1.11	0.58	0.27
1992	4	0.15	6.12	1.37	1.70	1.73	1.44	0.32
1992	5	0.20	5.05	1.66	1.90	1.69	1.06	0.53
1992	6	0.20	3.45	2.07	1.46	0.99	0.76	0.55
1992	7	0.38	5.95	2.03	1.06	0.54	0.53	0.58
1992	8	0.35	5.14	1.51	1.51	1.26	1.03	0.64
1992	9	0.26	3.68	1.05	1.51	1.51	1.22	0.69
1992	10	0.20	2.60	0.62	0.89	0.97	1.16	0.99
1992	11	0.16	2.08	0.43	0.59	0.63	0.76	1.08

The same type of effect occurs in Laguna Madre. When hypersaline conditions occur in the Laguna Madre, withdrawal of cooling water lowers the Laguna's salinity. The withdrawal by the Barney Davis Power Plant increases the flow from both north and south in the Laguna Madre, but the flow from Corpus Christi Bay is lower in salinity which reduces the Laguna Madre salinity near the power plant. This can be seen for June, July, and August of 1989 in Figures IV.3(c), IV.3(d), and IV.3(f) for JFK Causeway, Naval Air Station, and GIWW near Pita Island. The largest difference is 2.4‰ at the JFK site.

A similar but reverse effect occurs when Laguna Madre salinity is below about 30‰. In the 1992 wet period, the salinity at the same three locations would be lower if the power plant cooling water diversion were not operated, as much as 1.7‰ at the JFK site.

It is obvious that without power plant operation, Oso Bay salinity becomes independent of Laguna Madre salinity. In particular, the salinity of Oso Bay in August 1989 would probably have been much lower than the existing case indicated in Figure IV.1.

The effect of power plant operation is also felt in Baffin Bay as indicated by Figures IV.3(e) and IV.4(e). But the magnitude is generally small, less than 1‰, as can be seen from the Figures and from Table IV.4.

Table IV.5 compares the flows exchanged through three sections across the Laguna Madre near the Naval Air Station, Humble-JFK Causeway, and Pita Island areas, and Figures IV.7 and IV.8 compare the flows graphically. For the 1988-1989 existing condition, about 9000 ac-ft per day passed through the Humble-JFK/GIWW cross section toward the power plant area and about 5000 ac-ft per day flowed back to the north. From the 4000 ac-ft difference, about 2000 ac-ft per day went further south toward Baffin Bay and probably evaporated. Most of the remaining flow probably went through the power plant.

If the cooling water diversion had not been in operation in 1988-1989, about 8000 ac-ft per day would have flowed through the Humble-JFK/GIWW cross section southward and 6000 ac-ft per day would have flowed back to the north. The difference of about 2000 ac-ft per day still would have evaporated.

For the 1991-1992 simulation, similar flows pass through the Humble-JFK/GIWW cross section as for the 1988-1989 simulation, but the evaporation (net evaporation) would be close to zero. The flow to the south and flow to the north are nearly in balance. Note that the flow through the NAS-GIWW cross-section appears less than the Humble-JFK/GIWW section. This is likely the result of not including the very shallow section east of the GIWW in the NAS-GIWW cross-section.

The Pita-GIWW section in Table IV.5 represents the flow across Laguna Madre south of the Barney Davis Power Plant. These average flows depicted in Figure IV.8(a) show nearly the same flows for the existing condition and no power plant operation. This suggests that most of the water, on the average, comes from Corpus Christi Bay for power plant operation.

Table IV.5 Average daily flows (1000 ac-ft) through cross-sections.
In means flow to the south, out means flow to the north

Scenario	Simulation Year	In/Out	NAS-GIWW	Humble-JFK/GIWW	Pita-GIWW
Existing	1988-1989	In	8.36	9.30	7.63
Existing	1988-1989	Out	4.77	5.11	5.32
		Difference	3.59	4.19	2.31
No_Power	1988-1989	In	7.36	8.11	7.81
No_Power	1988-1989	Out	5.58	6.13	5.31
		Difference	1.78	1.98	2.50
Existing	1991-1992	In	7.86	8.72	6.84
Existing	1991-1992	Out	5.36	5.98	6.48
		Difference	2.50	2.74	0.36
No_Power	1991-1992	In	6.76	7.44	7.06
No_Power	1991-1992	Out	6.34	7.24	6.42
		Difference	0.42	0.20	0.62

The spatial extent of the effect of the withdrawal and discharge of seawater for cooling water from the Corpus Christi Ship Channel into Nueces Bay is very limited. Figure IV.5 shows there is virtually no effect in Corpus Christi Bay nor the bays to the north. Even in Nueces Bay, the effect of the return of cooling water is limited only to the area immediately adjacent to the discharge point. Consequently, there would not be a wide scale salinity change throughout the bay if cooling water discharge ceased.

In contrast, the spatial effect of cooling water withdrawal is extensive in the upper Laguna Madre although the magnitude of the change is not great. During periods of hypersaline conditions as in Figure IV.5, cooling water withdrawal reduces Laguna Madre salinity by 1 to 2‰ from the JFK Causeway to a point two-thirds of the way to Baffin Bay. In addition, cooling water withdrawal has the effect of increasing salinity by 1 to 2‰ throughout most of Baffin Bay except in the arms of the bay that receive freshwater inflow from San Fernando and Los Olmos creeks.

It is surprising that salinity of Baffin Bay is lower without power plant operation during extreme hypersaline conditions as in August and September of 1989, simulated to be 60‰. The northern Laguna Madre is very shallow, mostly 3 to 4 ft; the JFK Causeway area is even shallower, 2 to 3 ft. Without power plant operation, during very hypersaline conditions, there is more evaporation in the northern Laguna Madre and JFK Causeway area due to higher water temperature than with power plant operation. This causes, at least in the simulation, more flow to come into the system from the southern end of the modeled area near the Landcut. This inflowing water is of lower salinity than Baffin Bay water and mixes with it, thus causing Baffin Bay salinity to become lower by about 1‰. This result may be a combination effect of the increased flow and the boundary condition that is applied at the southern end which lets the flow come in and go out through the GIWW and lets salinity be varied with the surrounding salinities. If more area were included in the model, such as the entire Landcut area and a portion of Laguna Madre including the Port Mansfield Channel, there might be slightly different results in the salinity simulations, with Baffin Bay salinity becoming even higher. Nevertheless, the finding of increased flow due to higher evaporation is most likely to remain. (Notice the salinity level is 60‰ and at such a high level, salinity is very sensitive to flow conditions; a change of 1‰ at the 60‰ level is not the same as a change of 1‰ at the 30‰ level.)

Figure IV.6 shows the spatial differences in salinity in May 1992 for a wet period. The salinity difference due to power plant operation is felt most strongly at the discharge point in Nueces Bay where the difference is 20‰ or more. Although the effect is generally limited to Nueces Bay and Oso Bay, a small effect is exhibited in upper Corpus Christi Bay where salinity would be about 3‰ lower without power plant operation. JFK Causeway area is also influenced by power plant operation and the influence extends toward Baffin Bay although the magnitude is small, 1‰ or less. The Aransas Bay system shows very little influence from power plant operation.

To study power plant influence on the general circulation pattern in the Corpus Christi Bay area, simple environmental conditions were set up to highlight the test effect. A 1-foot amplitude (2-foot tidal range) sinusoidal tide (or sine wave) was applied at the Gulf boundary with a 24-hour tidal period. Simulation was initiated with all zero velocities and zero water surface elevations (i.e. cold start). No wind or evaporation was applied. Nueces River inflow was kept to 100 cfs, withdrawal by Barney Davis Power Plant was set to 800 cfs, and withdrawal by the Nueces Bay Power Plant was set to 600 cfs. Velocites were kept to zero at south end of GIWW and north end of GIWW in the modeled area. After modeling system dynamics for 360 hours, results were tabulated for the final 48 hours. Table IV.6 lists the peak discharges at various locations to provide relative magnitudes and Figure IV.9 show them graphically. Figure IV.10 is a sample vector plot with salinity distribution.

Figures IV.11 and IV.12 show the residual velocities, also referred to as net flows, for the existing condition with the two power plants in operation. Residual vectors were computed by summing all (regular) velocity vectors in the last 48 hours of the 360-hour simulation time. Although the 1-foot sinusoidal tide is hypothetical, it provides a clearer pattern of residual vectors than would be seen in applying a real tide. Because a real tide changes from diurnal to semi-diurnal, it is difficult to compute residual vectors.

Table IV.6 Peak discharges (1000 cfs) generated by a 1-foot sinusoidal tide

Location	Discharge	%
Entrance Channel	201.8	100.0
C.C.S. Channel at B&R	125.5	62.2
C.C.S. Channel near Ingleside	98.7	48.9
Nueces Causeway	10.9	5.4
Lydia Ann Channel	61.3	30.4
Aransas Channel	11.9	5.9
Copano Causeway	28.3	14.0
Oso Pier	2.8	1.4
GIWW at LM/CCBay	6.7	3.3
Pass near NAS	5.4	2.7
GIWW at JFK Causeway	7.1	3.5
Humble Channel	6.2	3.1
Pita-LM x-section	11.1	5.5

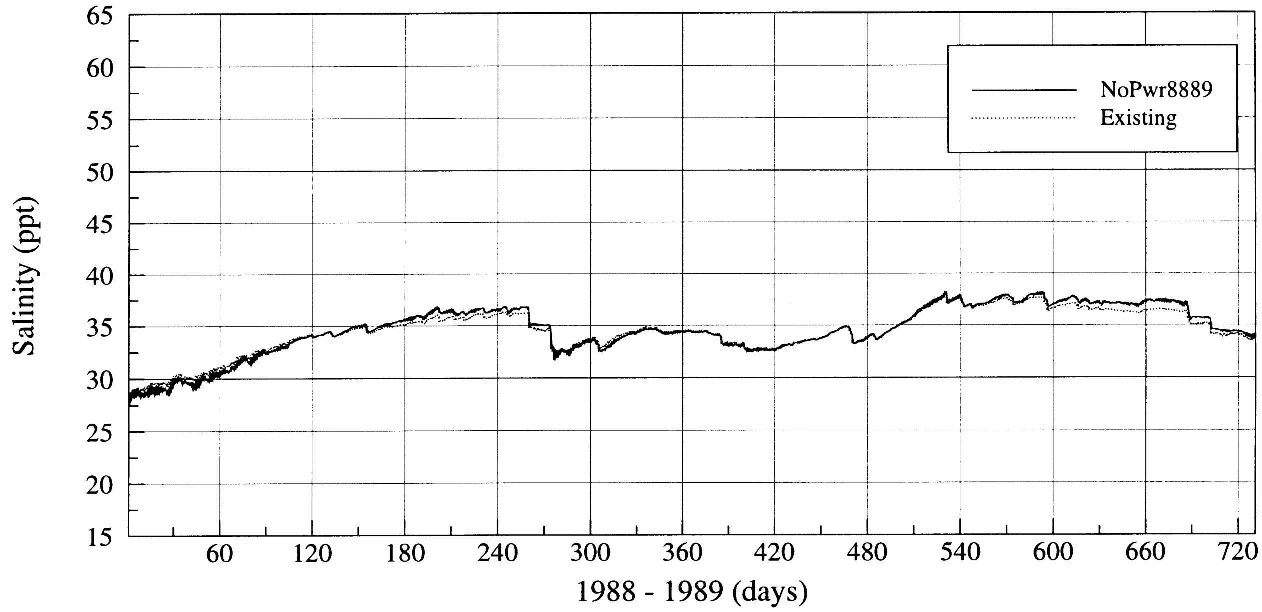
The residual vectors clearly show that the net movement of water is by power plant operation. Figure IV.11 shows that the Corpus Christi Ship Channel carries the flow and delivers it to the harbor intake of the Nueces Bay Power Plant. The water returns to Corpus Christi Bay mainly through the deep channel under the Nueces Causeway and circulates to the north side of the ship channel. Another portion of water carried by the ship channel turns to south near the entrance to the harbor and moves toward Oso Bay and Laguna Madre, and then into Laguna Madre through the opening near the Naval Air Station and the GIWW. Some of the water that leaves the ship channel near the harbor travels south to the middle of the bay and rejoins the channel at the point where the ship channel opens to Corpus Christi Bay near Ingleside Point. Similar recirculation is shown on the north side of the channel. The ship channel operates as though it were a hose shooting water through the mid section of the bay at the harbor area and creating two recirculating gyres, one on the north side of the channel circulating clockwise and the other on the south side of the channel circulating counterclockwise.

Residual vectors in the channels along the south side of the Corpus Christi Ship Channel near Mustang Point, Pelican Island, and the GIWW near Ingleside appear very small or inflow and outflow are nearly in balance. However, the north side of the ship channel in the same area shows strong movements; net flows in Redfish Bay and GIWW are drawn to the ship channel.

Figure IV.12 shows the residual vectors in Laguna Madre and Oso Bay. This figure indicates that the major portion of the water comes from Corpus Christi Bay through both the GIWW and Humble Channel, and moves toward the intake site of the power plant.

Figure IV.13 illustrates the flow traces which were created by making the residual vectors move and keeping track of the movements. The figure displays clearly the two loops in Corpus Christi Bay around the ship channel and the loops created by the power plant operation.

(a) Mid Nueces Bay



(b) Mid Corpus Christi Bay

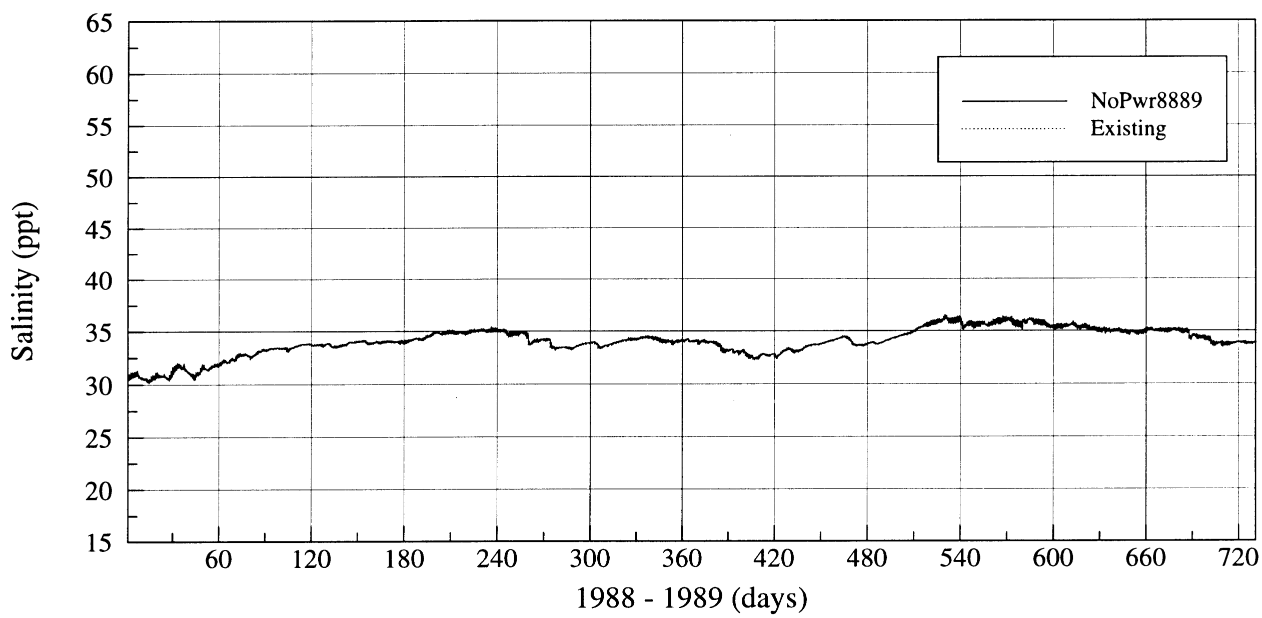
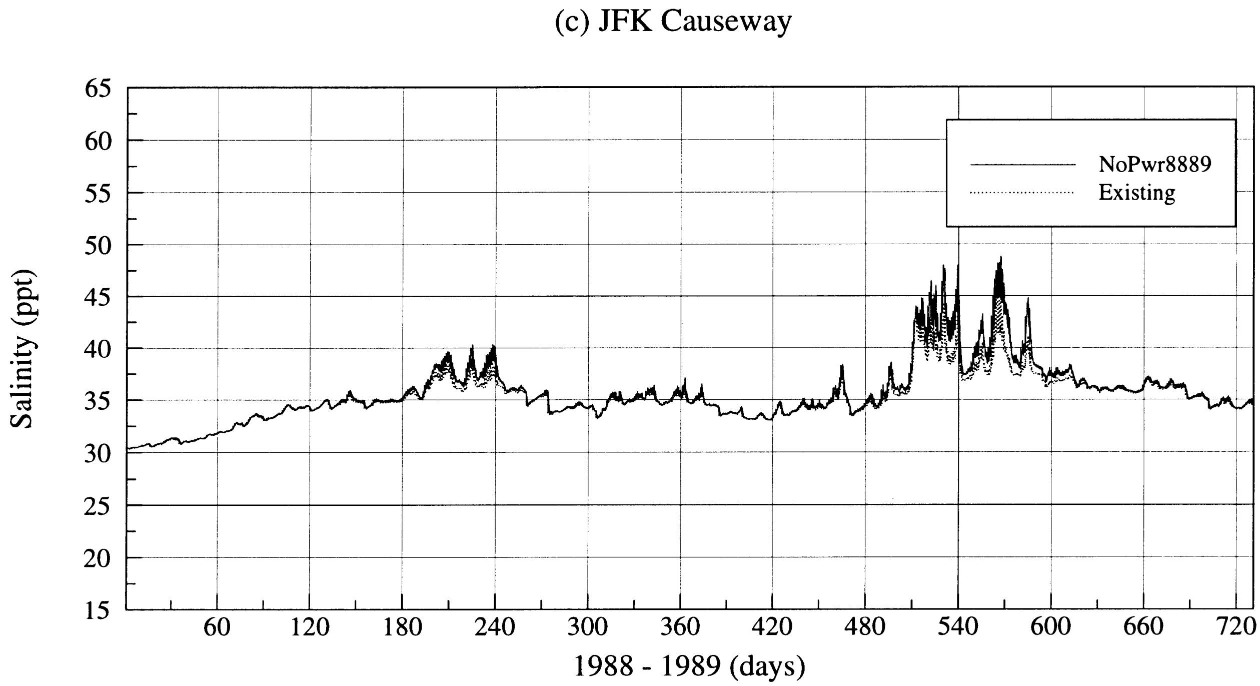


Figure IV.3 Simulated salinities in 1988-1989 for the existing condition and 'no power plant operation'



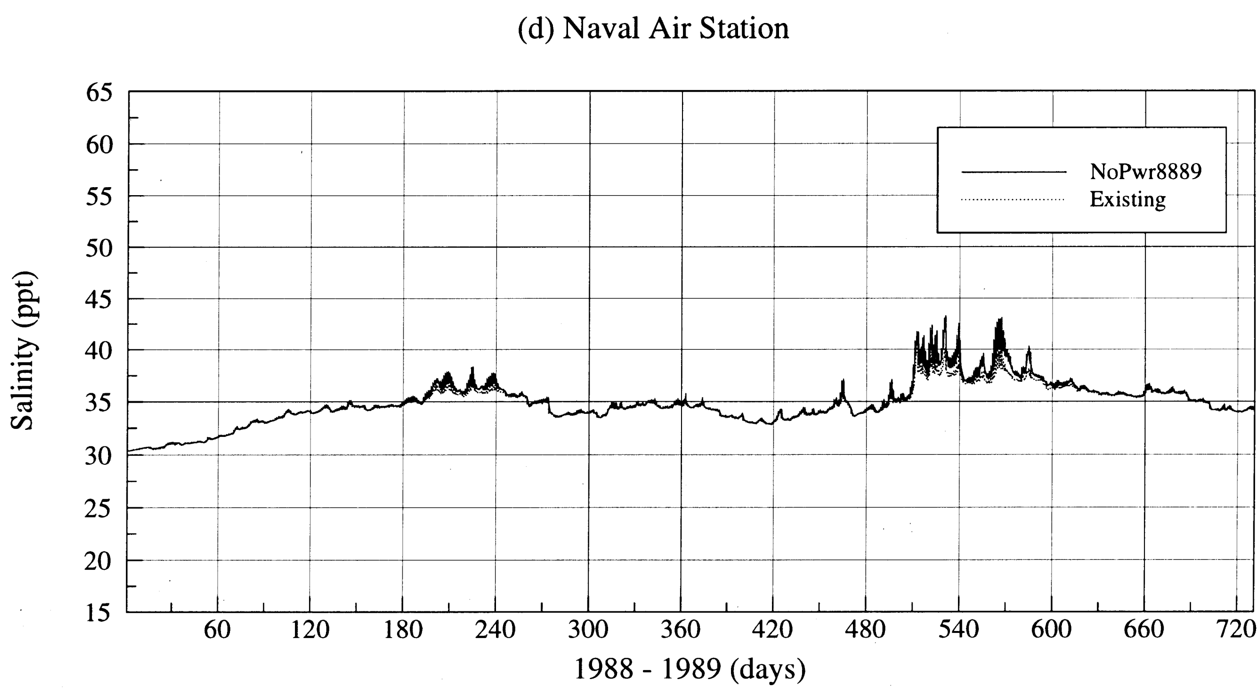
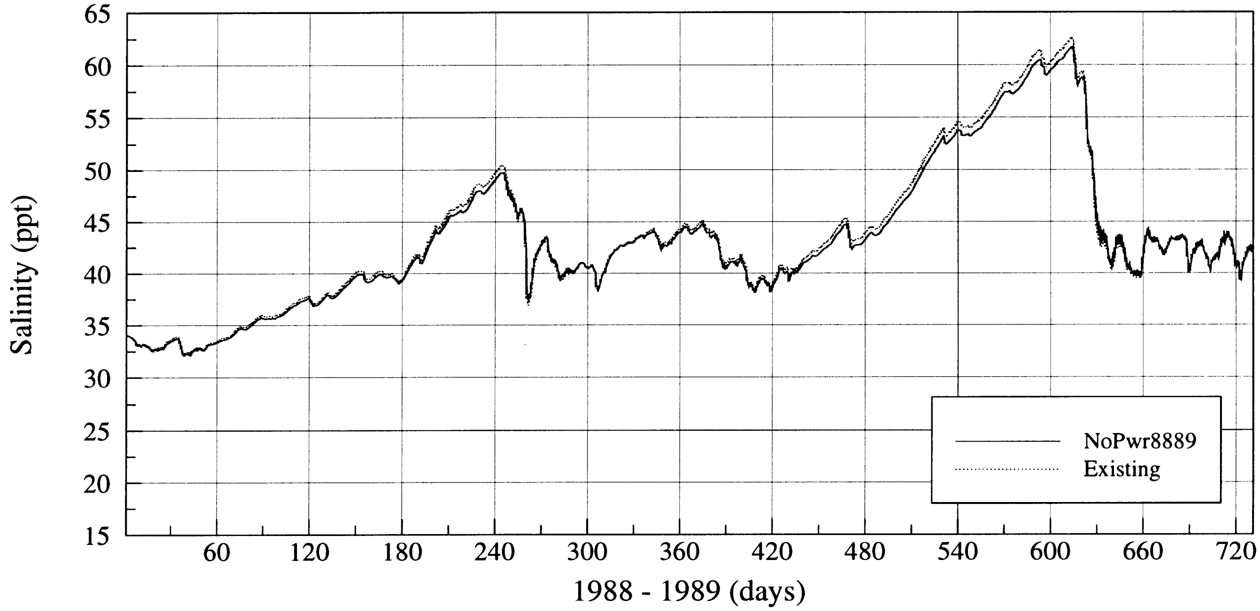


Figure IV.3 Simulated salinities in 1988-1989 for the existing condition and 'no power plant operation'

(e) Baffin Bay



(f) GIWW near Pita Island

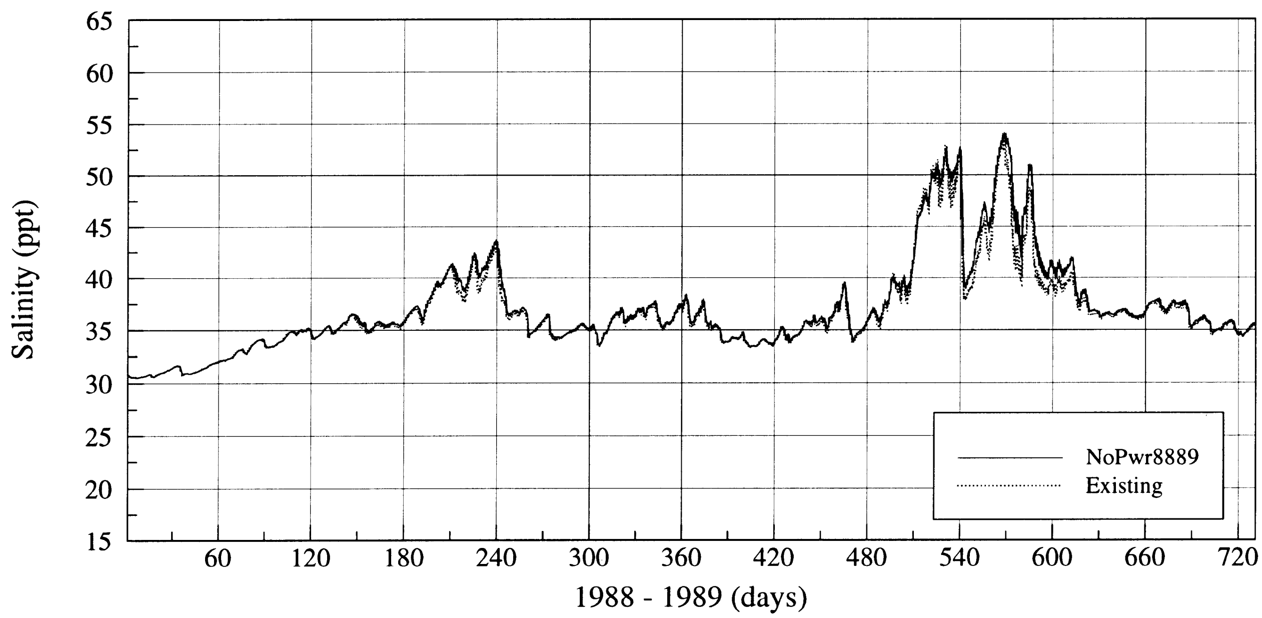
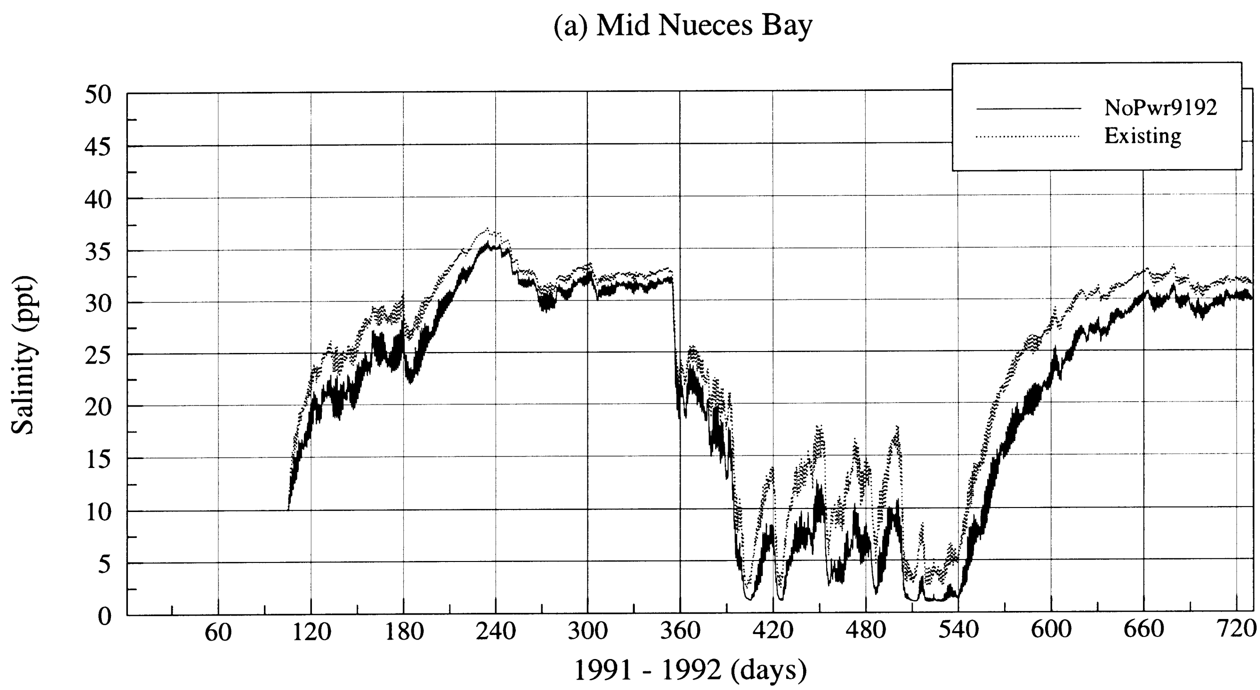


Figure IV.3 Simulated salinities in 1988-1989 for the existing condition and 'no power plant operation'



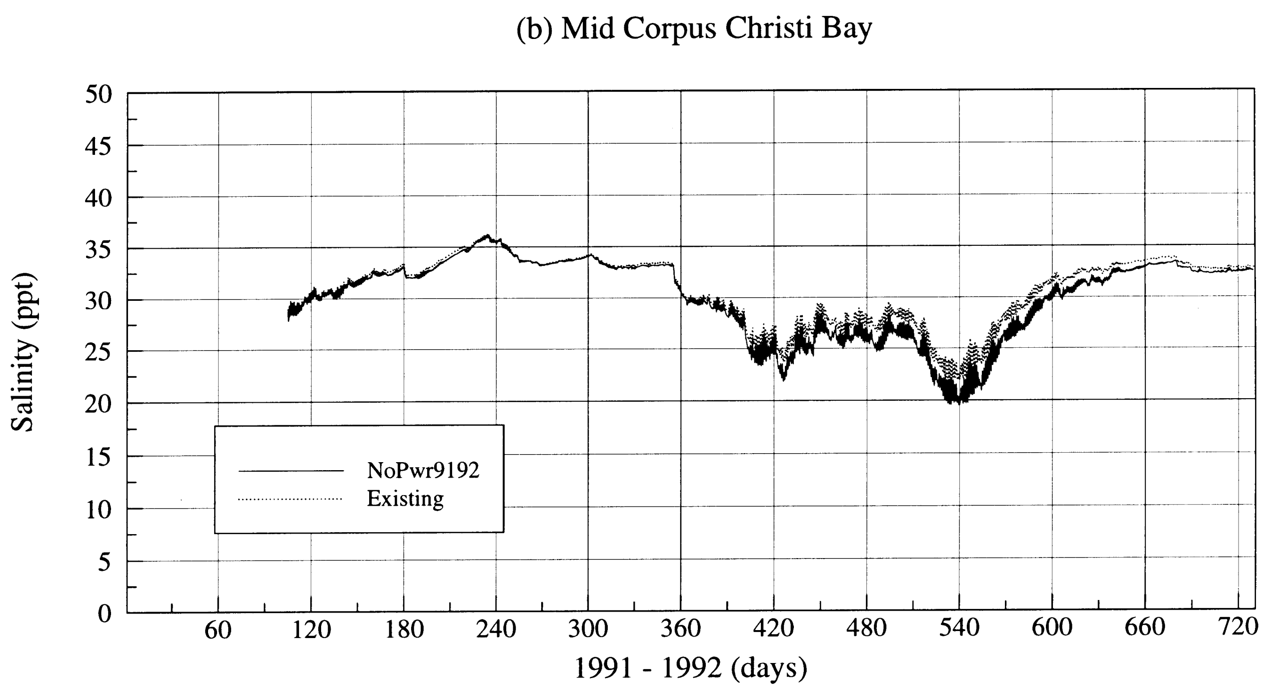
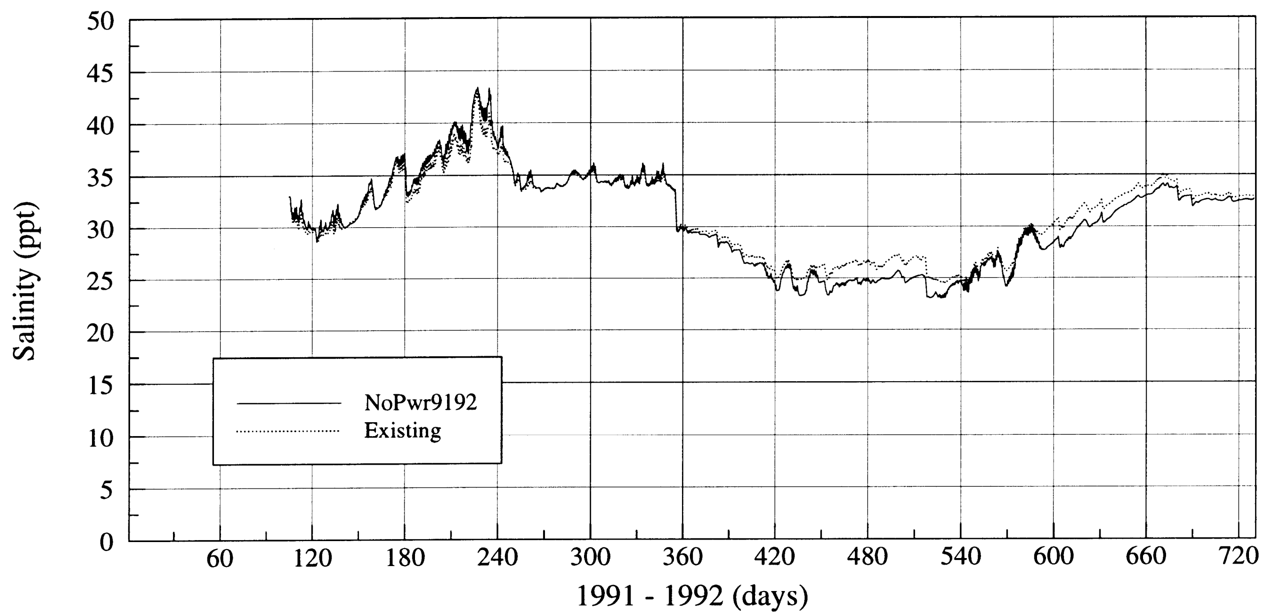


Figure IV.4 Simulated salinities in 1991-1992 for the existing condition and 'no power plant operation'

(c) JFK Causeway



(d) Naval Air Station

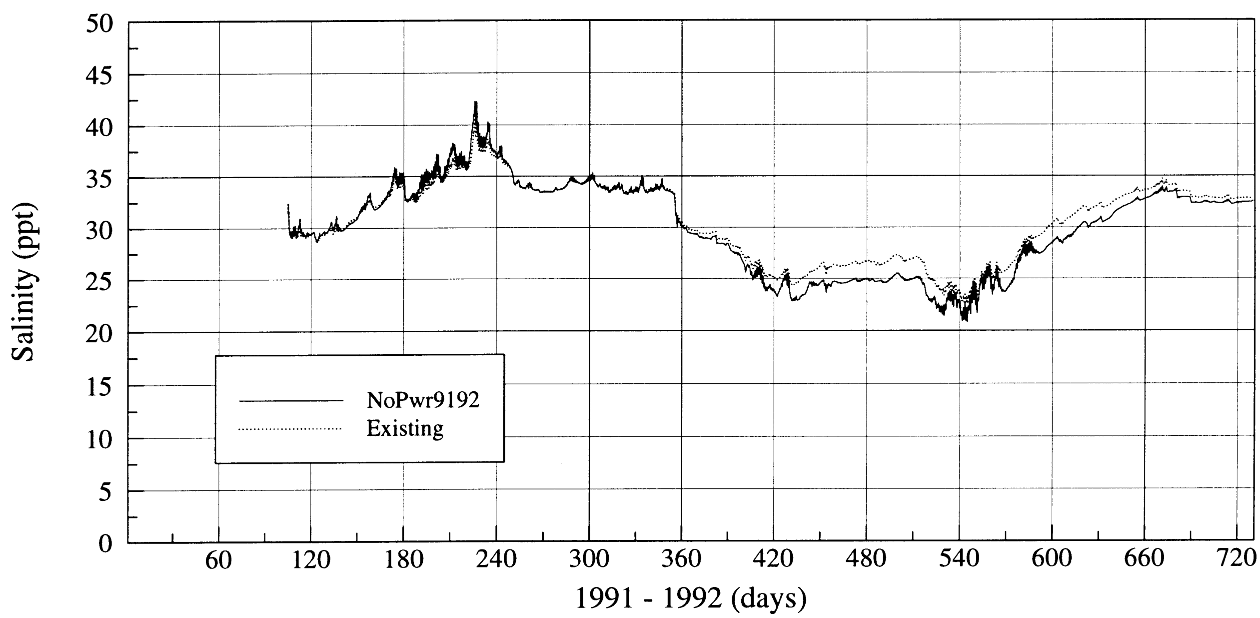
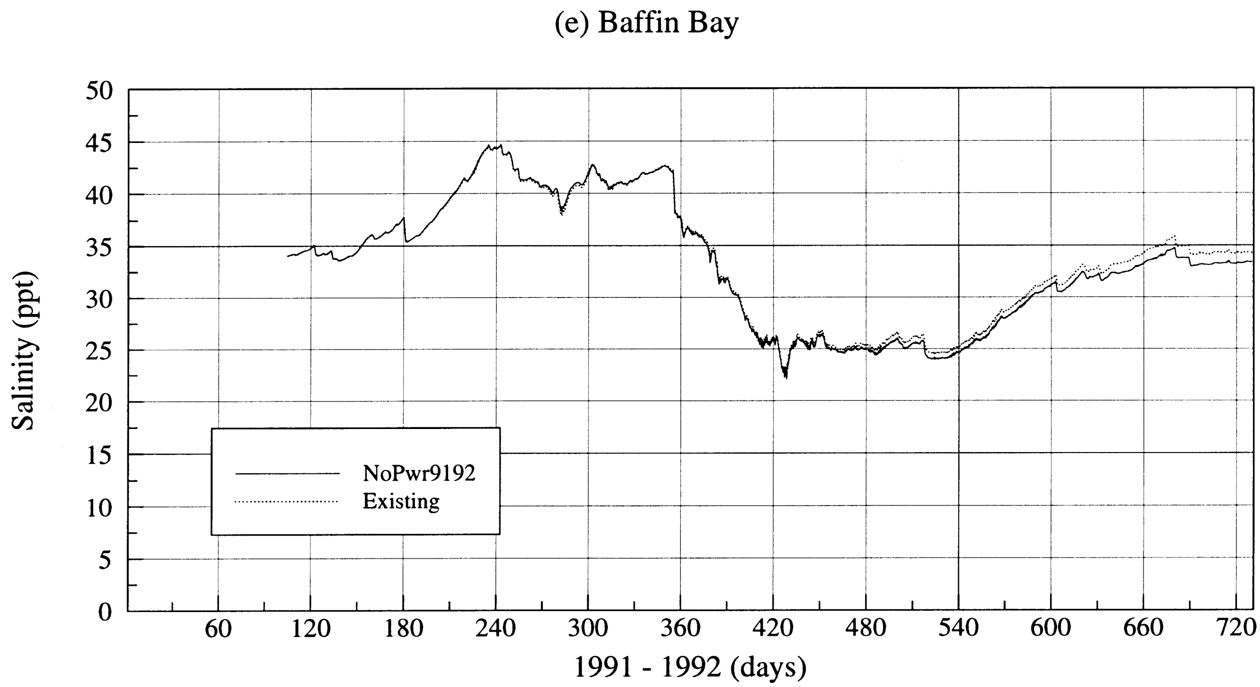


Figure IV.4 Simulated salinities in 1991-1992 for the existing condition and 'no power plant operation'



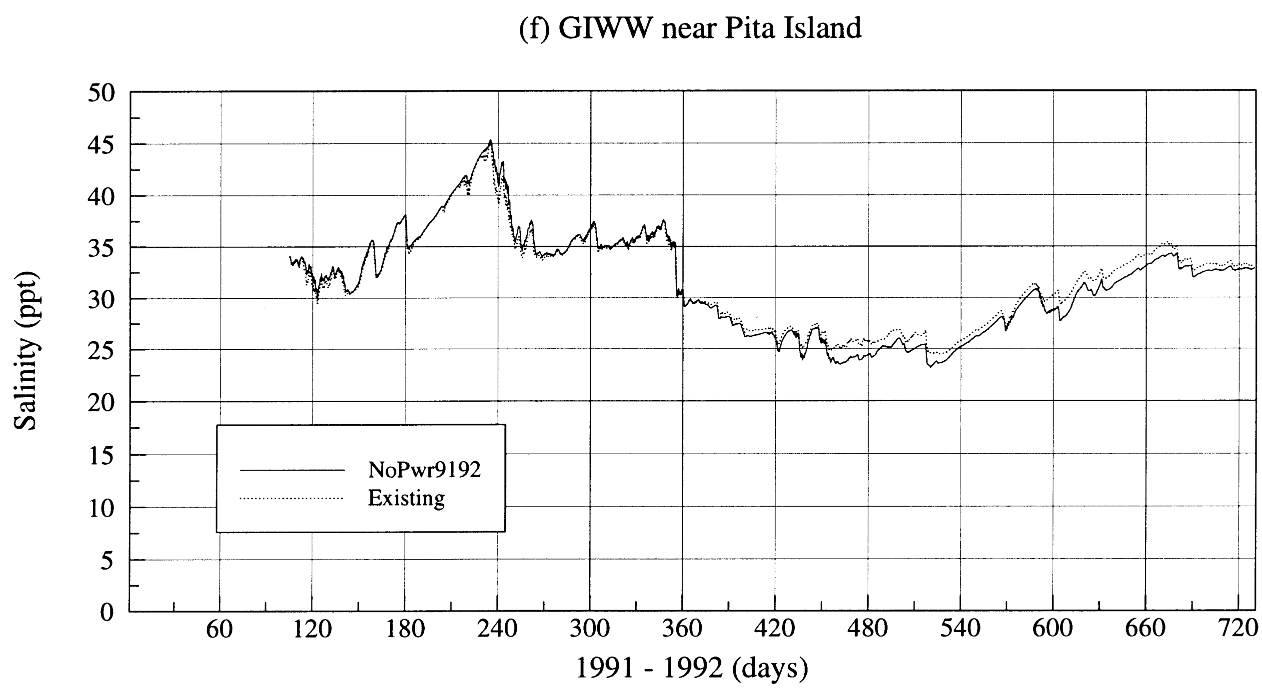


Figure IV.4 Simulated salinities in 1991-1992 for the existing condition and 'no power plant operation'

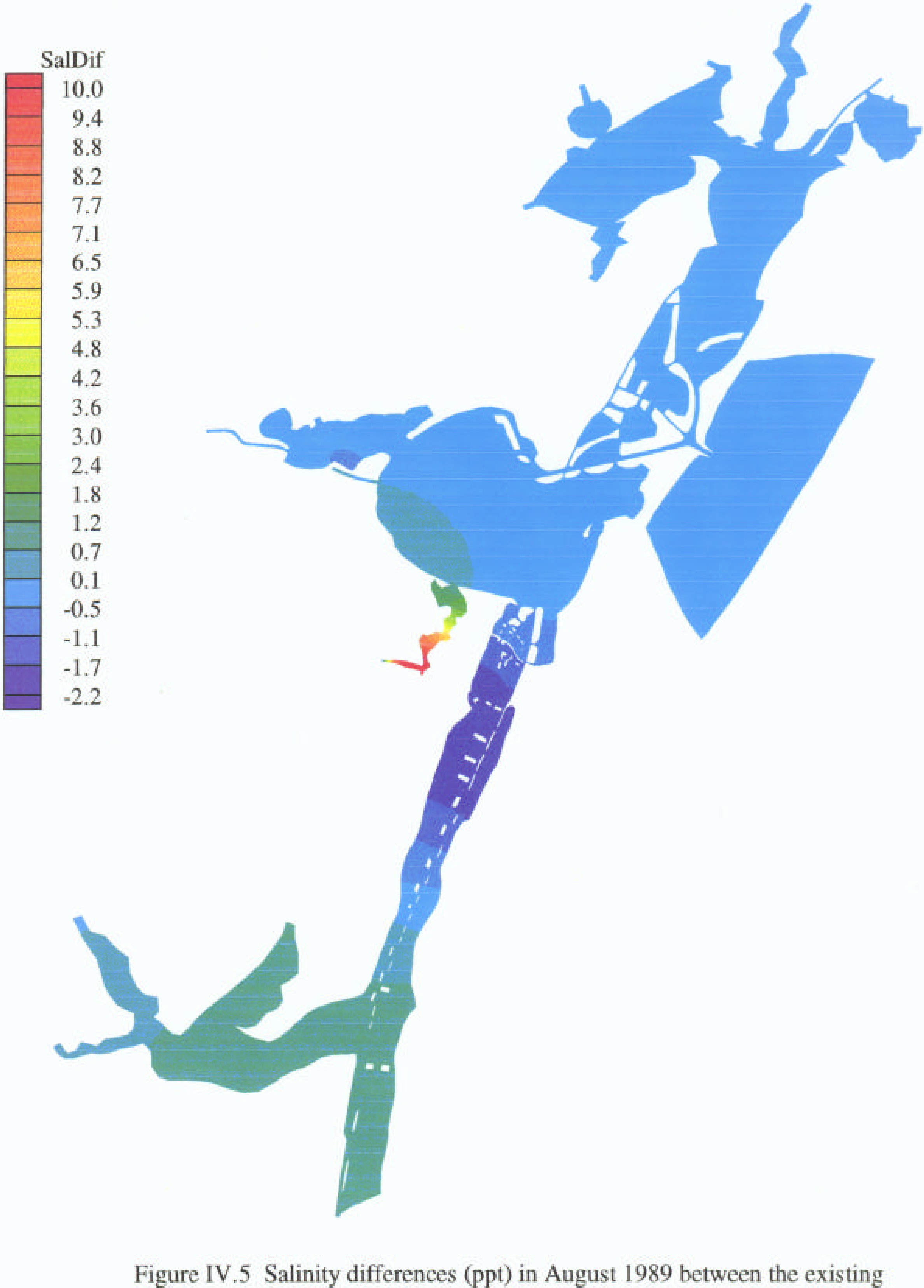


Figure IV.5 Salinity differences (ppt) in August 1989 between the existing and 'no power plant operation' conditions

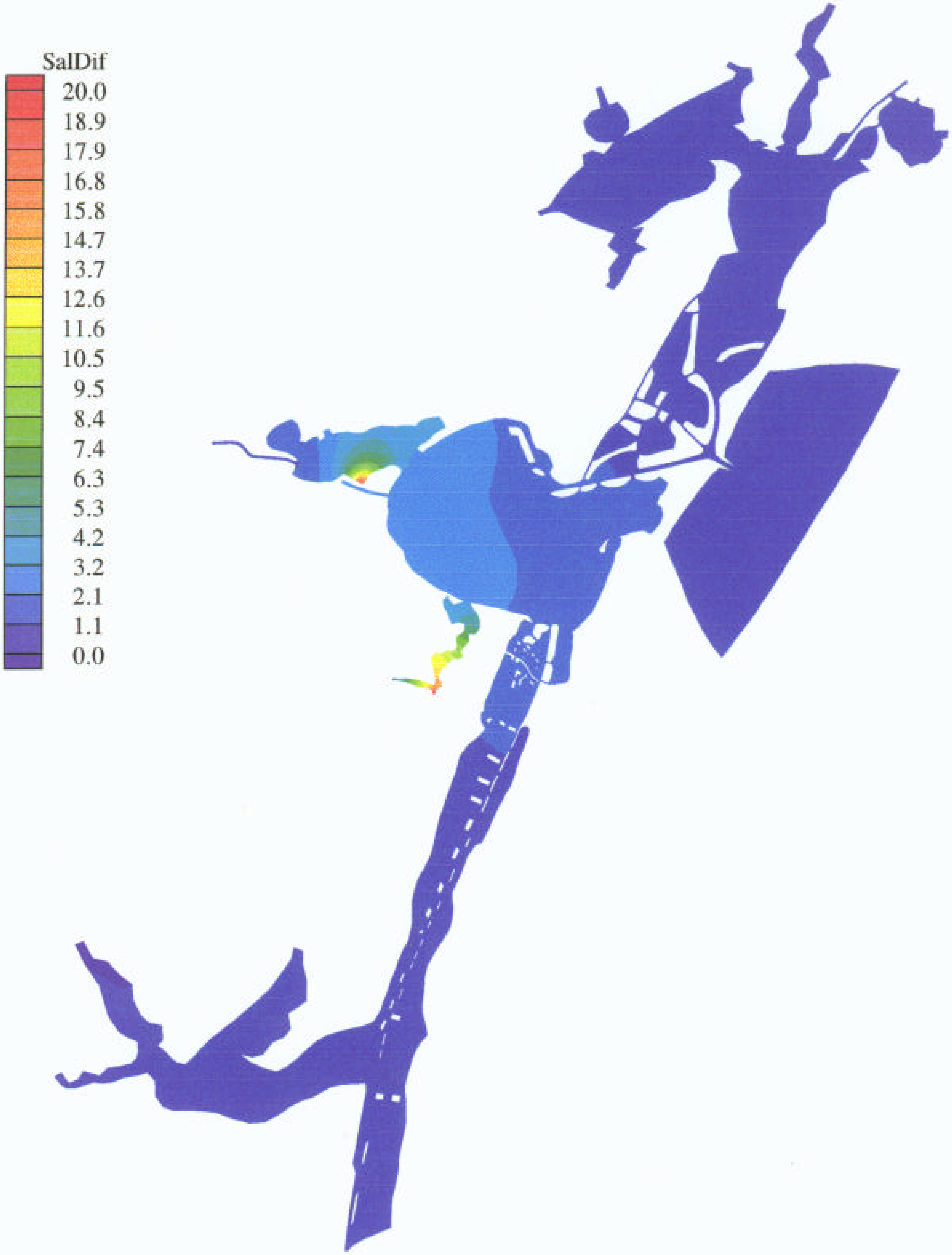
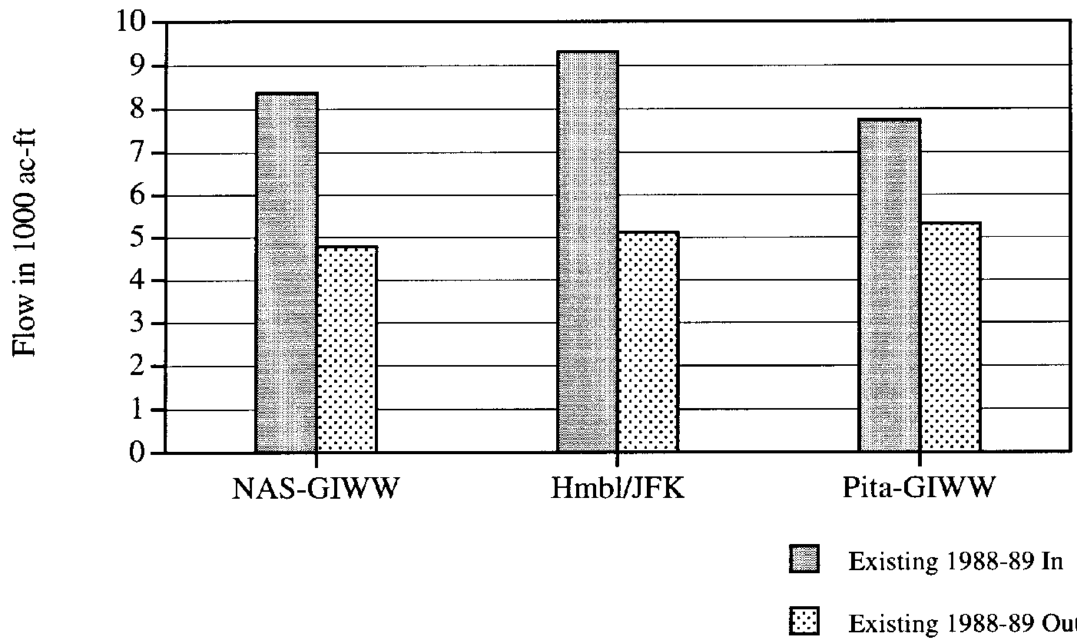


Figure IV.6 Salinity differences (ppt) in May 1992 between the existing and 'no power plant operation' conditions

(a) Inflows and outflows with power plant operation



(b) Inflows and outflows without power plant operation

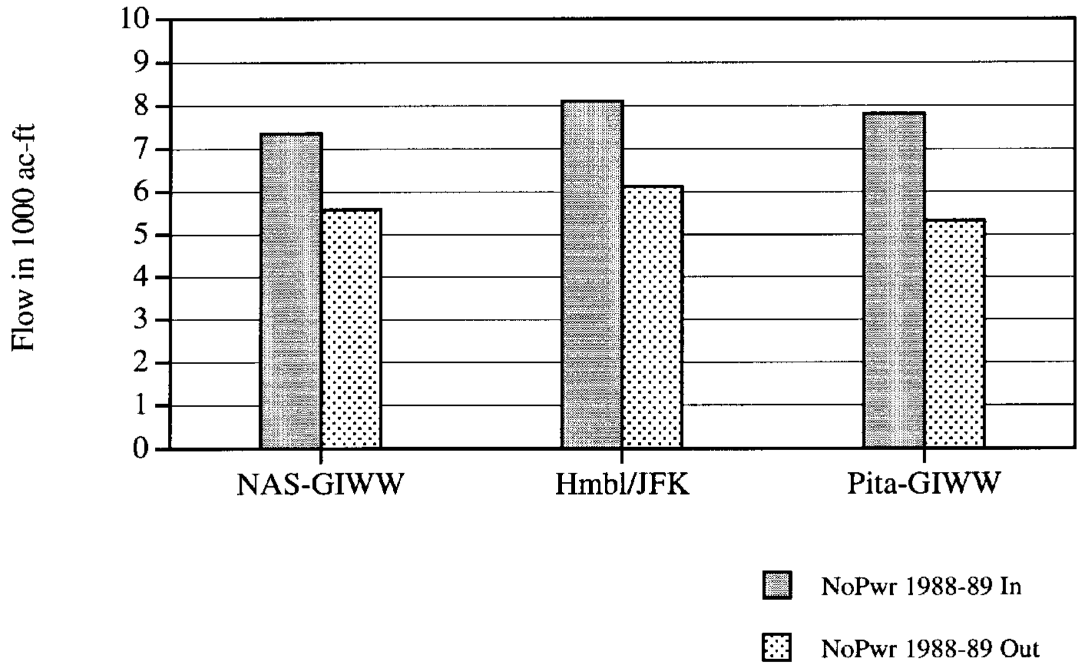
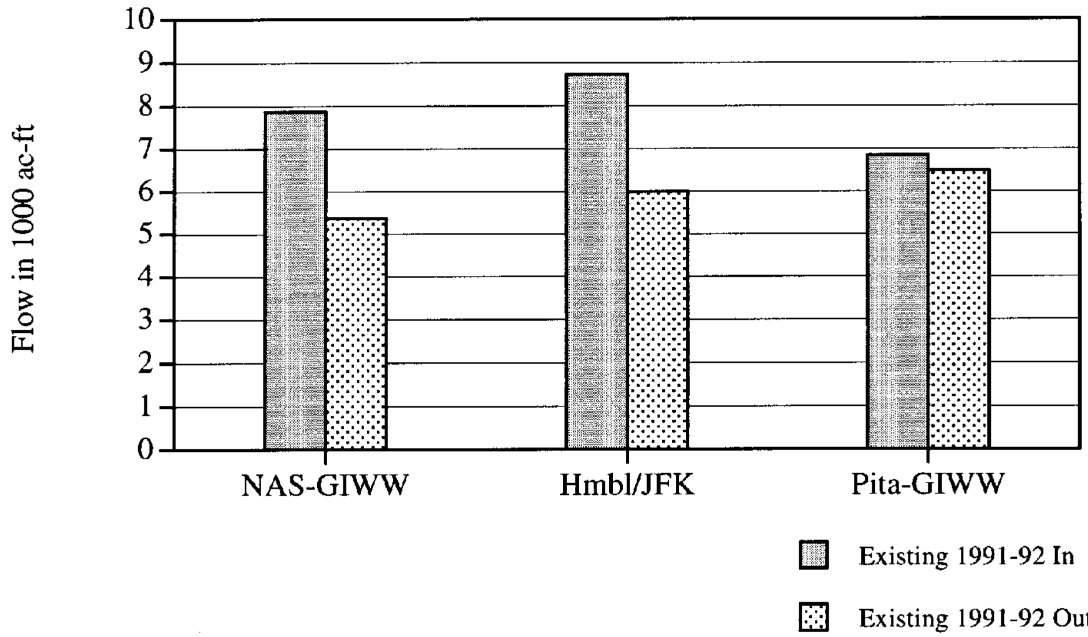


Figure IV.7 Average daily inflows and outflows for 1988-1989 at JFK Causeway area with and without power plant operation

(a) Inflows and outflows with power plant operation



(b) Inflows and outflows without power plant operation

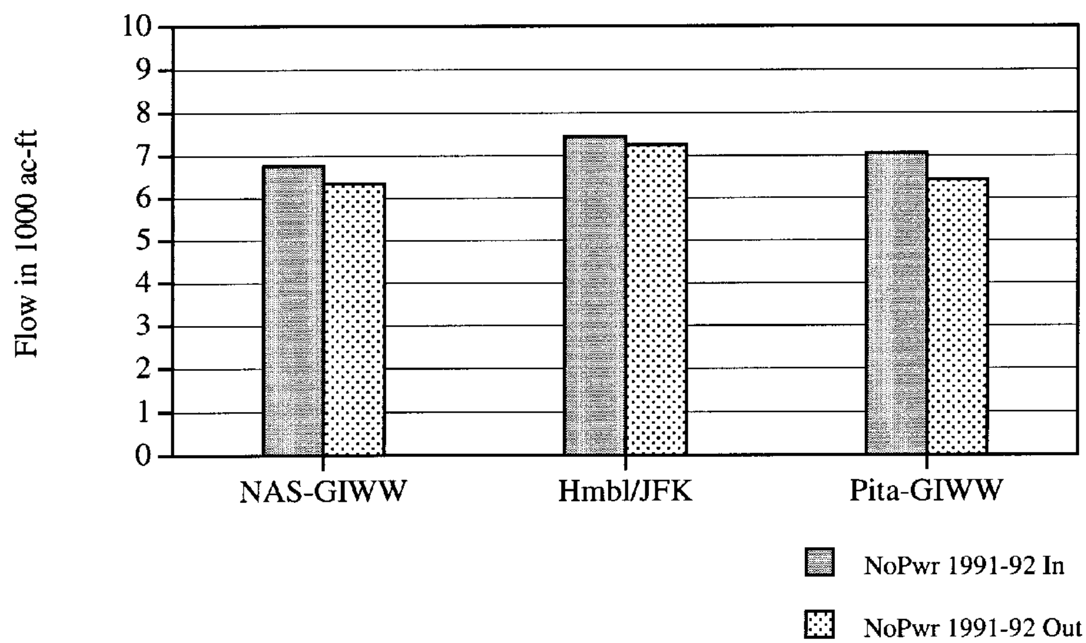
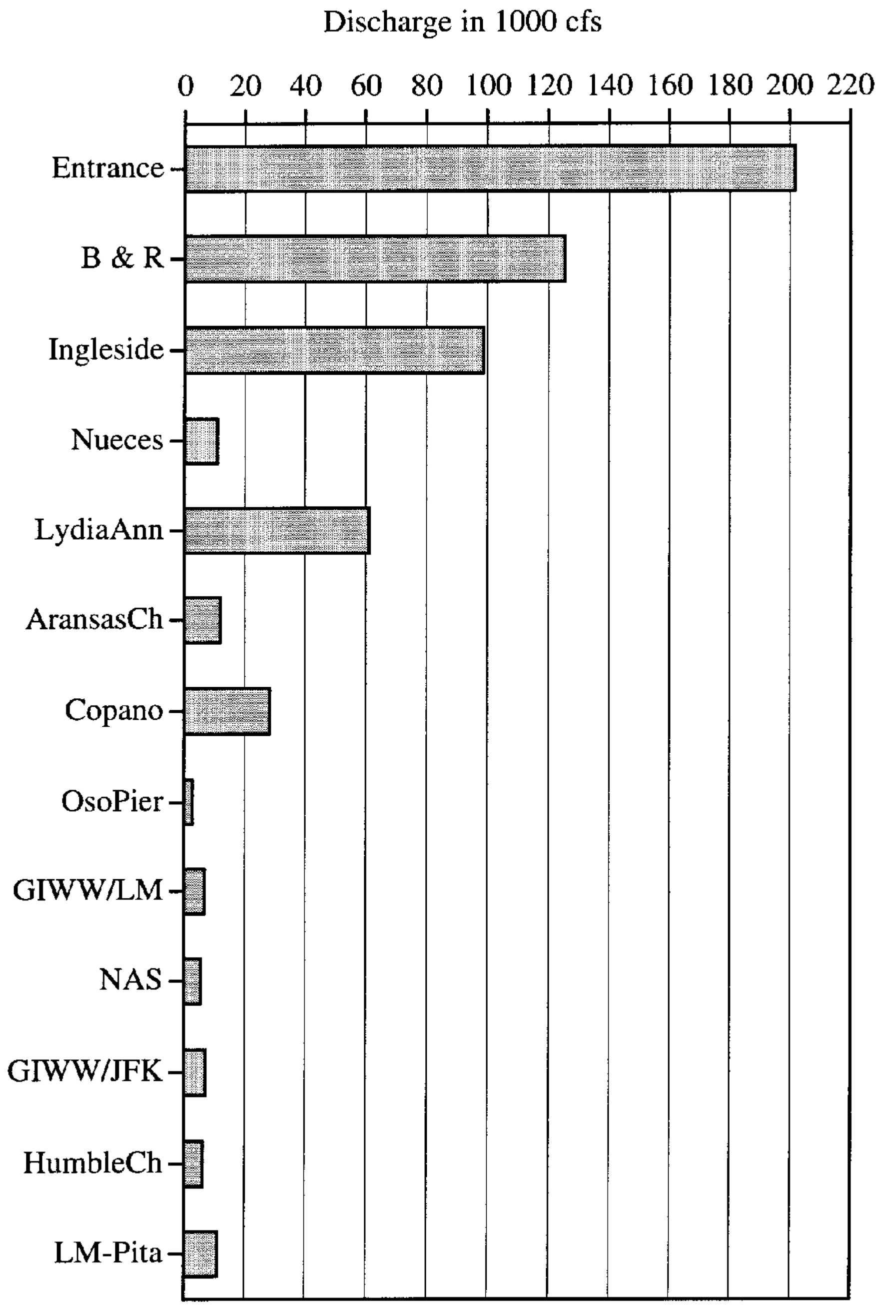


Figure IV.8 Average daily inflows and outflows for 1991-1992 at JFK Causeway area with and without power plant operation

Figure IV.9 Peak discharges generated by a 1-foot sinusoidal tide



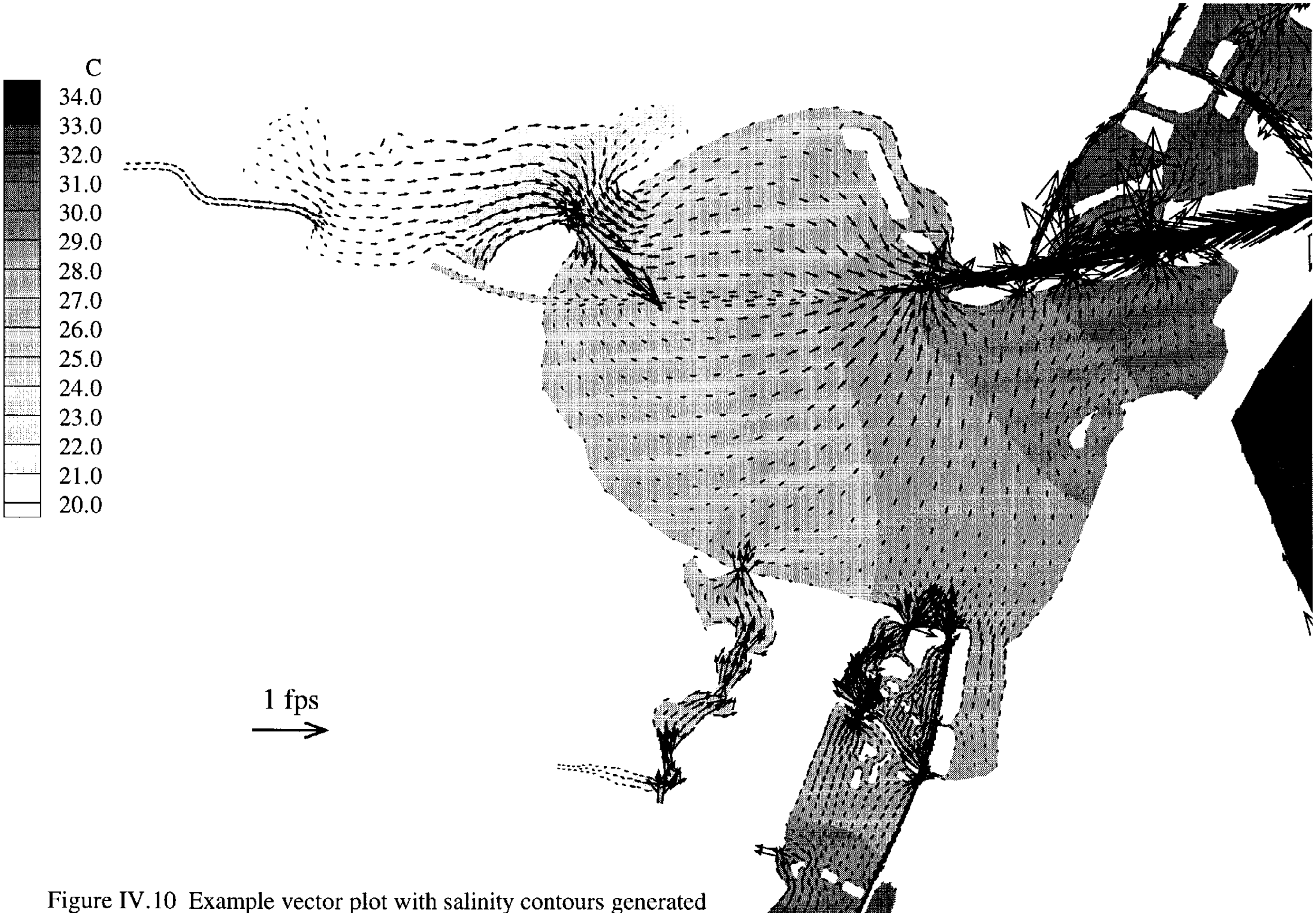


Figure IV.10 Example vector plot with salinity contours generated by a 1-foot sinusoidal tide; C at 20 means 20 ppt or less

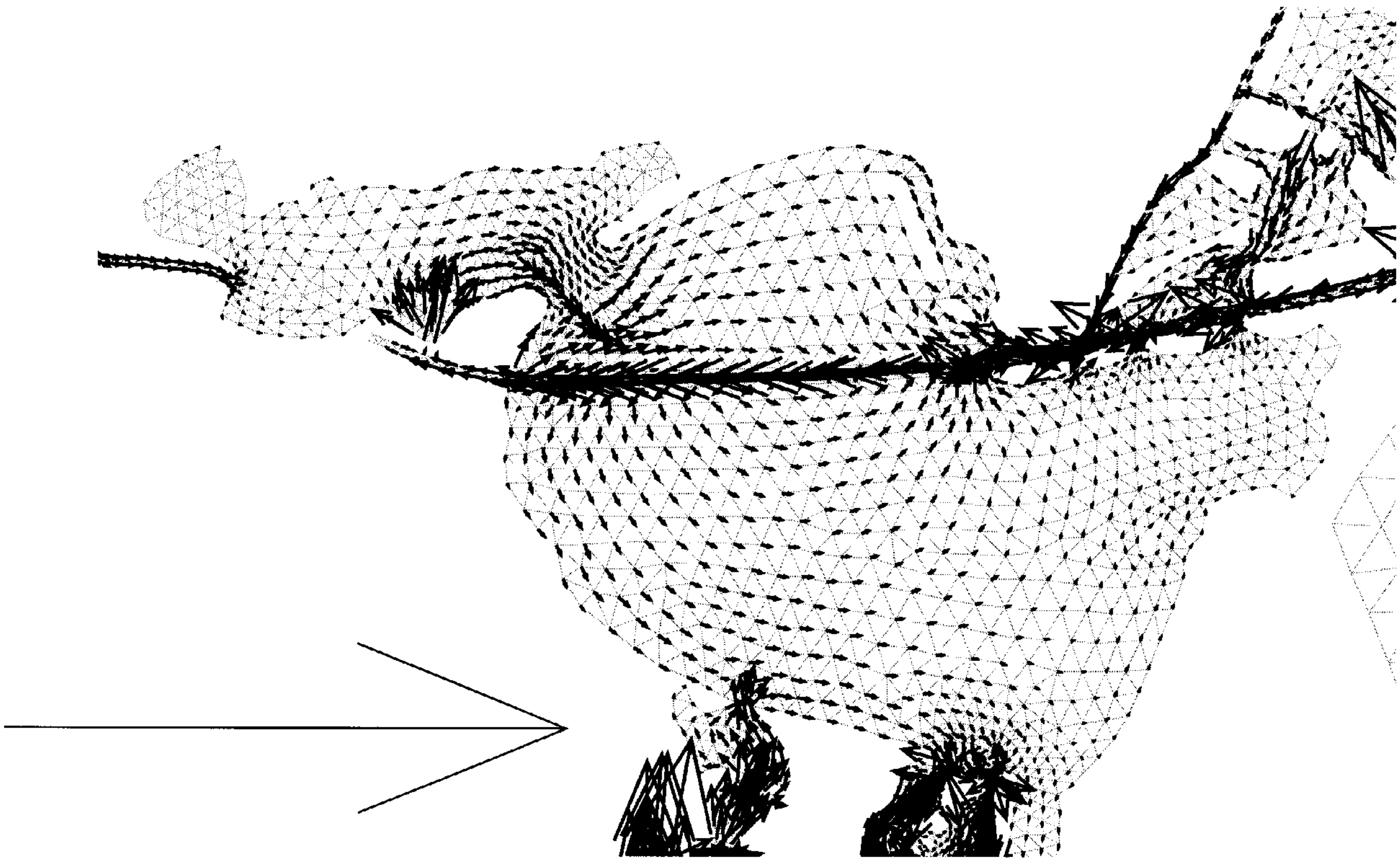


Figure IV.11 Residual vectors in Corpus Christi Bay and surrounding area for the existing condition; the length of the reference vector represents 1 fps

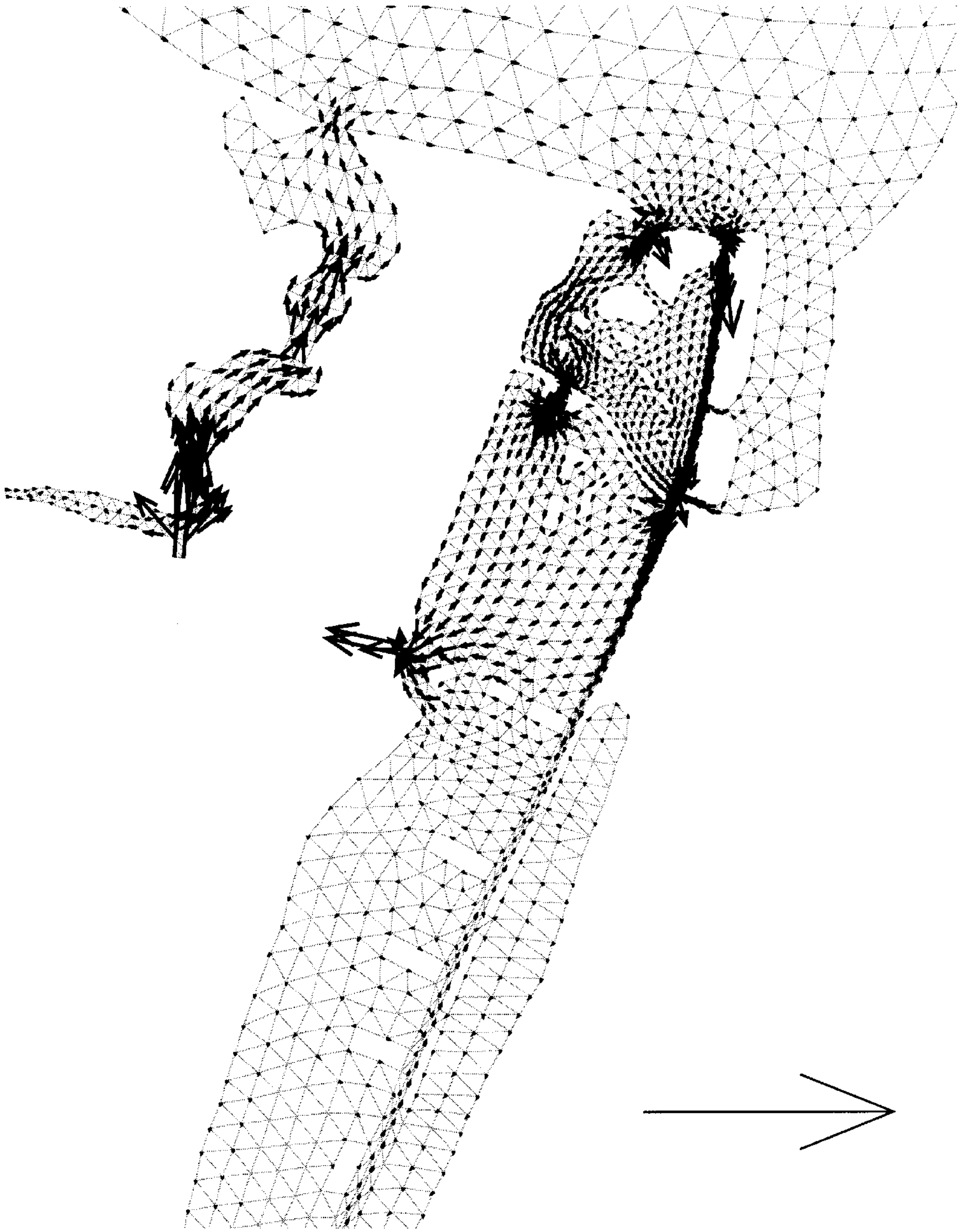


Figure IV.12 Residual vectors in Laguna Madre and Oso Bay for the existing condition; the reference vector represents 1 fps

Figure IV.13 Flow traces for the existing condition; flow traces were created by making the residual vectors move and kept the tracks of the movements

Scenario 2: Effect of River Diversions

The purpose of Scenario 2 is to examine the effect of Nueces River diversions and return flows on areas of Corpus Christi and Nueces bays. This effect is simulated by increasing the river inflows during the simulations by the amount of the diversion. A word of caution is necessary here. Most of water diverted during the dry period was probably water released from Lake Corpus Christi that was specifically allocated for municipal and industrial uses and withdrawn at Calallen. Use of this amount of water in the simulation is only to provide an amount of water for the purposes of the analysis. It does not imply that removal of the reservoir or cessation of upstream water uses would result in this quantity of water being restored to Nueces River flow in any specific month. Since the reservoir impounds water during periods of high river flow, the release of water during dry periods is the result of capture that may have occurred months or years earlier. Before upstream diversion began and the reservoir was constructed, there may have been times of little or no river flow during very dry periods.

The inflows for the no-diversion scenario in Table IV.7 were computed by adding the diversions taken from the Nueces River below the Mathis gage for the City of Corpus Christi (annual average of 98,788 ac-ft or 78.9% of the gaged flow over five-year period of 1988 through 1992), San Patricio M.W.D.(10,572 ac-ft or 8.5%), Koch Refinery (5,993 ac-ft or 4.8%), Hoechst Celanese (5,687 ac-ft or 4.5%), and Nueces County WCID #3 (4,144 ac-ft or 3.3%), and not adding the return flows to Nueces Bay and Corpus Christi Bay. A yearly average return flow over the same period was calculated to be 37,937 ac-ft. Several diversions were taken from reservoirs above the Mathis gage. From Choke Canyon Reservoir, water was diverted for the Choke Canyon W.S. (122 ac-ft); from Lake Corpus Christi, water was diverted for the City of Beeville (1,988 ac-ft), City of Mathis (682 ac-ft), and Alice Water Authority (2,828 ac-ft). These direct diversions were not added to Nueces inflow because the gaged flow at Mathis was used as the basis of the calculation. The diversions above the Mathis gage represent only a very small portion (4.3%) of the diversions taken from the reservoirs and river. The diversions below the Mathis gage average 125,184 ac-ft for the 1988-1992 period. Since diversions remove water from the system while return flows return water to the system, the net decrease in inflow with diversions is about 87,000 ac-ft (125,184 ac-ft - 37,937 ac-ft =87,247 ac-ft). Thus, the no-diversion simulation increases inflow by about 87,000 ac-ft per year.

The volume of diversions in relation to the inflows can be seen in Table IV.7, which lists the monthly inflows with and without diversions from 1987 to 1992. The amount of diversion is fairly constant ranging from 4,000 ac-ft to 10,000 ac-ft per month. This volume is not significant during wet periods but is very significant during dry periods like 1988 and 1989. For some months the diversion is as much as eight times the river inflow.

Table IV.8 lists the average salinity differences compared to the existing condition for the two simulations, 1988-1989 and 1991-1992. Figures IV.14(a) through IV.14(f) for 1988-1989 and Figures IV.15(a) through IV.15(f) for 1991-1992 are the time histories of scenario salinities at selected locations compared with the existing condition. Figure IV.16 is a plot of salinity differences for August 1989 and Figure IV.17 for May 1992.

As can be seen from Table IV.8, Figure IV.14, and Figure IV.15, the effect of freshwater diversion is limited only to Nueces Bay during both wet and dry periods. As expected, the influence is stronger during the dry period than the wet period, with salinities as much as 2.2‰ lower in the dry period in mid Nueces Bay. The influence of the diversion on Corpus Christi Bay is very small, 0.2‰ in the dry period. The volume of water, roughly 8000 ac-ft per month, is not large enough to make a difference in Corpus Christi Bay but is large enough to influence Nueces Bay where the salinity was consistently 1 to 2‰ lower at mid bay.

Over the entire Corpus Christi Bay National Estuary area, the effect of freshwater diversion from the Nueces River is limited to Nueces Bay. Figure IV.16 shows that there is virtually no salinity difference in any of the bays except Nueces Bay during August 1989. In Nueces Bay, the effect of the diversion can be seen throughout most of the length of the bay and ranges from no change near the mouth of Nueces Bay to 8‰ lower at the upper end of the bay near the entrance of the river.

The ‘no diversion’ scenario did not address the question of not returning the return flows to Corpus Christi Bay or any other locations. That would require modeling more detailed than this analysis of the system-wide responses. (The current model does not discharge individual return flows where they are actually returned. Instead, they are lumped and included in the net inflow calculation.)

Figure IV.17 depicts the salinity differences in May 1992 during a wet period between the existing and no diversion scenario. It shows overall differences are very small, 0.6‰ or less, and most of the effect is in Nueces Bay and Corpus Christi Bay.

Table IV.7 Comparison of inflows (ac-ft) with and without diversions

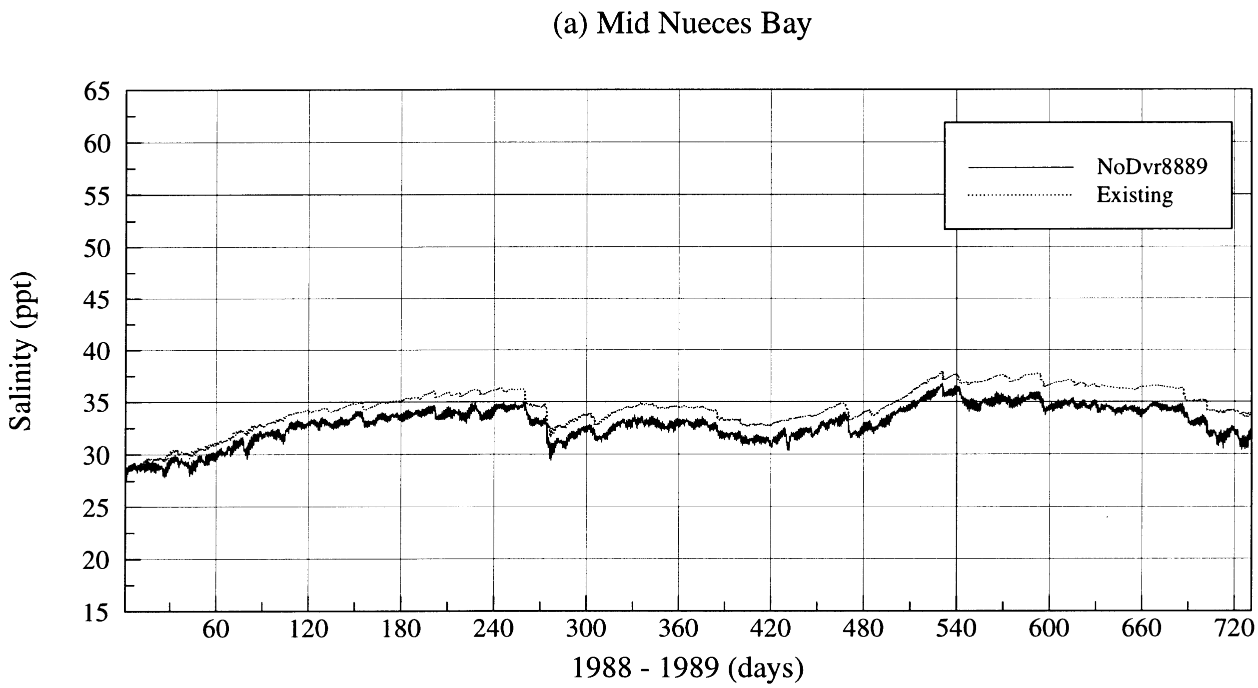
Year	Month	No-Diversion	With-Diversion	Difference
1987	1	21317	17659	3658
1987	2	29838	26338	3500
1987	3	26344	21601	4743
1987	4	8998	2908	6090
1987	5	18683	12080	6603
1987	6	505304	500504	4800
1987	7	120648	113983	6665
1987	8	18084	10241	7843
1987	9	14096	8156	5940
1987	10	10880	5672	5208
1987	11	12279	7809	4470
1987	12	10082	4967	5115
	yearly	796553	731918	64635
1988	1	8588	2977	5611
1988	2	7980	3108	4872
1988	3	8917	2500	6417
1988	4	9102	1724	7378
1988	5	10161	2504	7657
1988	6	11275	2545	8730
1988	7	12879	2959	9920
1988	8	12222	2643	9579
1988	9	14954	8624	6330
1988	10	11335	4639	6696
1988	11	8698	1978	6720
1988	12	8610	2007	6603
	yearly	124721	38208	86513
1989	1	8738	2941	5797
1989	2	7887	1727	6160
1989	3	9136	1839	7297
1989	4	9299	1190	8109
1989	5	10638	1024	9614
1989	6	10300	1266	9034
1989	7	12686	3231	9455
1989	8	12706	2414	10292
1989	9	12558	2898	9660
1989	10	11304	1671	9633
1989	11	9952	2335	7617
1989	12	10259	3439	6820
	yearly	125463	25975	99488
1990	1	9216	2214	7002
1990	2	10453	4797	5656
1990	3	17130	10992	6138
1990	4	16507	10897	5610
1990	5	39582	32514	7068
1990	6	21792	11101	10691
1990	7	98201	88830	9371

(Table IV.7 continued)

1990	8	94240	84320	9920
1990	9	28023	19743	8280
1990	10	19198	11076	8122
1990	11	8836	1786	7050
1990	12	9352	2532	6820
	yearly	372530	280802	91728
1991	1	7927	2099	5828
1991	2	8289	3417	4872
1991	3	15691	8747	6944
1991	4	24031	16441	7590
1991	5	38000	31397	6603
1991	6	31967	24617	7350
1991	7	11872	4184	7688
1991	8	12144	2658	9486
1991	9	24372	17832	6540
1991	10	20076	12885	7191
1991	11	11692	5555	6137
1991	12	31979	26771	5208
	yearly	238040	156603	81437
1992	1	83431	79153	4278
1992	2	205894	201834	4060
1992	3	92999	87729	5270
1992	4	127527	121947	5580
1992	5	211973	206238	5735
1992	6	209713	203173	6540
1992	7	15372	5607	9765
1992	8	19663	10921	8742
1992	9	17849	9659	8190
1992	10	17314	9874	7440
1992	11	14262	8232	6030
1992	12	10324	4291	6033
	yearly	1026321	948658	77663

Table IV.8 Salinity differences between the existing condition and no river diversion. The difference is positive if the existing salinity is higher than the simulated salinity

Year	Month	Aransas Bay	Nueces Bay	Corpus Bay	Naval Air Sta.	GIWW JFK	GIWW Pita	Baffin Bay
1988	1	0.00	0.52	0.01	0.00	-0.01	-0.01	0.00
1988	2	0.01	1.03	0.04	0.04	0.02	0.02	-0.01
1988	3	0.00	1.13	0.06	0.05	0.04	0.03	-0.01
1988	4	0.01	1.23	0.04	0.05	0.05	0.05	-0.01
1988	5	0.01	1.27	0.03	0.04	0.03	0.04	0.01
1988	6	0.01	1.40	0.03	0.02	0.03	0.04	0.03
1988	7	0.02	1.65	0.03	0.03	0.03	0.03	0.03
1988	8	0.02	1.92	0.05	0.04	0.04	0.04	0.03
1988	9	0.01	1.53	0.04	0.04	0.03	0.04	0.04
1988	10	0.01	1.46	0.07	0.06	0.05	0.05	0.04
1988	11	0.01	1.46	0.09	0.08	0.08	0.06	0.05
1988	12	0.01	1.64	0.11	0.10	0.10	0.08	0.05
1989	1	0.01	1.51	0.10	0.10	0.11	0.11	0.06
1989	2	0.00	1.50	0.09	0.10	0.10	0.10	0.08
1989	3	0.01	1.51	0.11	0.11	0.11	0.11	0.08
1989	4	0.01	1.43	0.08	0.10	0.10	0.11	0.09
1989	5	0.01	1.24	0.05	0.08	0.09	0.11	0.09
1989	6	0.01	1.41	0.04	0.06	0.07	0.10	0.09
1989	7	0.01	2.13	0.07	0.07	0.07	0.10	0.09
1989	8	0.02	2.13	0.08	0.07	0.07	0.09	0.10
1989	9	0.01	1.98	0.07	0.08	0.07	0.08	0.12
1989	10	0.01	2.06	0.09	0.08	0.08	0.07	0.08
1989	11	0.02	1.97	0.10	0.10	0.10	0.10	0.08
1989	12	0.01	2.28	0.19	0.15	0.13	0.11	0.09
1991	5	0.01	0.85	0.04	0.02	0.02	0.01	-0.01
1991	6	0.02	1.26	0.07	0.05	0.03	0.01	-0.01
1991	7	0.02	1.47	0.09	0.06	0.04	-0.01	-0.01
1991	8	0.02	1.70	0.07	0.07	0.06	0.01	-0.02
1991	9	0.02	1.68	0.06	0.06	0.06	0.06	-0.01
1991	10	0.02	1.52	0.09	0.08	0.08	0.07	0.01
1991	11	0.04	1.47	0.09	0.08	0.09	0.09	0.03
1991	12	0.04	1.39	0.10	0.10	0.10	0.09	0.03
1992	1	0.04	1.15	0.14	0.12	0.11	0.10	0.04
1992	2	0.05	0.36	0.25	0.23	0.19	0.14	0.07
1992	3	0.05	0.63	0.23	0.26	0.24	0.18	0.07
1992	4	0.07	0.57	0.19	0.22	0.21	0.21	0.07
1992	5	0.06	0.44	0.21	0.23	0.22	0.16	0.07
1992	6	0.07	0.23	0.23	0.20	0.16	0.10	0.07
1992	7	0.05	1.03	0.22	0.20	0.14	0.09	0.06
1992	8	0.05	1.67	0.19	0.21	0.20	0.16	0.07
1992	9	0.05	1.71	0.17	0.21	0.21	0.18	0.08
1992	10	0.04	1.62	0.13	0.16	0.17	0.19	0.13
1992	11	0.04	1.53	0.13	0.14	0.14	0.15	0.14



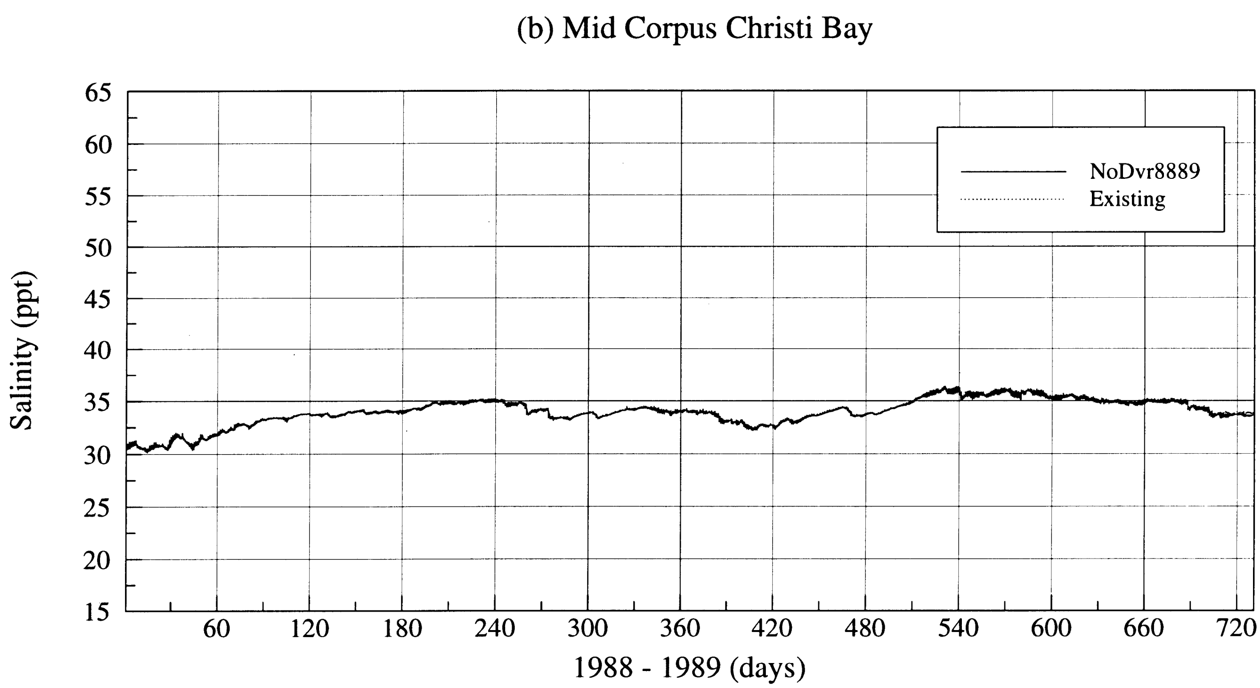
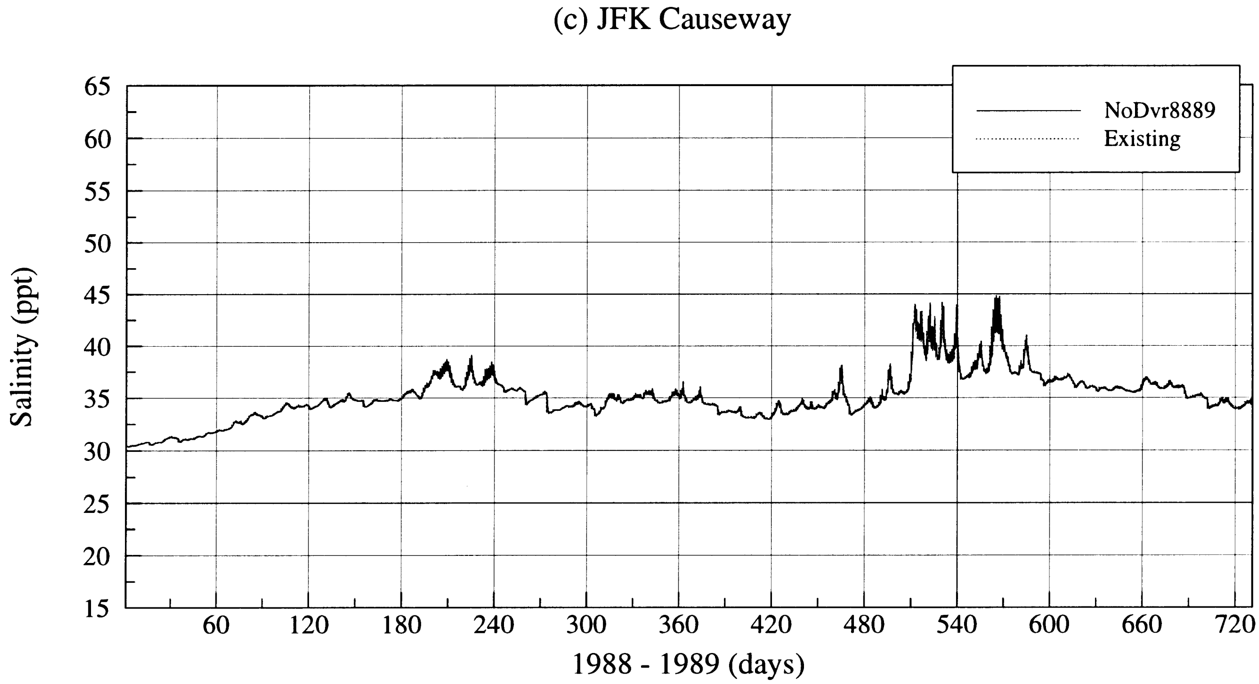


Figure IV.14 Simulated salinities in 1988-1989 for the existing condition and no diversions



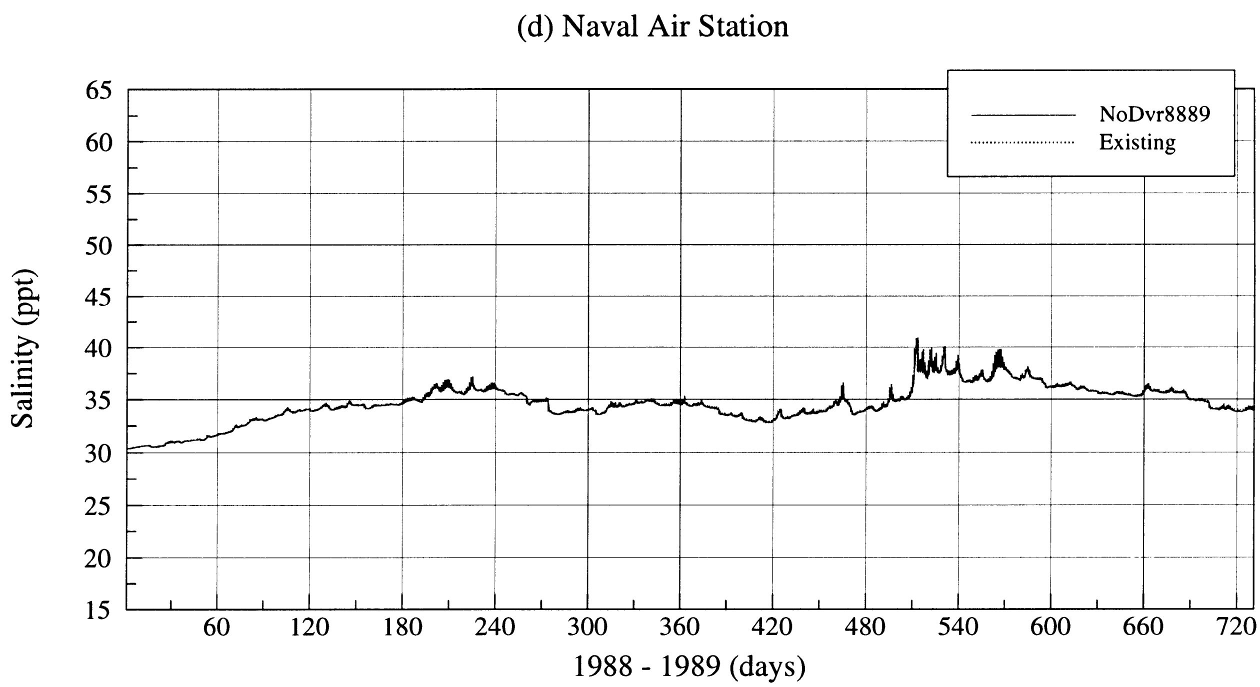
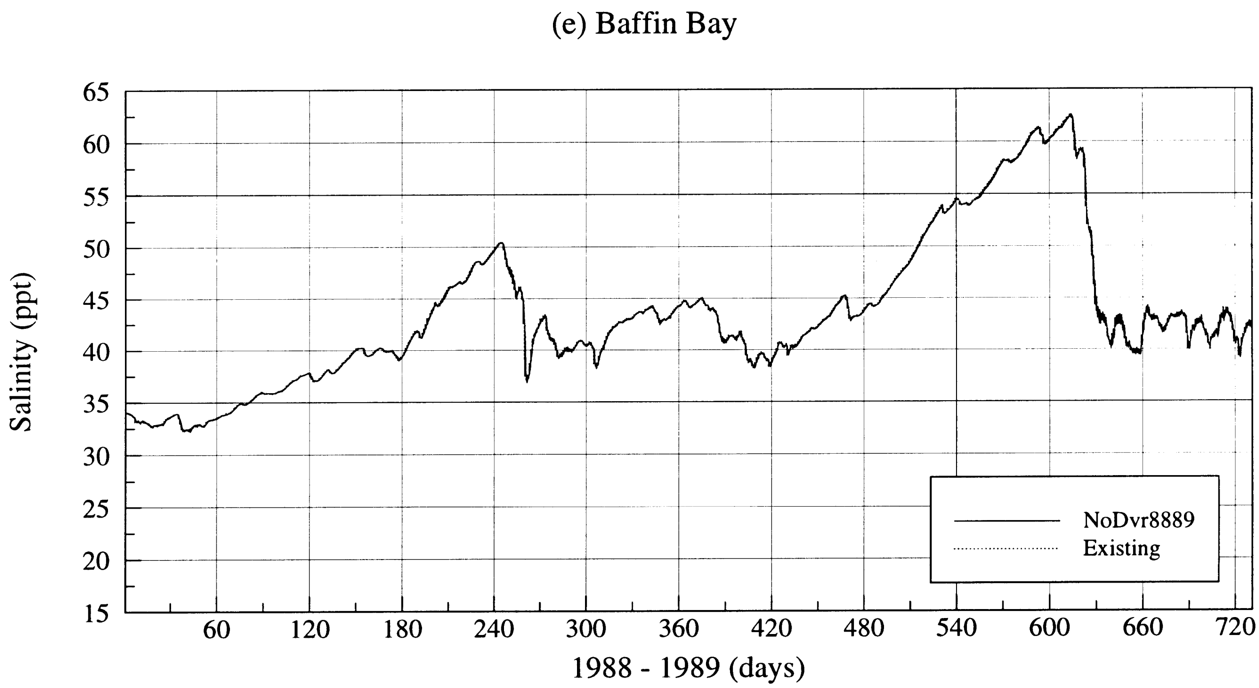


Figure IV.14 Simulated salinities in 1988-1989 for the existing condition and no diversions



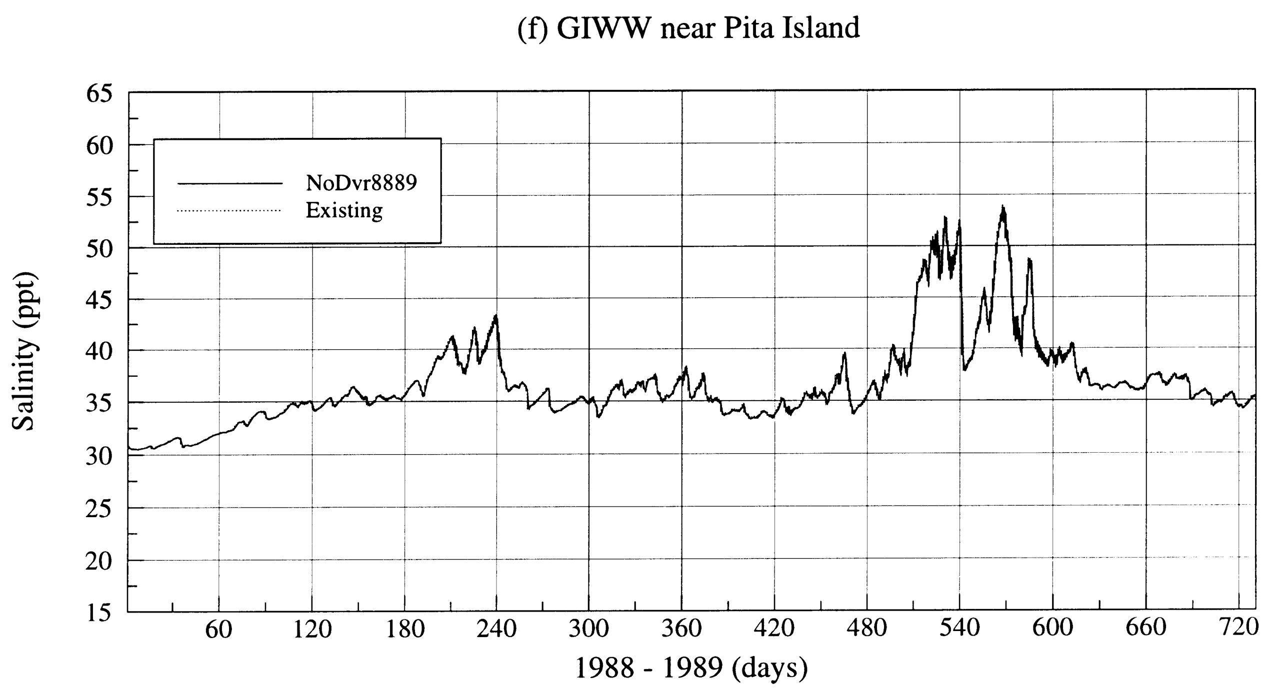
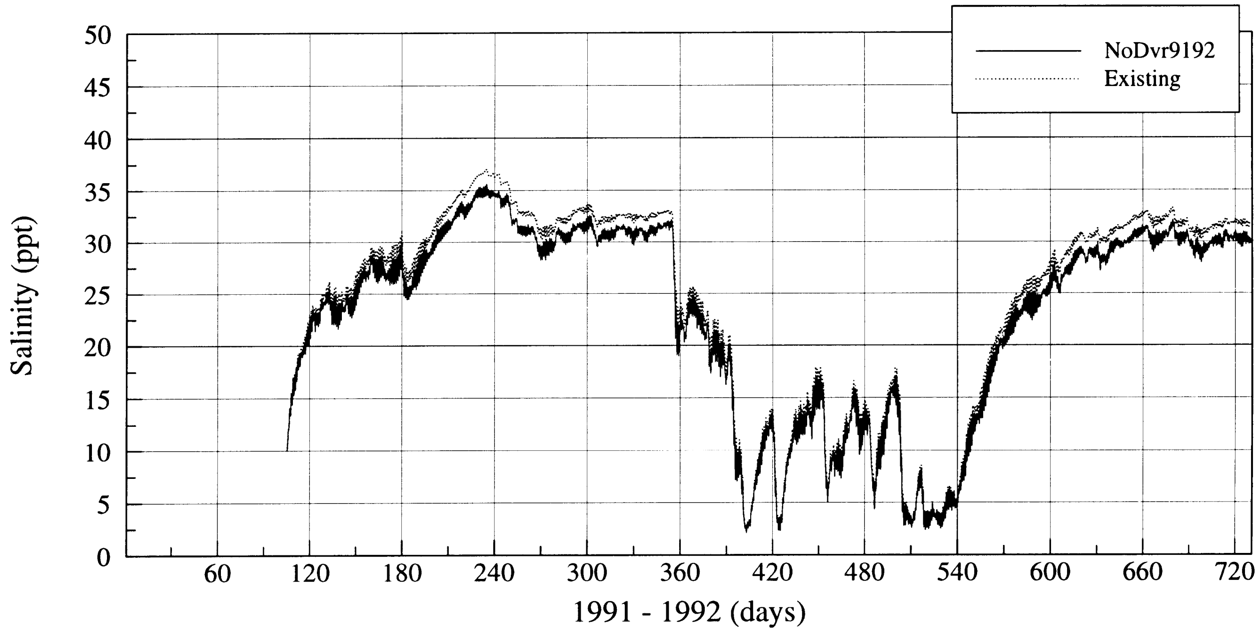


Figure IV.14 Simulated salinities in 1988-1989 for the existing condition and no diversions

(a) Mid Nueces Bay



(b) Mid Corpus Christi Bay

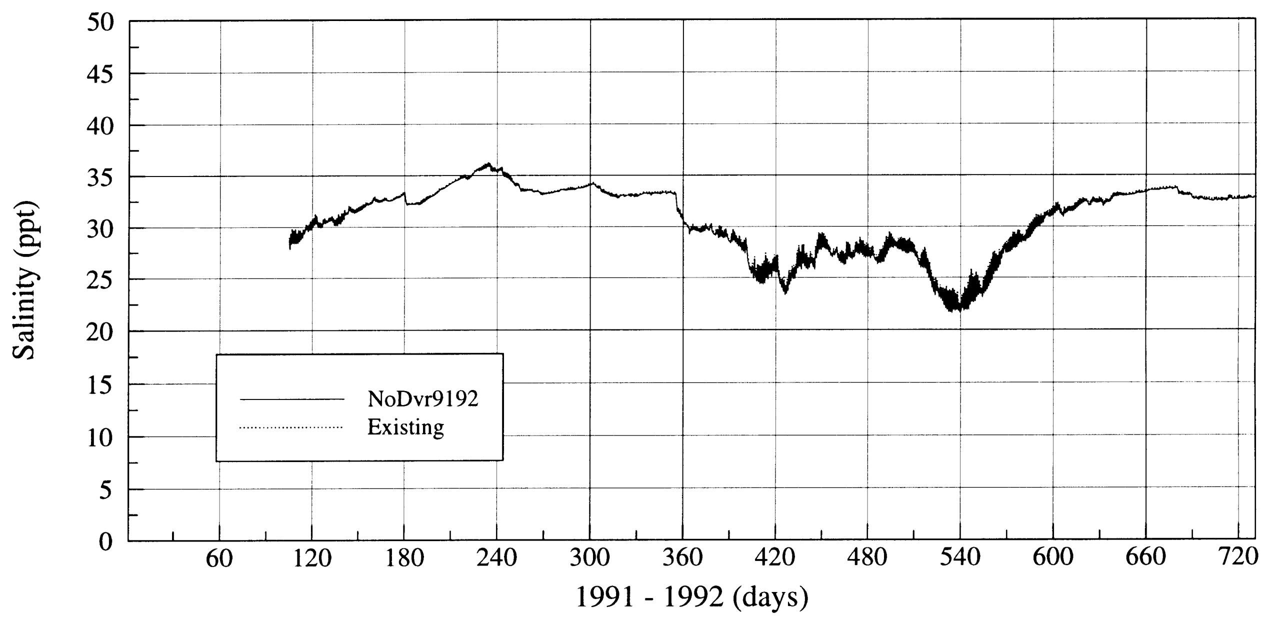
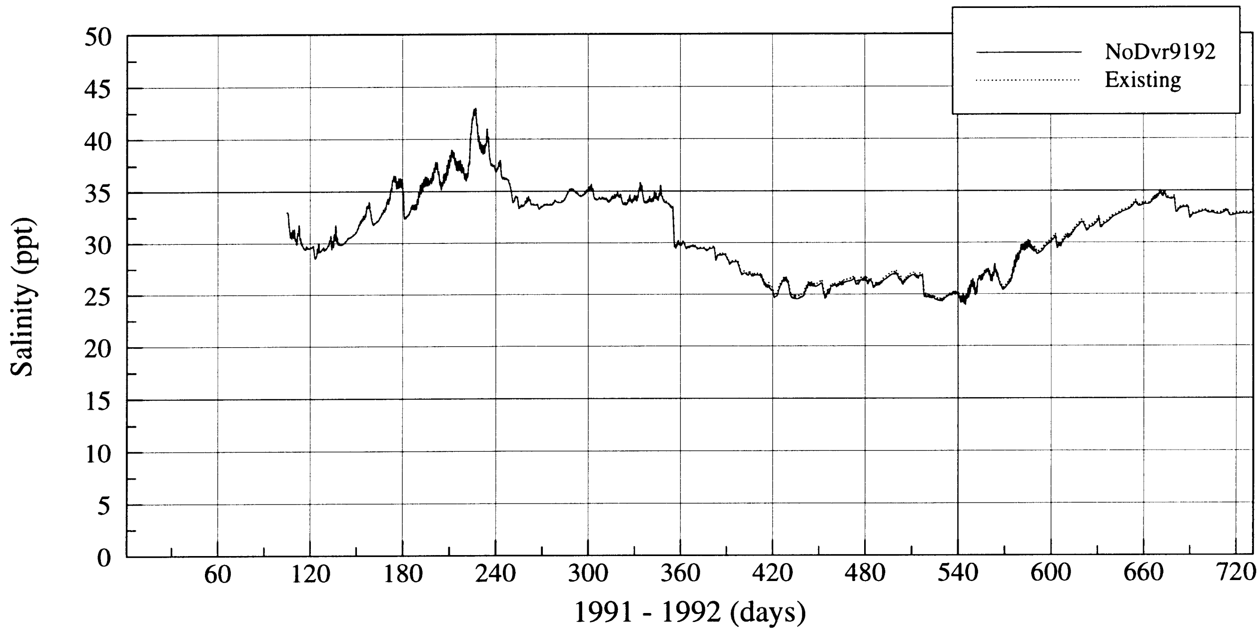


Figure IV.15 Simulated salinities in 1991-1992 for the existing condition and no diversions

(a) JFK Causeway



(b) Naval Air Station

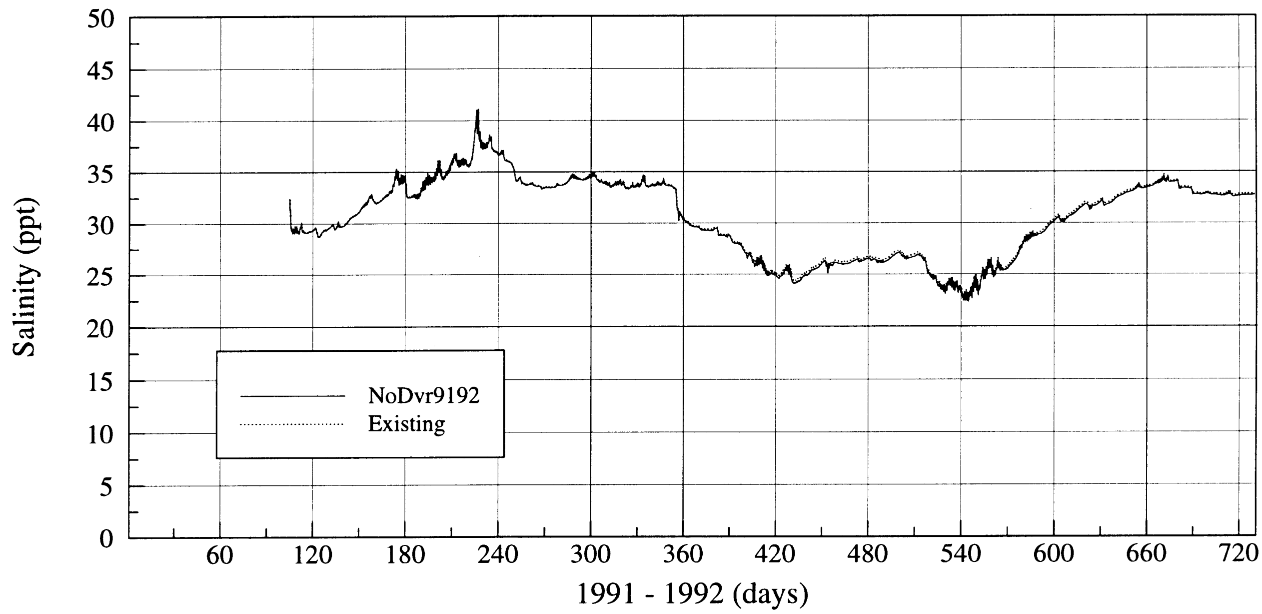
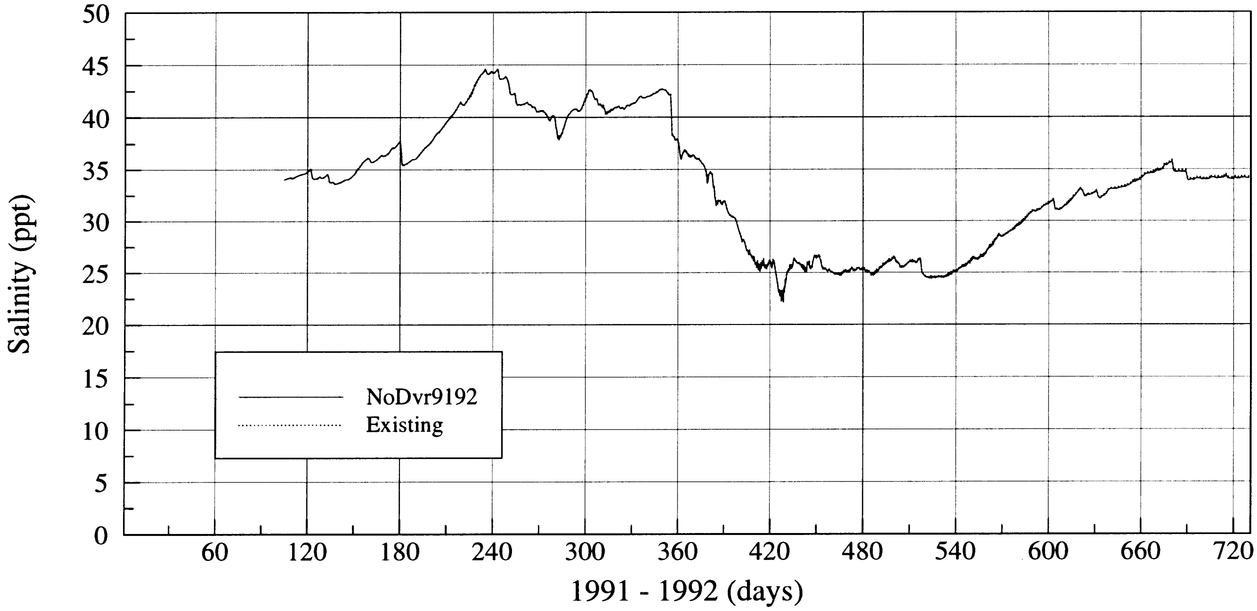


Figure IV.15 Simulated salinities in 1991-1992 for the existing condition and no diversions

(e) Baffin Bay



(f) GIWW near Pita Island

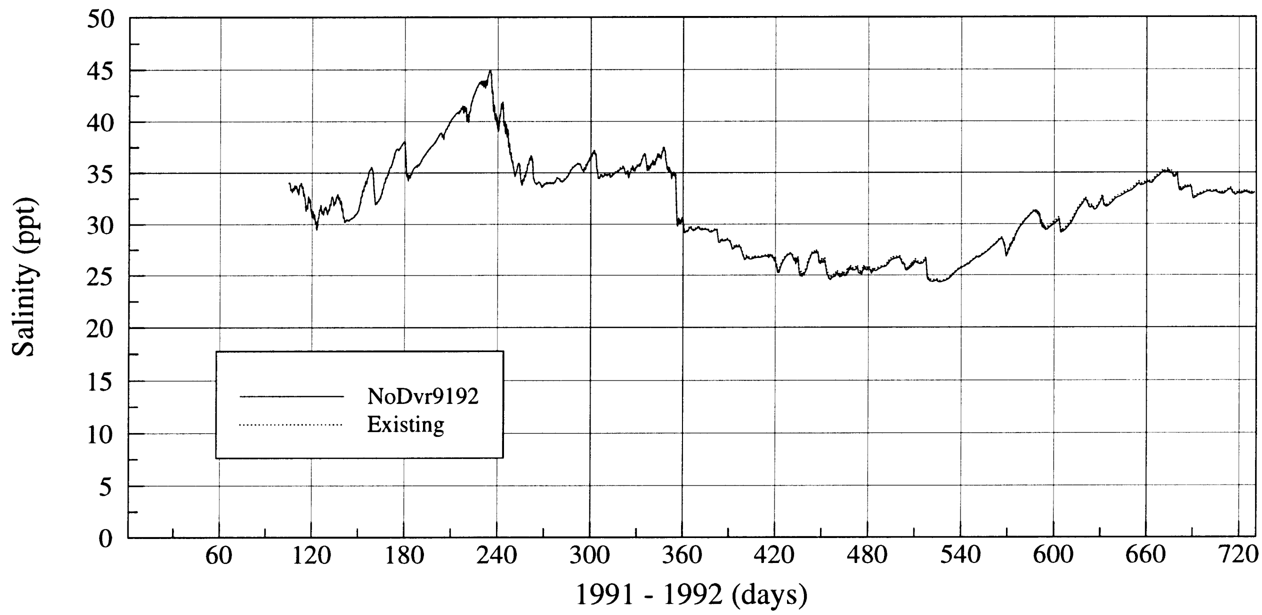


Figure IV.15 Simulated salinities in 1991-1992 for the existing condition and no diversions

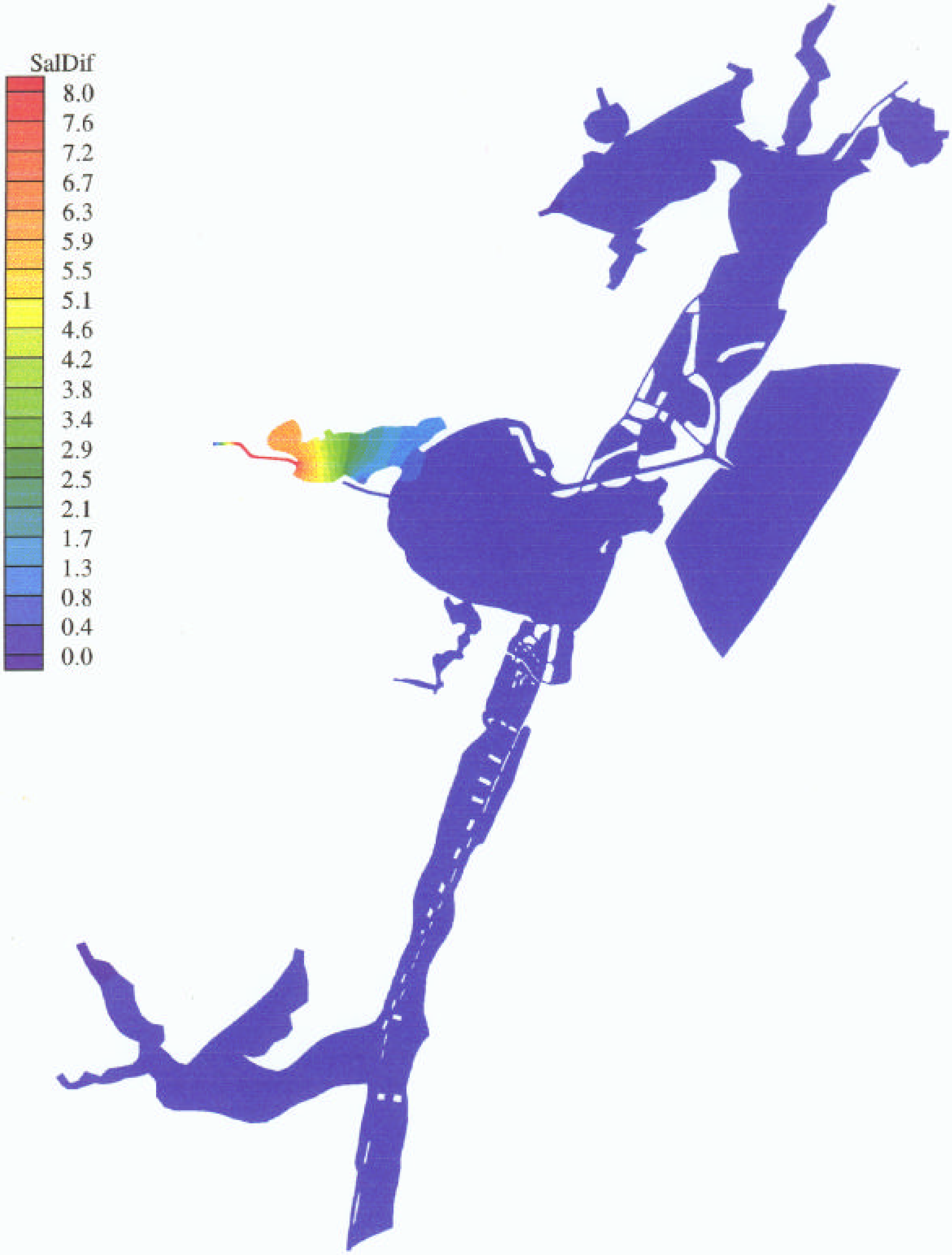


Figure IV.16 Salinity differences (ppt) in August 1989 between the existing and no diversion cases

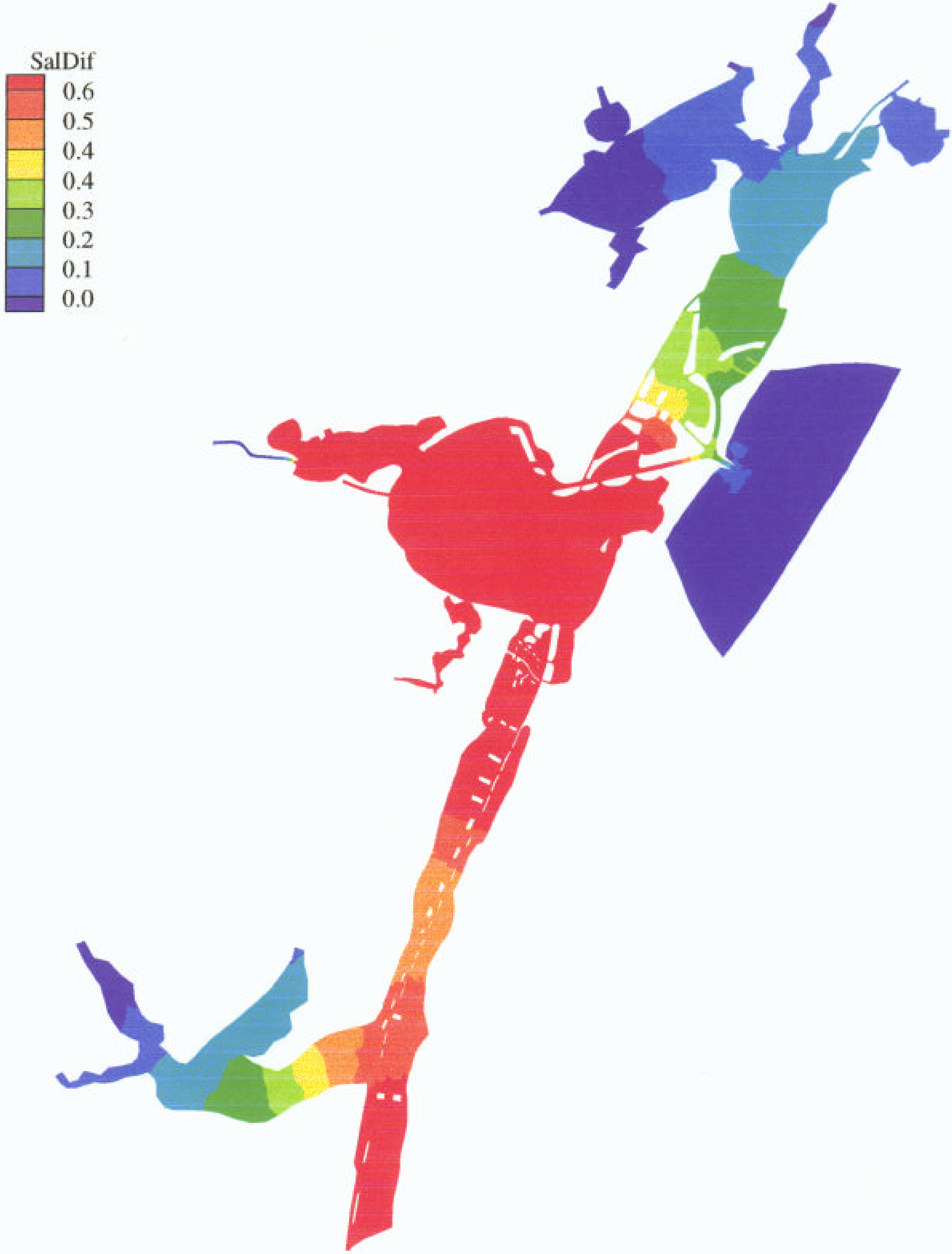


Figure IV.17 Salinity differences (ppt) in May 1992 between the existing and no diversion cases

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