ATTACHMENT 4

ENGINEERING DATA AND MODELS

ERDC/CHL TR-19-12

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Houston Ship Channel Expansion Channel Improvement Project (ECIP) Numerical Modeling Report

Jennifer McAlpin, Jared McKnight, and Cassandra Ross

June 2019

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Houston Ship Channel Expansion Channel Improvement Project (ECIP) Numerical Modeling Report

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Final report

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Prepared for U.S. Army Corps of Engineers, Galveston District
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Under Work Unit 451902; HSC Feasibility Study

Abstract

The Houston Ship Channel is one of the busiest deep-draft navigation channels in the United States and must be able to accommodate larger vessel dimensions over time. The U.S. Army Engineer District, Galveston (SWG), requested the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, perform hydrodynamic and sediment modeling of proposed modifications along the Houston Ship Channel from its connection to the Gulf of Mexico to the Port of Houston. The modeling results are necessary to provide data for salinity and sediment transport analysis as well as ship simulation studies.

SWG provided a project alternative that includes channel widening, deepening, and bend easing. The model is run for *present* year zero (2029) and *future* year 50 (2079) with and without project.

The model shows that the salinity does not vary greatly with project. Changes to salinity are 2 parts per thousand or less. The tidal prism increases by less than 2% when the project is included, and the tidal amplitudes increase by no more than 0.01 meter. The residual velocity vectors do vary in and around areas where project modifications are made — along the Houston Ship Channel, Bayport Channel, and Barbours Cut Channel. The model also indicates an increase in the shoaling along the ship channel when compared to the without project results, the largest increases being in the Bayport channel and flare.

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Preface

The model investigation presented in this report was authorized and funded by the U.S. Army Corps of Engineers, Galveston District, Work Unit 451902; HSC Feasibility Study.

The work was performed at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL), Vicksburg, MS, under the general direction of Mr. José E. Sánchez, Director, and Mr. Jeffrey R. Eckstein, Deputy Director, ERDC-CHL. Direct supervision was provided by Dr. Cary Talbot, Chief, Flood and Storm Protection Division, and Mr. Keith Flowers, Chief, River and Estuarine Engineering Branch.

At the time of publication of this report, Mr. Jeffrey R. Eckstein was the Deputy Director of CHL, and Dr. Ty V. Wamsley was the Director.

COL Ivan P. Beckman was Commander of ERDC, and Dr. David W. Pittman was Director.

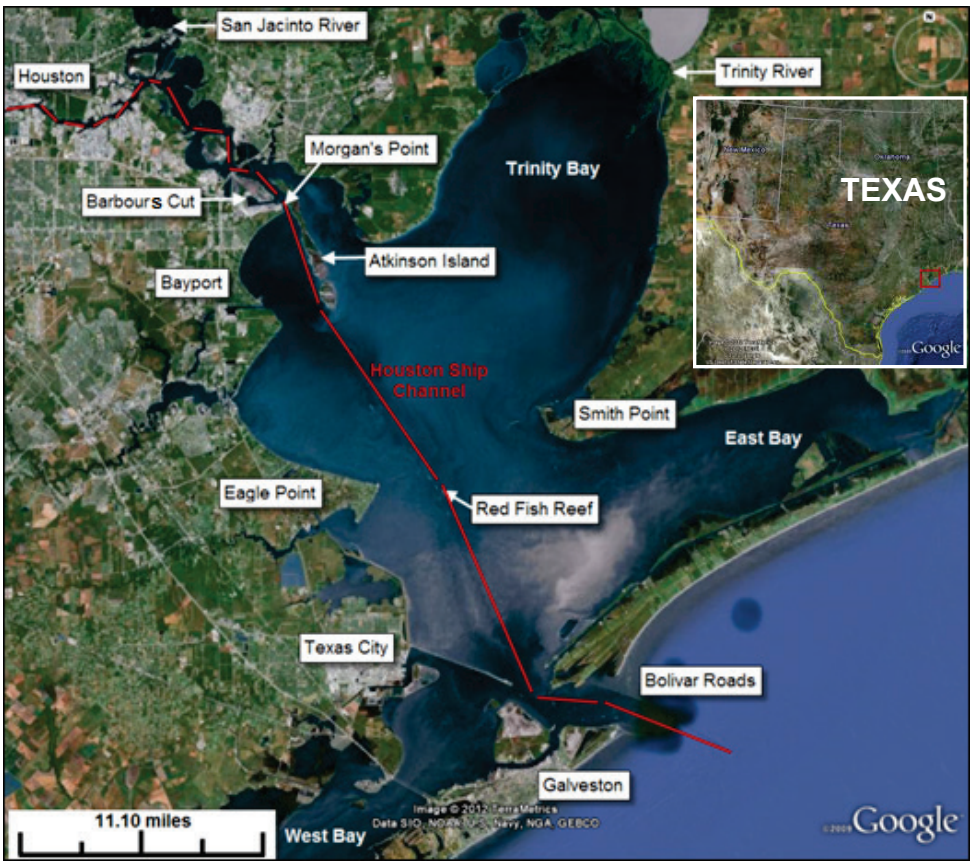
1 Introduction

Background

Since the early 1800s, vessels have transited Galveston Bay both to and from Galveston and Houston (Galveston Bay Estuary Program 2002).

Galveston Bay is a tidal estuary such that the effect of the tide on the water surface elevation is observed from the Gulf of Mexico to locations near Houston, TX. The Houston Ship Channel (HSC) is a deep-draft navigation channel that allows for vessel passage from the Gulf to the city of Houston, approximately 53 miles upstream. Since 1903, Operations and Maintenance dredging has been conducted in the bay portion to maintain authorized channel dimensions. Figure 1 shows the HSC as it passes through Galveston Bay from its entrance at Bolivar Roads to the Port of Houston.

Figure 1. HSC area map.



The U.S. Army Corps of Engineers (USACE), Galveston District (SWG), recently enlarged the HSC from a 12.2-meter (m) (40-foot [ft]) depth by 122 m (400-ft) width to a 13.7 m (45 ft) depth by 162 m (530 ft) width. Previously, a three-dimensional (3D) numerical model study was implemented at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), to evaluate the salinity and circulation impact of this enlargement. In Berger et al. (1995a) the model was shown to represent the salinity and circulation in the earlier channel configuration. Berger et al. (1995b) used the model to predict the impact of the enlarged channel. Carrillo et al. (2002) used the model to evaluate the addition of barge lanes along the ship channel flanks. Tate and Berger (2006) looked into possible reasons for increased shoaling in the ship channel by analyzing vessel effects and sediment properties in the area. In Tate et al. (2008), the sediment model was validated using the same hydrodynamic model, and the results included the effects of vessel transport on the sedimentation patterns. The model was utilized again to investigate proposed changes to the Bayport Flare (Tate and Ross 2012).

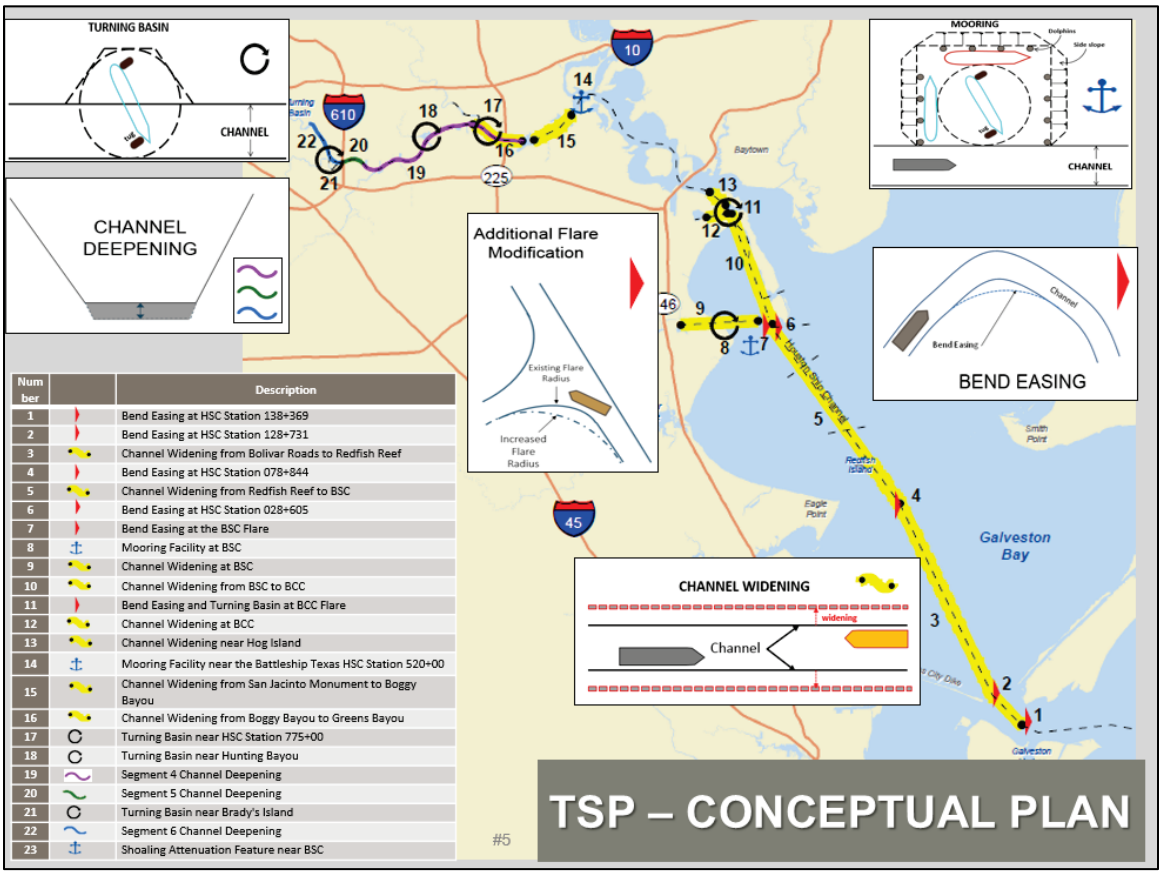
The deep navigation channel acts as a natural pathway for salinity to travel upstream since high-saline water is heavier than fresh water and tends to flow up-channel along the channel bottom. The residual velocity, or net drift, is flood in much of the channel (Tate and Berger 2006) (i.e., the tendency is for suspended material to move upstream into the Galveston Bay.) The velocity magnitudes drop in the Atkinson Island reach due to tidal reflections from the bay boundaries. More stratification occurs as a result in this reach, and material from farther downstream in the estuary will tend to collect near Atkinson Island.

The behavior of the salinity and hydrodynamics in Galveston Bay during May through June is different than the remainder of the year due to a salinity drop in the northern Gulf of Mexico as the Mississippi, Sabine-Neches, and Atchafalaya Rivers and other northern Gulf river systems provide a significant influx of fresh water. When the salinity in the Gulf of Mexico drops, the salt water tends to evacuate from the bays. A reduction in bay salinity is hypothesized to result in different suspended concentrations. Therefore fresh deposit characteristics may change during this time period when compared to data collected at other times during the year. If this is the case, sediment would tend to collect farther down the channel toward Red Fish Reef during this period.

Objective

In 2016, SWG requested the ERDC-CHL to perform hydrodynamic and sediment modeling of proposed modifications along the HSC from its connection to the Gulf of Mexico to the Port of Houston (see Figure 2). The modeling results are necessary to provide data for salinity and sediment transport analysis as well as ship simulation studies in which pilots test the navigational effects of the modifications. The model results of project year zero (2029) and project year 50 (2079) with and without project results will be documented.

Figure 2. Proposed modifications to the HSC (figure from SWG).



Number		Description
1		Bend Easing at HSC Station 138+369
2		Bend Easing at HSC Station 128+731
3		Channel Widening from Bolivar Roads to Redfish Reef
4		Bend Easing at HSC Station 078+844
5		Channel Widening from Redfish Reef to BSC
6		Bend Easing at HSC Station 028+605
7		Bend Easing at the BSC Flare
8		Mooring Facility at BSC
9		Channel Widening at BSC
10		Channel Widening from BSC to BCC
11		Bend Easing and Turning Basin at BCC Flare
12		Channel Widening at BCC
13		Channel Widening near Hog Island
14		Mooring Facility near the Battleship Texas HSC Station 520+00
15		Channel Widening from San Jacinto Monument to Boggy Bayou
16		Channel Widening from Boggy Bayou to Greens Bayou
17		Turning Basin near HSC Station 775+00
18		Turning Basin near Hunting Bayou
19		Segment 4 Channel Deepening
20		Segment 5 Channel Deepening
21		Turning Basin near Brady's Island
22		Segment 6 Channel Deepening
23		Shoaling Attenuation Feature near BSC

Approach

A 3D Adaptive Hydraulics (AdH) model will be developed and validated for simulation of hydrodynamics, salinity, and sediment transport. Previous modeling efforts used the TABS-MDS finite element code. This code is no longer supported by CHL, requiring a new model to be built utilizing the latest technology and updated to represent present conditions. The model will be validated to available field data for all

parameters and then utilized to test project alternatives for present and future conditions. For all simulations, the model will be set up to run for 2 years — the first year being a spin-up period to obtain an accurate initial salinity field as well as an accurate sediment bed, and the second year will be used for all analyses.

The model development and boundary condition definitions for the hydrodynamic, salinity, and sediment transport model as well as the model to field data comparisons, including water surface elevation, velocity, salinity, and HSC dredge volumes are documented in a separate report (McAlpin et al. 2019). Chapter 2 focuses on the plan alternatives and simulation periods. Chapter 3 focuses on the comparisons of these modifications to the present condition for hydrodynamics, salinity, and sedimentation. Chapter 4 provides the conclusions of this numerical model study.

2 Plan Alternatives

Documentation of the plan alternatives will include the geometric modifications to the system, defined as *project*, as well as the input conditions for the *present* project year zero (2029) and *future* project year 50 (2079). Therefore, there will be four alternatives — present without project (PWOP), present with project (PWP), future without project (FWOP), and future with project (FWP).

Project modifications

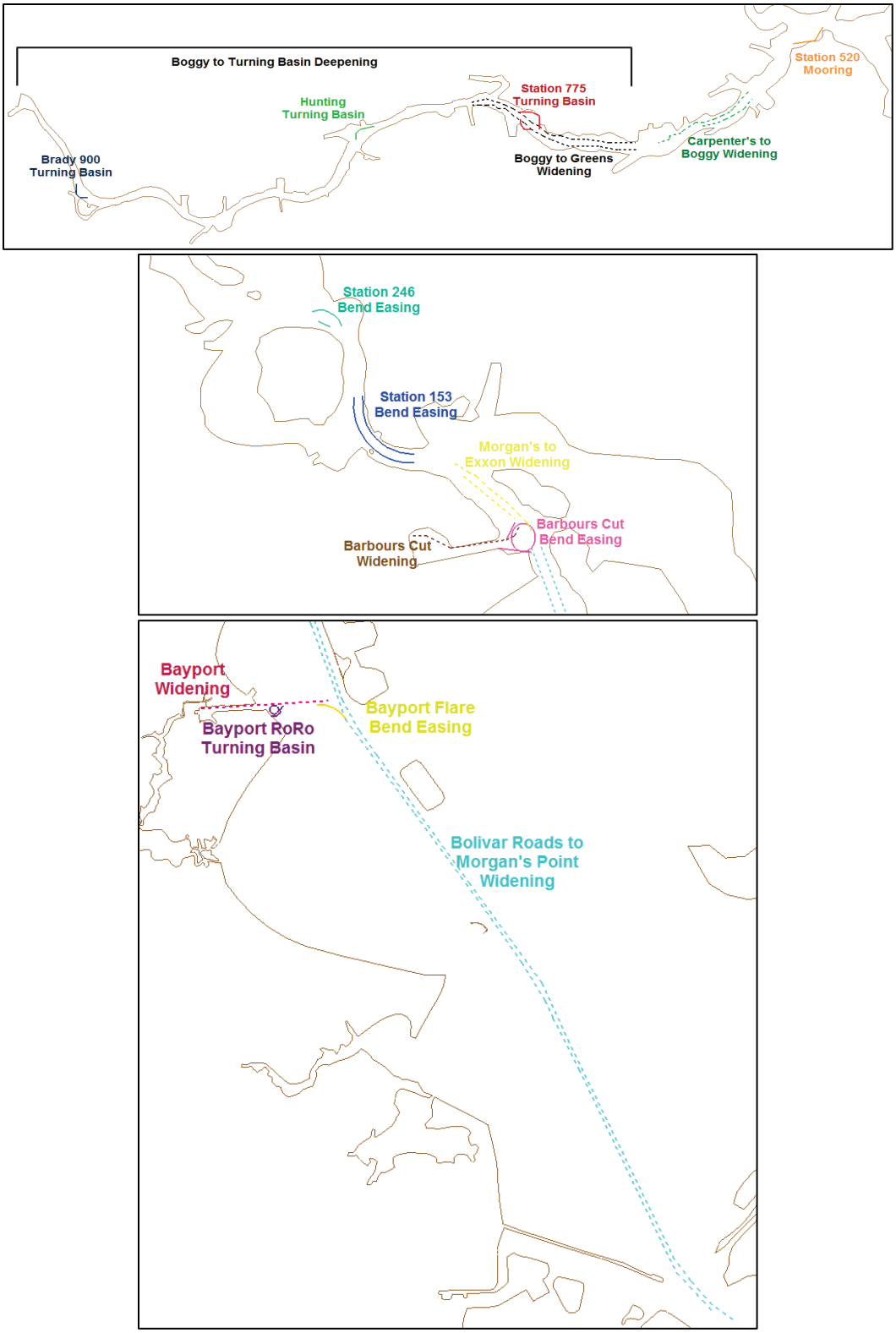
SWG along with the Port of Houston developed several potential channel modification plans. These plans were analyzed for cost/benefit based on labor for dredging, mitigation for habitat adjustment, and other factors. The final tentatively selected plan (TSP) was alternative 8, otherwise known as the *everything plan*. This plan includes widening the bay portion of the HSC to a width between 650 ft to 820 ft, widening and deepening several sections of the bayou portion of the HSC, as well as bend easings, mooring facilities, and turning basins. Figure 2 is a schematic of this alternative.

Details of the TSP, or project, are provided in Table 1 and Figure 3. Deepening segments are not included in Figure 3. All depths given in the table are based on Mean Lower Low Water and include advanced maintenance (AM) and allowable overdepth (AO) where specified. The width of the bay portion of the HSC from Bolivar Roads to Morgan's Point was modeled at 650 ft as requested by SWG knowing that later ship simulation may require a wider channel dimension.

Table 1. Details of TSP. Dimensions in feet.

HSC Segment	Widening	Deepening	Bend Easing	Mooring Facility	Turning Basin
Bolivar Roads to Red Fish Light 1	650				
Redfish Light 1 to Beacon 76	650				
Beacon 76 to Lower End Morgan's Point Cut	650				
Morgan's Point to Exxon	600		Station 153+06 Station 246+54		
Exxon to Carpenter's Bayou					
Carpenter's Bayou to Boggy Bayou	530			Station 520+00 41.5	
Bayport Ship Channel	455		Flare		RoRo 46.5
Barbours Cut Ship Channel	455		Flare		
Boggy Bayou to Greens Bayou	530	46.5 +2 AM +1 AO			Station 775+00 46.5
Greens Bayou to Sims Bayou[1]		46.5 +2 AM +1 AO			Hunting 46.5
Sims Bayou to I-610 Bridge		41.5 +2 AM +1 AO			
I-610 Bridge to End Main Turning Basin		41.5 +2 AM +1 AO			Brady 900 46.5

Figure 3. TSP location map.



Input conditions

Most USACE design projects require a 50-year project life span; therefore, analysis at some year zero and year 50 are required. This type of analysis requires projecting future inputs to the numerical model. Sea level rise (SLR) curves are available to determine the adjustments necessary for potential changes to the tidal elevation. Predictions of future freshwater inflows are often available and primarily include urban growth projections. However, future wind conditions, sediment loads, and rainfall/evaporation are much more difficult to determine. For this project, the 2010 validation year was determined suitable by SWG as a base or starting point for the year zero (present) and year 50 (future) model inputs. (For details of the 2010 model boundary conditions, see McAlpin et al. [2019]). The tidal water surface elevation, freshwater inputs, and sediment loads (because they are based on the freshwater input) are the only model inputs that will vary from the 2010 base condition. All simulations will be made for a 2-year period with the first year-long simulation serving to generate an accurate initial salinity field and initial sediment bed. Data availability for each input parameter determines if consecutive years of data are used for the 2-year simulations or if a single year of data is repeated.

Given the variability in several input parameters for the present and future conditions, great care should be taken when reviewing the model results. Changes from present to future must be understood with no project in place to understand the project impacts. In other words, comparison of with and without project should be done on the present conditions and the future conditions separately and only mixed when well understood.

Sea level rise (SLR)

The tidal boundary condition at the Gulf of Mexico is based on harmonics and measured data from National Oceanic and Atmospheric Administration gages at Freeport (8772447) and Sabine Pass (8770822), Texas. To account for potential SLR at year zero (2029) and year 50 (2079), guidance defined in USACE EC 1165-2-212, *Sea-Level Change Considerations for Civil Works Programs*, was used (USACE 2011). The 2010 data applied for the model validation were adjusted to 2017 based on the low SLR curve to obtain present conditions. The intermediate SLR projection curve was then applied to the 2017 adjusted elevations. Table 2 provides the elevation shift applied to the 2010 tide elevation for the year

2029 and year 2079 model scenarios. The elevation shift was constant over the length of the model boundary and the time of the model simulation for each year.

Table 2. SLR adjustment for model tidal boundary conditions.

Adjustment Period	SLR Curve	Elevation Shift
2010 to 2017	Low	0.148 ft (0.045 m)
2017 to 2029	Intermediate	0.322 ft (0.098 m)
2017 t0 2079	Intermediate	1.914 ft (0.583 m)

Freshwater inflow

Freshwater inflow into the model domain was applied at the two major rivers — Trinity River and San Jacinto River — and at seven ungaged flow locations. These flow values were obtained from the Texas Water Development Board (TWDB) hydrology model which computes flows for the area from the 1970s to present (Schoenbaechler and Guthrie 2012). SWG determined that years 1985 and 1986 were typical flow conditions for the region and would be a good estimate of future flow patterns. Based on findings by SWG in coordination with TWDB, the freshwater flow into the Trinity and Galveston Bay system will decline by approximately 12% over the 50-year project life. This reduction is primarily due to projections of increased water needs for the surrounding municipalities, meaning that more volume will be diverted for local water supply and less will be available to enter the bay system.

For year 2029 (present) conditions, 2009 (spin-up year) and 2010 (analysis year) inflows are used for all freshwater inflow locations. Figure 4 shows the year 2029 inflows. For year 2079 (future) conditions, 88% of the 1985 (spin-up year) and 1986 (analysis year) freshwater inflows are used for the Trinity River and San Jacinto River, and 88% of the 2009 and 2010 inflows are used at the ungaged locations. Figure 5 shows the 2079 inflows.

Figure 4. Year 2029 (present) freshwater inflows.

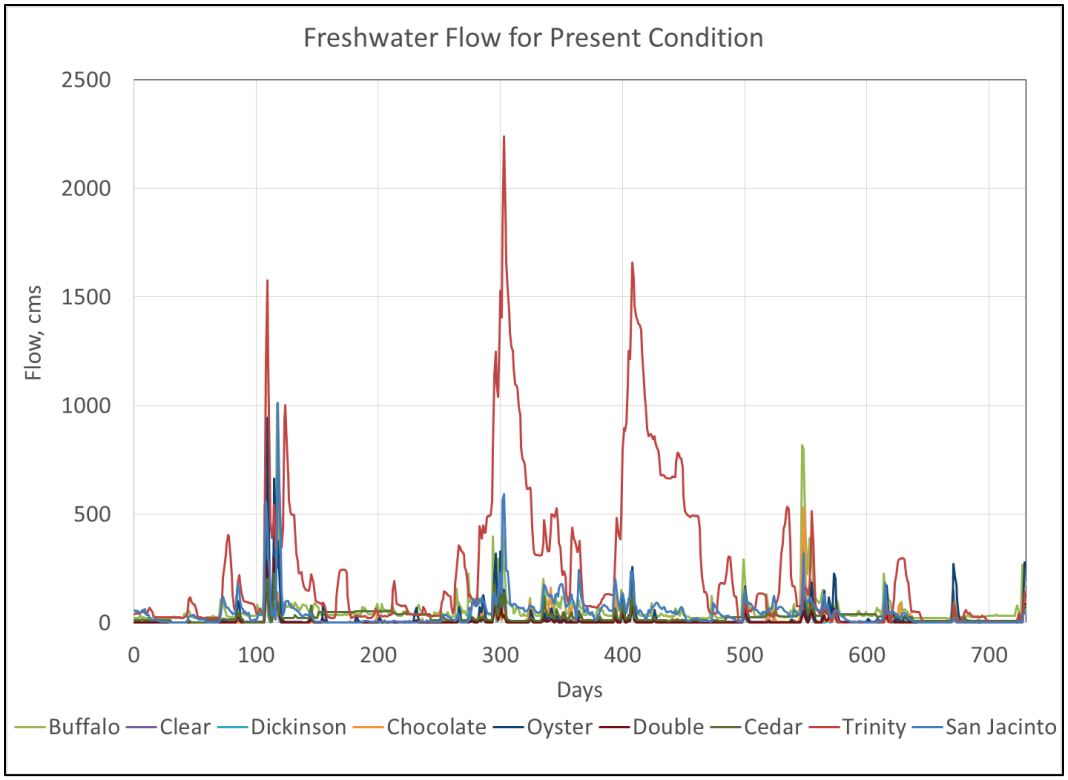
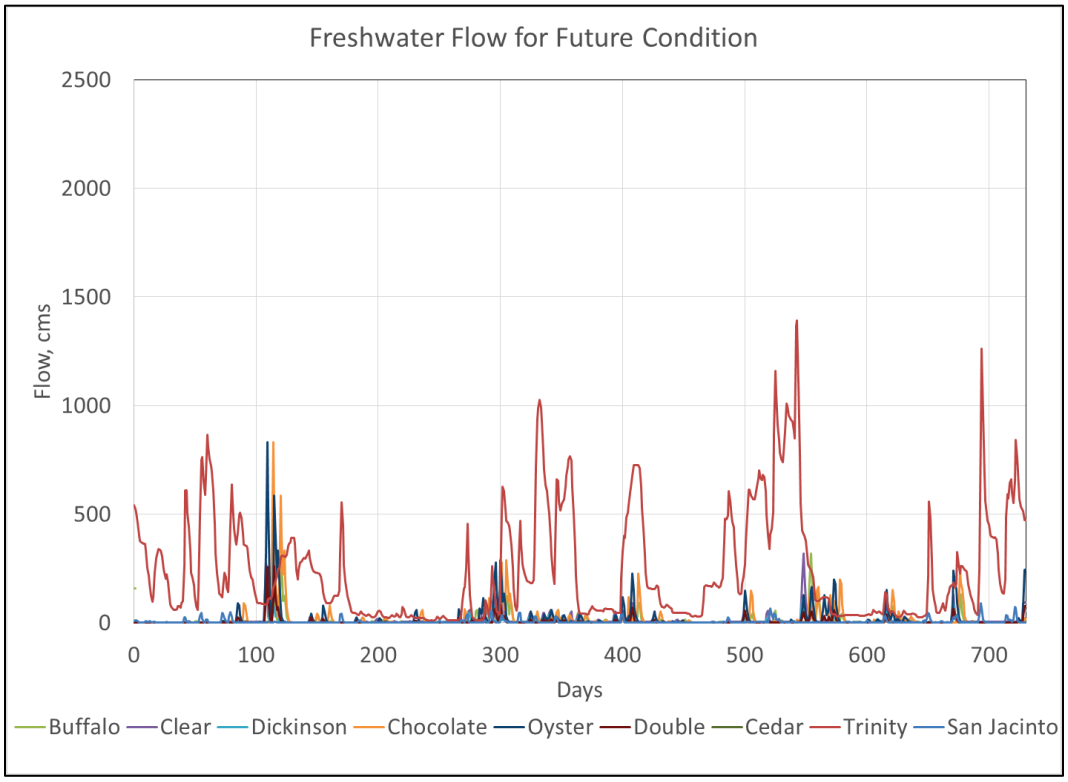


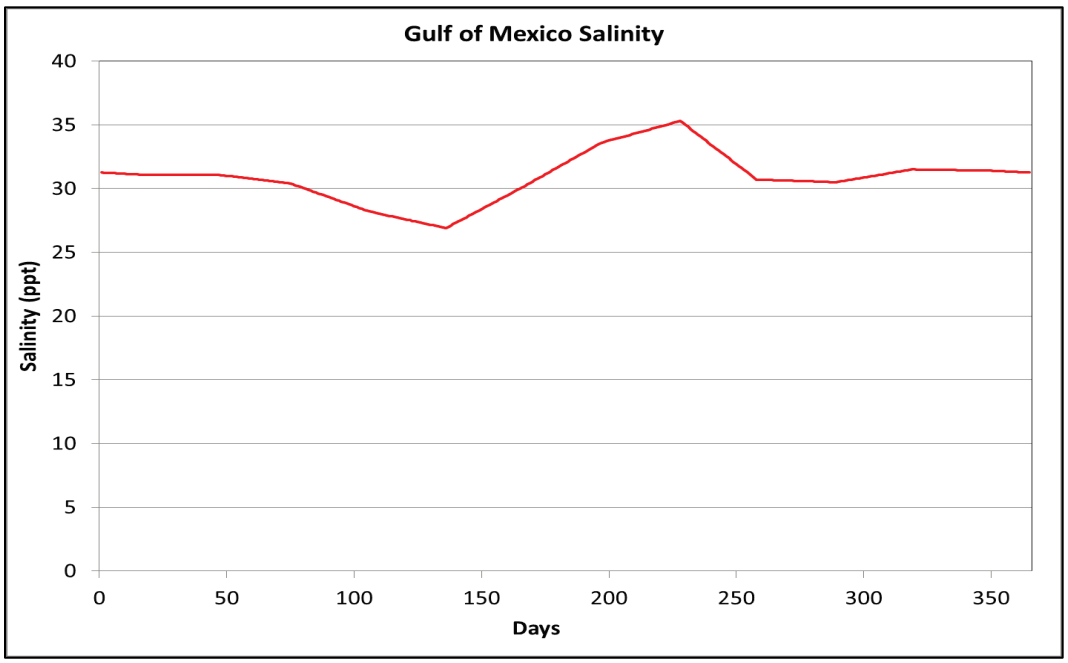
Figure 5. Year 2079 (future) freshwater inflows.



Salinity

The salinity input at the model's ocean boundary is unchanged from the model validation and shown in Figure 6 (McAlpin et al. 2019). The time-varying boundary condition is based on monthly averages over a 15-year period. The single year of data was repeated such that the same input was applied for the spin-up year and the analysis year.

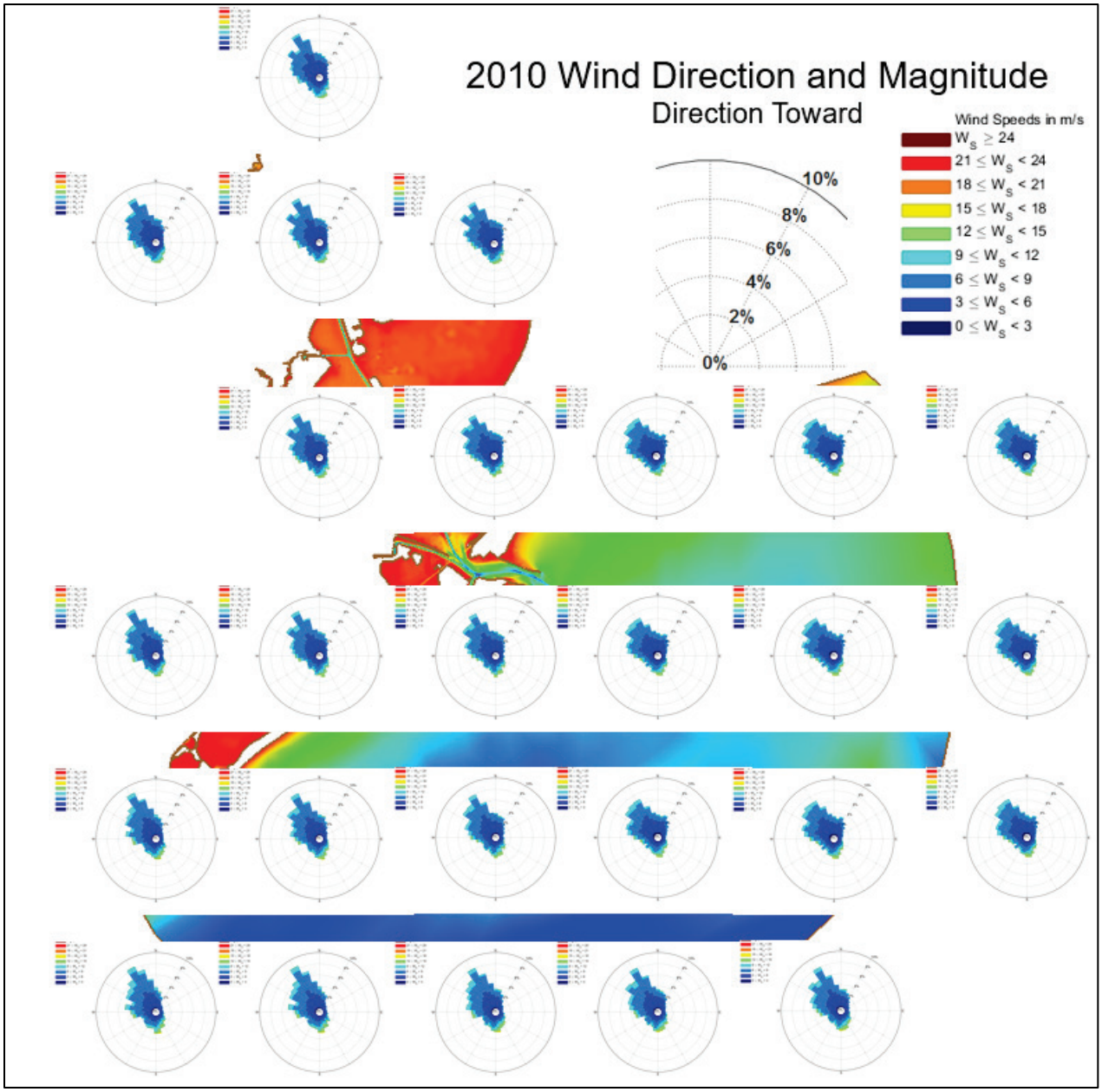
Figure 6. Salinity boundary condition for present and future conditions.



Wind

The 2010 wind data set was obtained from the Wave Information Studies computed wind field at 26 points in the vicinity of the model domain. This data set was maintained from the model validation (McAlpin and Ross et al. 2019). This wind data set was unchanged and repeated for the spin up and analysis years for both the present and future conditions. Figure 7 shows the 2010 wind rose for the 26 computed wind series locations.

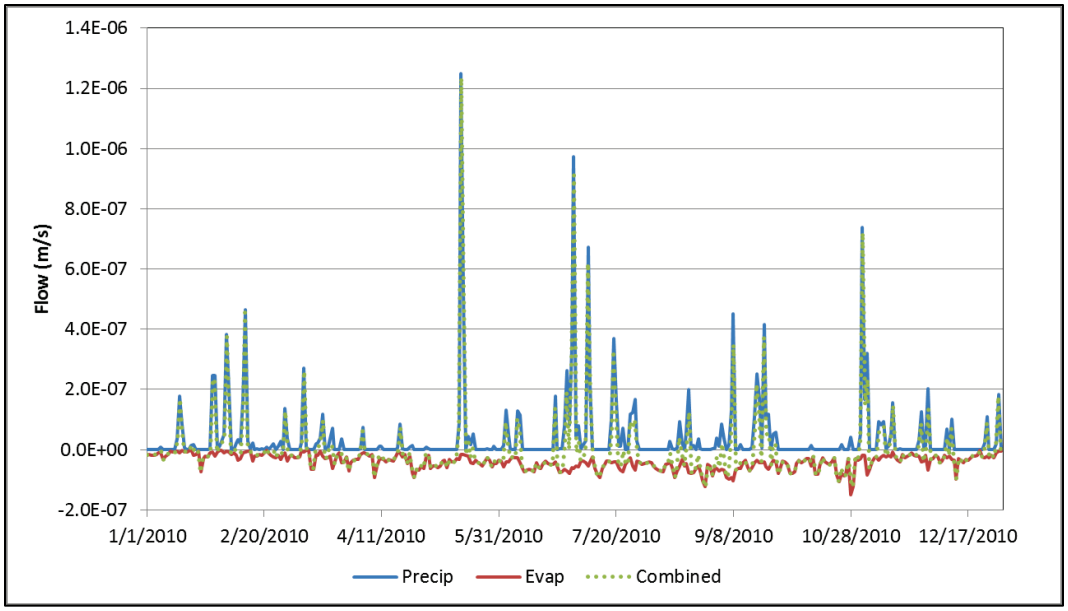
Figure 7. 2010 wind rose at all sites for 2029 (present) and 2079 (future) alternatives.



Meteorological conditions

Precipitation and evaporation were included in the alternative conditions as in the model validation (McAlpin et al. 2019). The 2010 data from the TWDB were applied equally over the model domain. The data were unchanged and repeated for the spin-up and analysis years for the present and future conditions. Figure 8 shows the time series of the meteorological data.

Figure 8. 2010 meteorological conditions for 2029 (present) and 2079 (future) alternatives.



Sediment

The sediment grain and bed parameters are maintained from the validation effort (McAlpin et al. 2019). The loads are applied to the two major rivers in the same manner as in the model validation — by applying a rating curve that correlates river discharge with the total concentration.

Figure 9 shows the 2029 sediment loads, which are based on 2009 and 2010 inflow data. Figure 10 shows the 2079 loads, which are based on the reduced 1985 and 1986 inflow data. These total loads are divided equally among the five simulated grain classes when applied in the model. No sediment is applied at the ungaged inflow locations, as done in the model validation.

The model validation (McAlpin et al. 2019) details sediment loads that are not included in this model. These include unaccounted sediment loads from the ungaged freshwater inflows, from wind-generated wave erosion along the shallows, and from vessel-induced erosion in the bays. A historical scaling method for each channel segment was determined to be the best option to account for the combined effect of the various unknown loads.

Figure 9. Year 2029 (present) total sediment load.

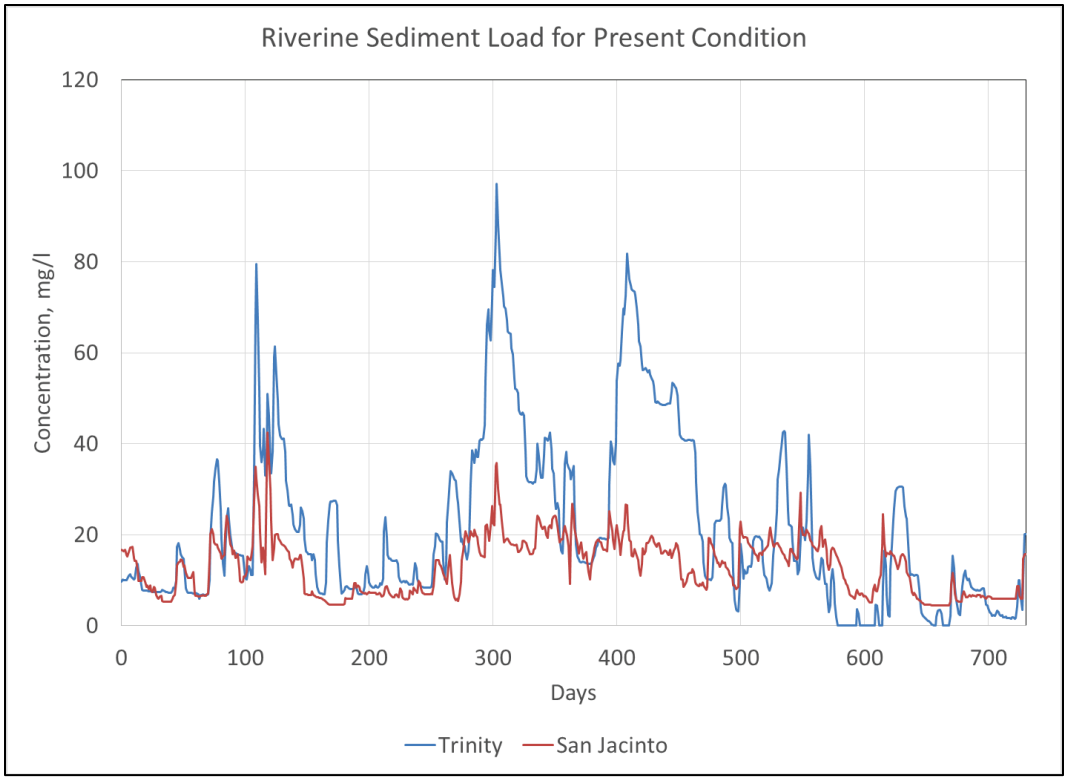
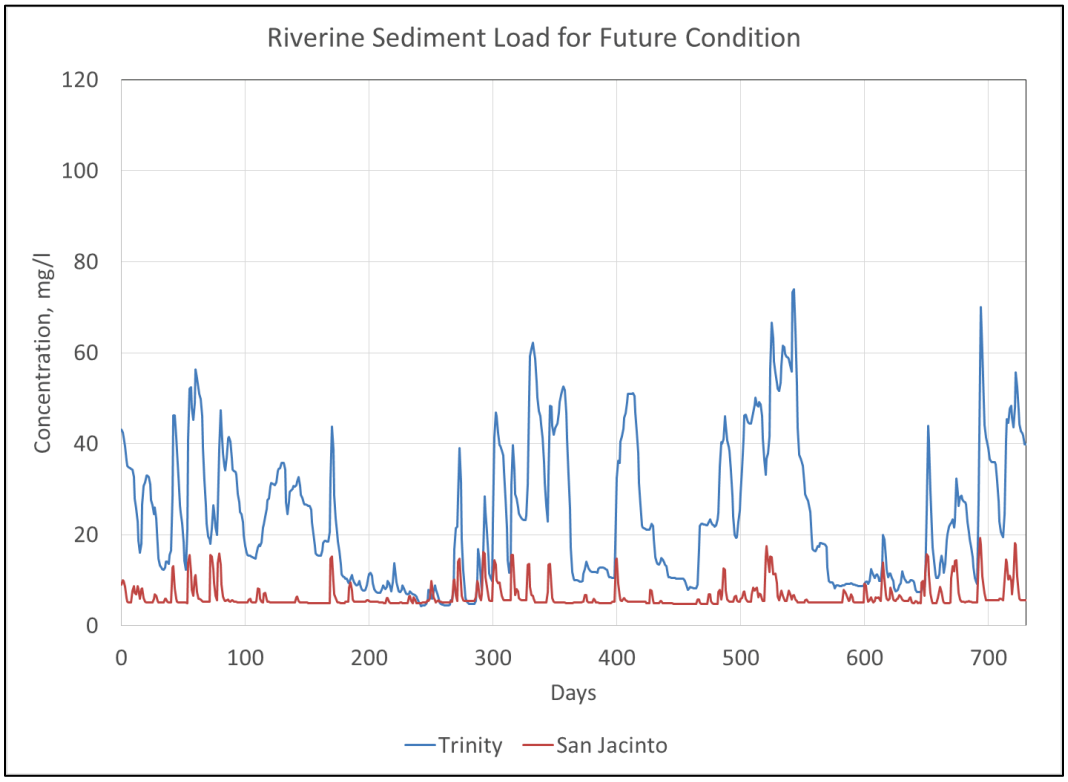


Figure 10. Year 2079 (future) total sediment load.



3 Model Results and Discussion

The four alternatives —PWOP, PWP, FWOP, and FWP — were simulated using 3D AdH as stated in the previous chapters. Present is year 2029 and future is 2079 assuming a 50-year project lifespan. The results will include changes in salinity and velocity throughout the model domain under the various alternative conditions. Additionally, changes to the shoaling in the HSC and sedimentation patterns in the surrounding bays will be observed.

Comparison of with and without project should be done on the present conditions and the future conditions separately to isolate impacts due to the project alone. Given the variability in several input parameters for the present and future conditions, it is not recommended to compare present and future results directly unless careful consideration is given to understanding the difference in the present and future input parameters.

Salinity

Salinity point analysis

Several locations were identified for specific analysis such as time history, percent-less-than, and maximum/minimum/average computations of salinity. These locations are shown in Figure 11 and labeled in Table 3. A subset of these locations, circled in red in Figure 11 and the shaded rows in Table 3, will be included and discussed in the text. All analysis plots and images will be included in the appendix.

Figure 11. Point analysis locations. Circled locations discussed in this section.

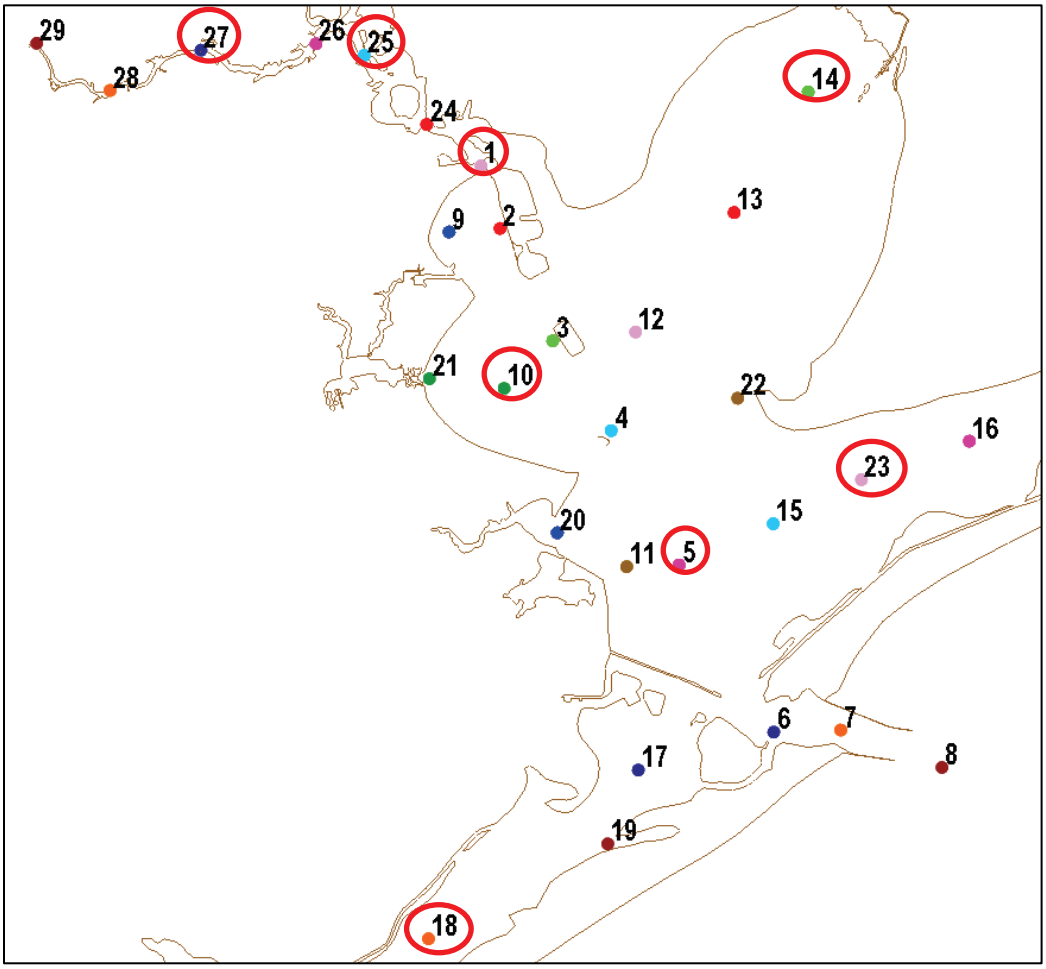


Table 3. Point analysis location names. Highlighted locations discussed in this section.

Point #	Name
1	HSC at Morgan's Point
2	HSC at Atkinson Island
3	HSC at Mid Bay Marsh
4	HSC at Red Fish Reef
5	HSC at Lower Galveston Bay
6	HSC at Bolivar Roads
7	HSC at Entrance
8	HSC at Gulf
9	Upper Galveston Bay 1
10	Upper Galveston Bay 2

Point #	Name
16	Eastern East Bay
17	Eastern West Bay
18	Mid West Bay
19	Offatts Bayou
20	Dickinson
21	Clear Creek
22	Smith Point
23	Mid East Bay
24	HSC at Fred Hartman Bridge
25	HSC at Goat Island

Point #	Name
11	Lower Galveston Bay
12	Lower Trinity Bay
13	Mid Trinity Bay
14	Upper Trinity Bay
15	Western East Bay

Point #	Name
26	HSC at Carpenters Bayou
27	HSC at Greens Bayou
28	HSC at Sims Bayou
29	HSC at Turning Basin

Time history of salinity is shown for several points within the HSC and several in the bays. Also provided are plots showing the maximum, average, and minimum salinity at each location for the year-long analysis period. The salinity shown in the plots is bottom values, which will be larger than or equal in magnitude to the surface values due to the density stratification of salt water. For all plots of salinity, PWP is blue, PWOP is red, FWP is yellow, and FWOP is purple.

Additionally, percent-less-than plots are provided to show how the bottom salinity varies over the analysis period. The maximum salinity value is given at 100% and the minimum value at 0%. The 50% salinity value indicates that the salinity is less than this value for 50% of the analysis time and greater than this value for 50% of the time.

Vertical salinity profiles are also included for all of the salinity analysis points.

To isolate impacts due to the project, when viewing these results, focus on changes between the present with and without project separately from the future with and without project. The future conditions have changes in the input conditions that make comparisons between present and future results harder to interpret.

Figures 12 – 43 show the point salinity analysis at the eight selected locations. The results for all 29 locations are provided in the appendix.

The variation in salinity between present and future conditions is significant as expected. The rise in water surface elevation due to sea level changes as well as a reduction in freshwater inflow for future conditions generates very different salinity magnitudes throughout the analysis year. In most locations the mean salinity is larger for the future conditions. However, the variation in salinity between with and without project alternatives is quite

small for most locations — generally less than 2 parts per thousand (ppt). The largest variation in salinity between with and without project results is in the upstream locations of the HSC. The salinities are almost identical near the entrance but begin to diverge farther into the system at Mid Bay Marsh, Morgan's Point, and locations farther up the HSC. However, the change in the mean salinity between with and without project remains within 2 ppt. This behavior is visible in the point analysis as well as in the cross-sectional analysis to be discussed in the next section. The time history of salinity includes dotted lines for 10 ppt and 15 ppt thresholds. The with project conditions generally maintain the pattern of the salinity over time but do increase above these thresholds for short periods of time at some locations.

Point salinity analysis

Figure 12. Salinity time history at HSC at Greens Bayou.

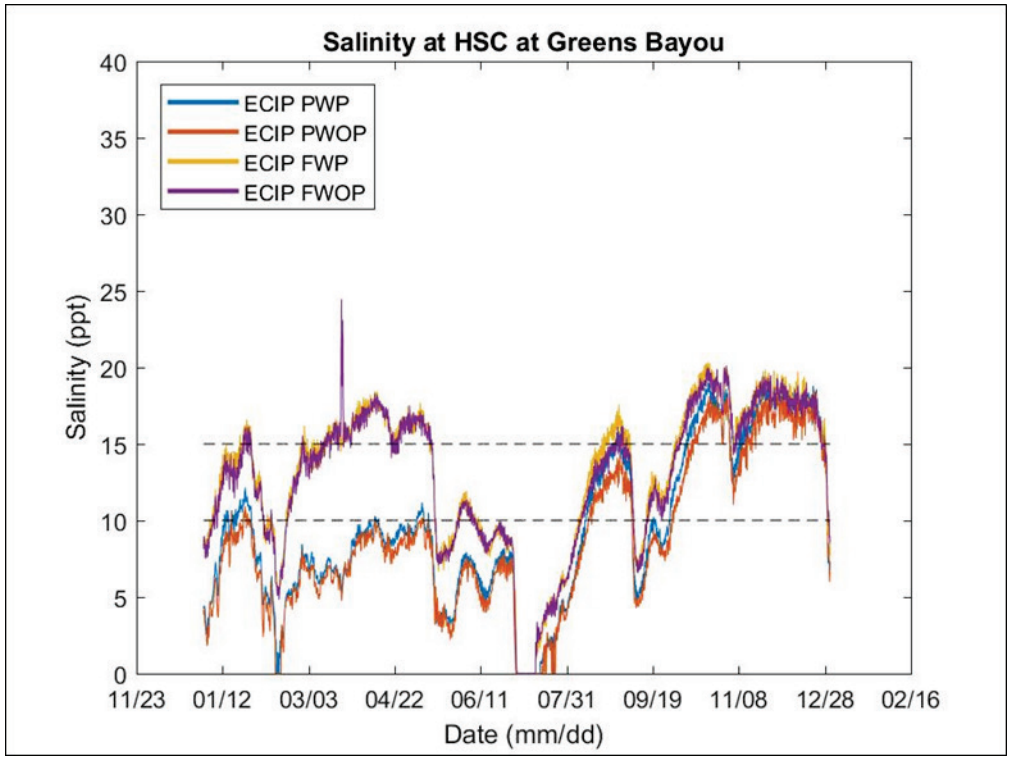


Figure 13. Maximum, minimum, and mean salinity at HSC at Greens Bayou.

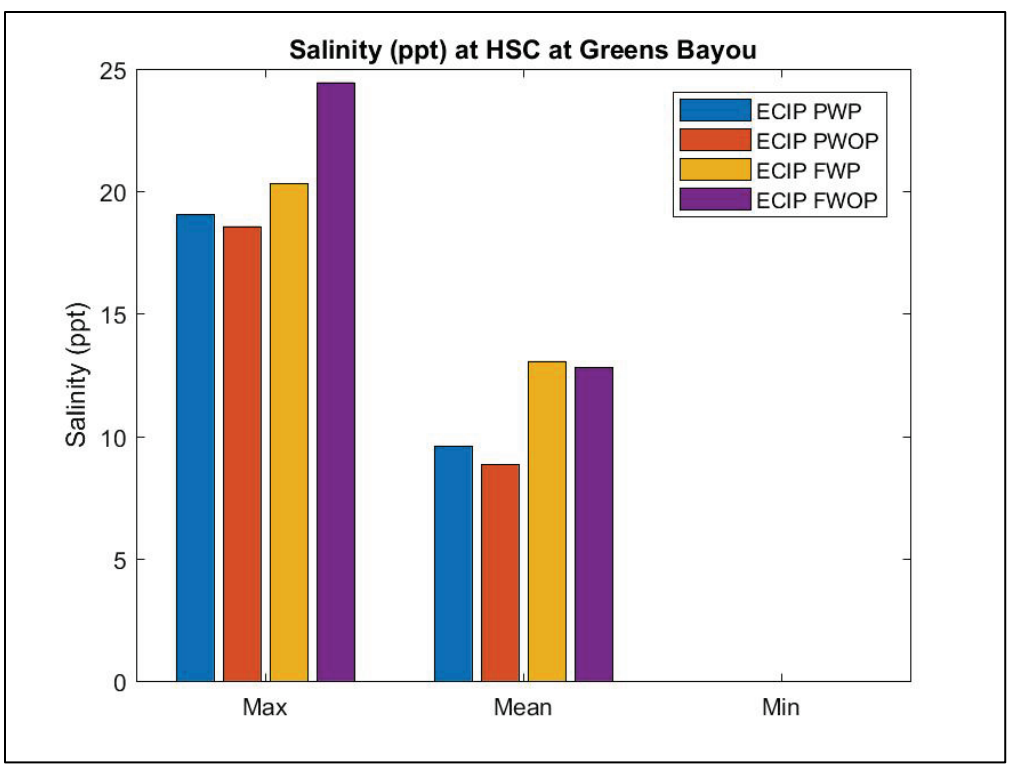


Figure 14. Percent-less-than salinity at HSC at Greens Bayou.

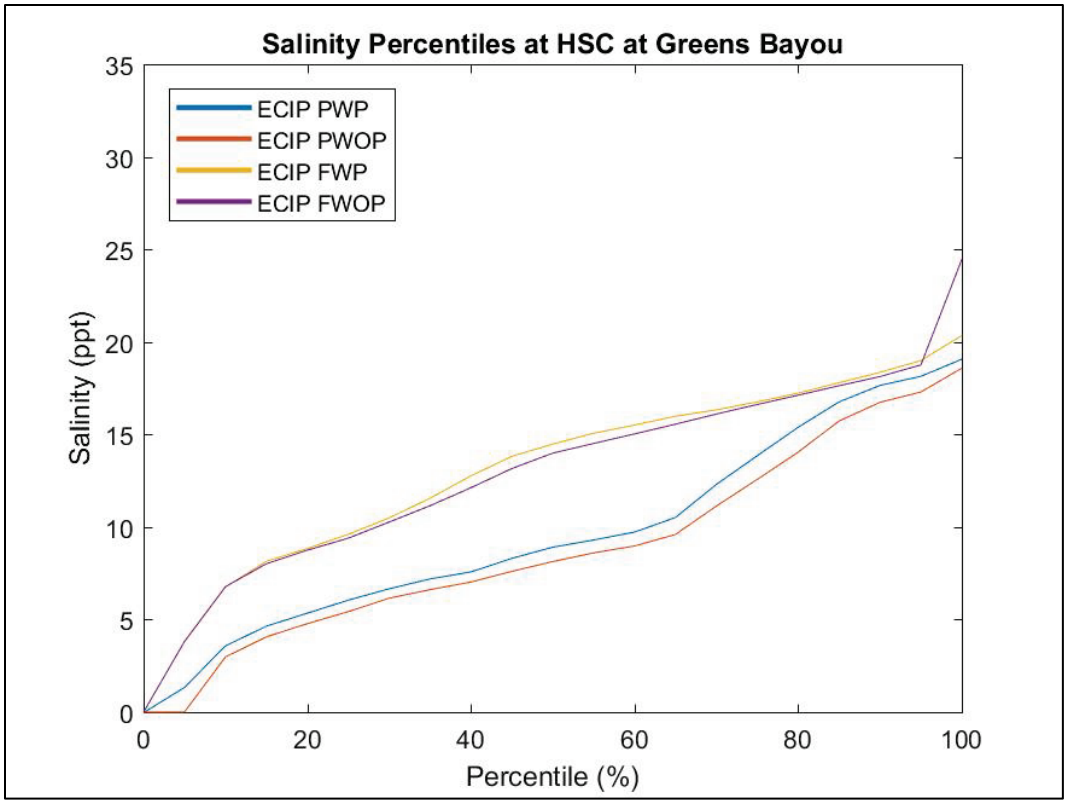


Figure 15. Vertical salinity profile at HSC at Greens Bayou.

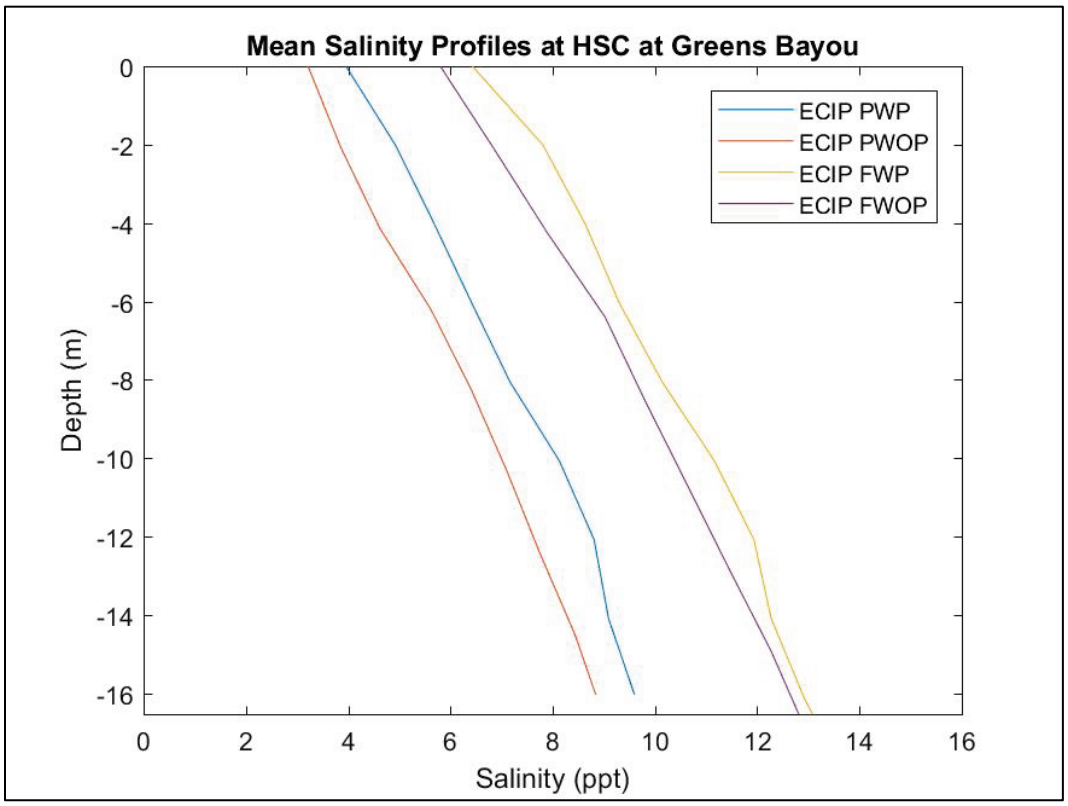


Figure 16. Salinity time history at HSC at Goat Island.

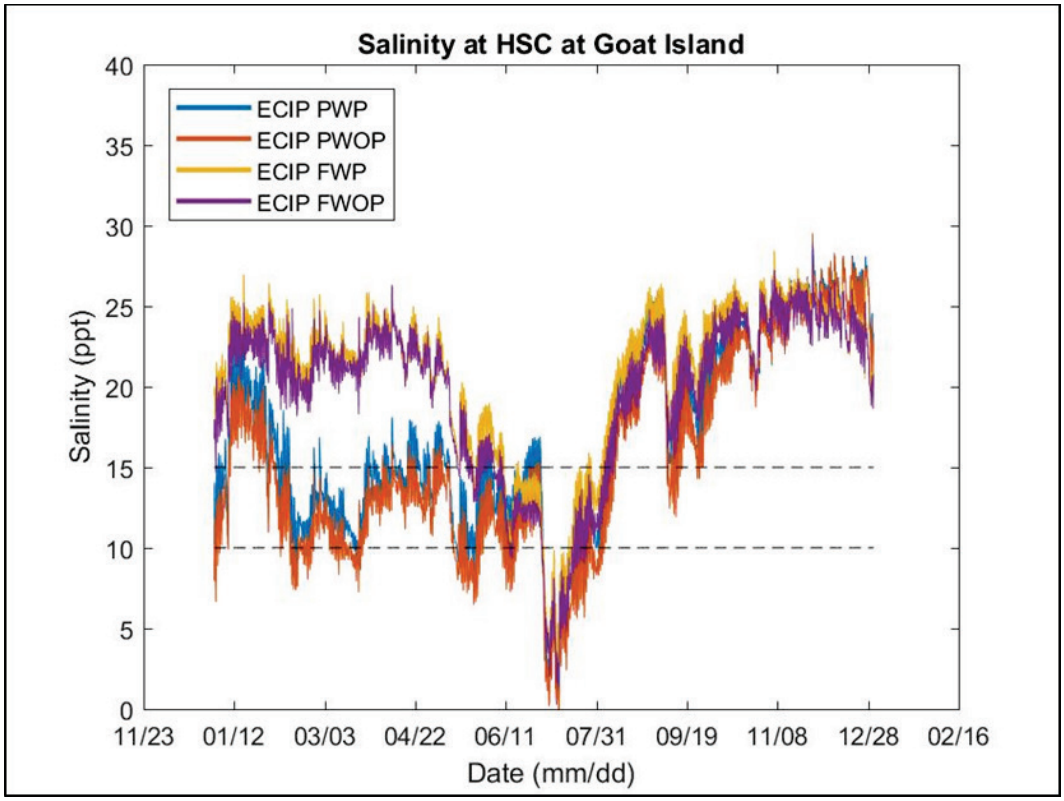


Figure 17. Maximum, minimum, and mean salinity at HSC at Goat Island.

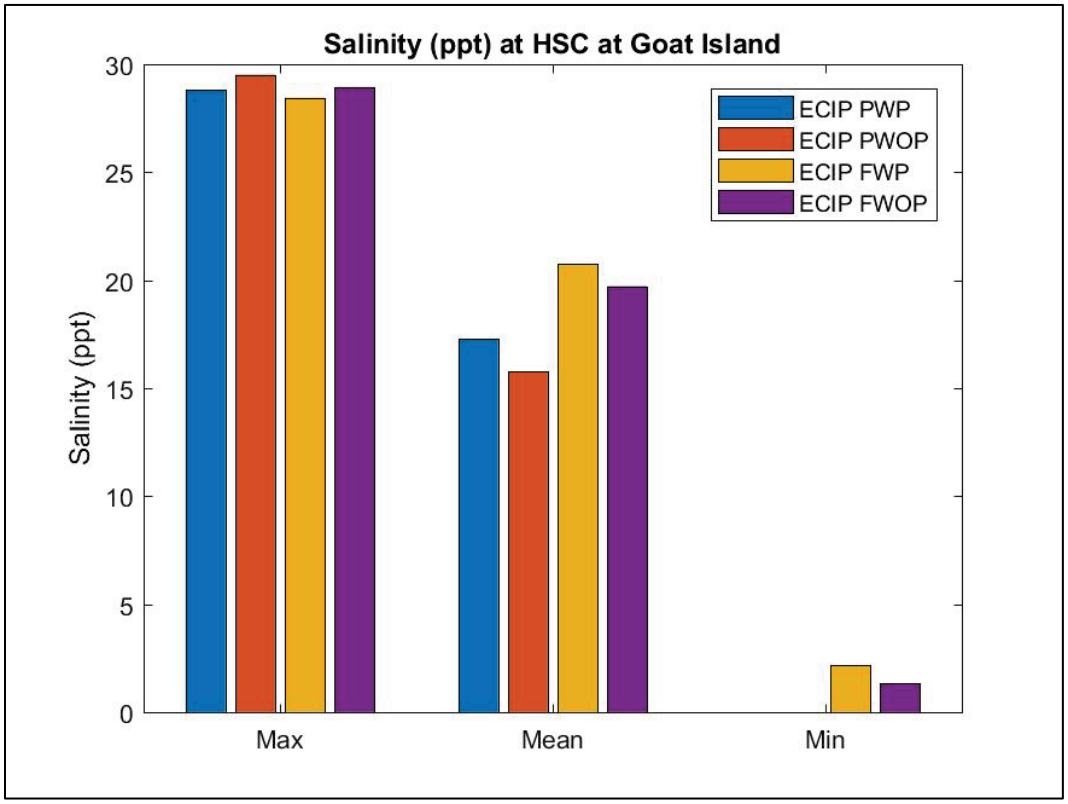


Figure 18. Percent-less-than salinity at HSC at Goat Island.

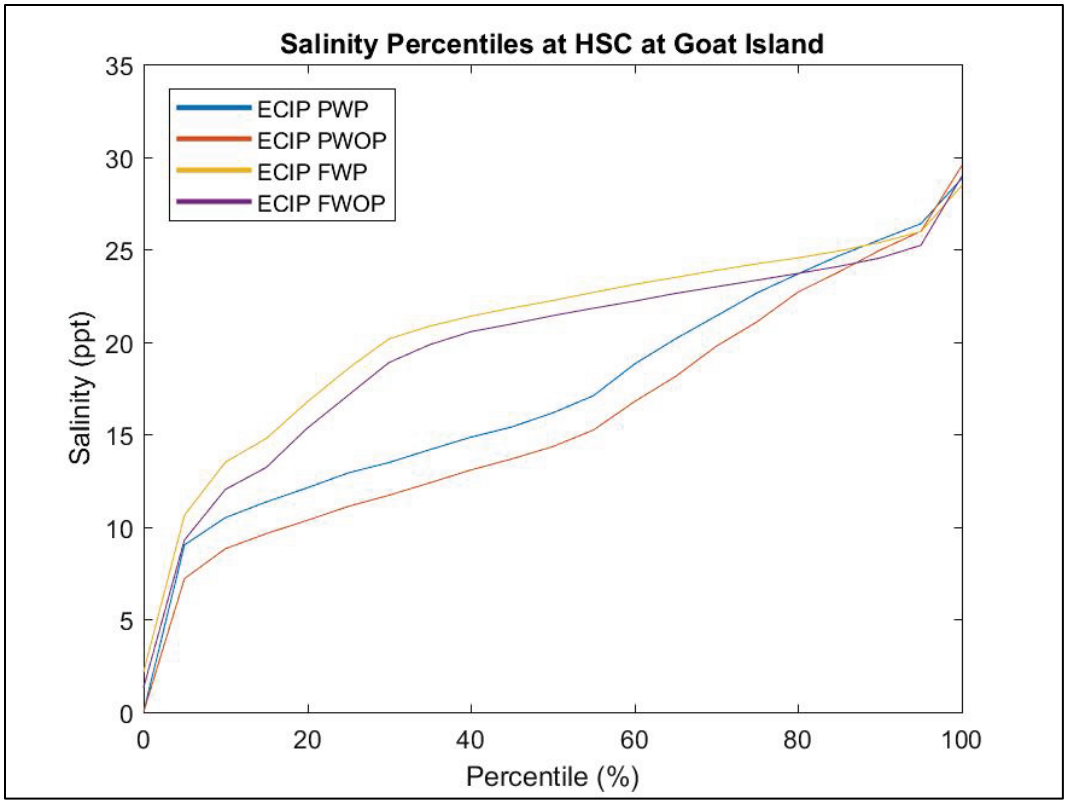


Figure 19. Vertical salinity profile at HSC at Goat Island.

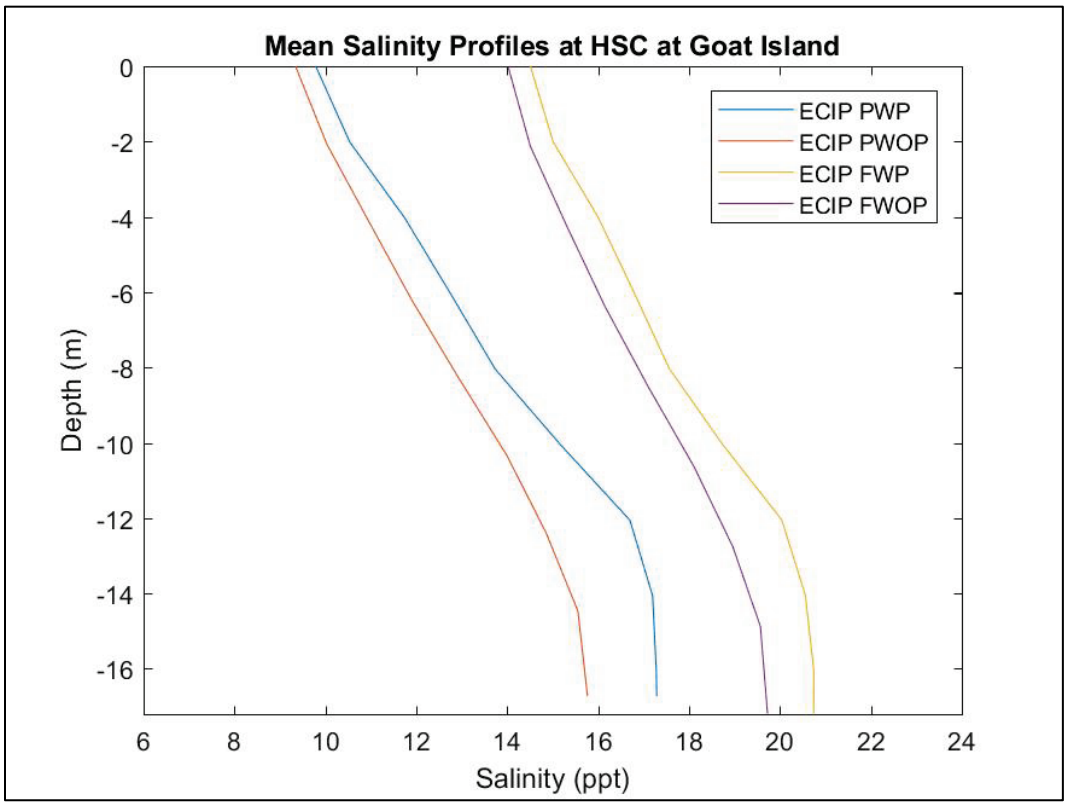


Figure 20. Salinity time history at HSC at Morgan's Point.

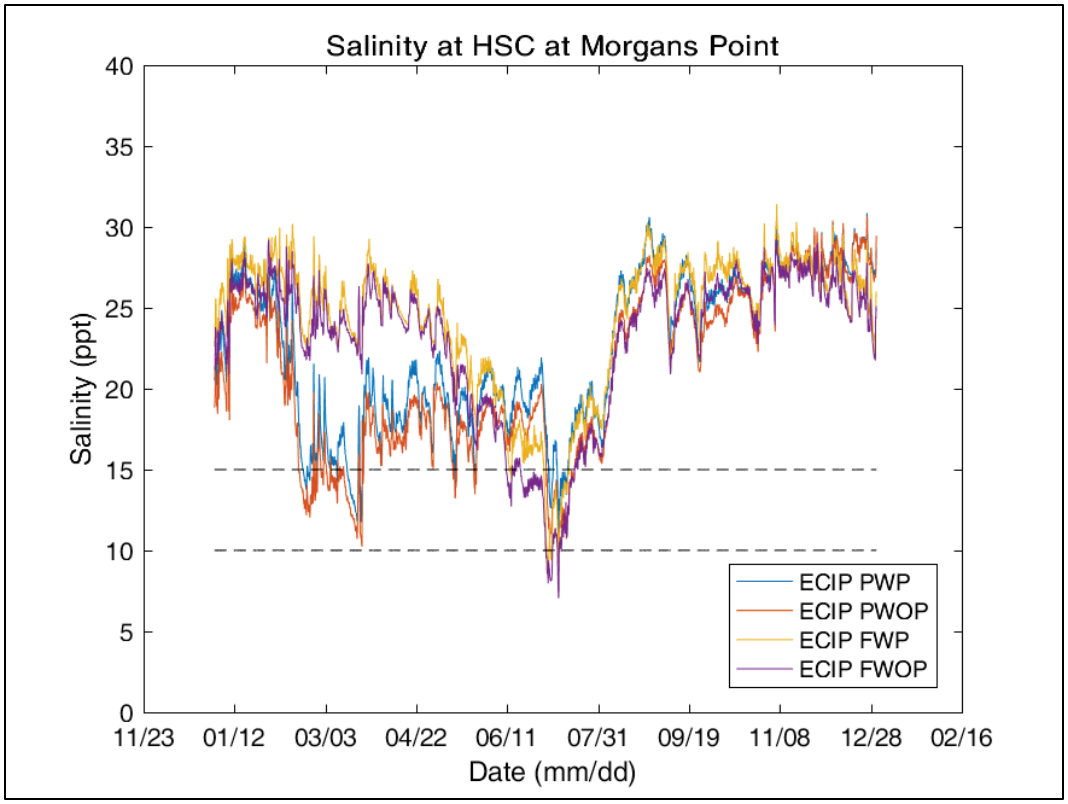


Figure 21. Maximum, minimum, and mean salinity at HSC at Morgan's Point.

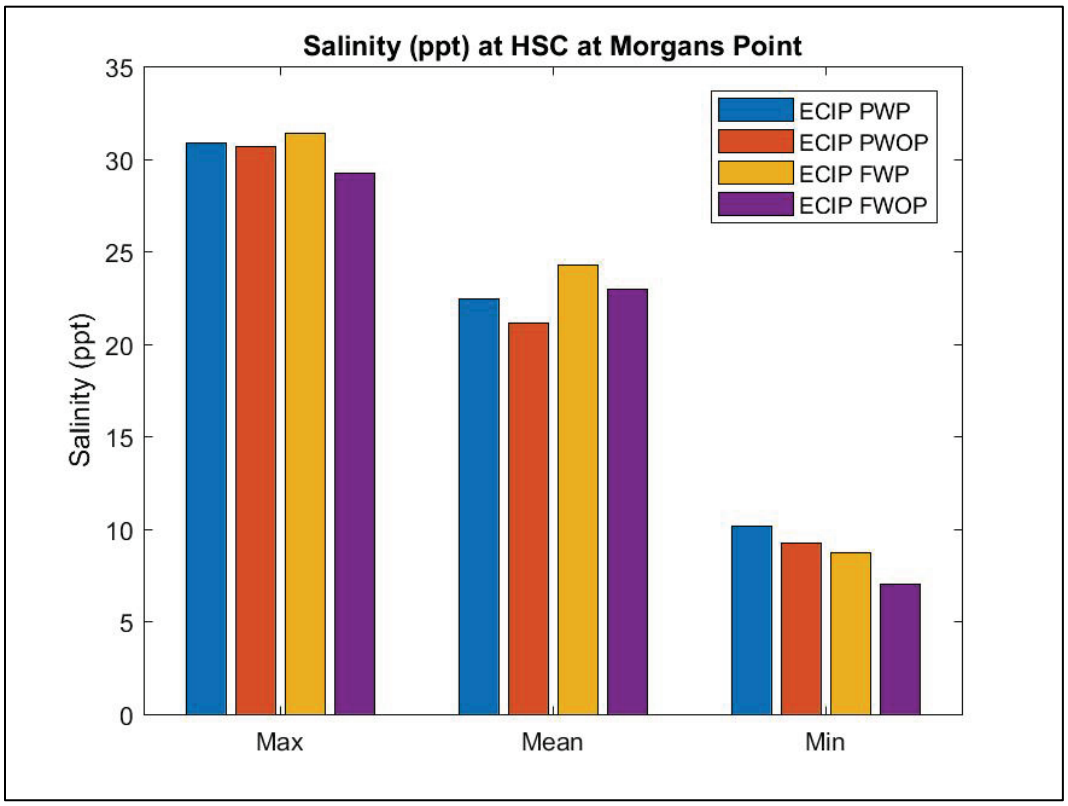


Figure 22. Percent-less-than salinity at HSC at Morgan's Point.

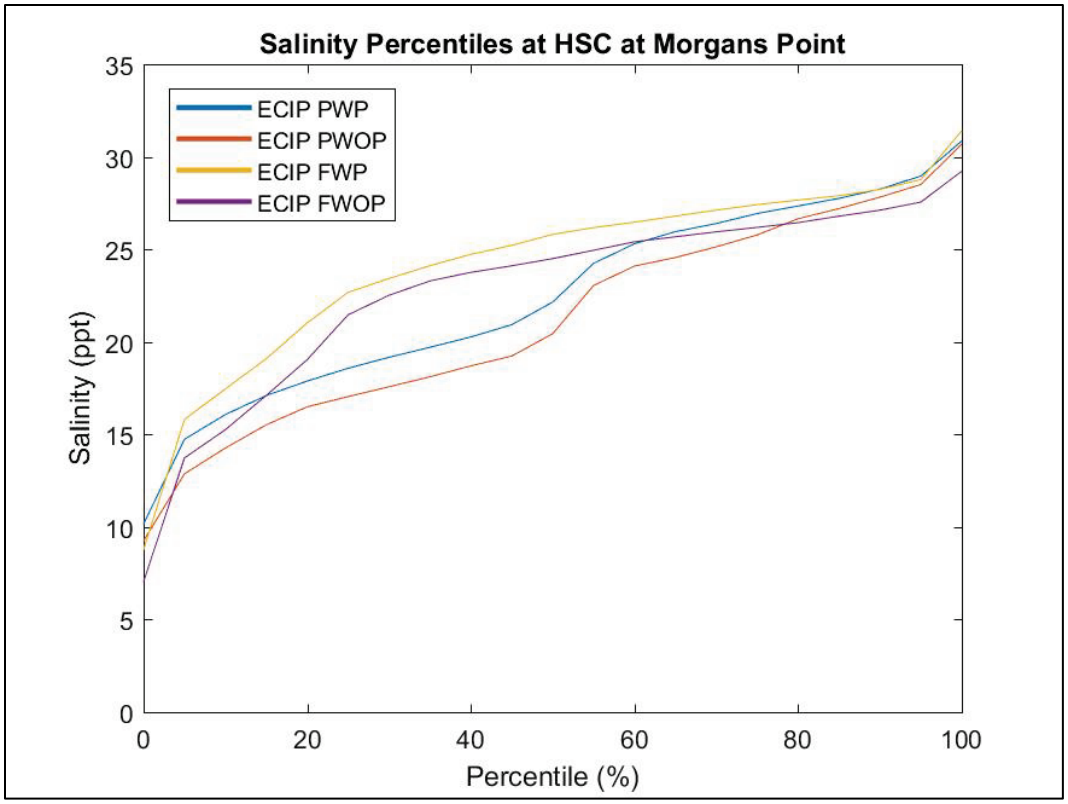


Figure 23. Vertical salinity profile at HSC at Morgan's Point.

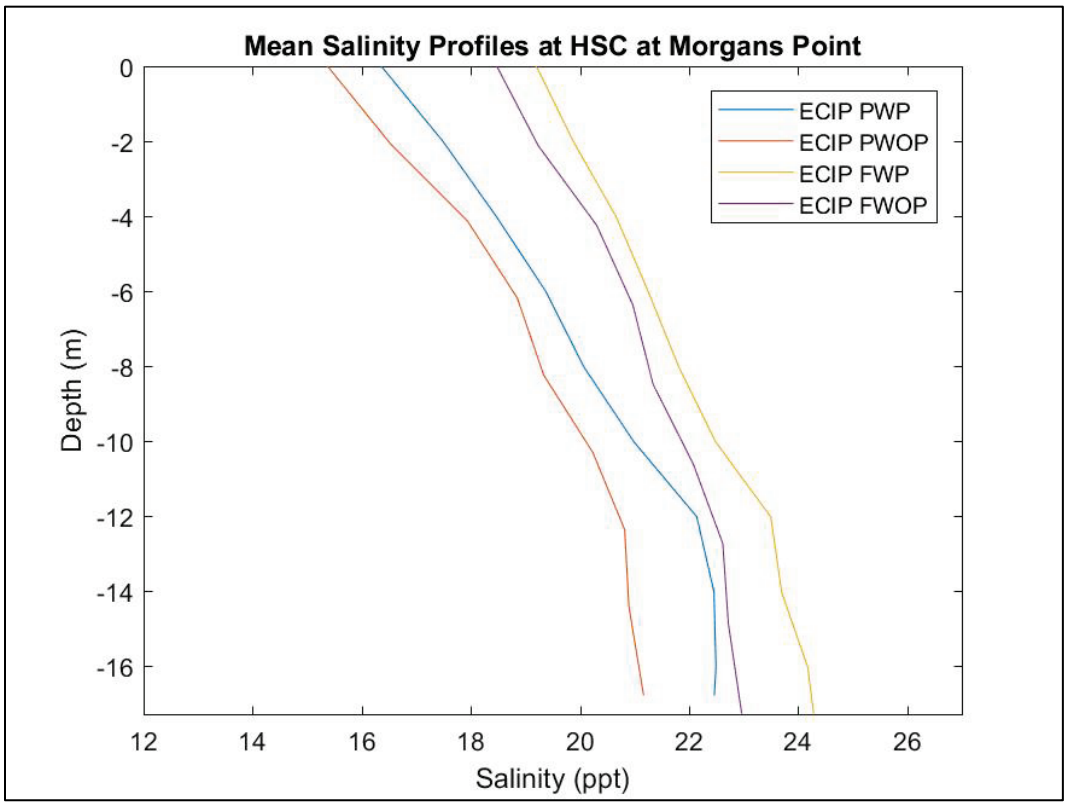


Figure 24. Salinity time history at HSC at Lower Galveston Bay.

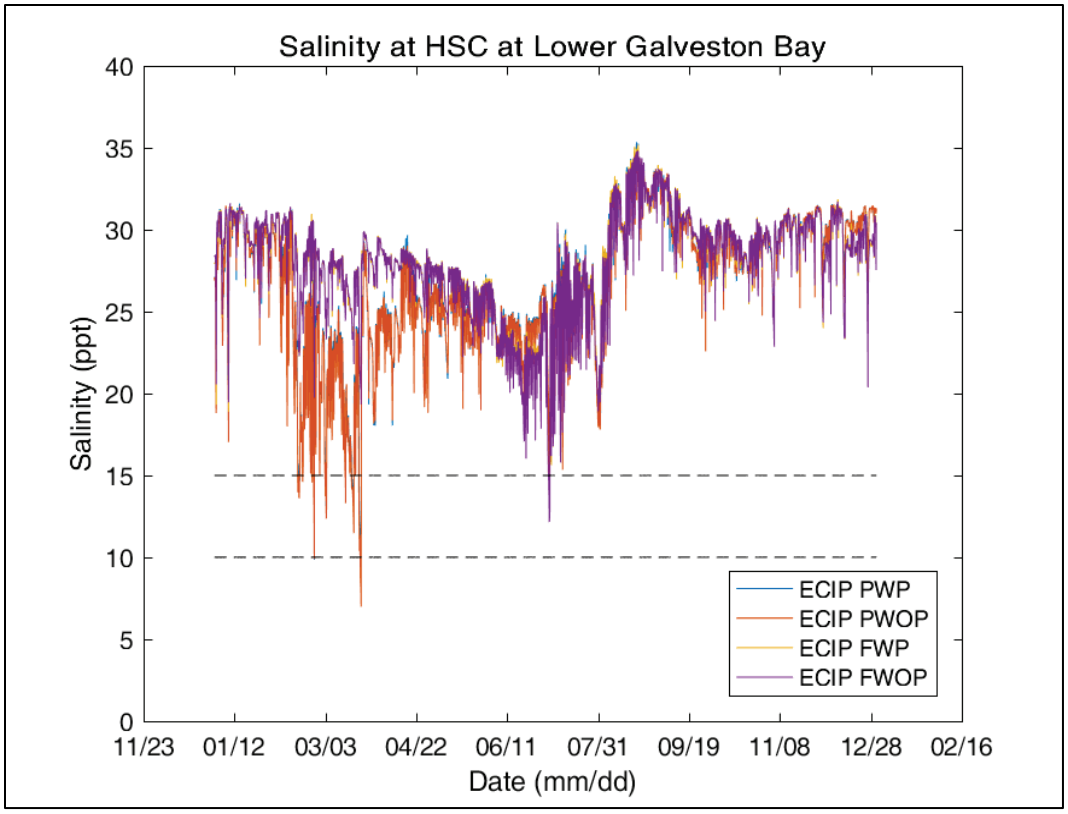


Figure 25. Maximum, minimum, and mean salinity at HSC at Lower Galveston Bay.

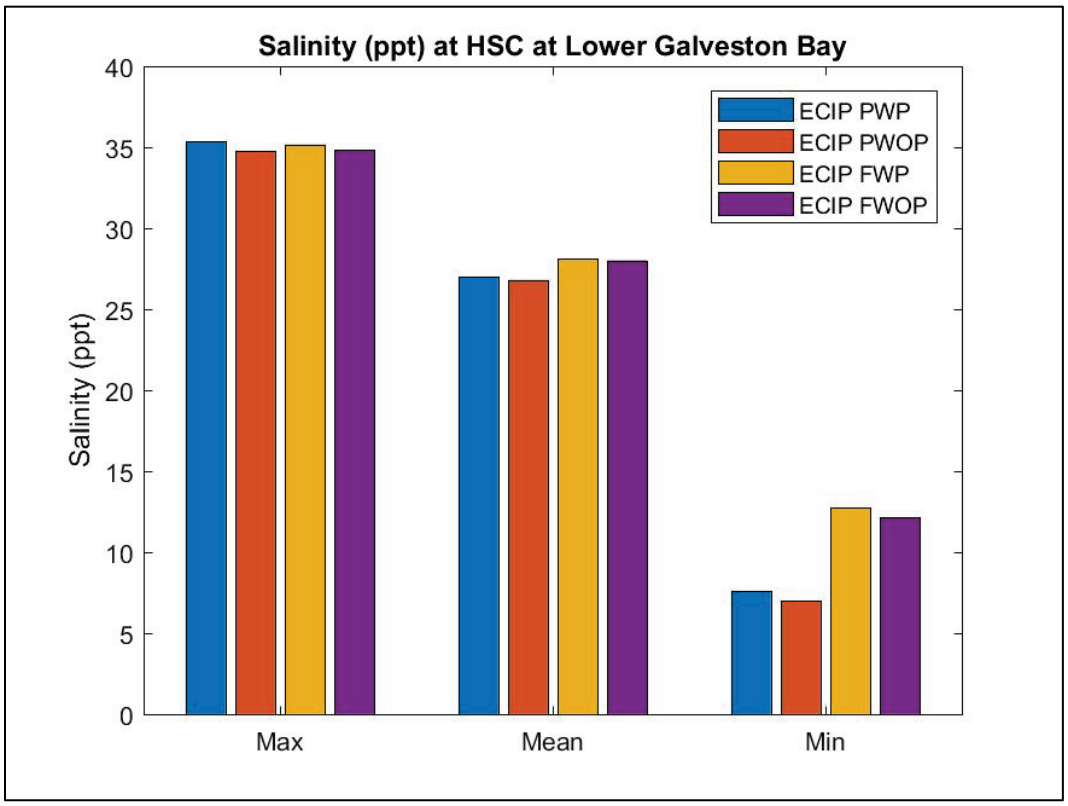


Figure 26. Percent-less-than salinity at HSC at Lower Galveston Bay.

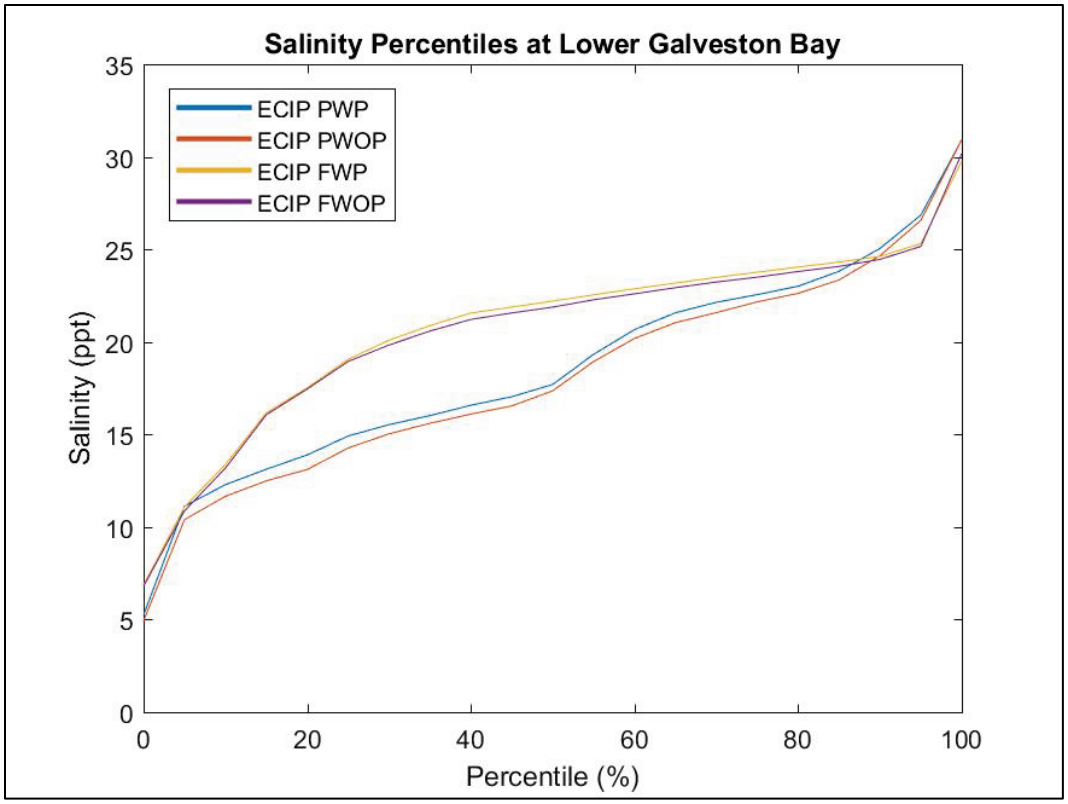


Figure 27. Vertical salinity profile at HSC at Lower Galveston Bay.

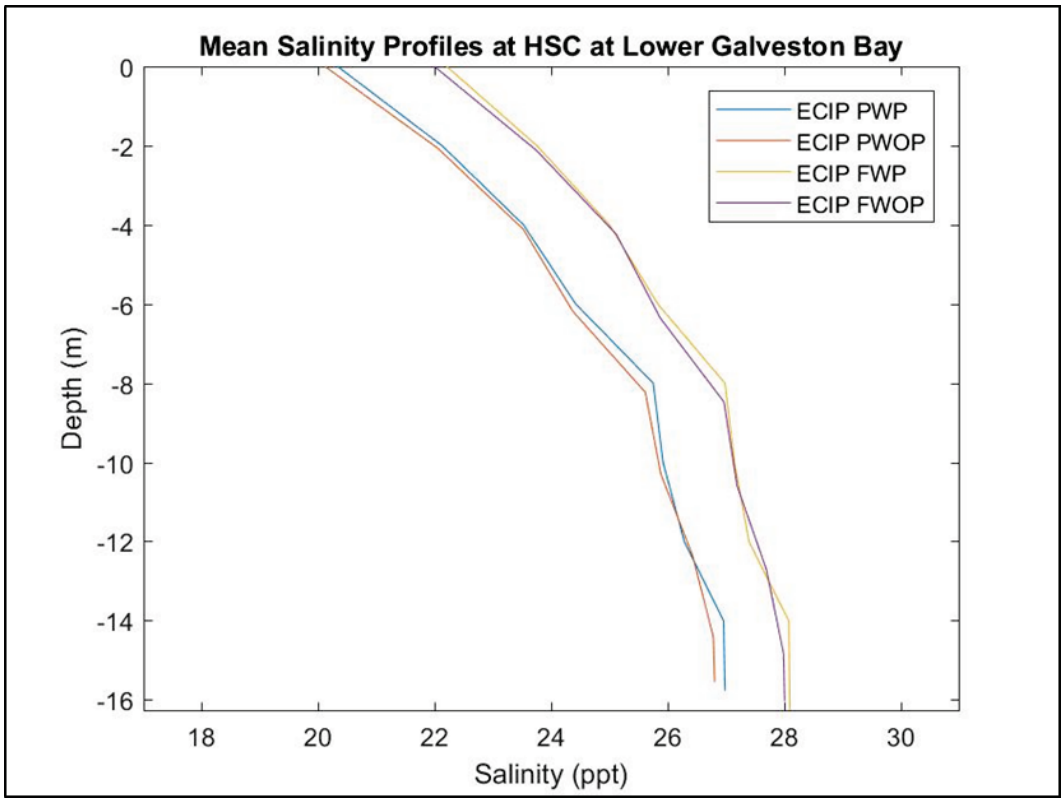


Figure 28. Salinity time history at Upper Galveston Bay 2.

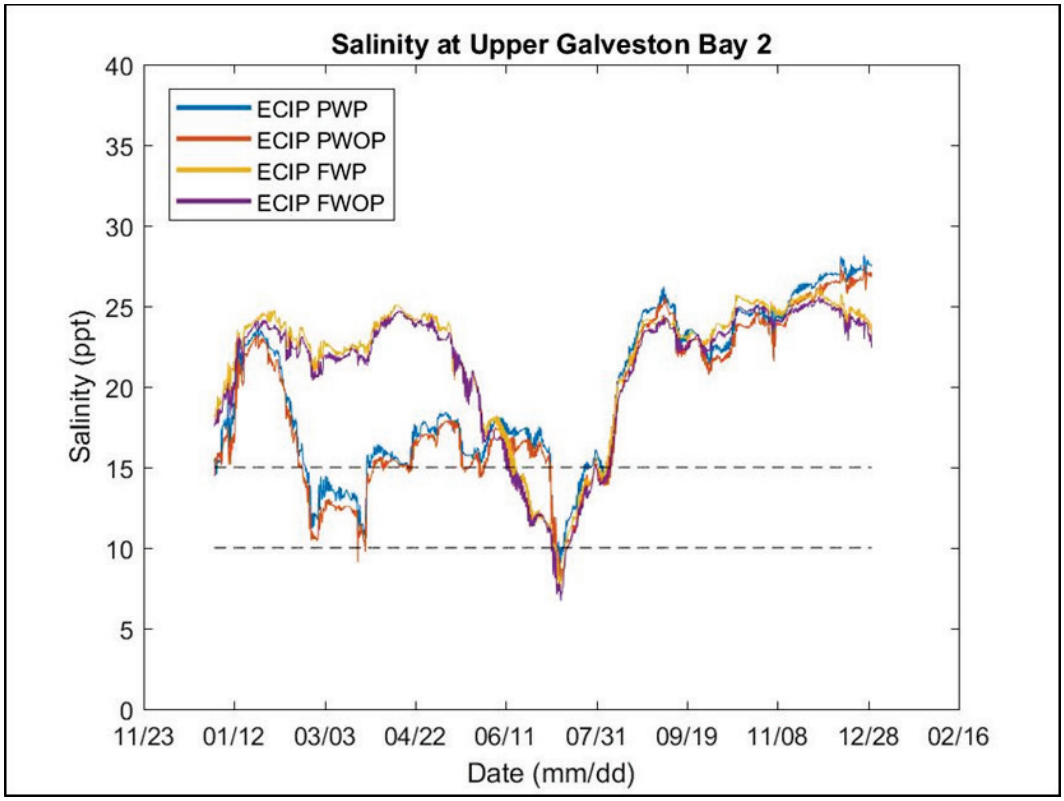


Figure 29. Maximum, minimum, and mean salinity at Upper Galveston Bay 2.

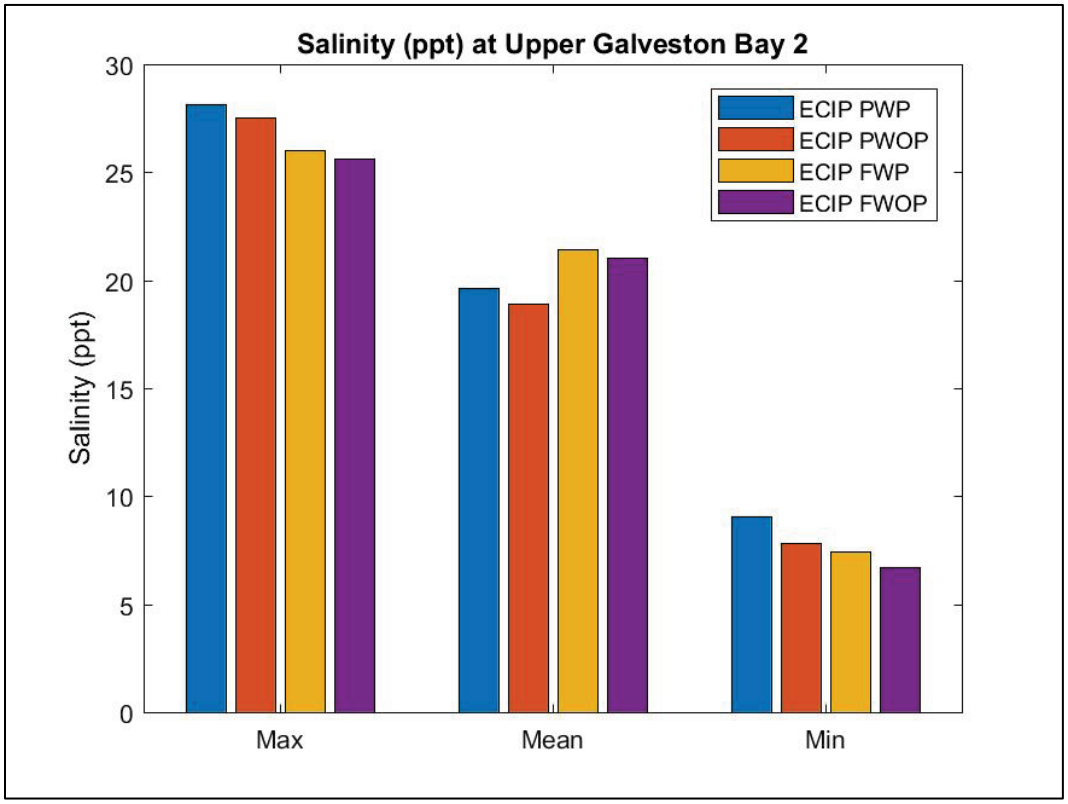


Figure 30. Percent-less-than salinity at Upper Galveston Bay 2.

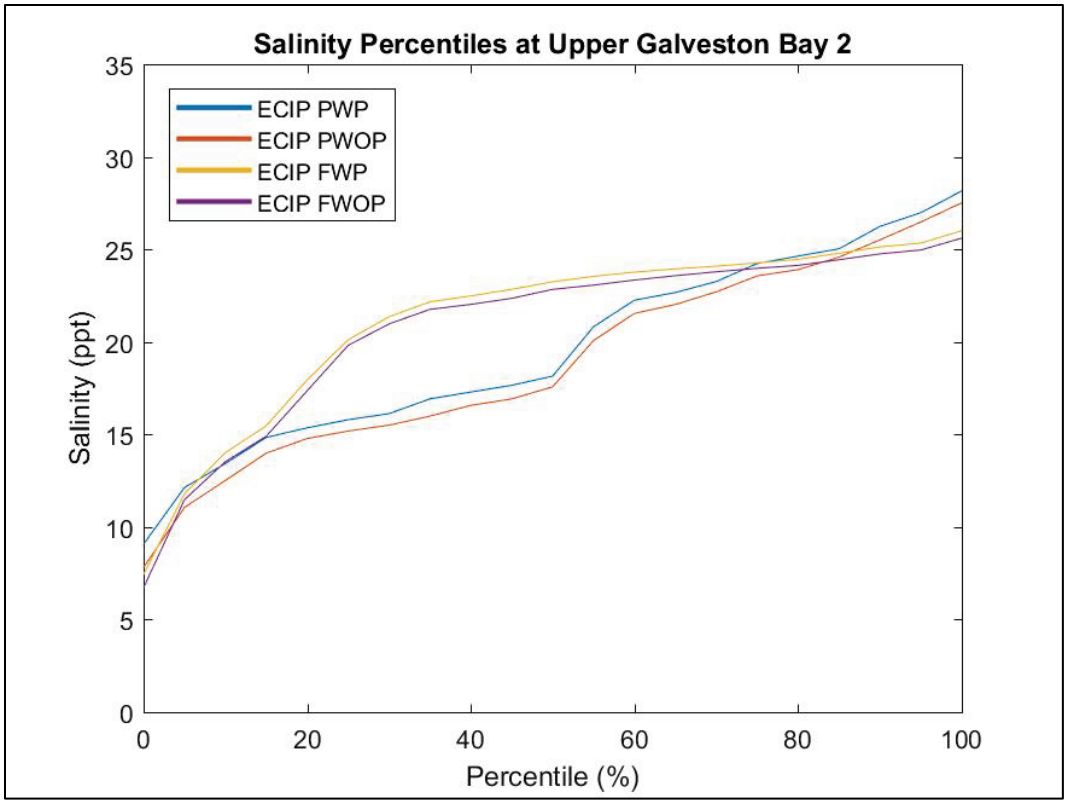


Figure 31. Vertical salinity profile at Upper Galveston Bay 2.

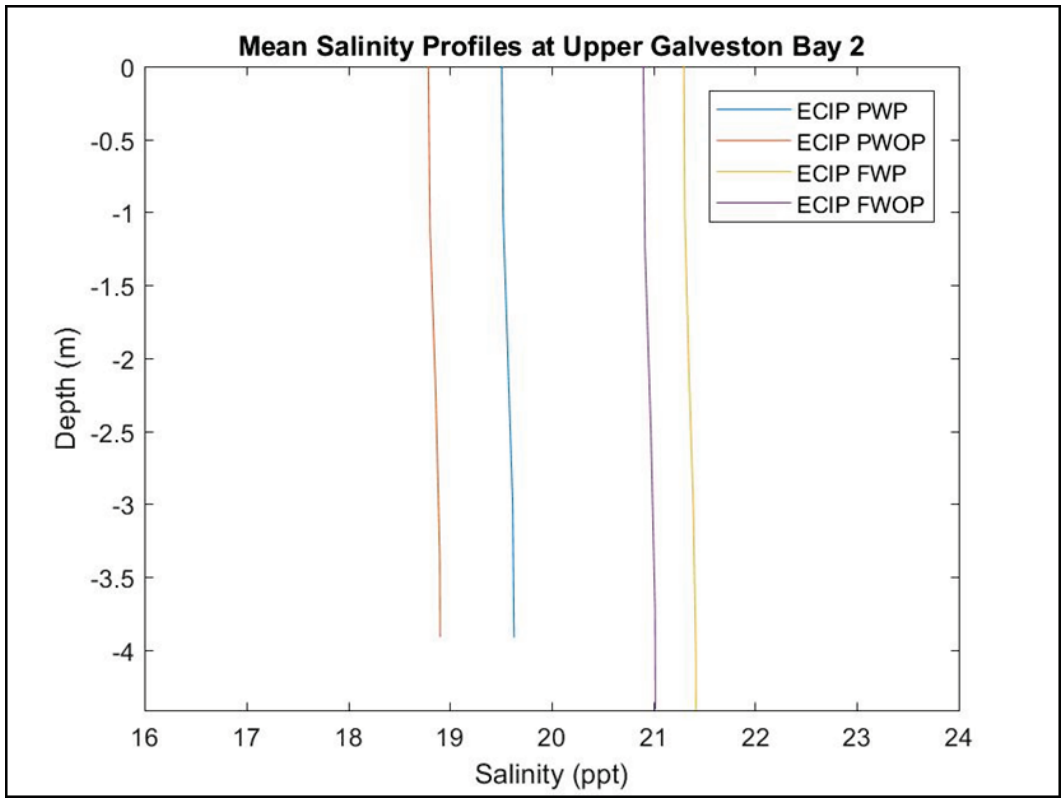


Figure 32. Salinity time history at Upper Trinity Bay.

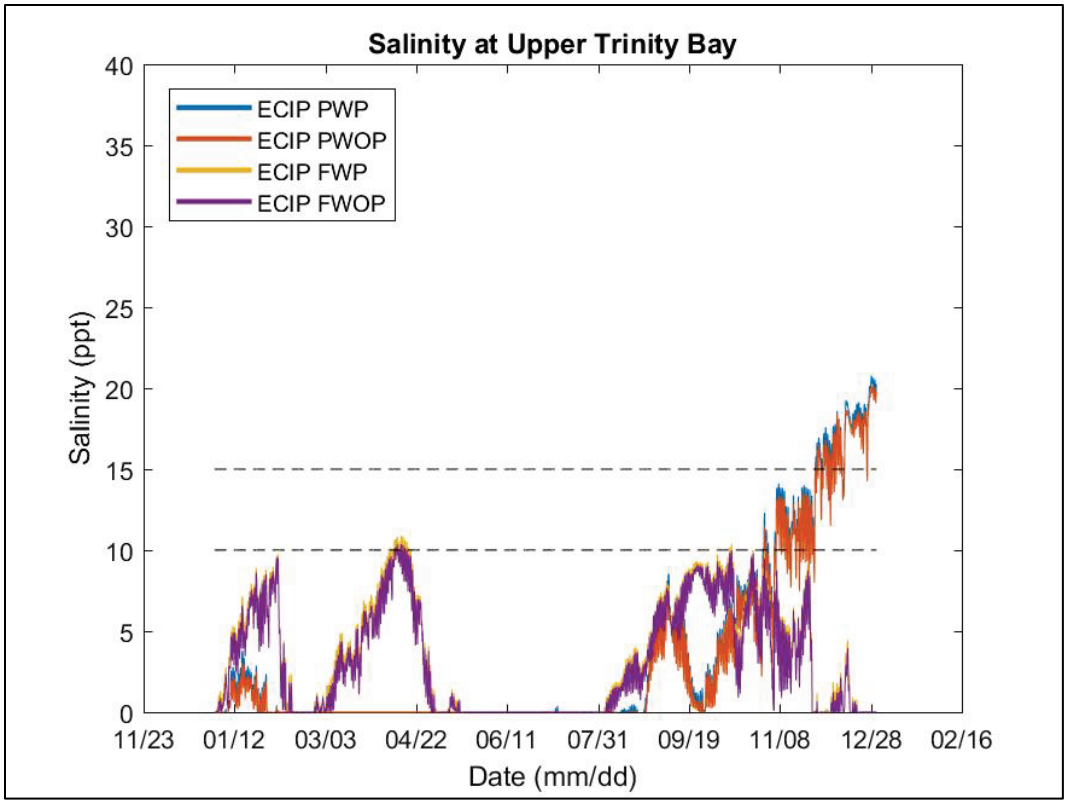


Figure 33. Maximum, minimum, and mean salinity at Upper Trinity Bay.

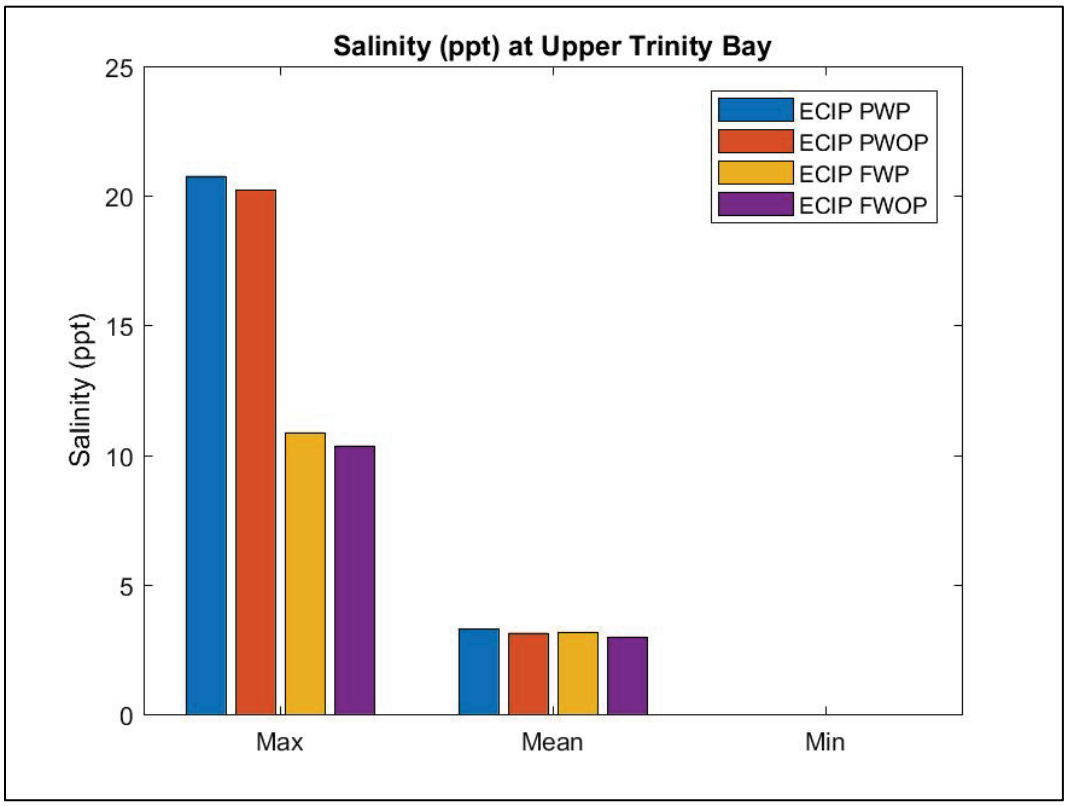


Figure 34. Percent-less-than salinity at Upper Trinity Bay.

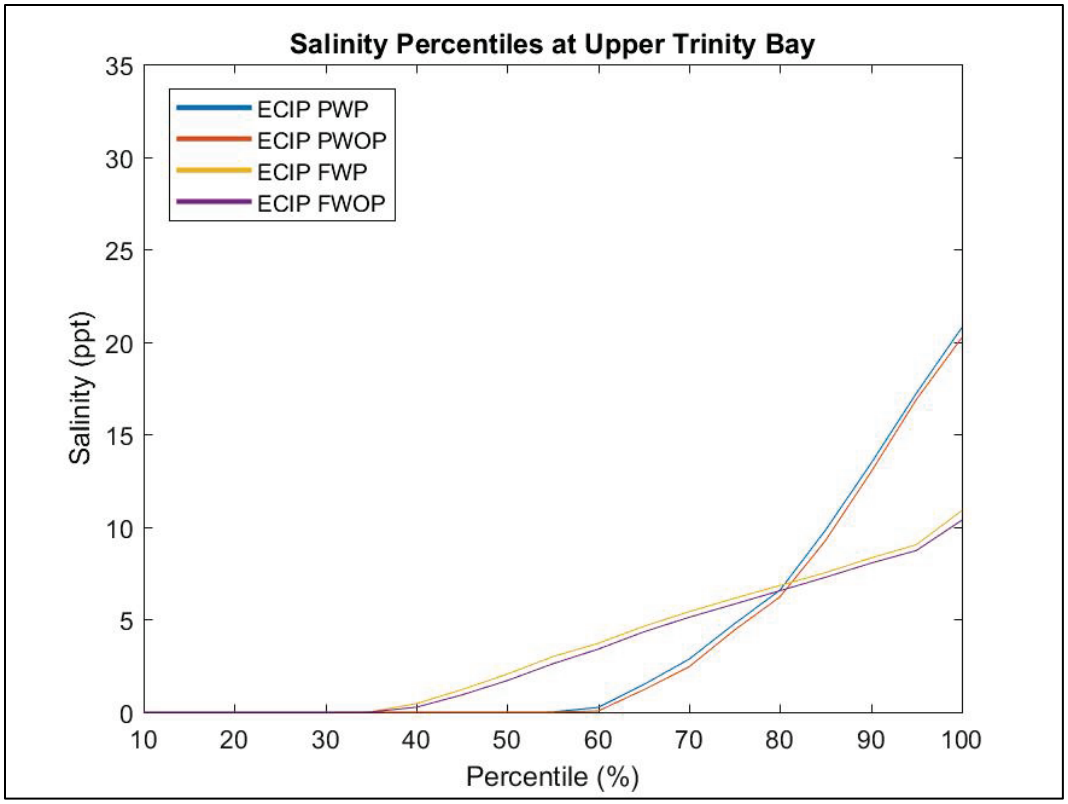


Figure 35. Vertical salinity profile at Upper Trinity Bay.

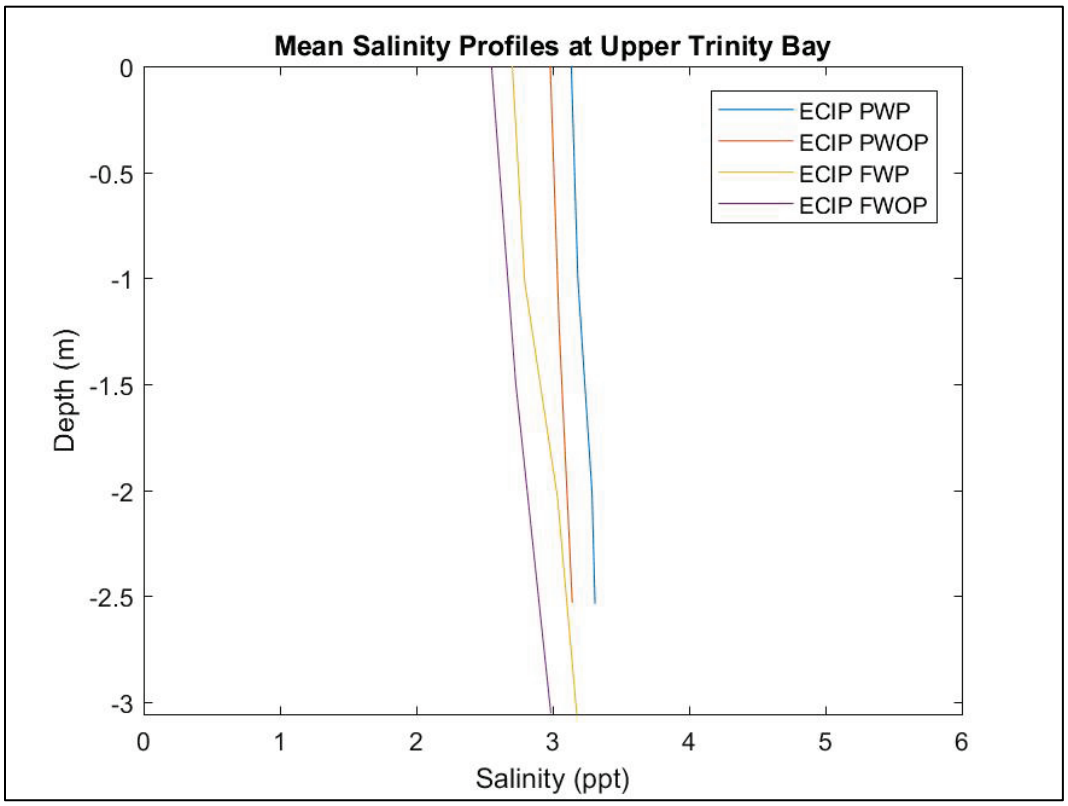


Figure 36. Salinity time history at Mid West Bay.

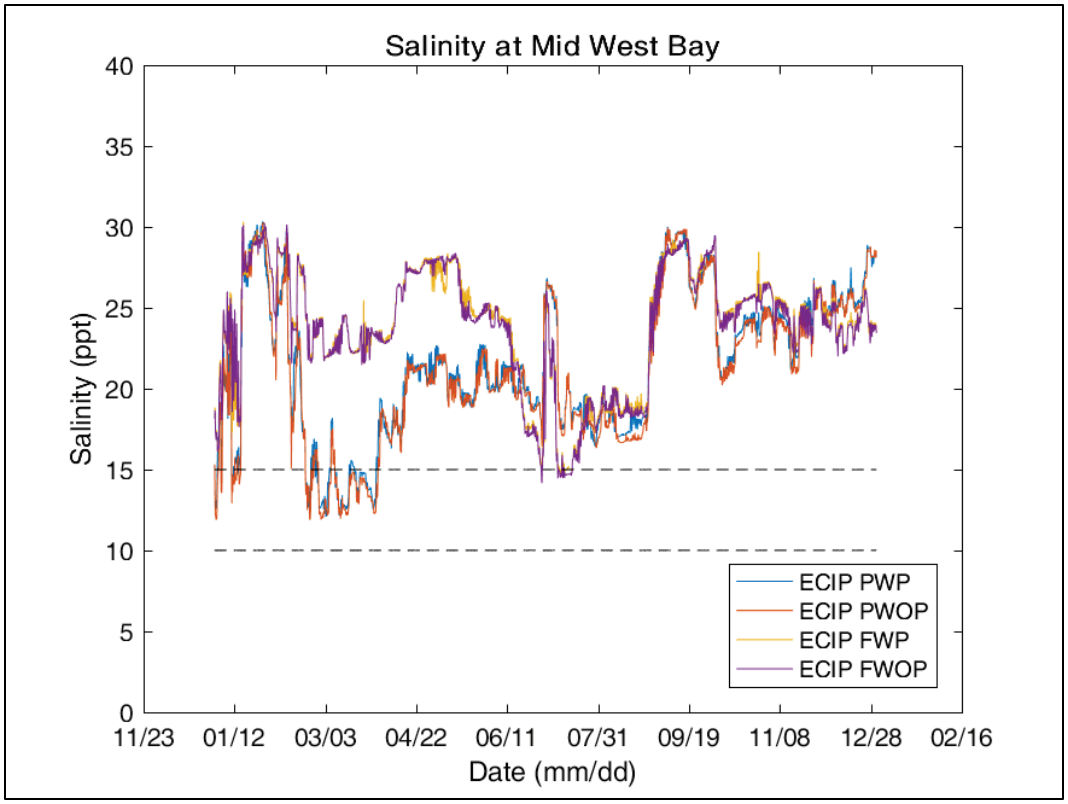


Figure 37. Maximum, minimum, and mean salinity at Mid West Bay.

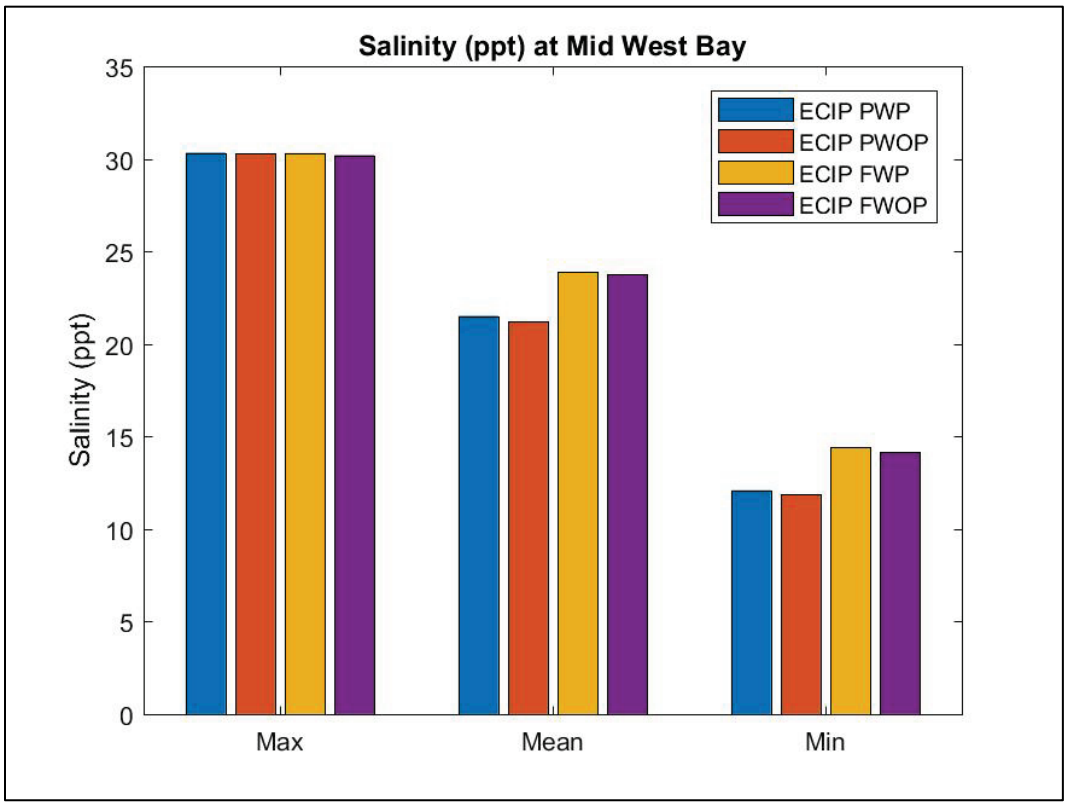


Figure 38. Percent-less-than salinity at Mid West Bay.

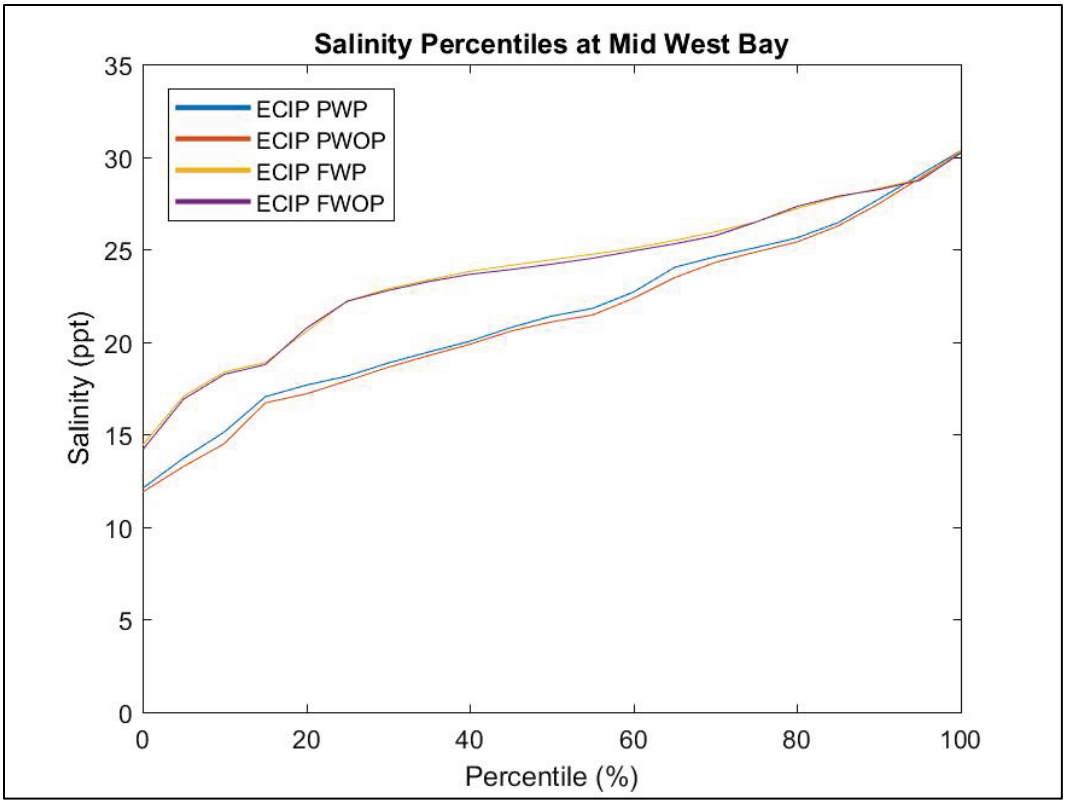


Figure 39. Vertical salinity profile at Mid West Bay.

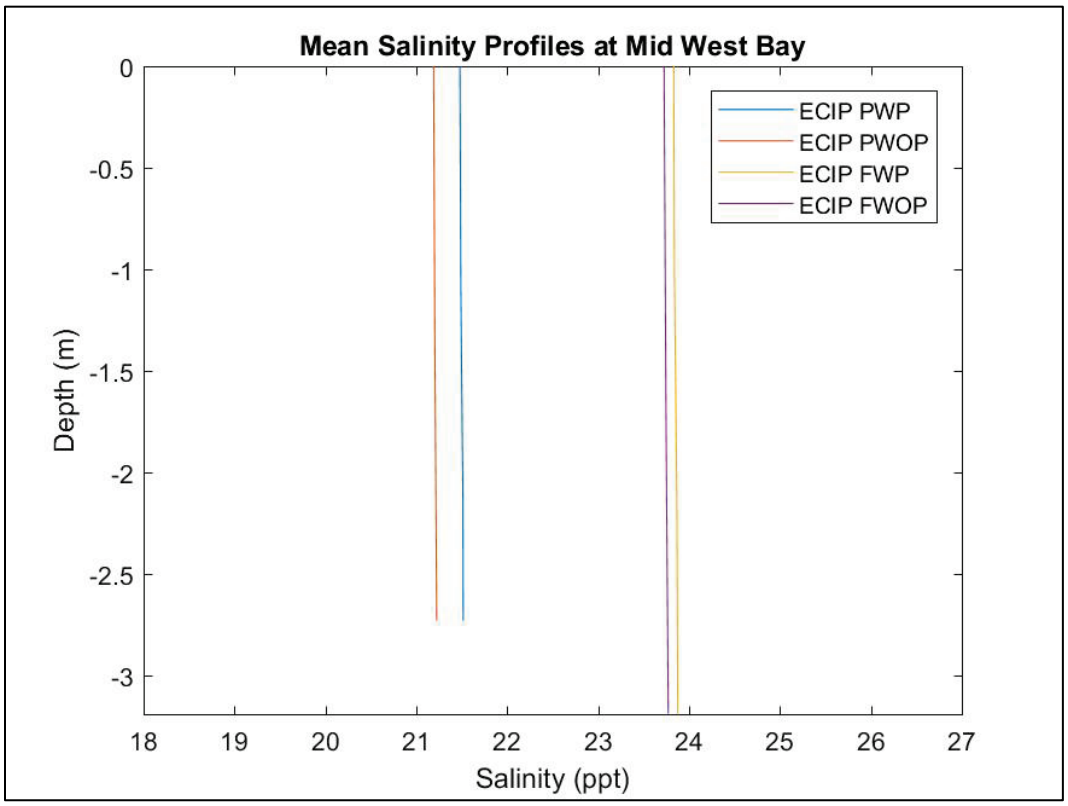


Figure 40. Salinity time history at Mid East Bay.

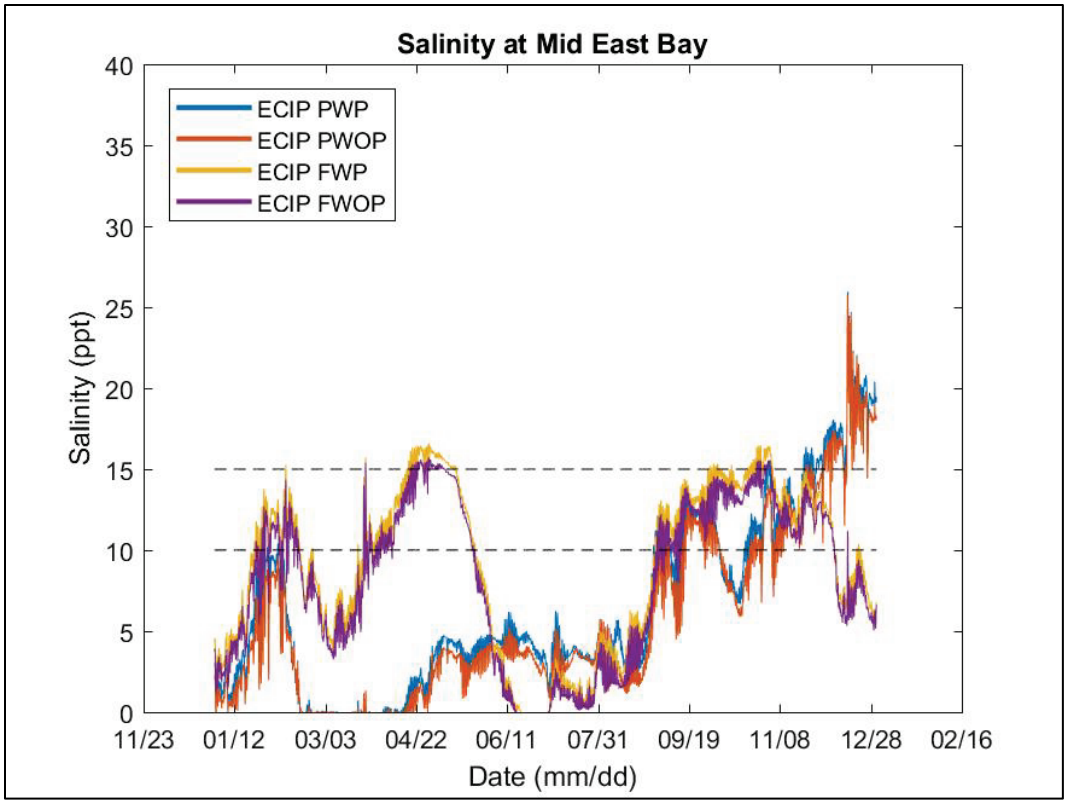


Figure 41. Maximum, minimum, and mean salinity at Mid East Bay.

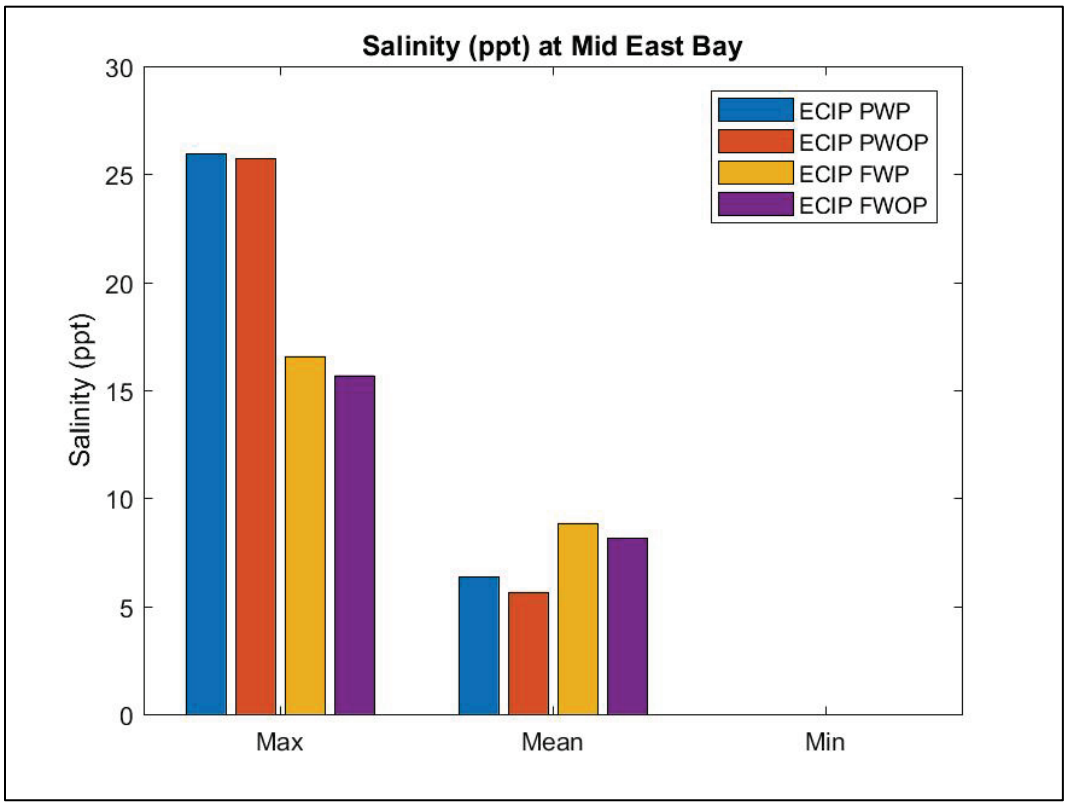


Figure 42. Percent-less-than salinity at Mid East Bay.

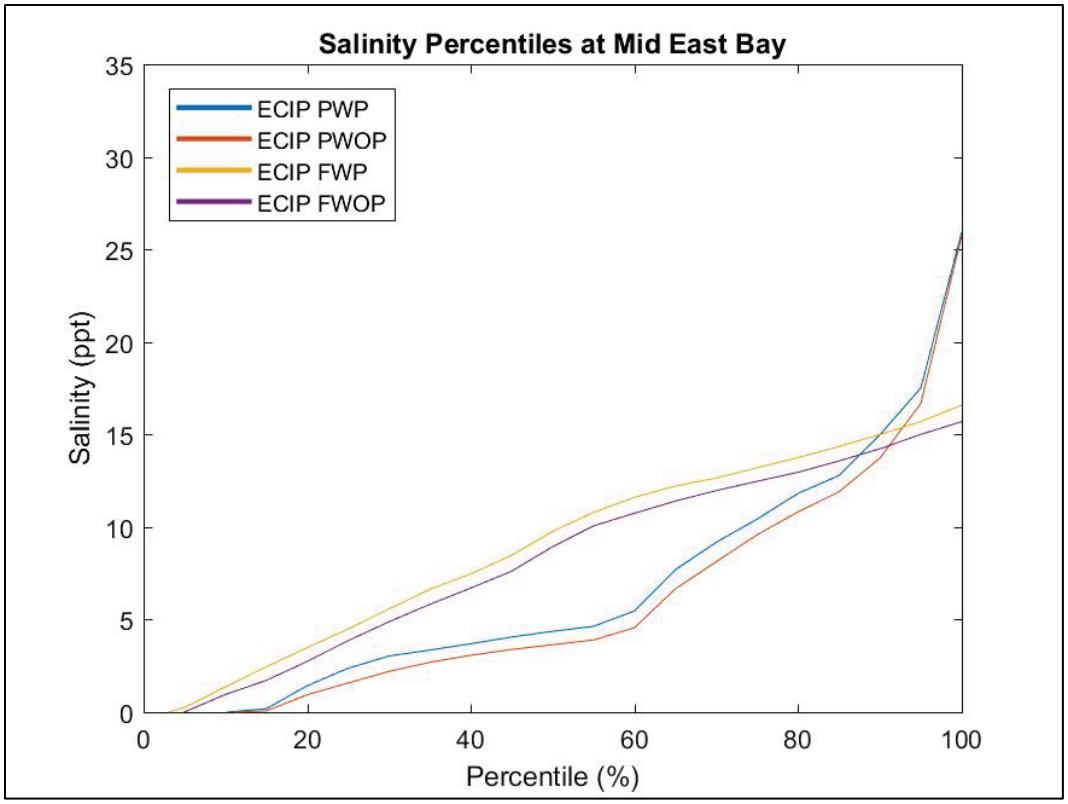
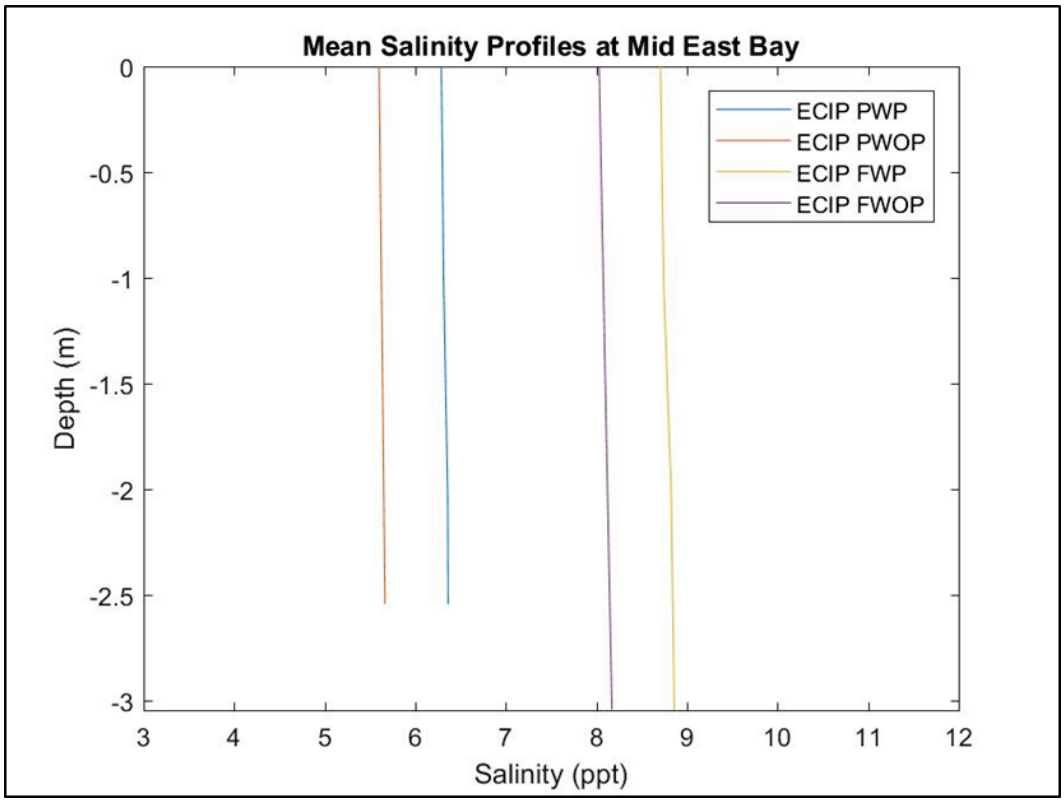


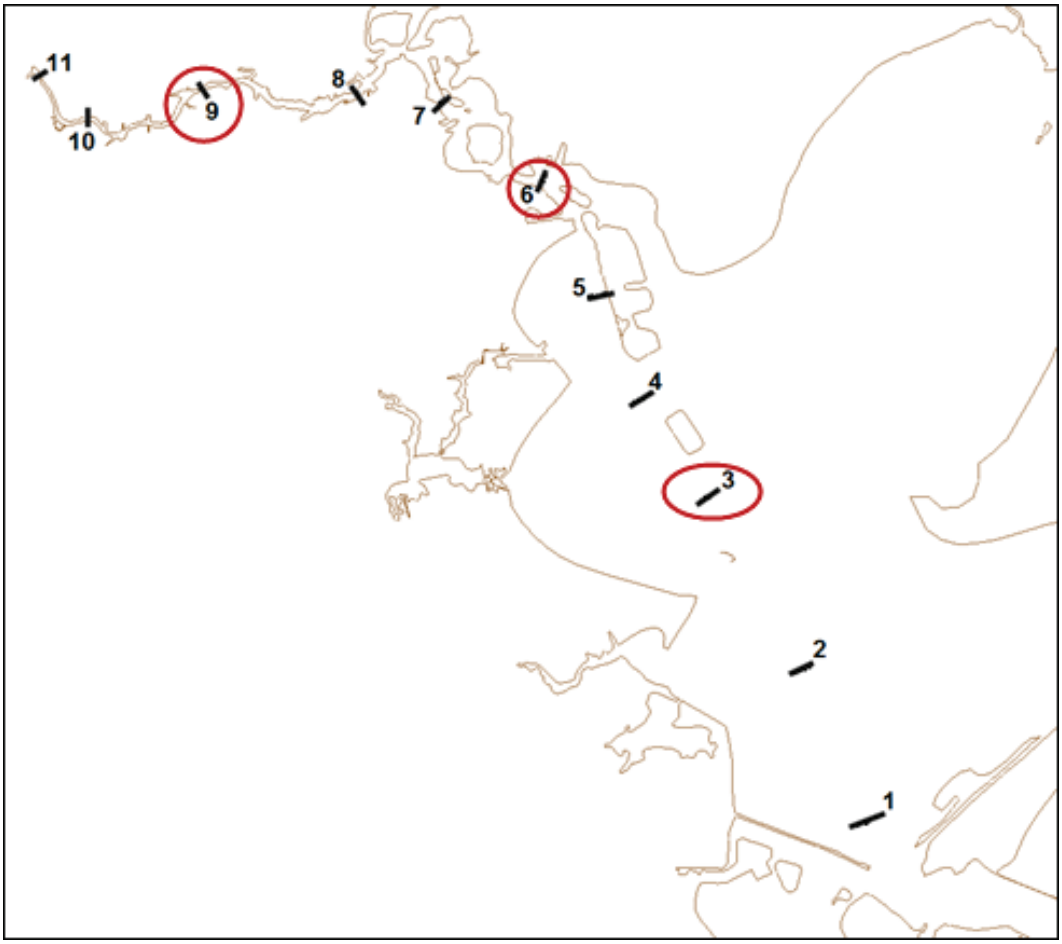
Figure 43. Vertical salinity profile at Mid East Bay.



Cross-sectional salinity analysis

Cross-sectional analysis of mean salinity along the HSC is provided for 11 cross sections beginning near the Texas City Dike and ending near the Houston turning basin. Figure 44 shows the location of these cross sections. Again, a subset of these cross sections (Figure 45 – Figure 47) — those circled in red in Figure 44 — will be provided in the text with all locations included in the appendices.

Figure 44. HSC cross sectional analysis locations. Circled locations discussed in this section.



Again, when viewing these results, focus on changes between the present with and without project separately from the future with and without project to isolate impacts due to the project. The future conditions have changes in the input conditions that make comparisons between present and future results harder to interpret.

Figure 45. Cross section 3 salinity.

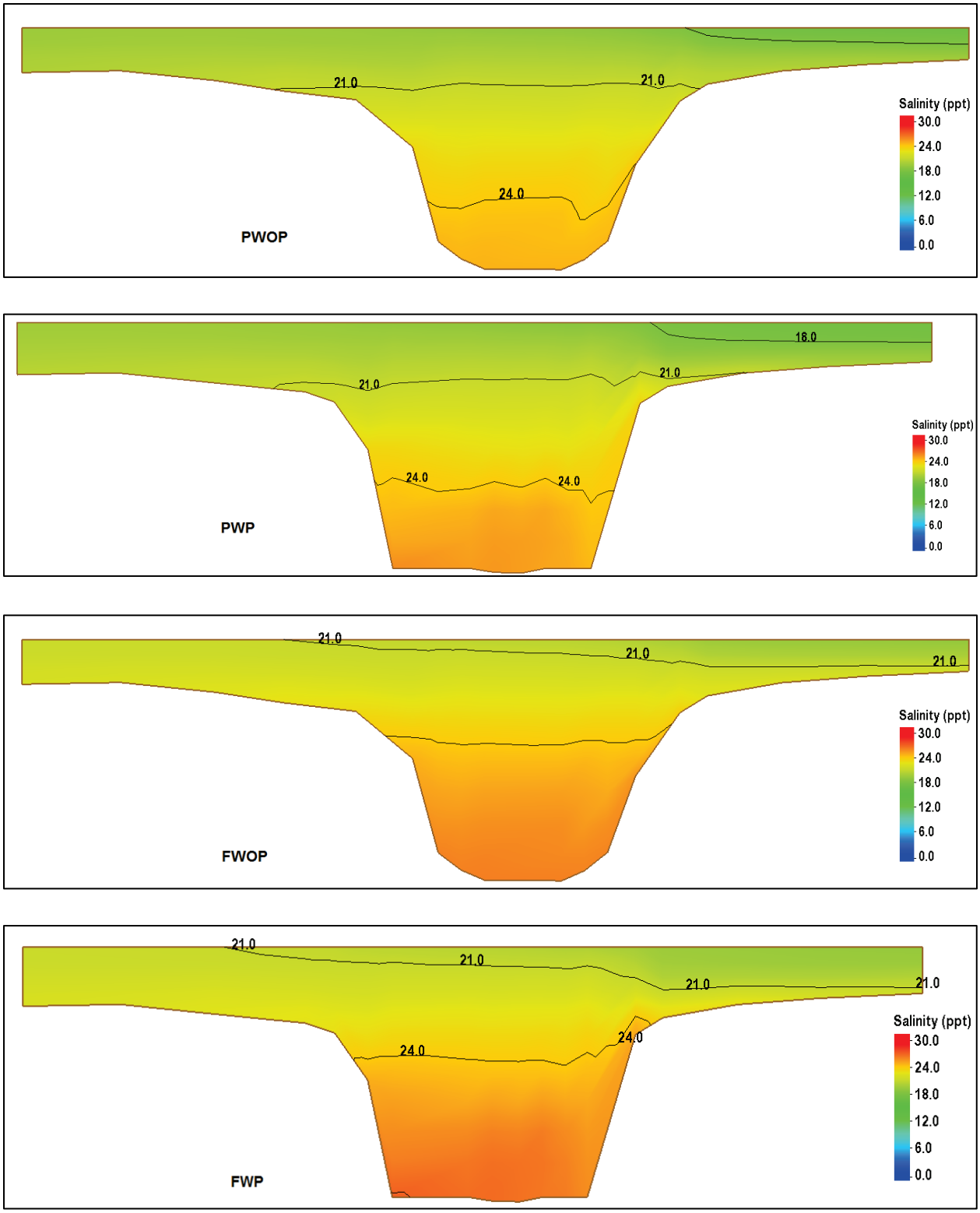


Figure 46. Cross section 6 salinity.

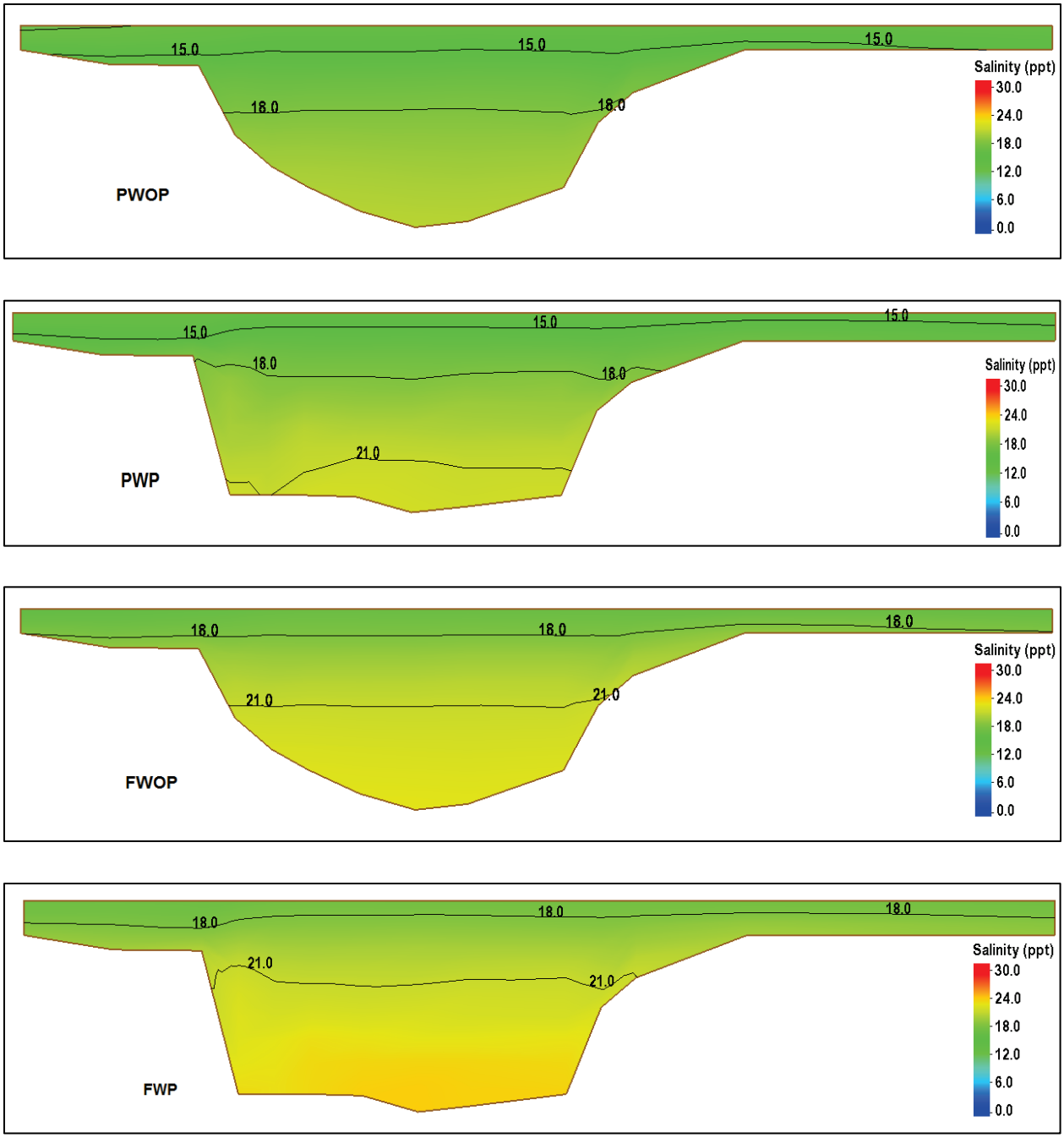
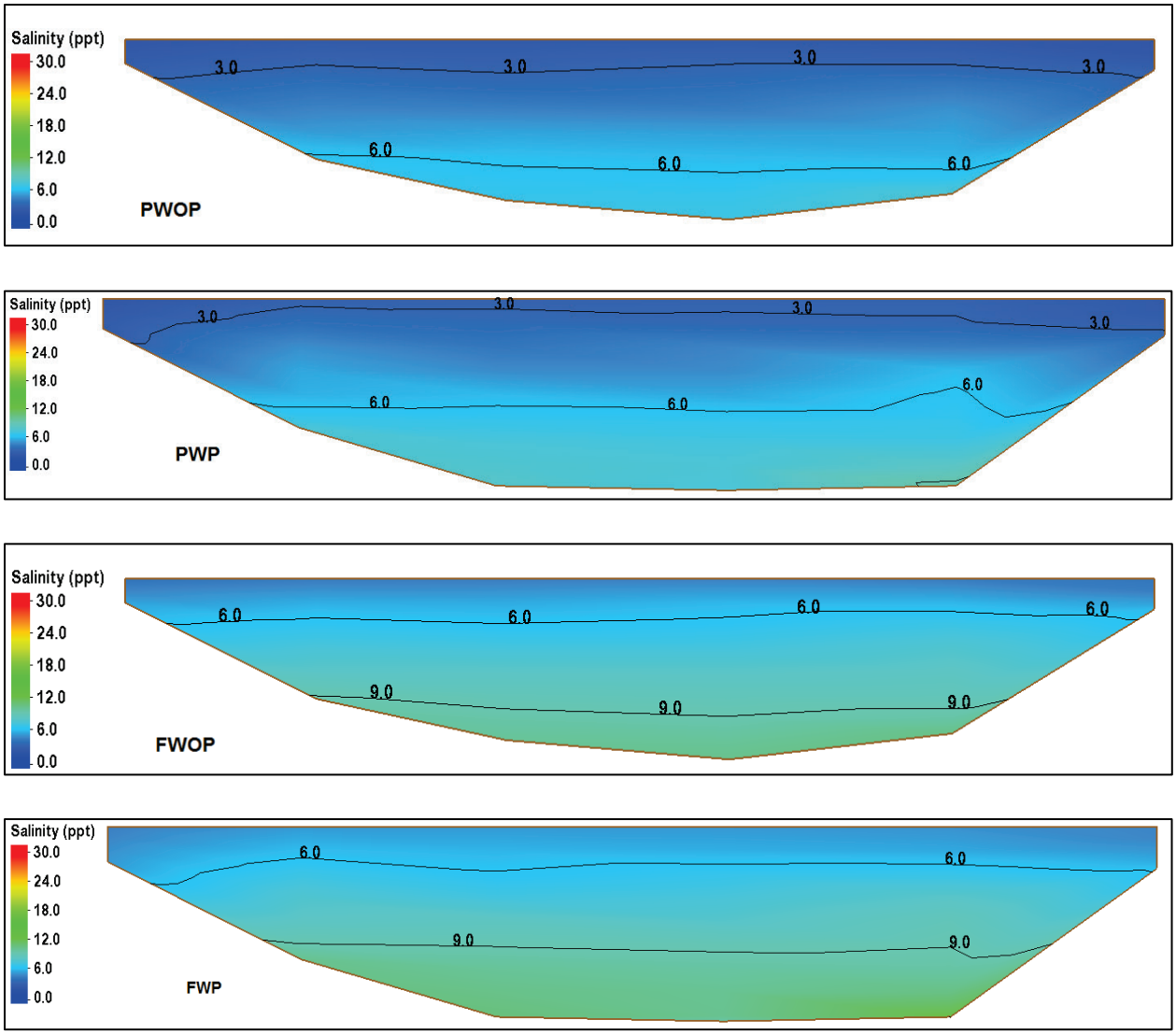


Figure 47. Cross section 9 salinity.



Salinity HSC slice analysis

A slice along the center of the HSC from the Gulf of Mexico to the HSC Turning Basin allows for the comparison of the salinity wedge migration along the ship channel. These results are for mean salinity over the year-long analysis period. Figure 48 shows the location of key features along the HSC for reference. Figure 49 shows the mean salinity along the HSC for all four alternatives. Again, when viewing these results, focus on changes between the present with and without project separately from the future with and without project to isolate impacts due to the project.

Figure 48. HSC slice analysis reference map.

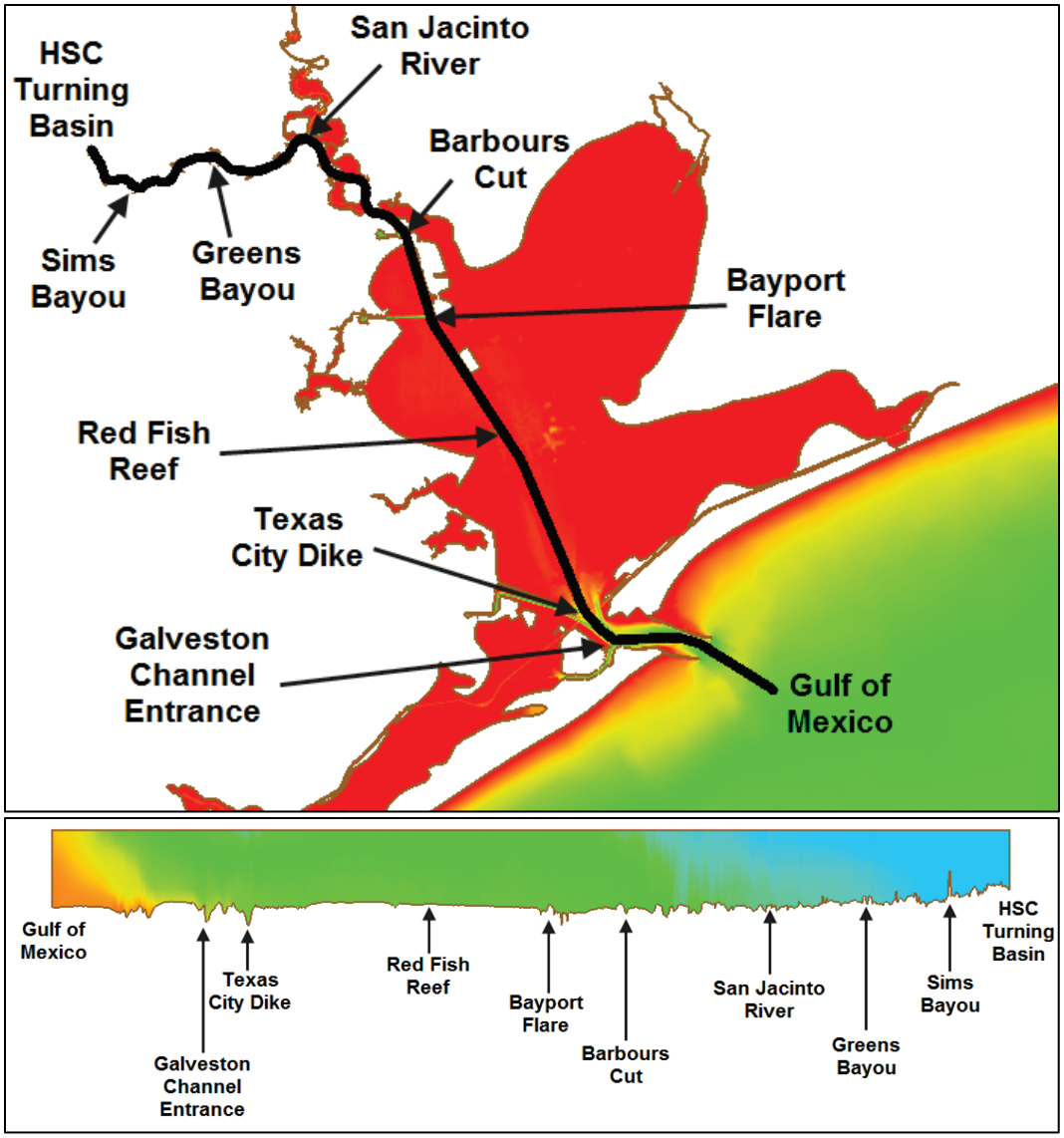
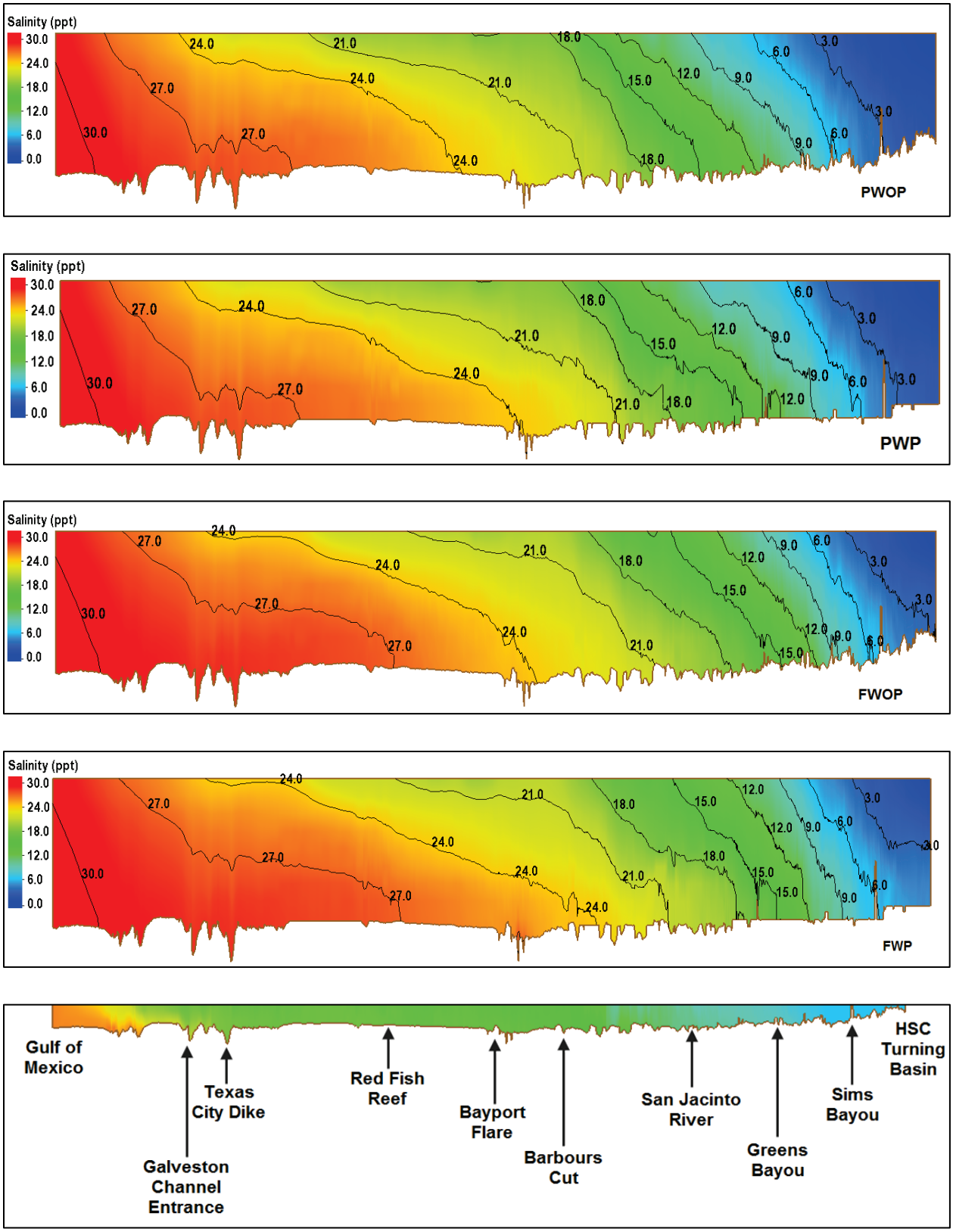


Figure 49. HSC average salinity slice results.



Tidal prism and amplitude

Changes to the system geometry can impact the tidal exchange into a bay environment such as Galveston and Trinity Bays. Although the entrance into the bay area is not modified in these alternatives, the HSC channel depth and width are modified and will allow for changes in the volume of flow being exchanged through the inlets. The tidal prism is a calculation of the volume of water that enters and leaves through the inlets with each tide. This volume was computed for all tides over the analysis year, and the average tidal prism was determined. Table 4 shows the volume of the average tidal prism for each alternative as well as the percentage change in the with project alternative as compared to the without project alternative for present and future conditions. The change is less than 2%, which indicates that the modifications to the HSC do not greatly impact the volume of water entering and leaving the system.

Table 4. Average tidal prism volume for analysis year and percent change of the with project from the without project alternative for present and future conditions.

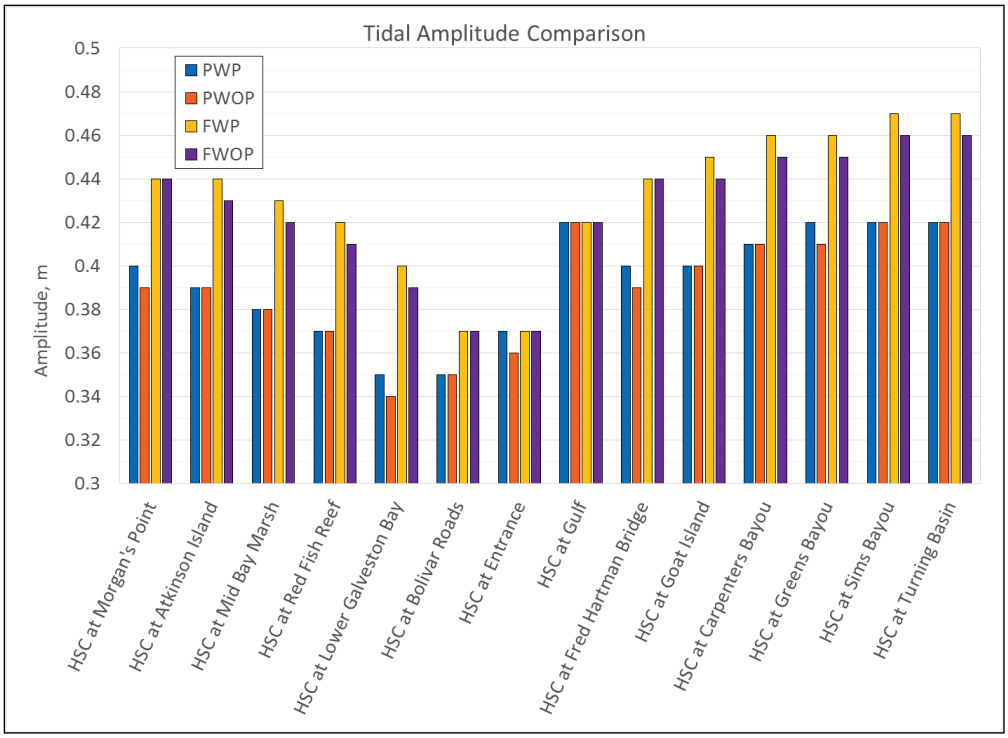
	PWP (m^3)	PWOP (m^3)	PWP % change from PWOP	FWP (m^3)	FWOP (m^3)	FWP % change from FWOP
Average	532,306,623	527,608,754	0.89	587,213,984	578,371,465	1.53

The tidal amplitude is the change in the water level from low-tide to high tide and vice versa. The tidal prism gives an overall impact on the water exchange whereas the tidal amplitude may vary at locations depending on where the system modifications are made and changes in the flow patterns within the system. Table 5 shows the percentage change between present without and with project alternatives and future without and with project alternatives. Locations (labeled in Figure 11 and Table 3) where both present and future changes were zero have been removed from the list. All locations see less than a 3% increase in the tidal amplitude when the project modifications are included. Figure 50 and Figure 51 show the tidal amplitudes for all alternatives for the HSC locations and bay locations, respectively. There is very little impact on the tidal amplitude when the present and future with project conditions are compared to the without project conditions — no more than 0.01 m at any location.

Table 5. Percent change in tidal amplitude of the with project from the without project alternative for present and future conditions.

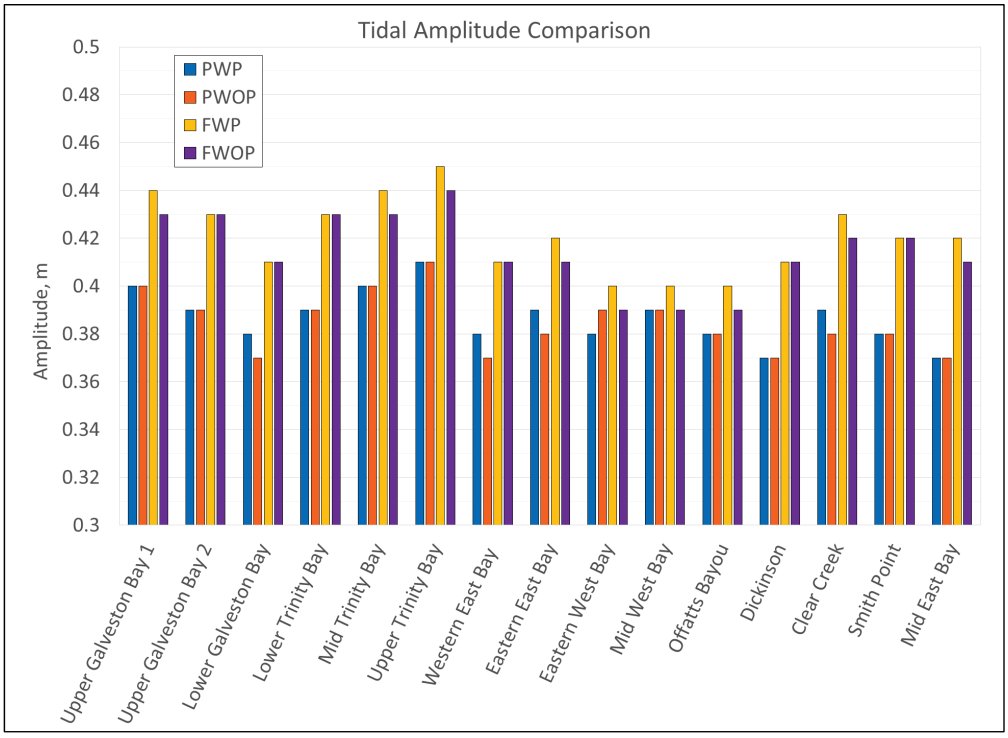
	PWP % change from PWOP	FWP % change from FWOP
HSC at Morgan's Point	2.56	0.00
HSC at Atkinson Island	0.00	2.33
HSC at Mid Bay Marsh	0.00	2.38
HSC at Red Fish Reef	0.00	2.44
HSC at Lower Galveston Bay	2.94	2.56
HSC at Entrance	2.78	0.00
Upper Galveston Bay 1	0.00	2.33
Lower Galveston Bay	2.70	0.00
Mid Trinity Bay	0.00	2.33
Upper Trinity Bay	0.00	2.27
Western East Bay	2.70	0.00
Eastern East Bay	2.63	2.44
Eastern West Bay	-2.56	2.56
Mid West Bay	0.00	2.56
Offatts Bayou	0.00	2.56
Clear Creek	2.63	2.38
Mid East Bay	0.00	2.44
HSC at Fred Hartman Bridge	2.56	0.00
HSC at Goat Island	0.00	2.27
HSC at Carpenters Bayou	0.00	2.22
HSC at Greens Bayou	2.44	2.22
HSC at Sims Bayou	0.00	2.17
HSC at Turning Basin	0.00	2.17

Figure 50. Tidal amplitude comparison at HSC points for all alternatives.



* Focus separately on changes between the present and future to isolate project impacts.

Figure 51. Tidal amplitude comparison at bay points for all alternatives.



* Focus separately on changes between the present and future to isolate project impacts.

Velocity

The velocity comparisons among the alternatives will focus on residual velocity vectors. Residual velocity is the velocity that remains when the tidally varying velocity has been averaged out. This vector defines the predominant flow direction and speed of a particle of water. Although the tide will cause the particle to move back and forth, there is generally a flow direction that is dominant, allowing for a particle to migrate along a certain path. Typically, in a tidally driven environment with a deep navigation channel such as the HSC, the predominant flow direction is upstream along the channel bottom and downstream along the channel surface. The surface and bottom velocity comparisons for with project and without project are shown in Figure 52 through Figure 55. The red vectors indicate the direction of the with project residual velocity and the black vectors, the without project. The contours represent the difference in the velocity magnitudes — with project minus without project such that positive values (reds/yellows) indicate the with project residual velocity magnitude is greater, and negative values (blues) indicate that the without project residual velocity magnitude is greater.

The comparisons show that the residual vector directions are very similar for with and without project alternatives. There are locations where they vary, but the general flow patterns are maintained. The area of the most variation is along western Galveston Bay, primarily between Red Fish Reef and Morgan's Point. There is widening of the HSC, bend easing, and turning basins added to this area, so the variation is not unexpected. The change in the residual velocity magnitudes are less than 0.1 meter per second (m/s). The impact of the project is greater along the HSC upstream of Barbours Cut. The residual velocity magnitudes vary more there than in the bay portion of the project, although the variation from the without project magnitude remains in the range of 0.1 m/s or less. The vector directions also show more variation in the upper HSC area. Again, this is an area of many modifications, such as channel widening and additional turning basins and moorings — all of which are going to modify the velocity patterns.

Figure 52. Surface average residual velocity comparison for present conditions. (red vectors – with project; black vectors – without project)

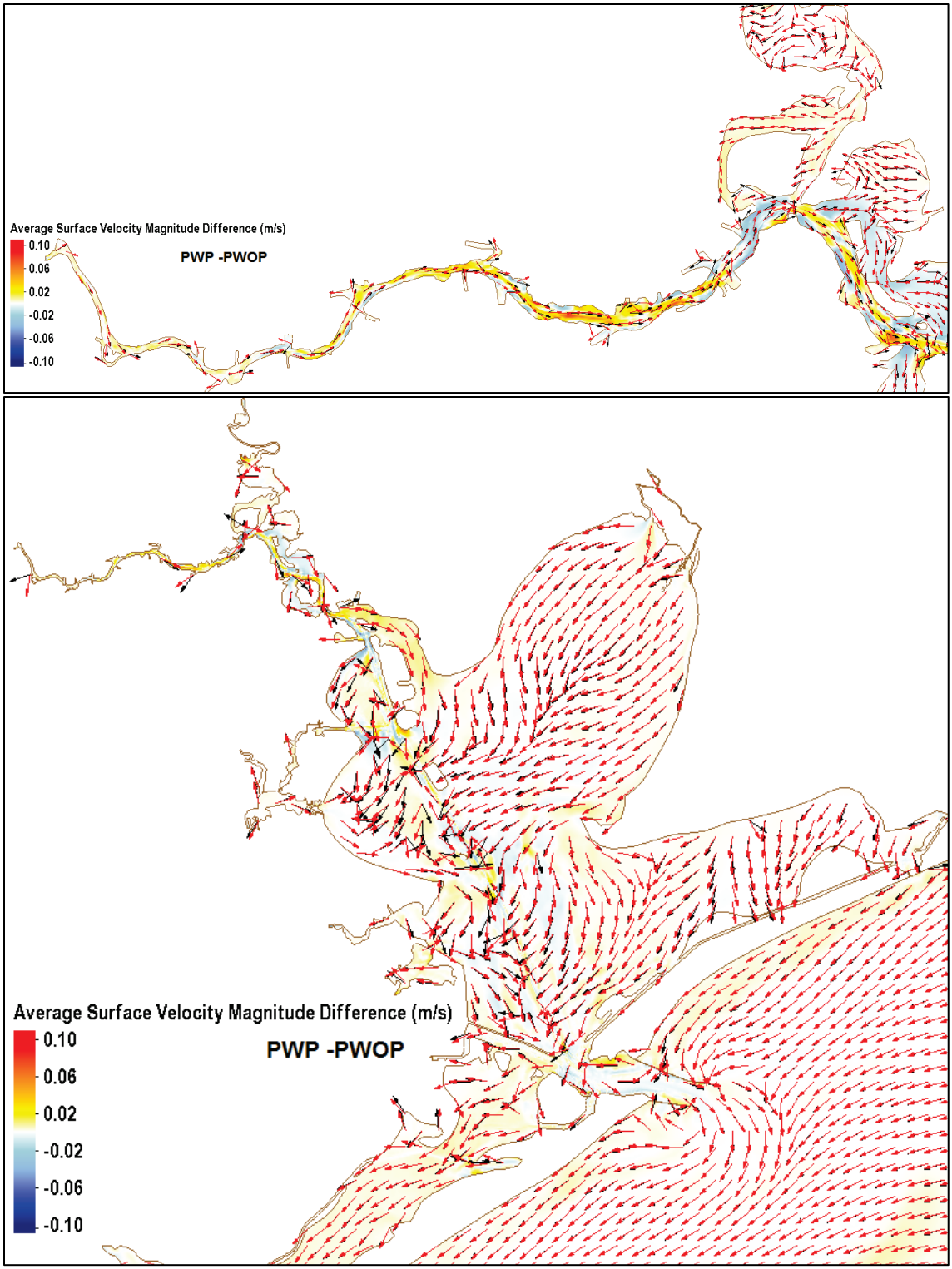


Figure 53. Bottom average residual velocity comparison for present conditions.
(red vectors – with project; black vectors – without project)

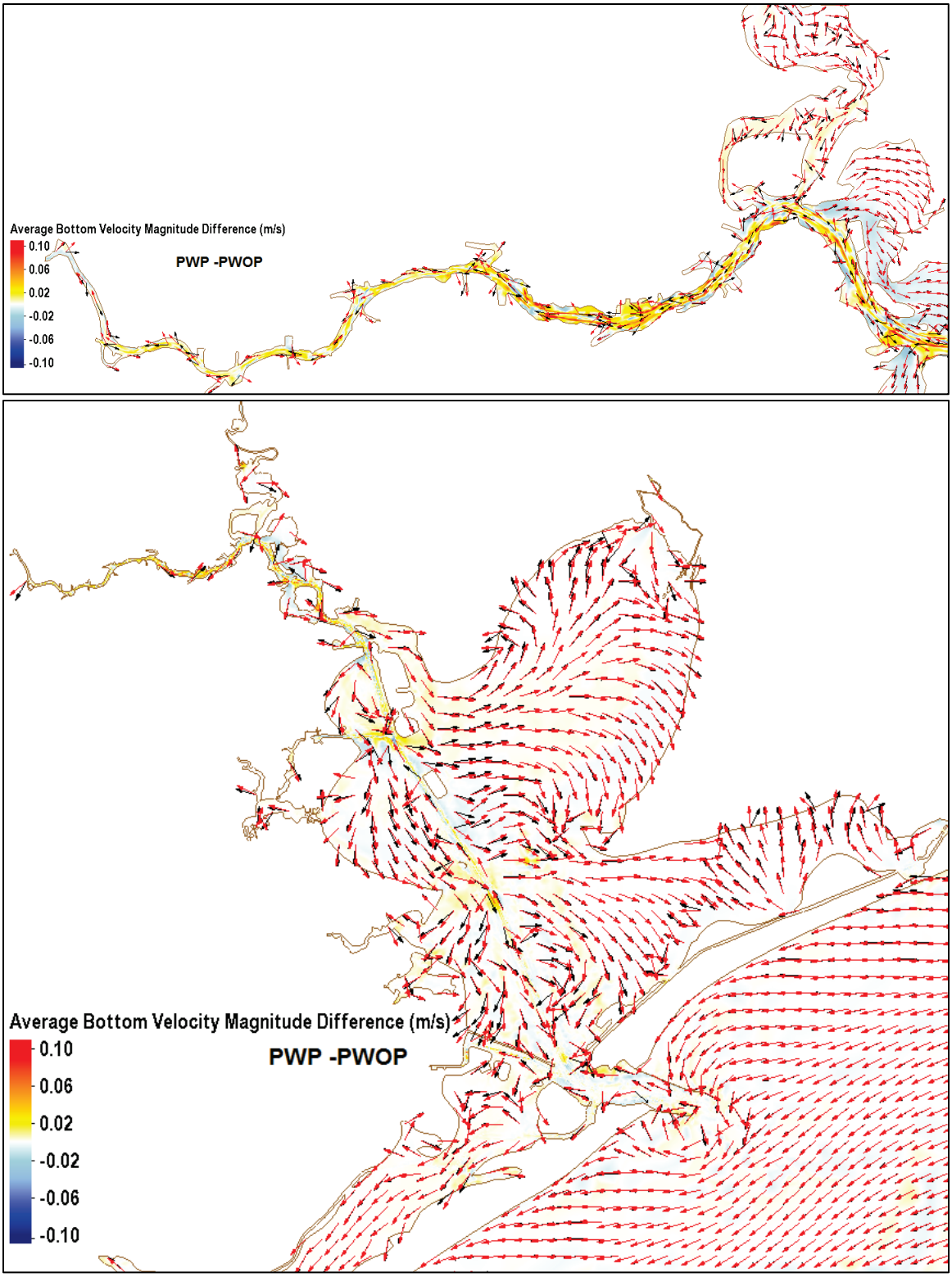


Figure 54. Surface average residual velocity comparison for future conditions.
(red vectors – with project; black vectors – without project)

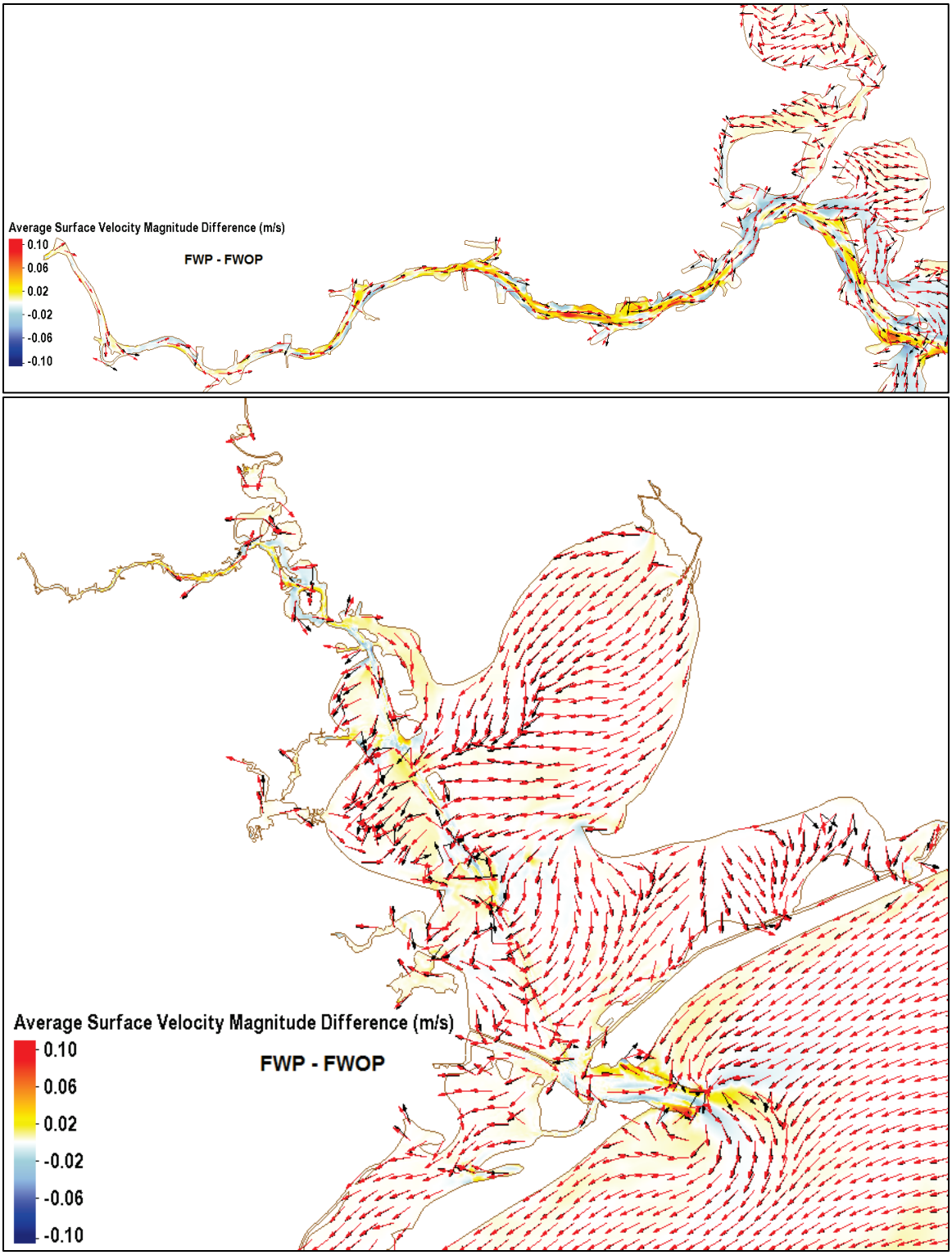
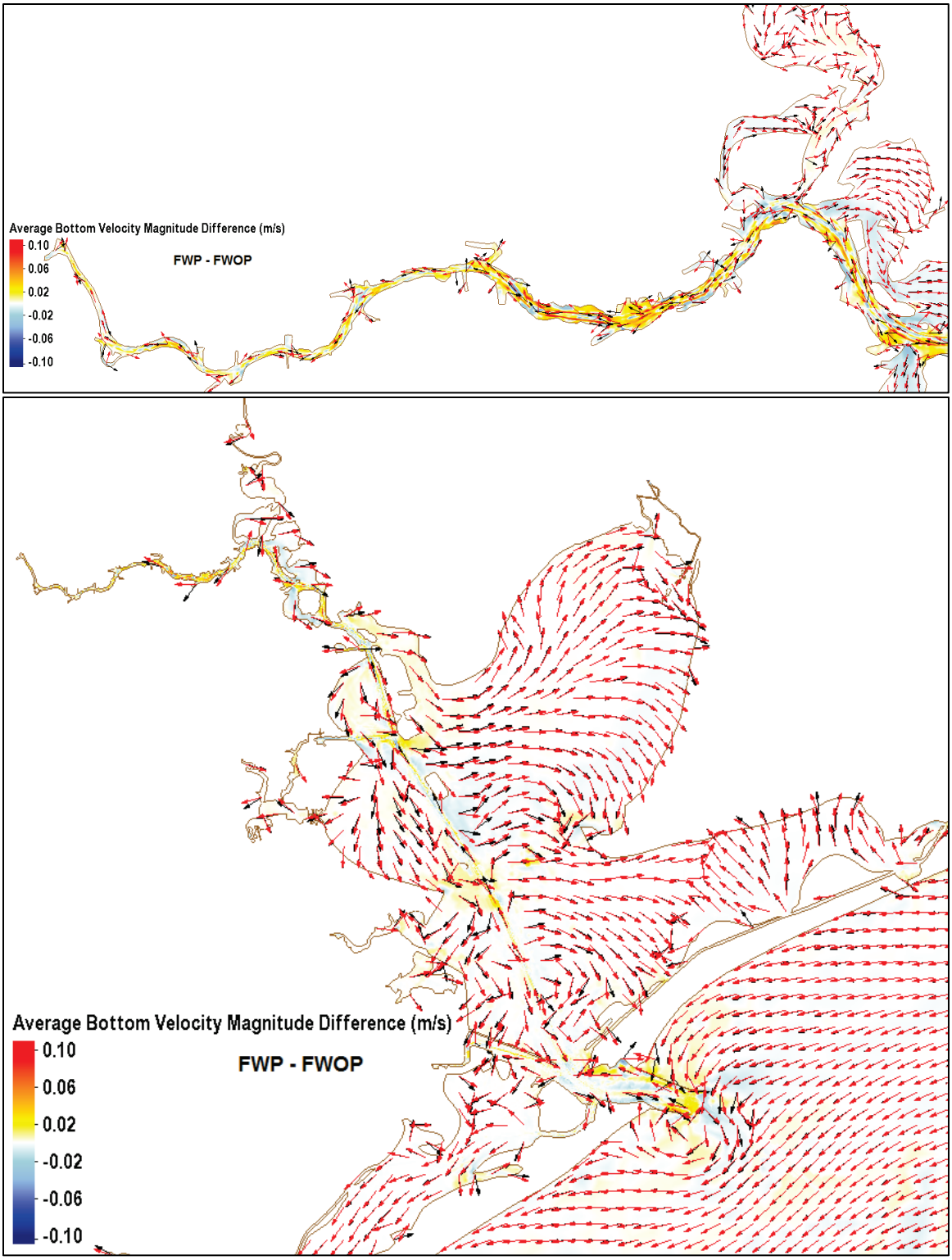


Figure 55. Bottom average residual velocity comparison for future conditions.
(red vectors – with project; black vectors – without project)



Shoaling

The sediment analysis is based on the historic dredge records from the USACE annual reports as done in the model validation (McAlpin et al. 2019). These volumes are provided for several reaches of the HSC as noted in the dredge template shown in Figure 56. This template will be used to show how the alternative shoaling estimates from the numerical model compare to each other for each channel reach.

Figure 56. HSC dredge template for shoaling analysis.

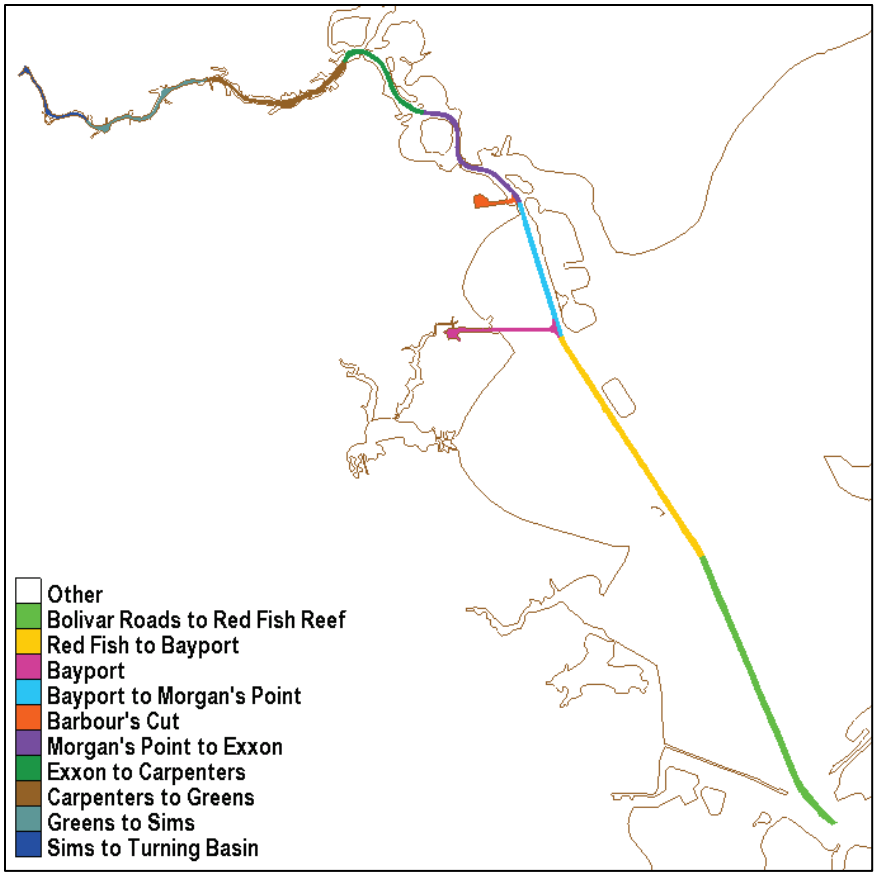


Figure 57 shows the scaled shoaling volume within each segment for the 2010 base condition and all four alternatives — PWP, PWOP, FWP, and FWOP. The with project shoaling is larger for all segments except at the farthest upstream and downstream segments. Bolivar Roads to Red Fish Reef indicates a small decrease in the shoaling with the project changes in place likely due to the slight increase in the tidal prism, which will generate some higher velocity magnitudes. The Bayport area shows the largest increase in shoaling volume. The flare is already a sediment trap due to its present size, and the project alternative of widening the Bayport

channel and to ease the bend further increase the footprint and therefore the tendency to trap sediment. Figure 58 shows the model-computed, unscaled bed displacement along the HSC from the Texas City Dike to the Houston Turning Basin. These results show a similar pattern to those in Figure 57, although no scaling has been done to ensure a correlation to historic data as in the shoaling volume plot. However, the comparison between with and without project will remain if scaled to replicate actual shoaling volumes/depths. The plot does show that the with project alternatives increase the deposition along most of the HSC. It also indicates a potential shift in the shoaling locations for the PWP alternative to areas upstream of Red Fish Reef and upstream of Bayport. The increase upstream of Bayport may actually be a simple increase in shoaling as opposed to a shift since there are still peaks in the bed displacement at the Bayport Flare. It is not uncommon for channel modifications to change the flow patterns such that the turbidity maximum (the location where the sediment tends to collect and often tied to the location of the salinity wedge) moves upstream, especially in the case of channel deepening. The future alternatives do not show this shift most likely because the sediment loads are reduced in the future condition simulations.

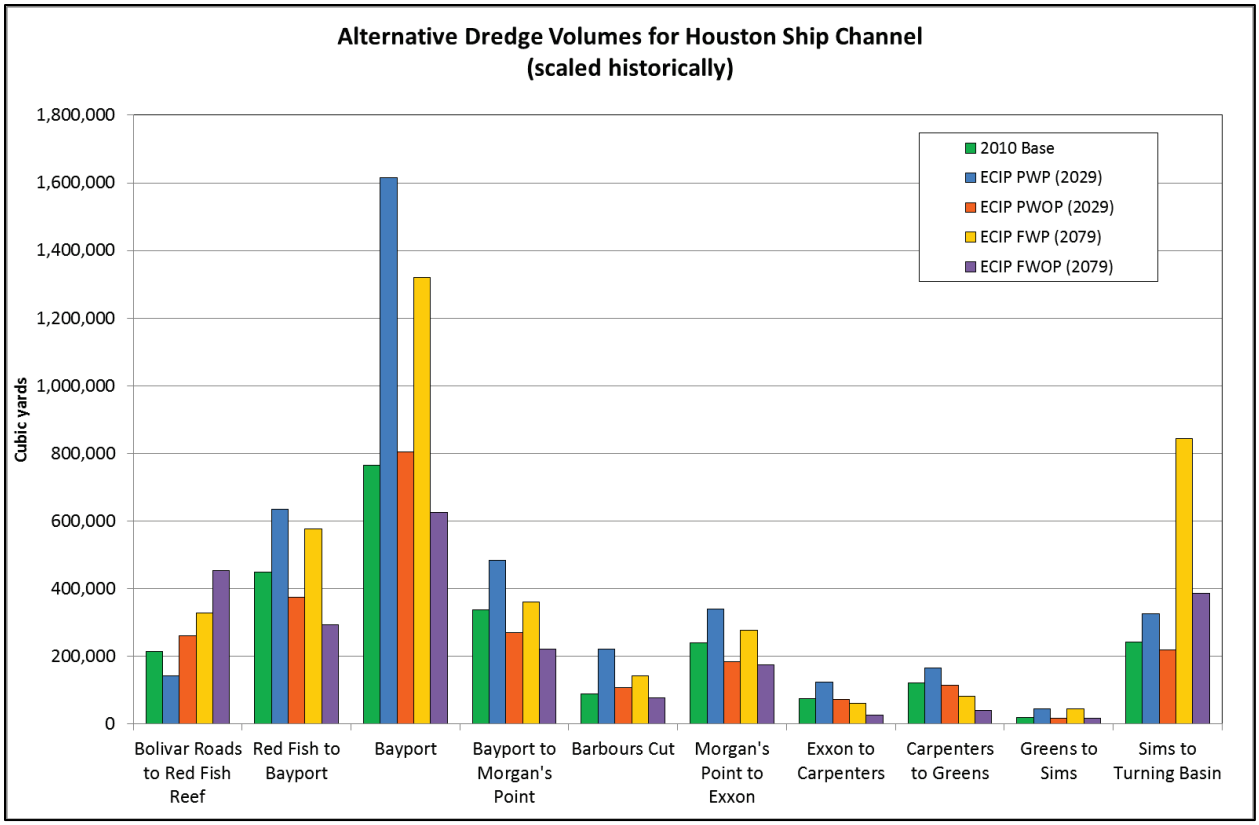
The deepened portion of the HSC in the project alternatives is located upstream of the San Jacinto River. Sediment loads from the bayous entering the HSC in the area of the deepening may have a tendency to migrate upstream due to the salinity being pushed farther upstream along the channel bottom, although the salinity change is less than 1 ppt for most of this area. This model does not include these bayou sediment loads because they are unknown and therefore is unable to predict this potential upstream sediment migration.

Due to the increase in the with project cross-sectional area (where the HSC is being widened or deepened), the same shoaling volume will equate to a reduced shoaling depth for the larger cross section. Figure 59 shows schematically how the shoaling volume can be interpreted for different channel modifications. A wider channel and the same shoaling depth or elevation will produce a larger shoaling volume. Therefore, the increased shoaling volume does not mean dredging must occur sooner, but it does indicate the dredging may cost more due to more volume. A constant shoaling volume will mean a lower shoaling depth for a channel widening condition; therefore, again, the dredging may not be required as often. For

a deepened channel condition, the same results are true as in the widened condition; however, for a constant shoaling elevation, the shoaling volume and depth will be increased, but dredging will only be required more often if the required dredging elevation is also deepened. These conditions should be considered when viewing the modeled shoaling volume and bed displacement changes for the various locations along the HSC due to the different areas of deepening and widening.

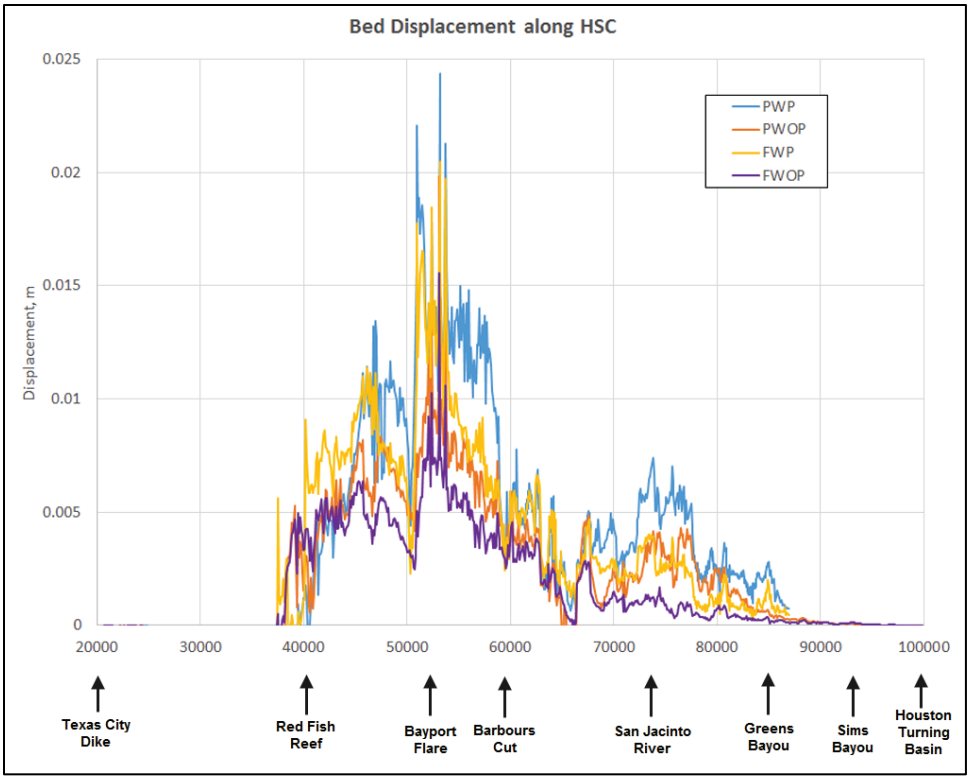
An additional sediment model calibration effort will be performed using the Corps Shoaling Analysis Tool. This tool computes historic shoaling rates and provides estimates of future rates on a fine scale (5–10 m). This calibration effort will be documented in McAlpin et al. (2019) and will provide shoaling estimates similar to those presented in this chapter but on a finer scale than the dredge template allows.

Figure 57. Shoaling results by reach for all alternatives.



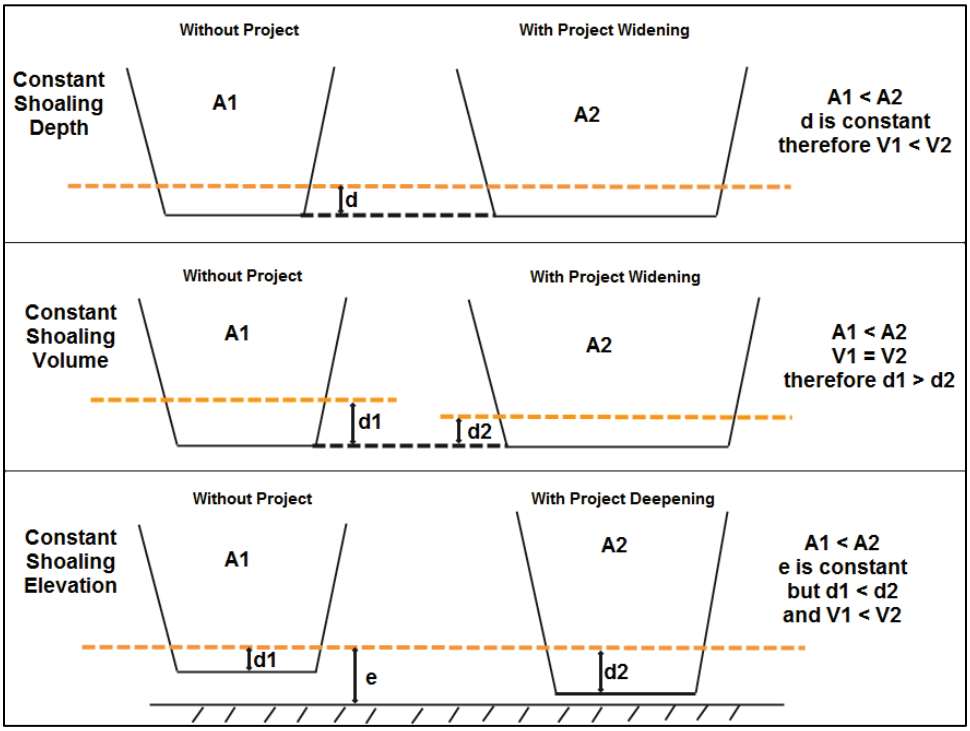
* Focus separately on changes between the present and future to isolate project impacts.

Figure 58. Modeled bed displacement along HSC (non-scaled, focus on the change).



*Focus separately on changes between the present and future to isolate project impacts.

Figure 59. Shoaling impacts under various alternative conditions.



4 Conclusions

Overall, the proposed alternative has little effect on salinity, but it does generate larger shoaling and localized changes in velocity patterns.

Comparison of with and without project should be done on the present conditions and the future conditions separately to isolate impacts due to the project alone. Comparing present and future results directly means that the impact of the project is included with the impact of modified input parameters since several were adjusted for the future condition and therefore difficult to determine which change is generating the difference between alternatives.

The salinity was analyzed at 29 locations along the HSC and in the surrounding bays and on average, did not vary by more than 2 ppt between with and without project conditions at any location. At some locations the maximum or minimum salinity values varied by more but these are extreme values and likely only occur a couple of times throughout the simulation year. The percent-less-than plots of salinity show the range of salinity values for all locations over the simulation period and again, show little variation between with and without project results. The salinity wedge does have a tendency to migrate a bit farther upstream due to the channel widening and deepening, but that distance is small which supports the 2 ppt or less increase for the with project condition.

The average tidal prism and average tidal amplitudes also remained fairly consistent between with and without project over the simulation year. The tidal prism change with the project alternative in place is less than 2% for both present and future conditions. The tidal amplitudes varied by no more than 0.01 m at any of the 29 locations.

The residual velocity indicates the predominant flow direction and magnitude when the tide is removed from the velocity throughout the model domain. The change from the without project condition is limited to areas in and immediately around where the modifications are made. Significant differences in residual velocity direction and magnitude are visible around Bayport as well as in the upper HSC area where widening and deepening occur, but these changes are less than 0.1 m/s. There are impacts to velocity magnitude into the bay areas, but they are much smaller than the impacts at the locations of the modifications.

The alternative condition does indicate an increase in the shoaling along the HSC when compared to the without project results. The largest increases are in the Bayport channel and flare. This is not unexpected since this area is presently a sediment trap due to its large, deep footprint, and the alternative condition increases the channel and flare area. The shoaling volume results should be reviewed in connection with shoal height to determine the overall impacts of the channel shoaling analysis and how they relate to the proposed modifications. A widened channel with an increased shoal volume may mean that although more volume must be removed when dredged, the number of dredging occurrences may be reduced.

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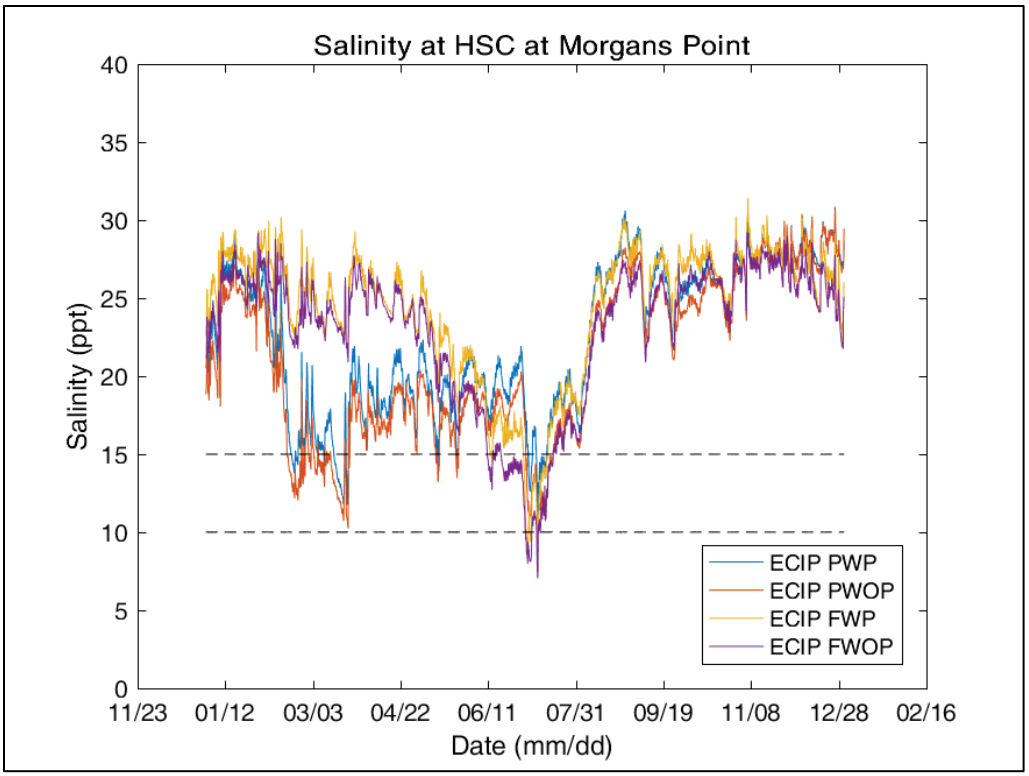
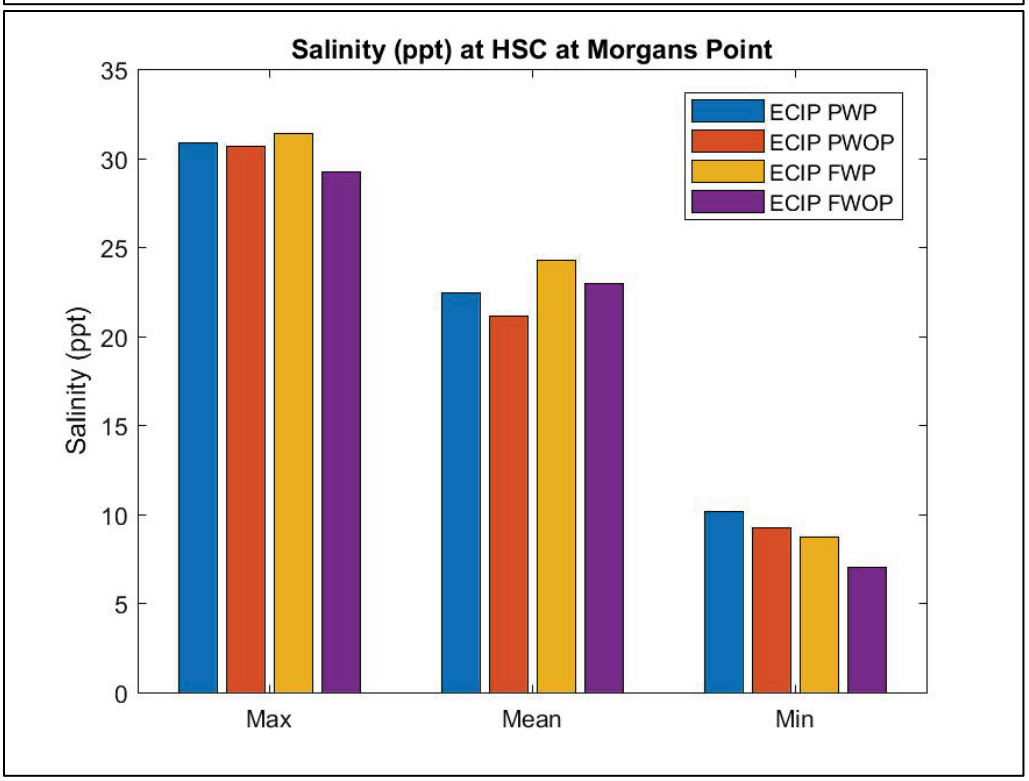
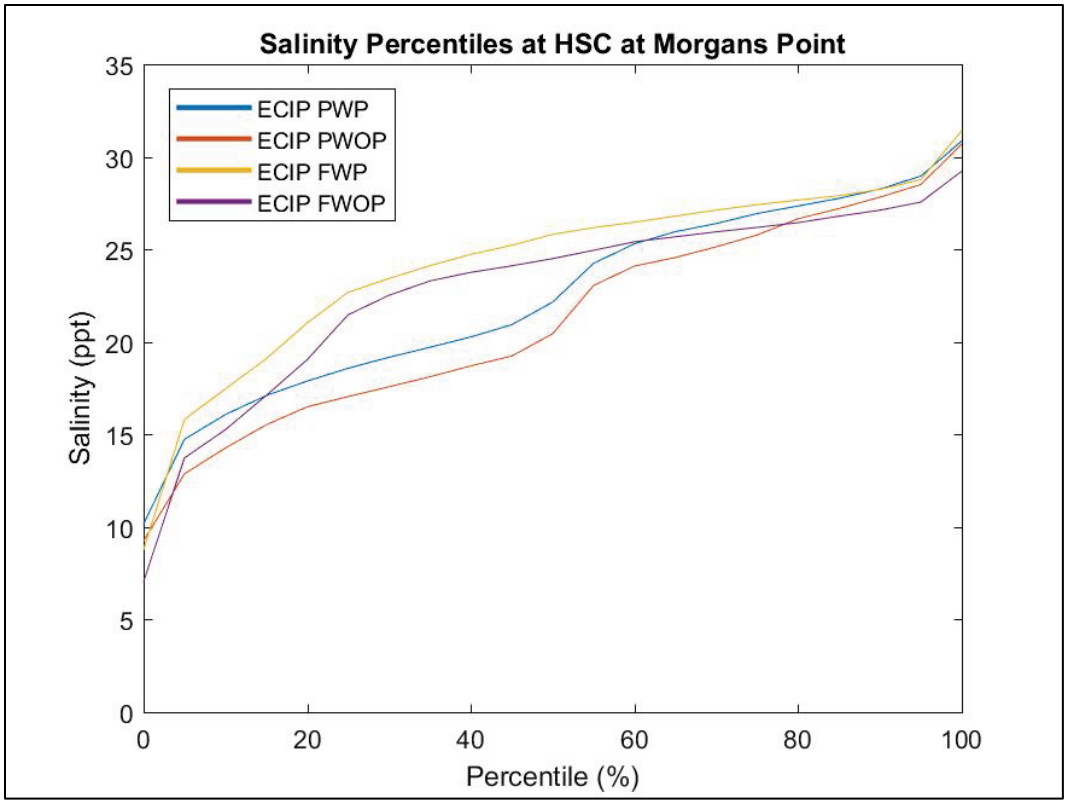
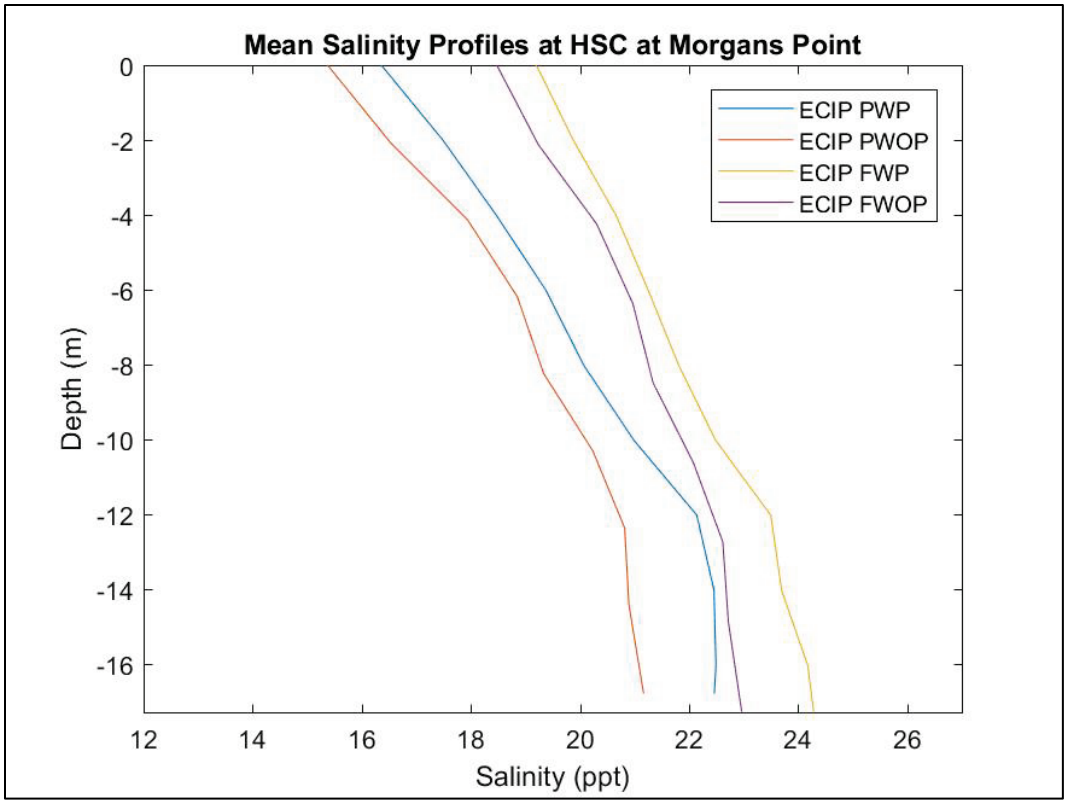
Appendix

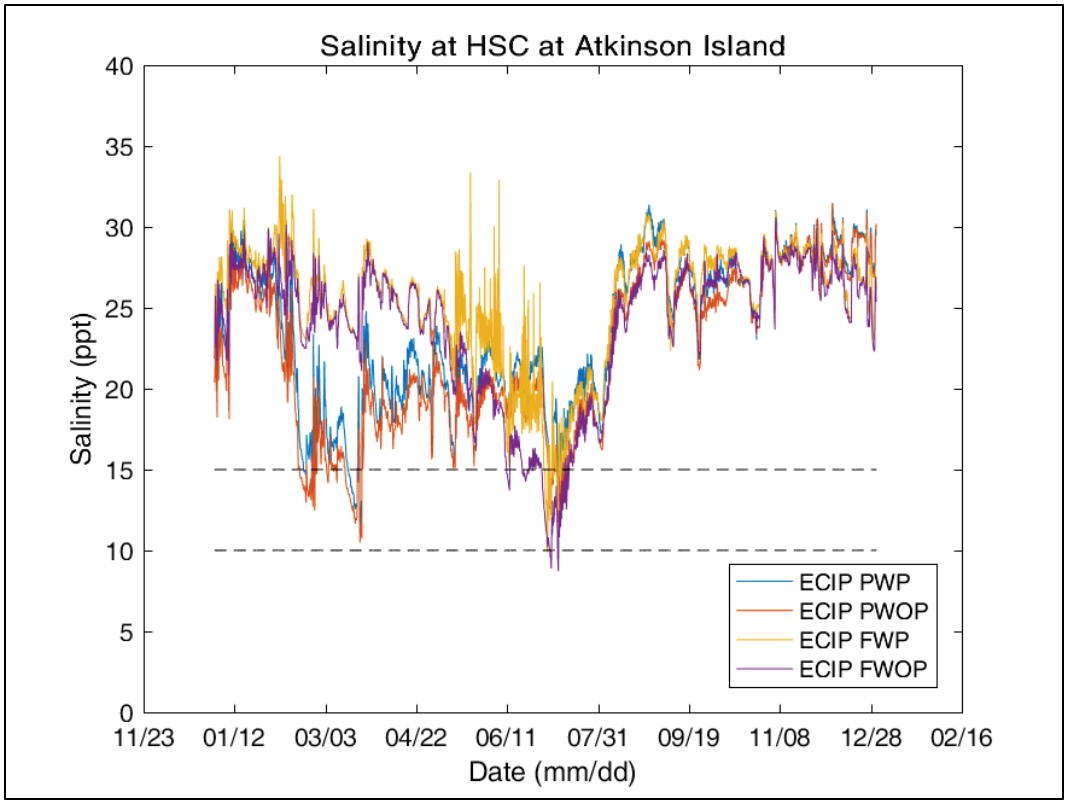
Point salinity analysis

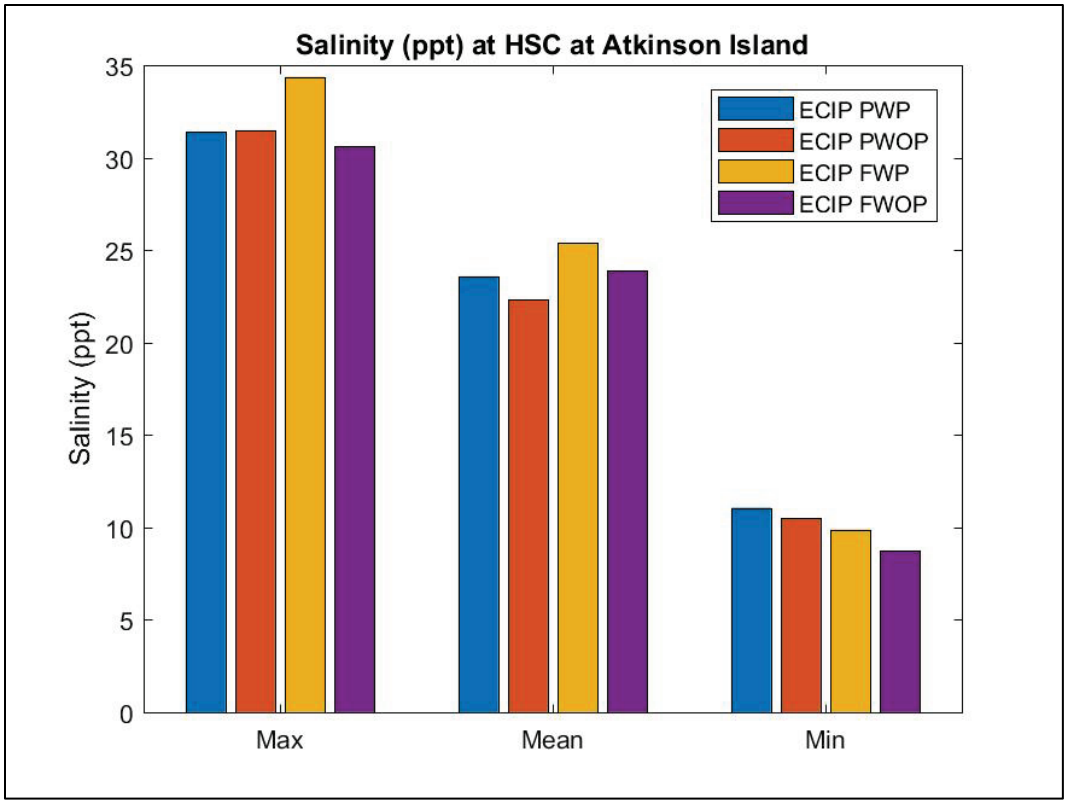


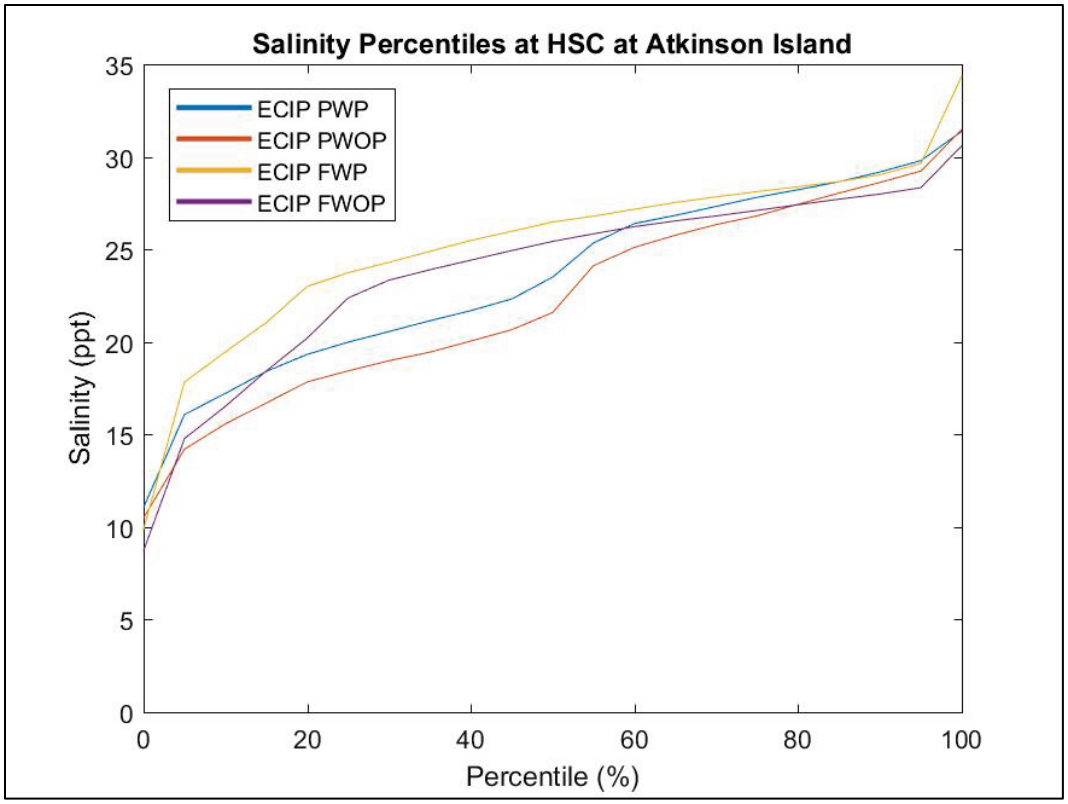


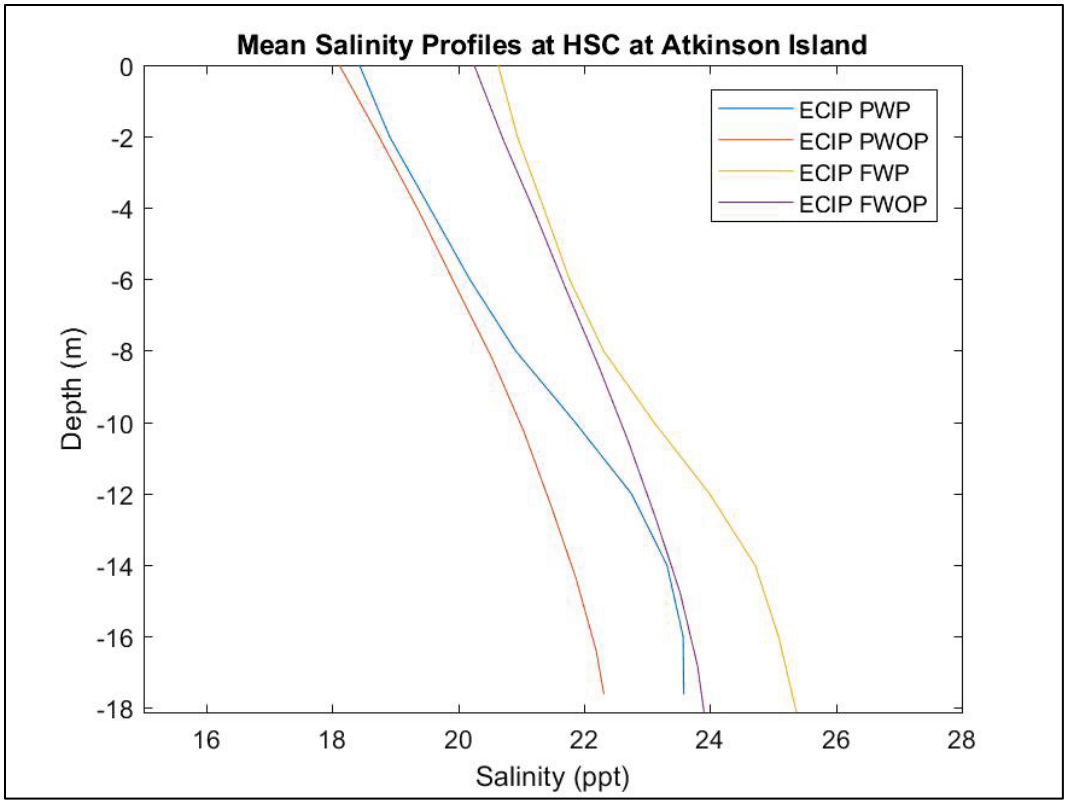

Salinity Percentiles at HSC at Morgans Point
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

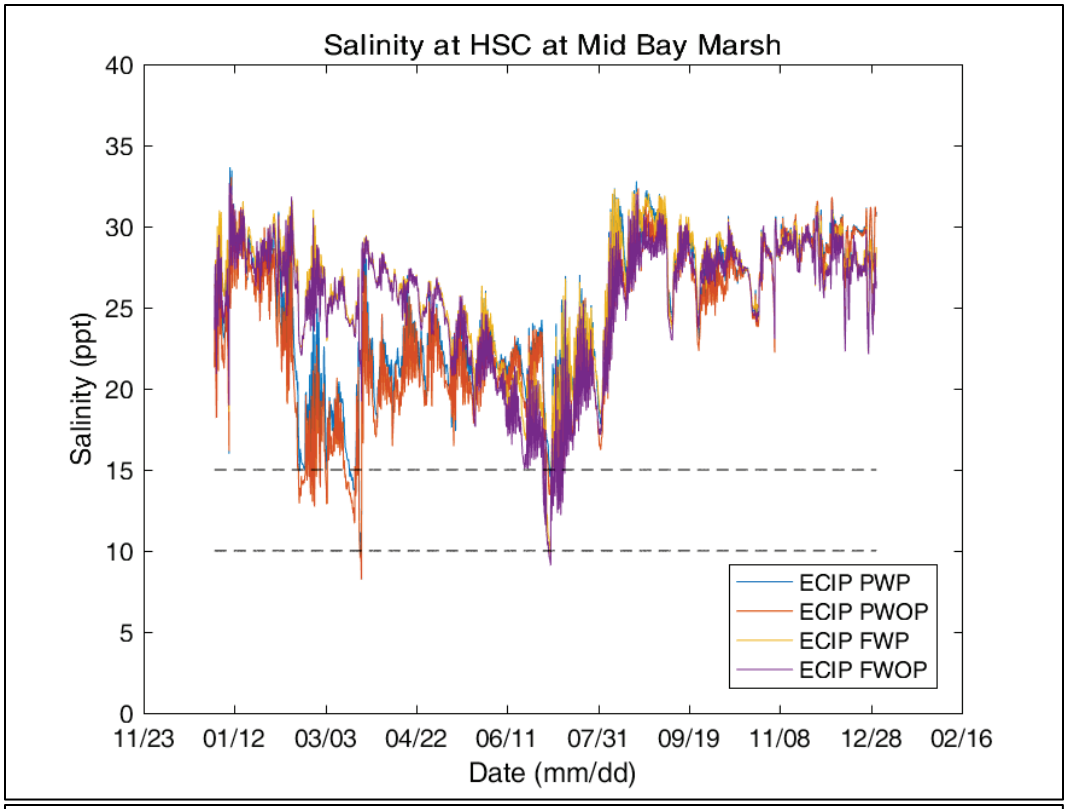

Mean Salinity Profiles at HSC at Morgans Point
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
12
14
16
18
20
22
24
26

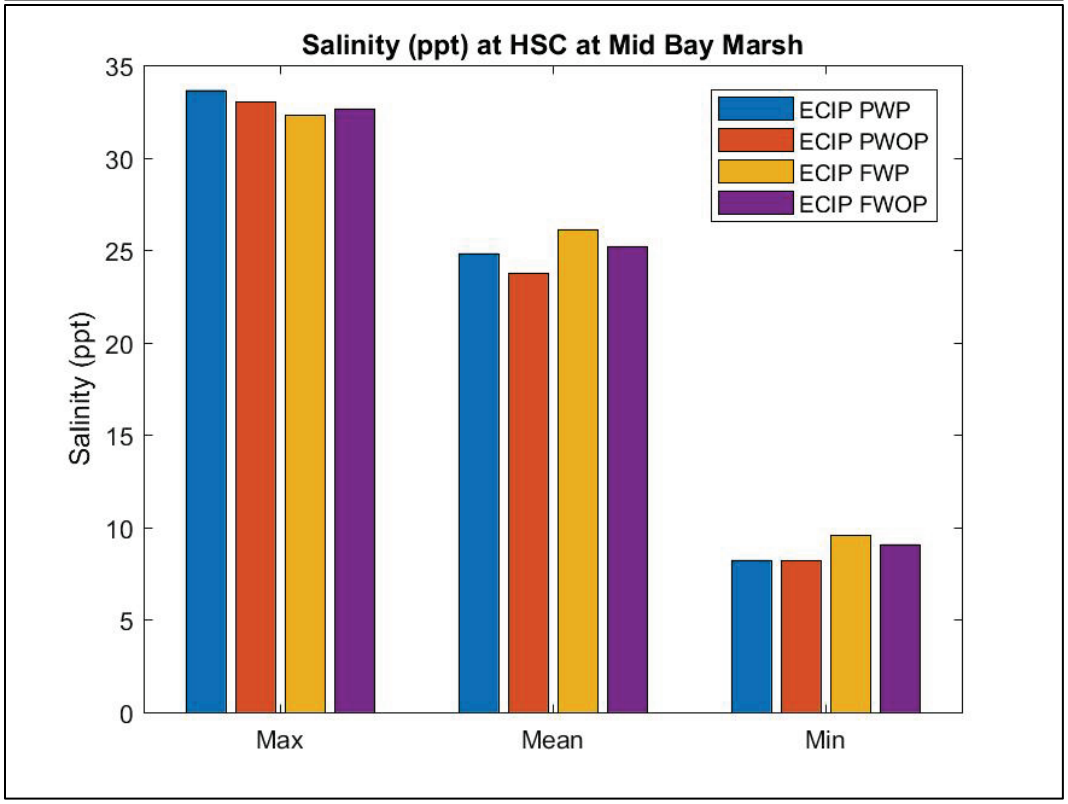

Salinity at HSC at Atkinson Island
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

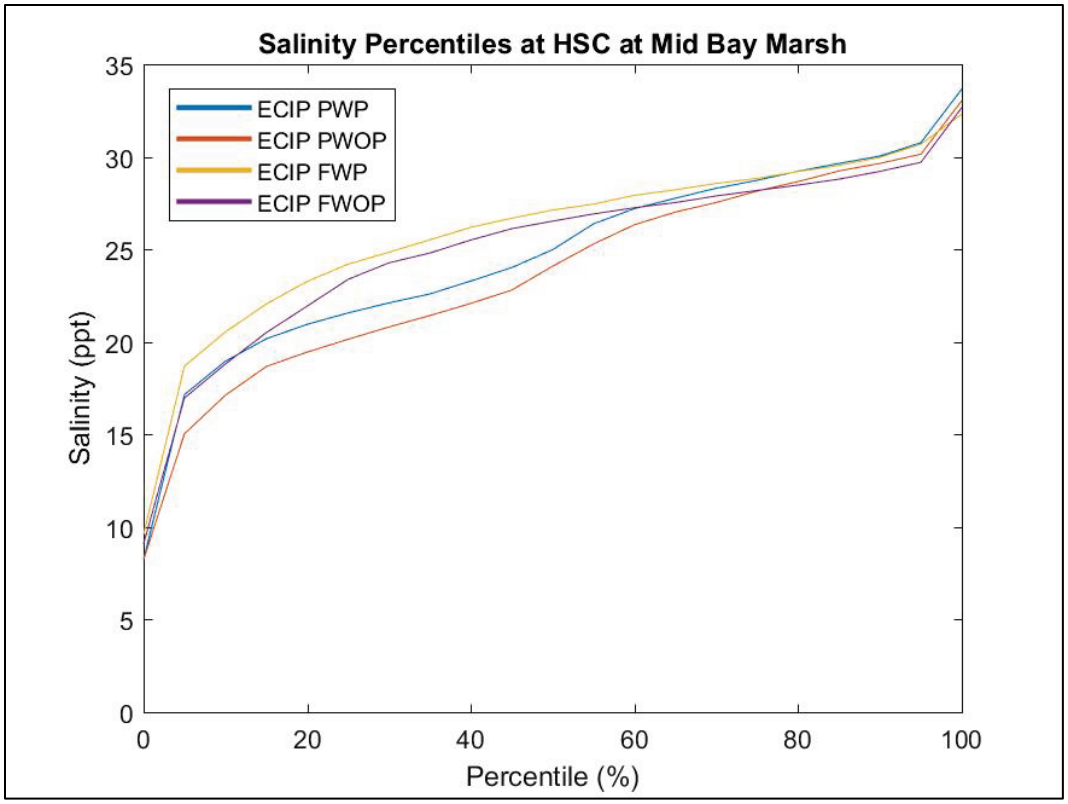

Salinity (ppt) at HSC at Atkinson Island
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

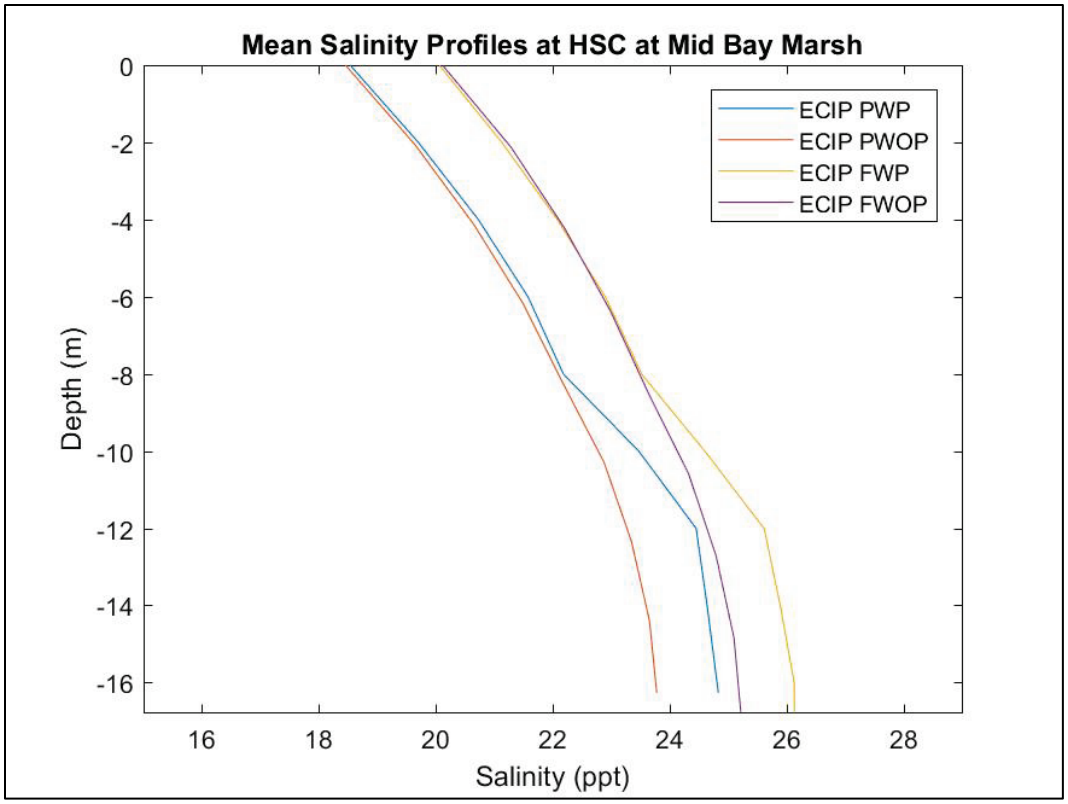

Salinity Percentiles at HSC at Atkinson Island
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

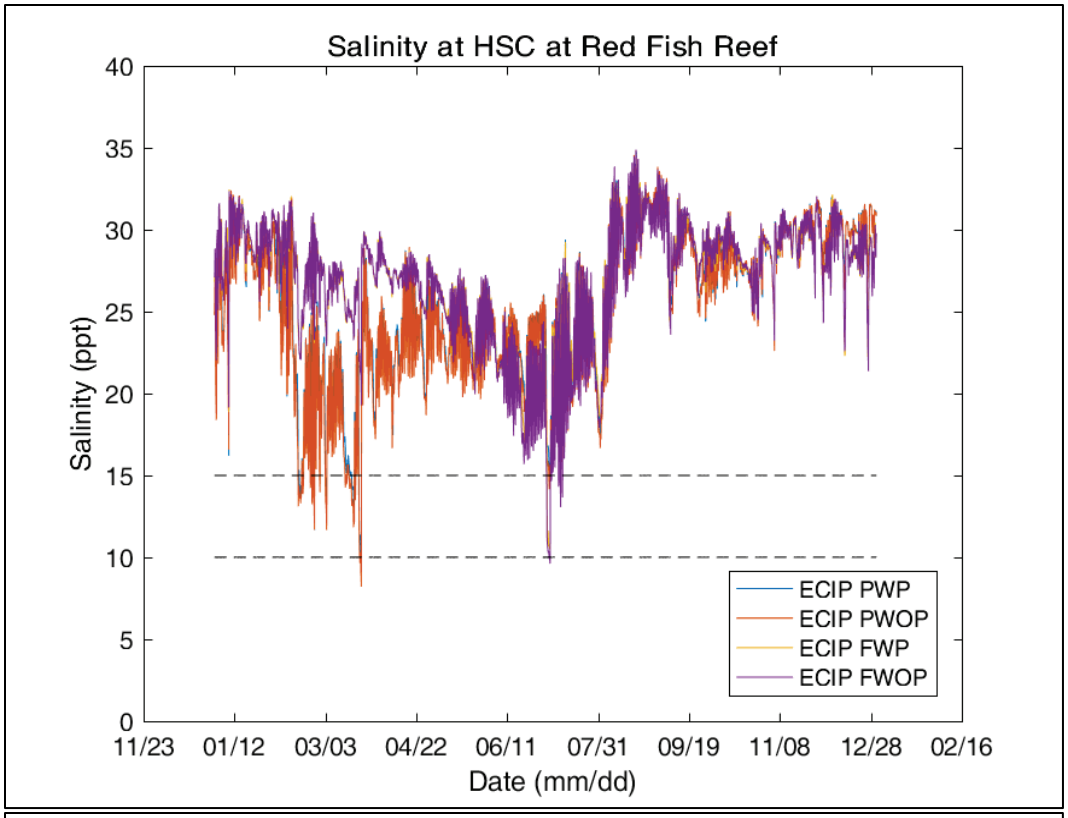

Mean Salinity Profiles at HSC at Atkinson Island
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
16
18
20
22
24
26
28

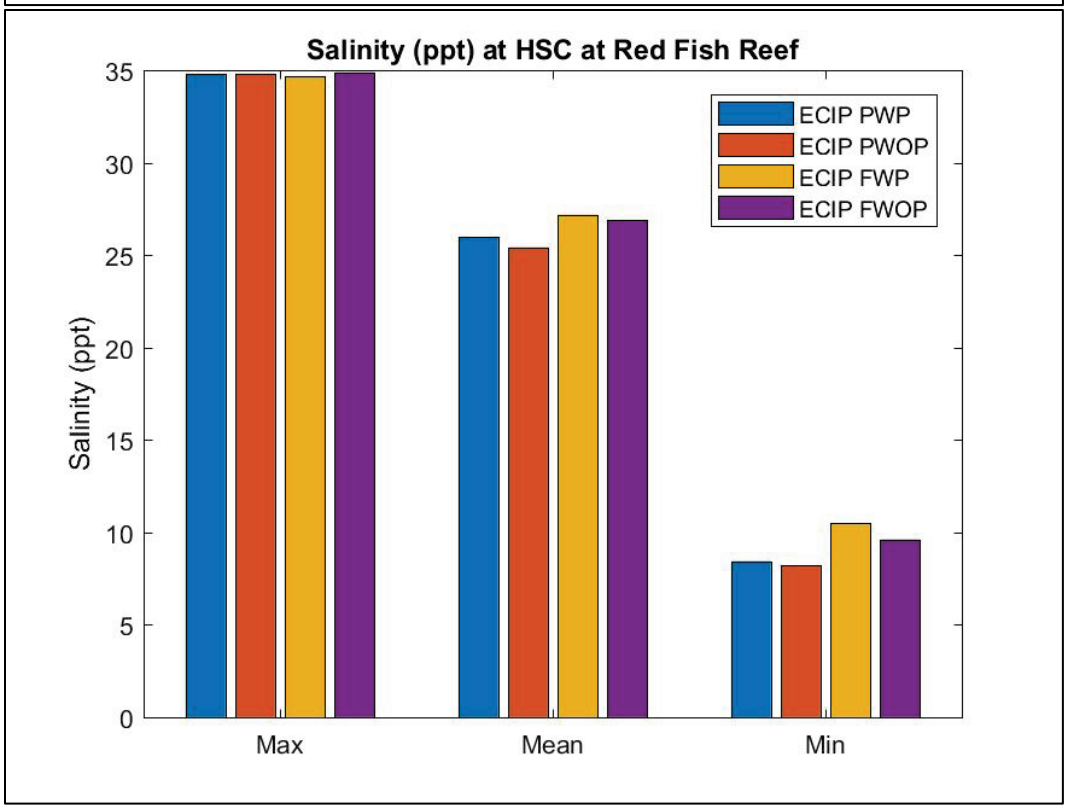

Salinity at HSC at Mid Bay Marsh
Salinity (ppt)
Date (mm/dd)
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP


Salinity (ppt) at HSC at Mid Bay Marsh
Salinity (ppt)
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP


Salinity Percentiles at HSC at Mid Bay Marsh
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100


Mean Salinity Profiles at HSC at Mid Bay Marsh
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
16
18
20
22
24
26
28


Salinity at HSC at Red Fish Reef
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP


Salinity (ppt) at HSC at Red Fish Reef
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
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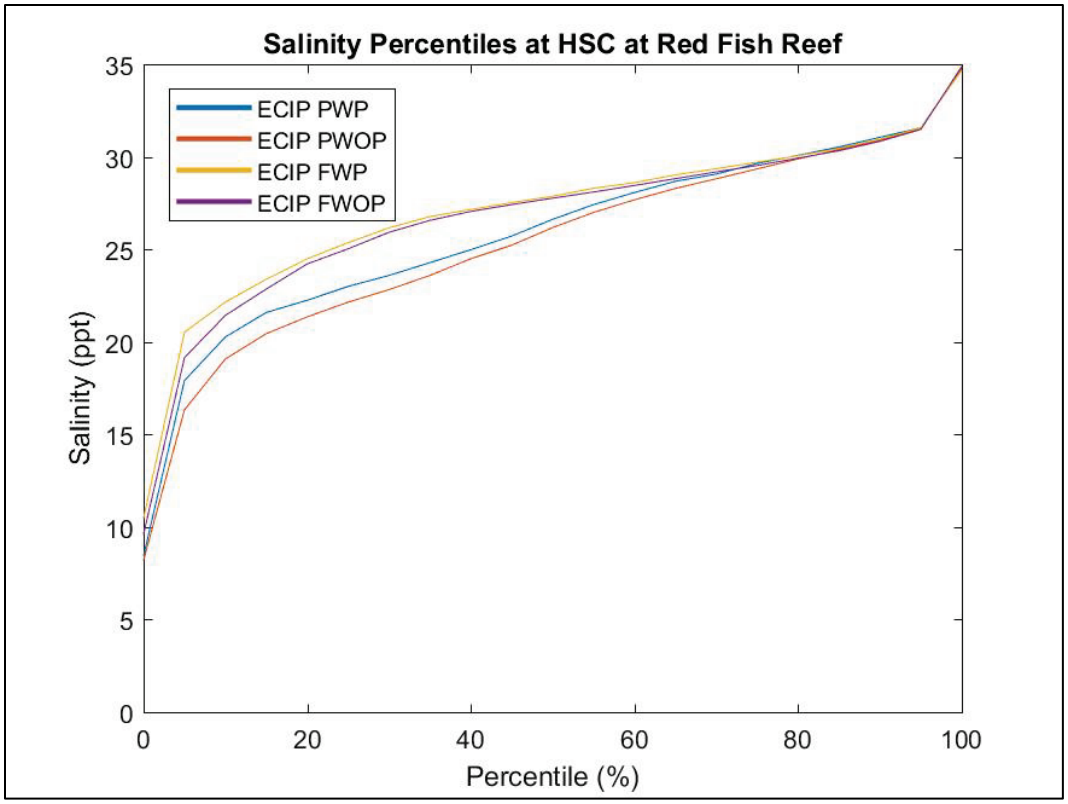
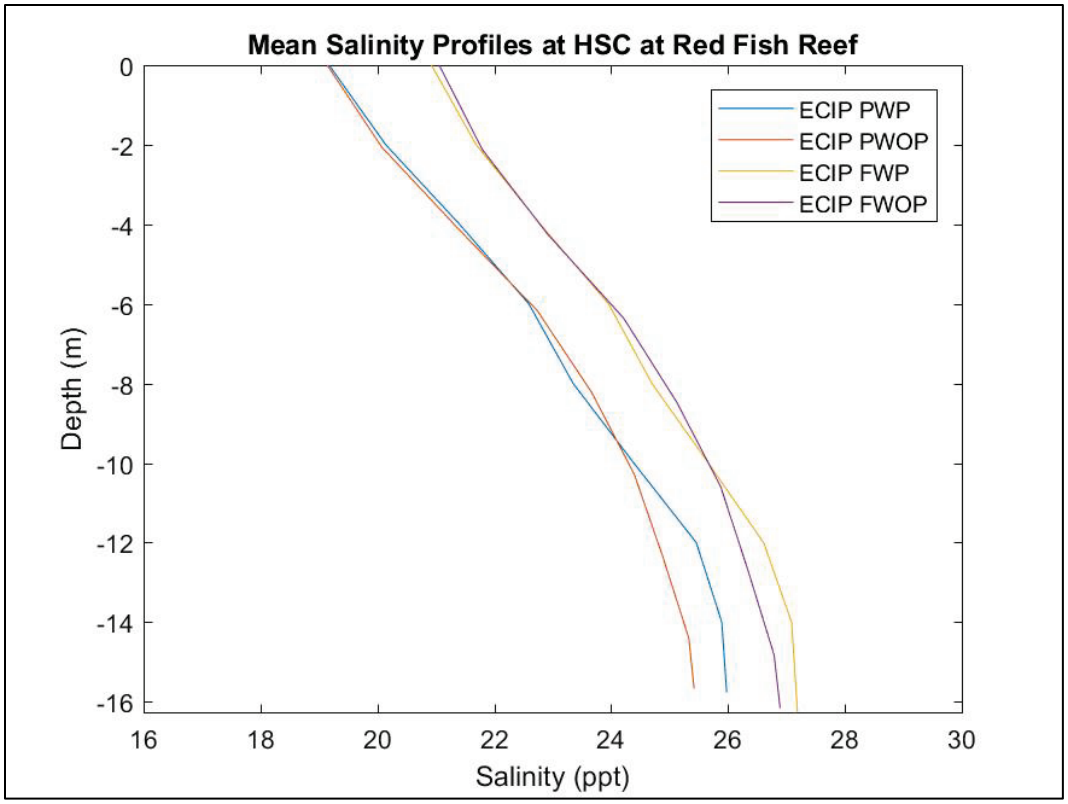
ECIP PWOP
ECIP FWP
ECIP FWOP


Salinity Percentiles at HSC at Red Fish Reef
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100


Mean Salinity Profiles at HSC at Red Fish Reef
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ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
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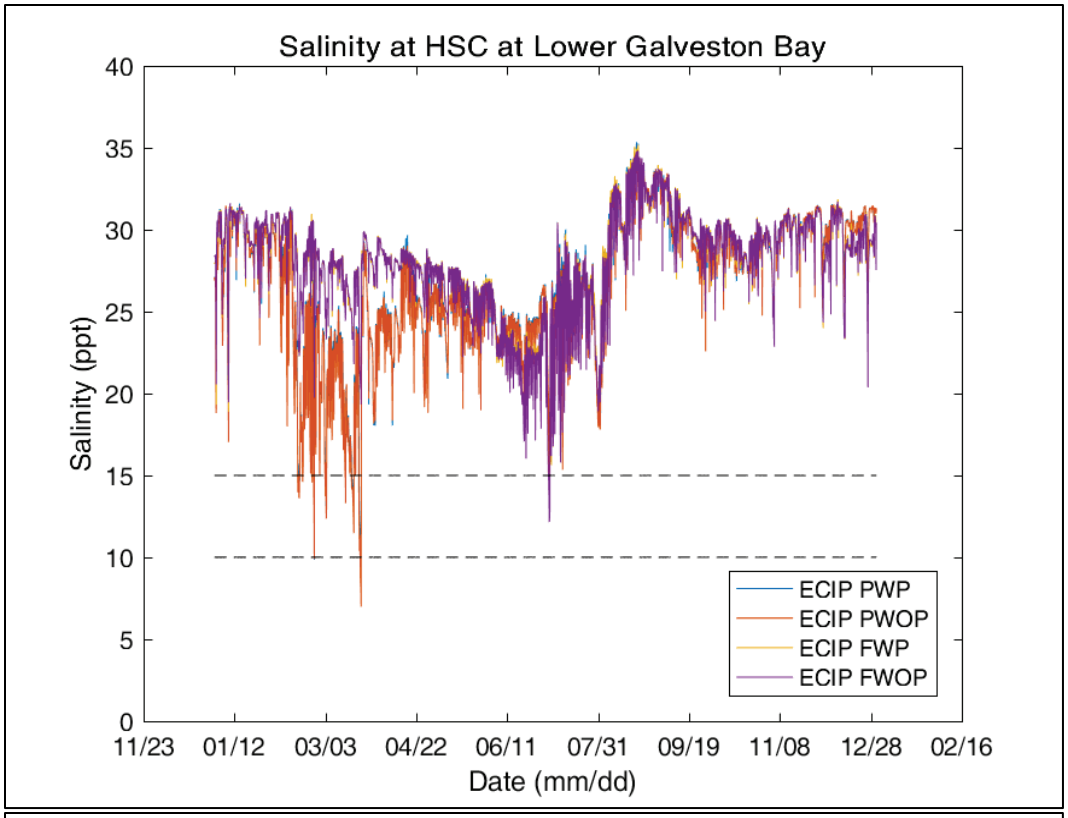
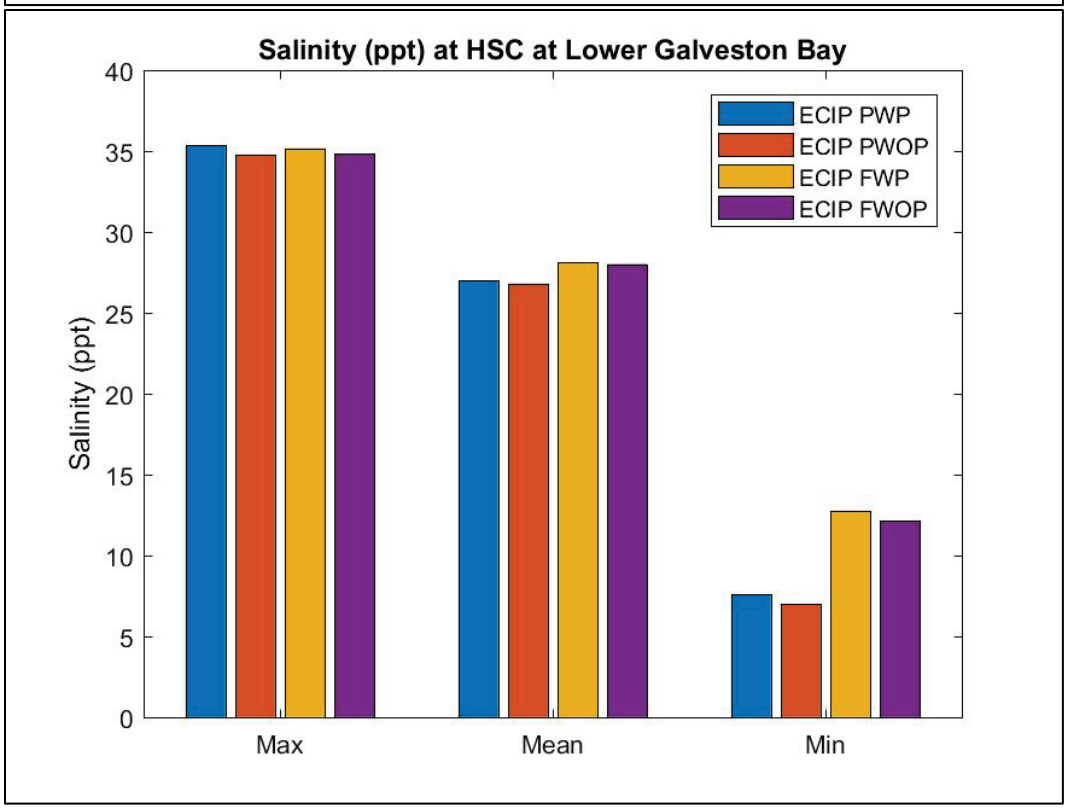
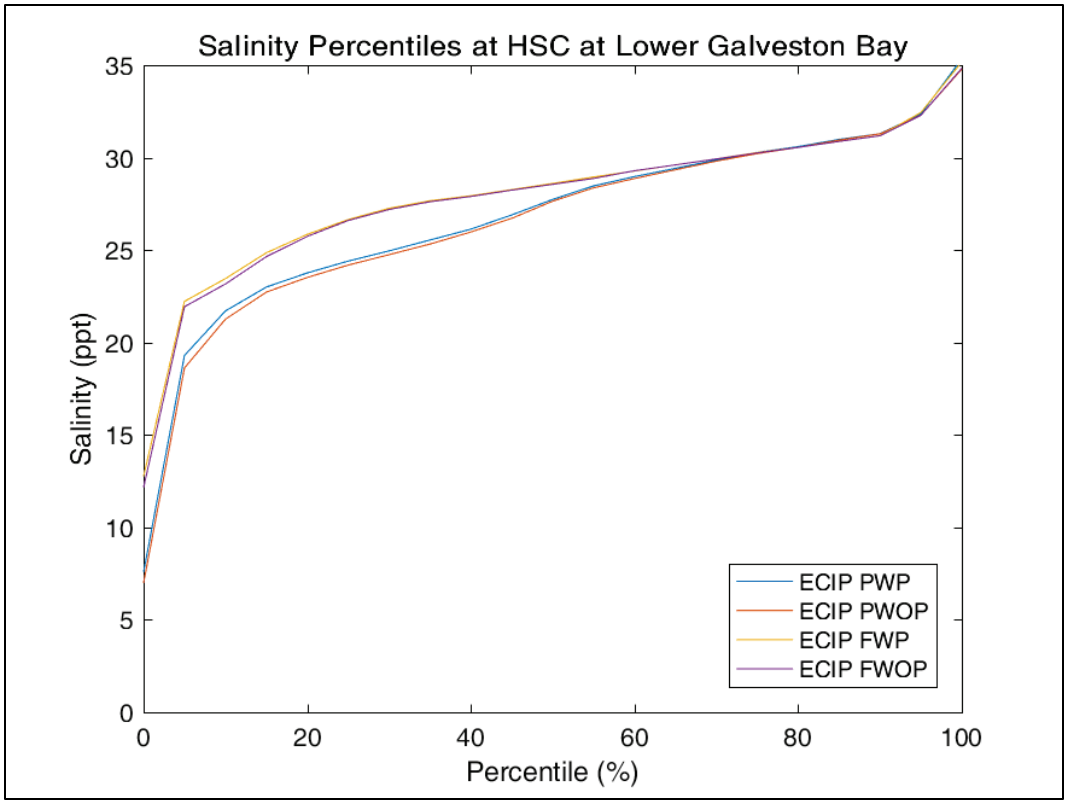
-4
-6
-8
-10
-12
-14
-16
16
18
20
22
24
26
28
30


Salinity at HSC at Lower Galveston Bay
Salinity (ppt)
Date (mm/dd)
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP


Salinity (ppt) at HSC at Lower Galveston Bay
Salinity (ppt)
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP


Salinity Percentiles at HSC at Lower Galveston Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
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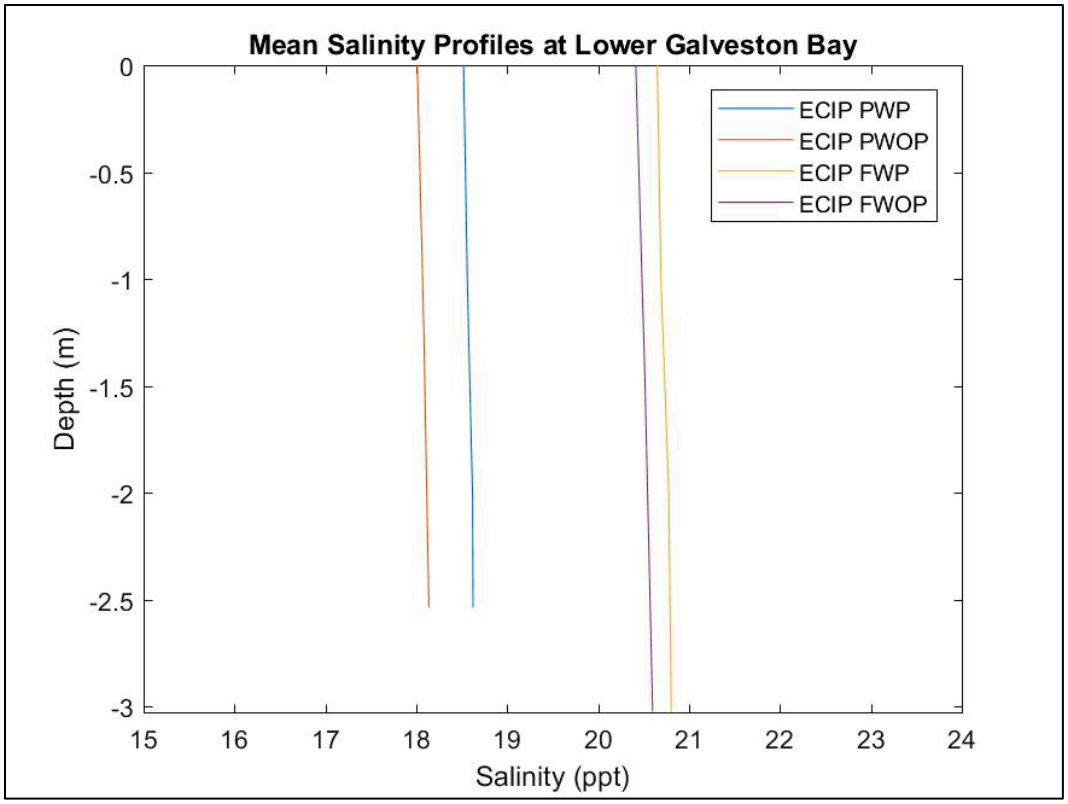
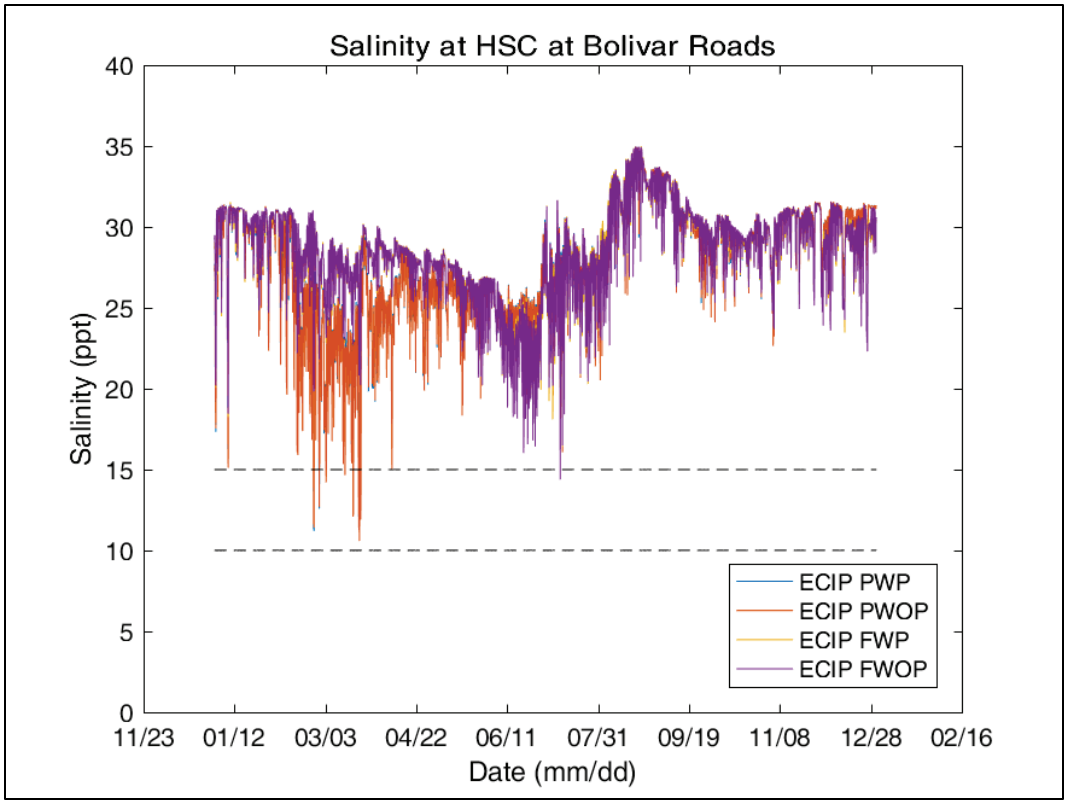
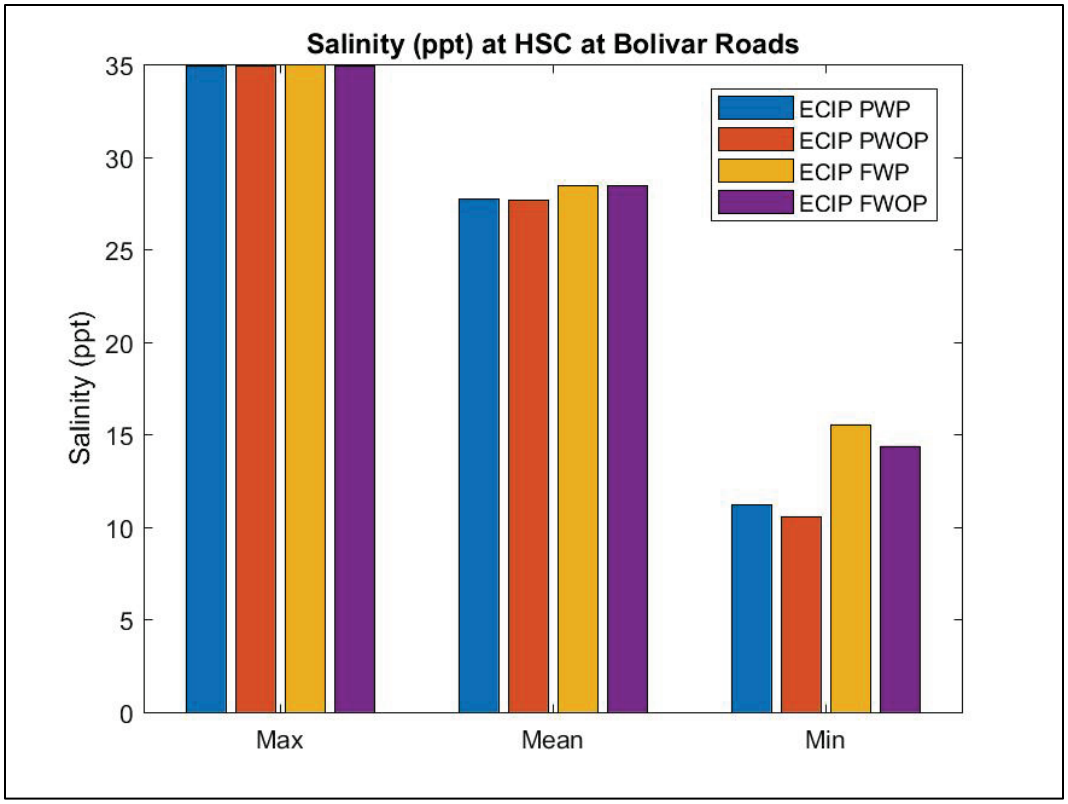
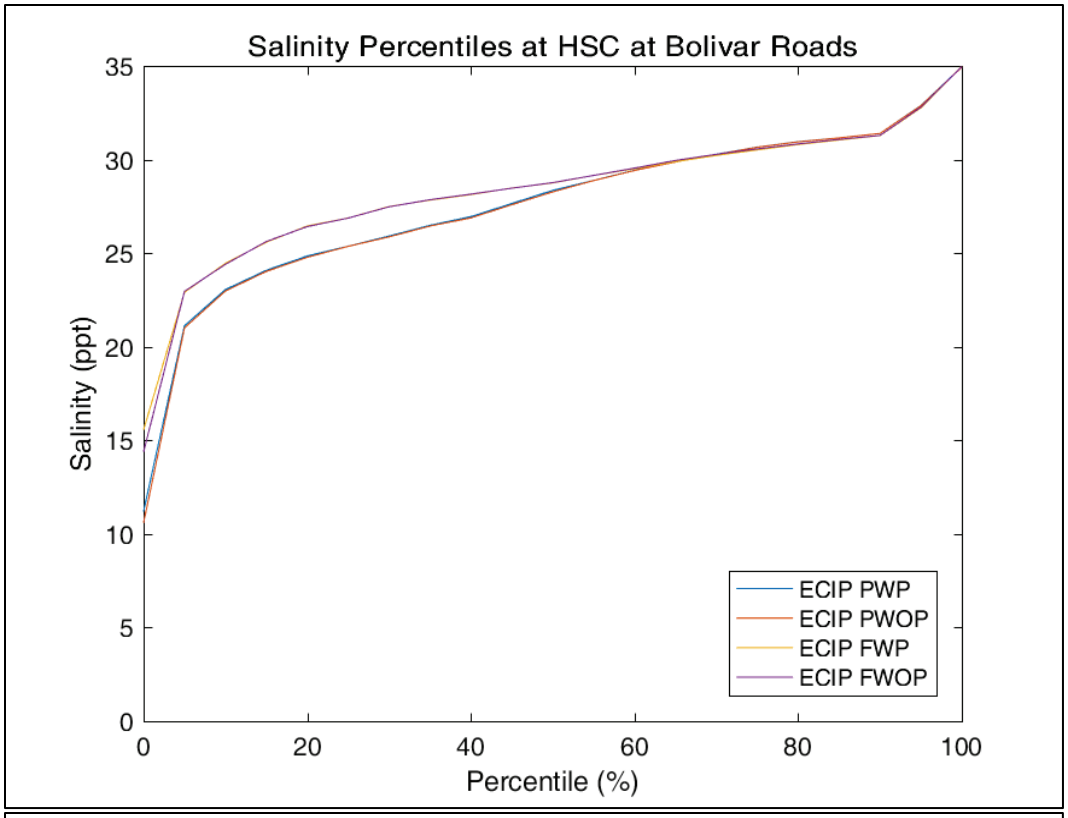
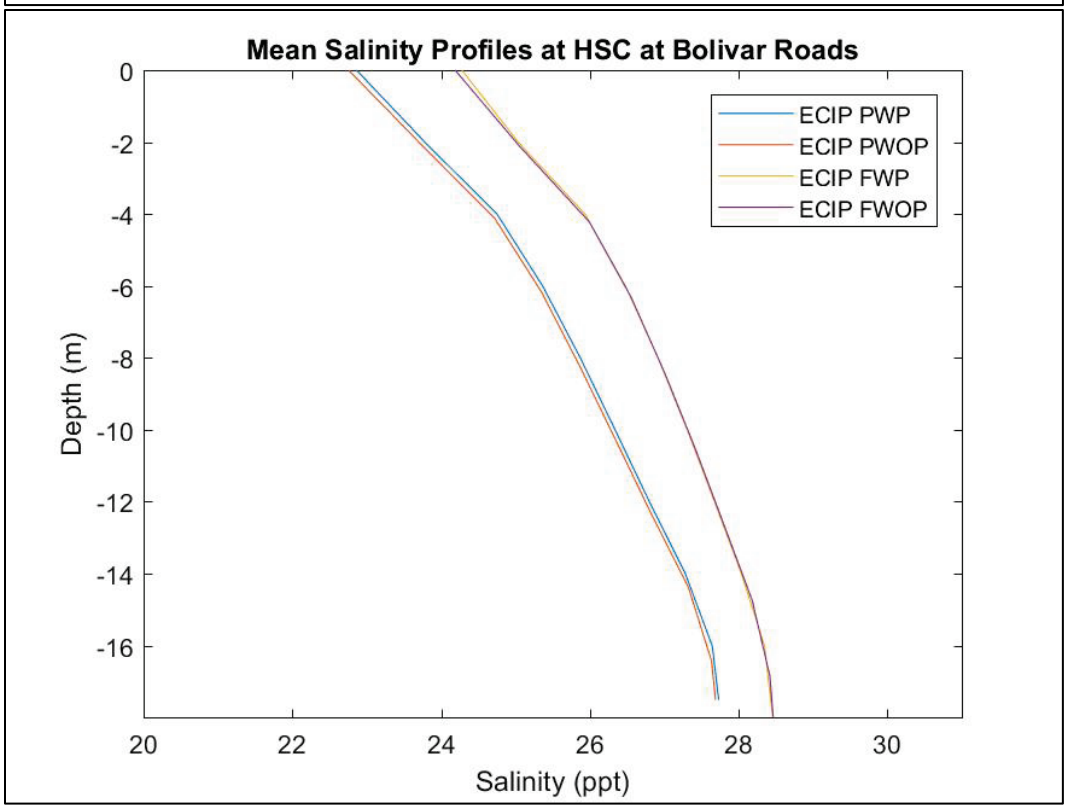
100
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

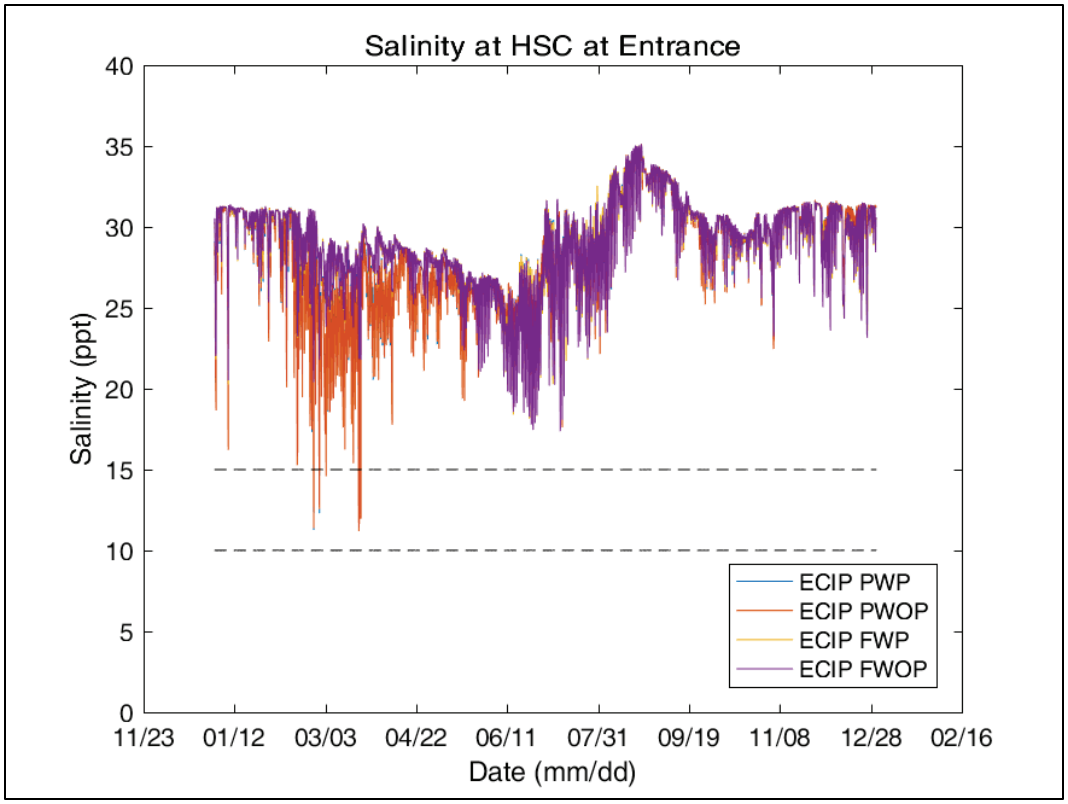

Mean Salinity Profiles at Lower Galveston Bay
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
15
16
17
18
19
20
21
22
23
24
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

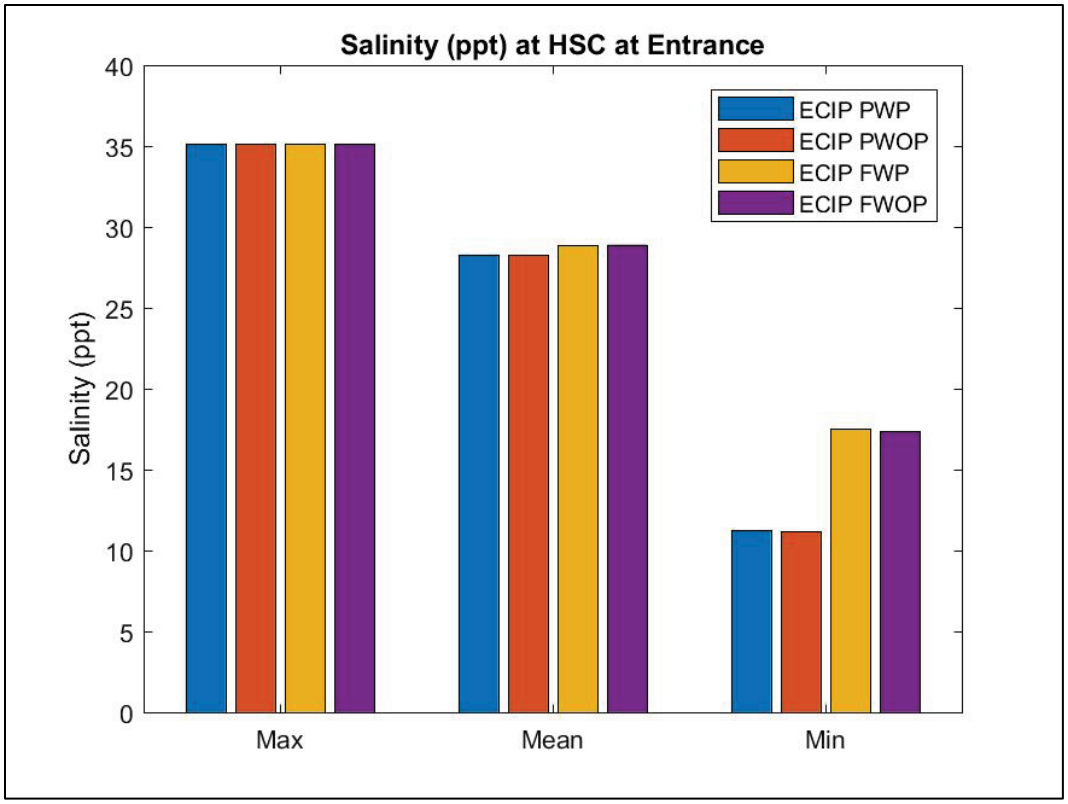

Salinity at HSC at Bolivar Roads
Salinity (ppt)
Date (mm/dd)
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

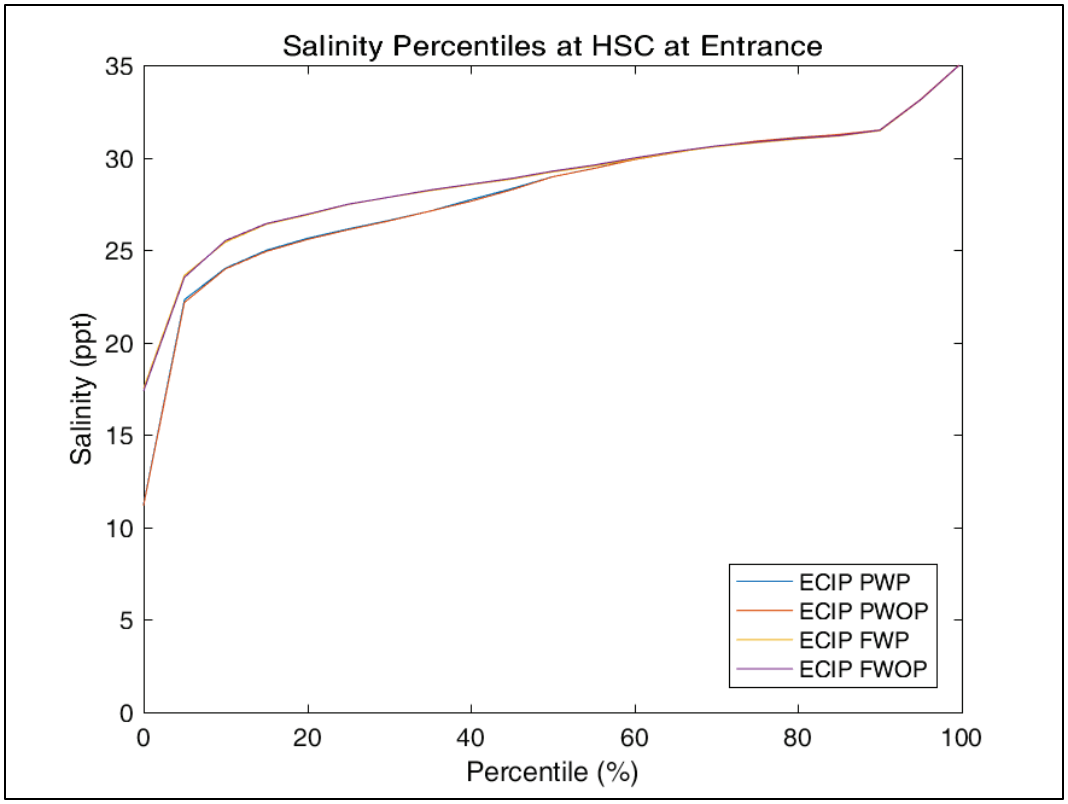

Salinity (ppt) at HSC at Bolivar Roads
Salinity (ppt)
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

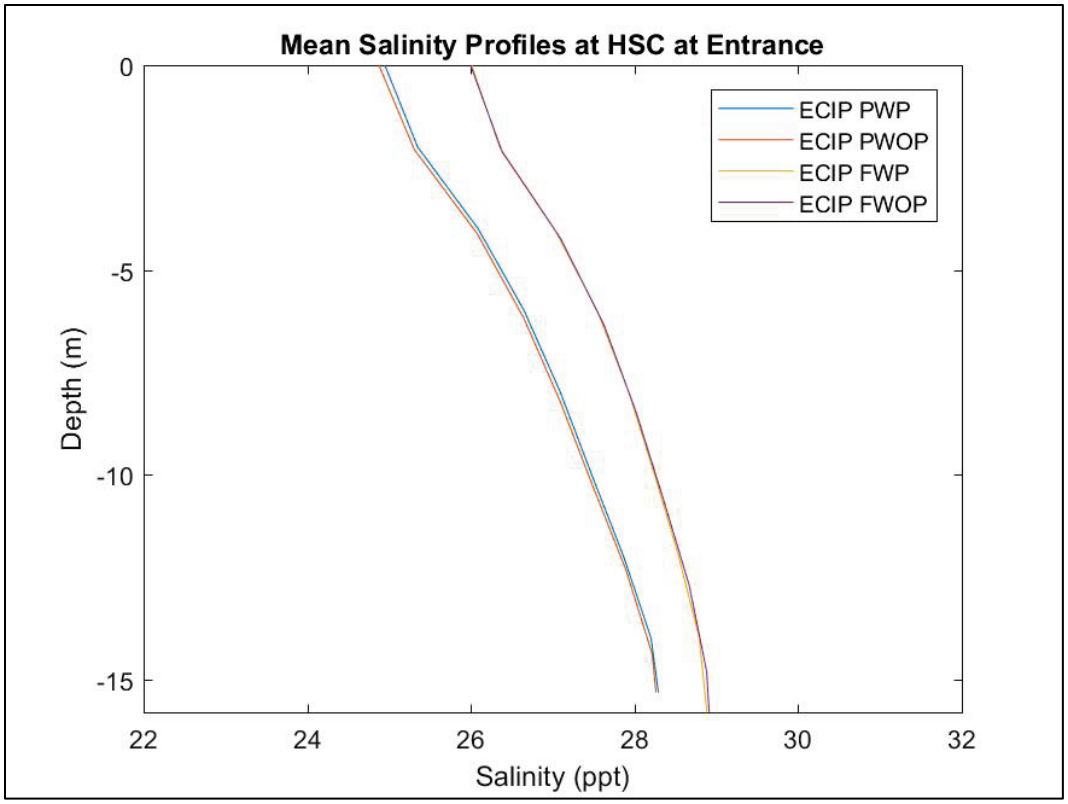

Salinity Percentiles at HSC at Bolivar Roads
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

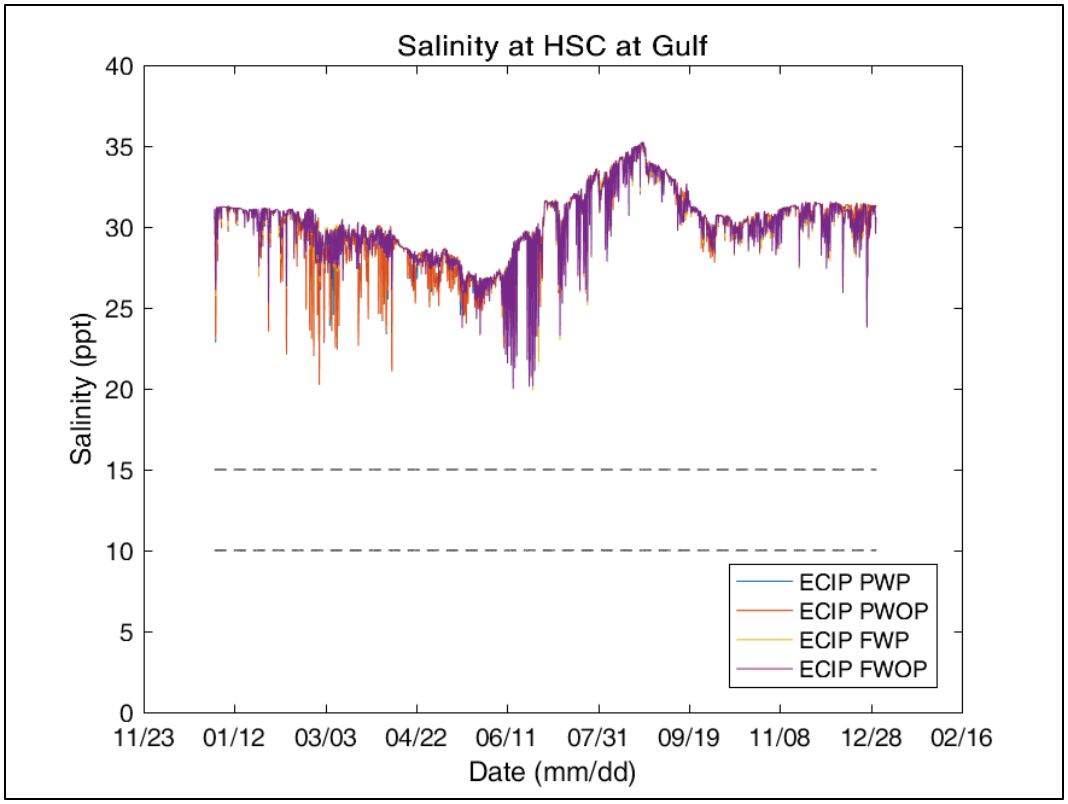

Mean Salinity Profiles at HSC at Bolivar Roads
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
20
22
24
26
28
30
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

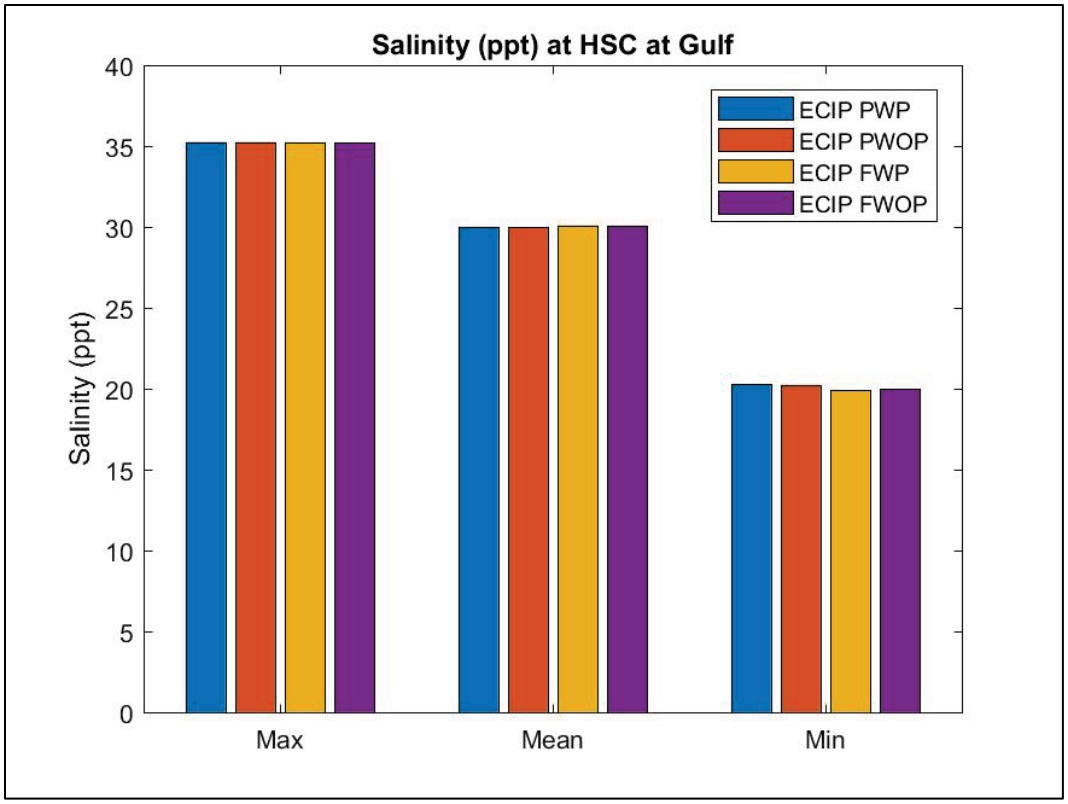

Salinity at HSC at Entrance
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

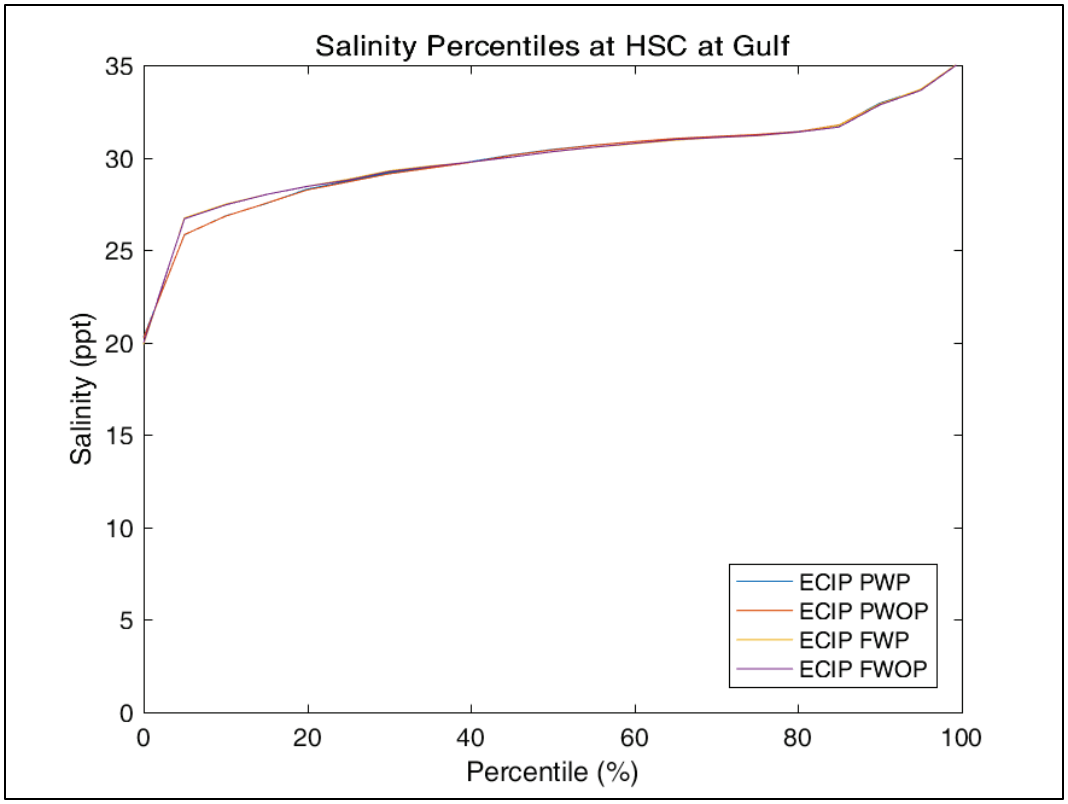

Salinity (ppt) at HSC at Entrance
Salinity (ppt)
0
5
10
15
20
25
30
35
40
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

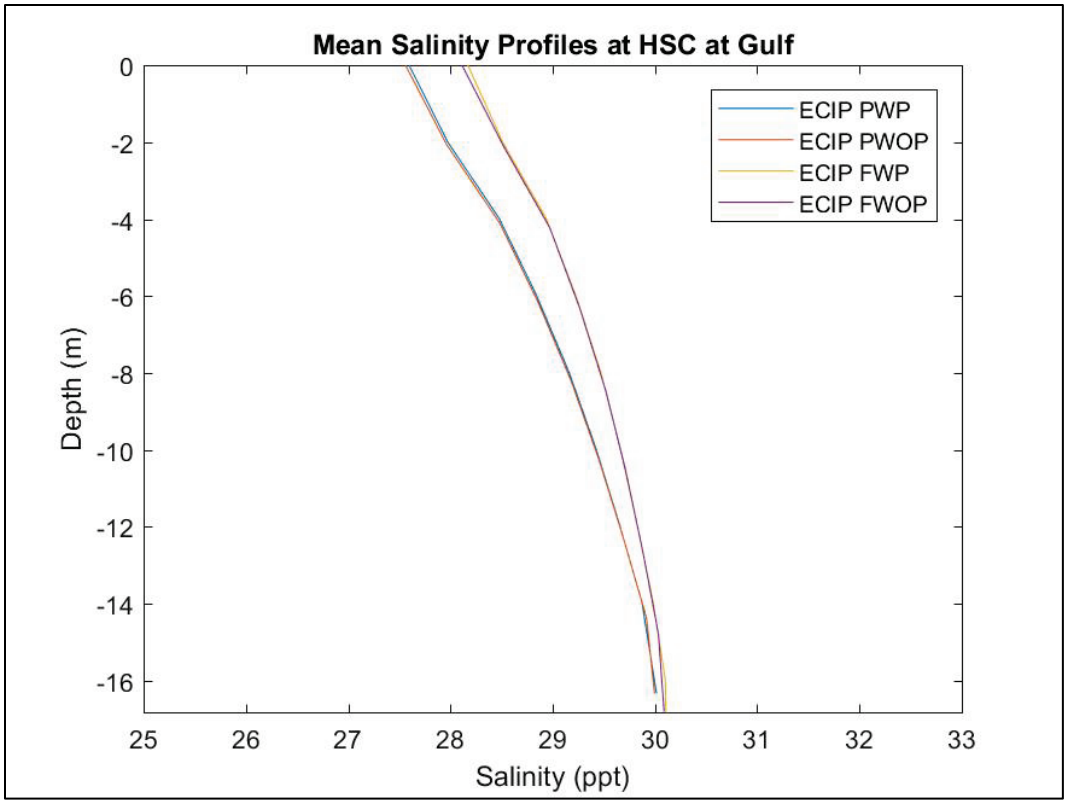

Salinity Percentiles at HSC at Entrance
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

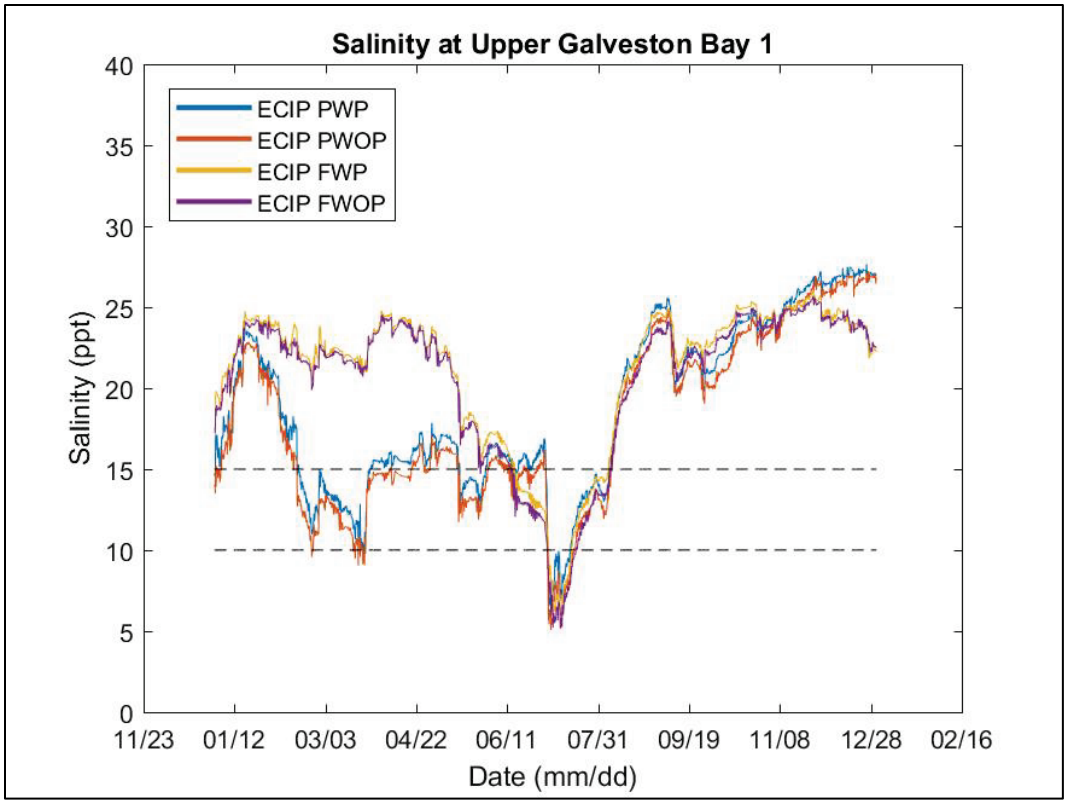

Mean Salinity Profiles at HSC at Entrance
Depth (m)
Salinity (ppt)
0
-5
-10
-15
22
24
26
28
30
32
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

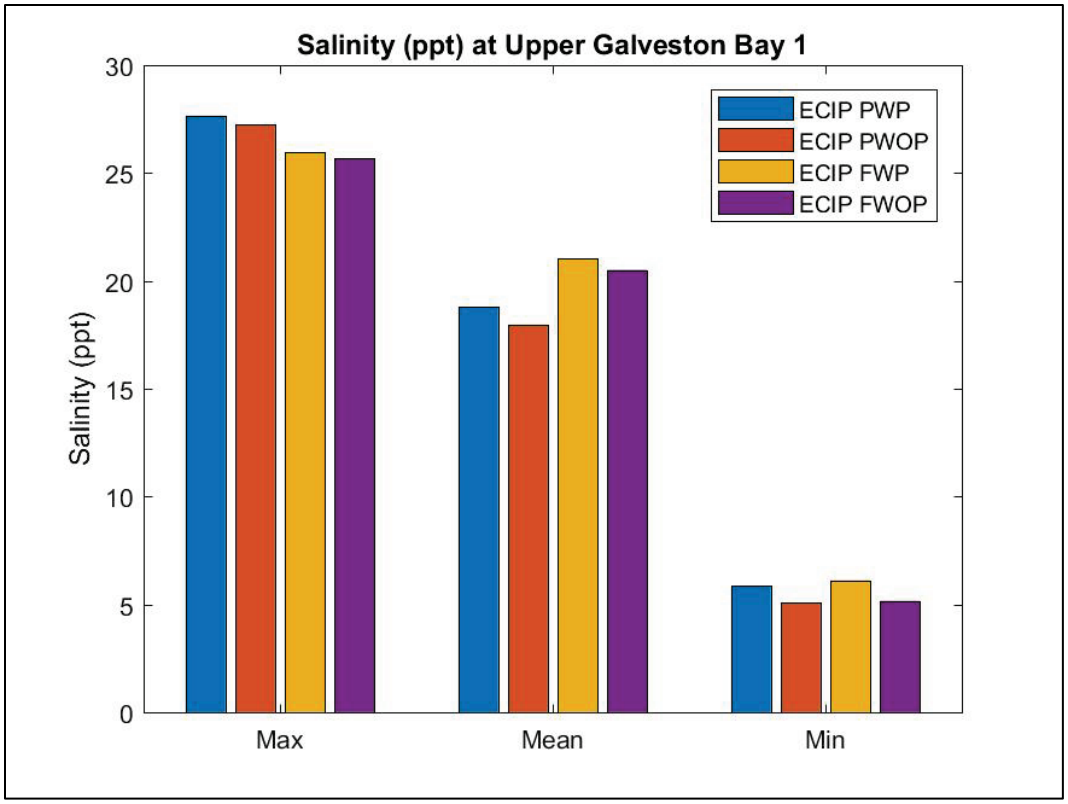

Salinity at HSC at Gulf
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

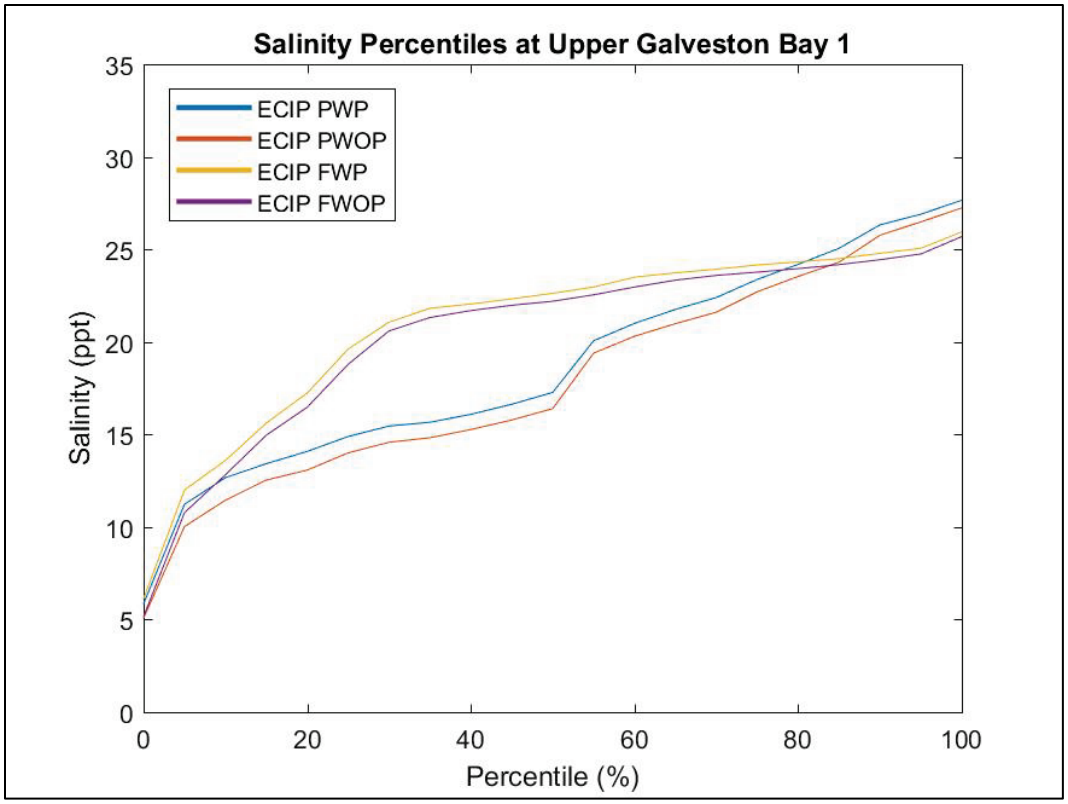

Salinity (ppt) at HSC at Gulf
Salinity (ppt)
0
5
10
15
20
25
30
35
40
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

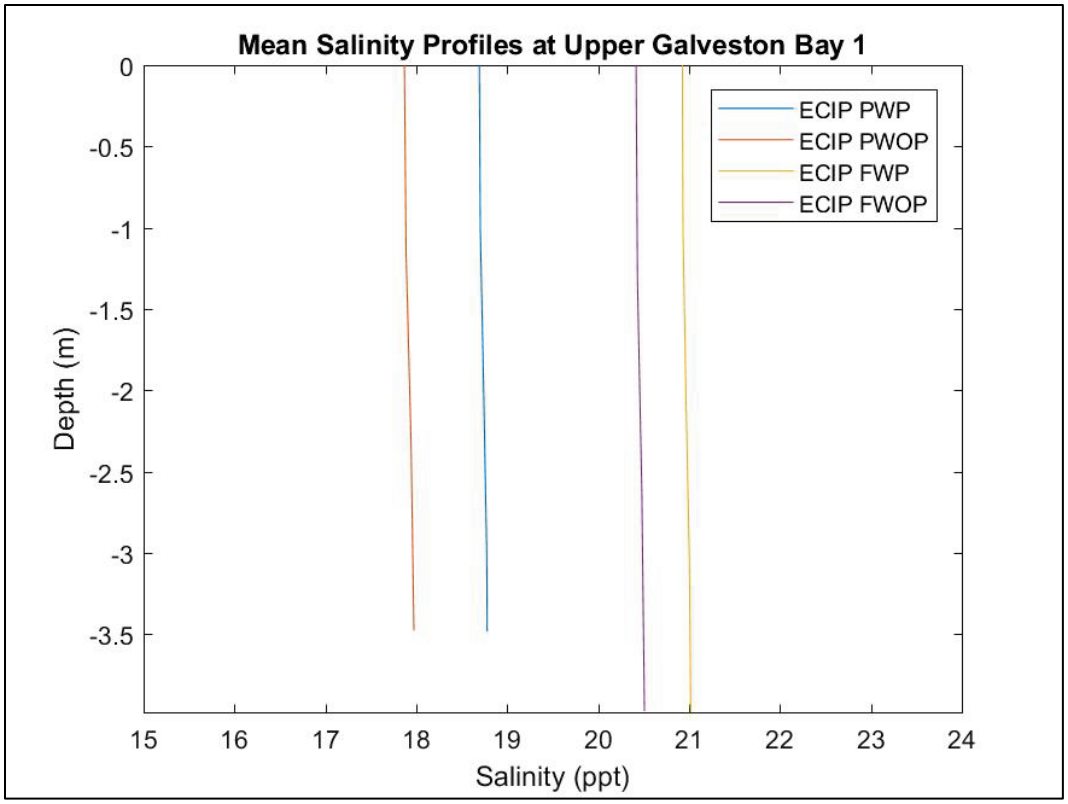

Salinity Percentiles at HSC at Gulf
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

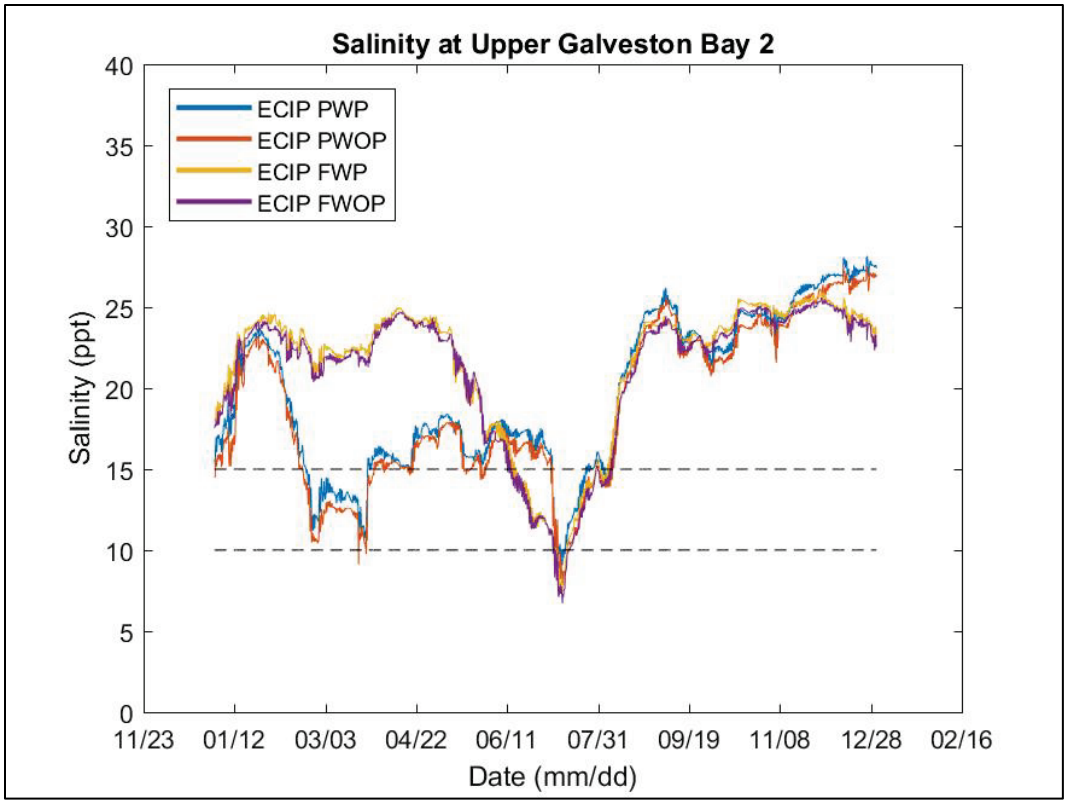

Mean Salinity Profiles at HSC at Gulf
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
25
26
27
28
29
30
31
32
33
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

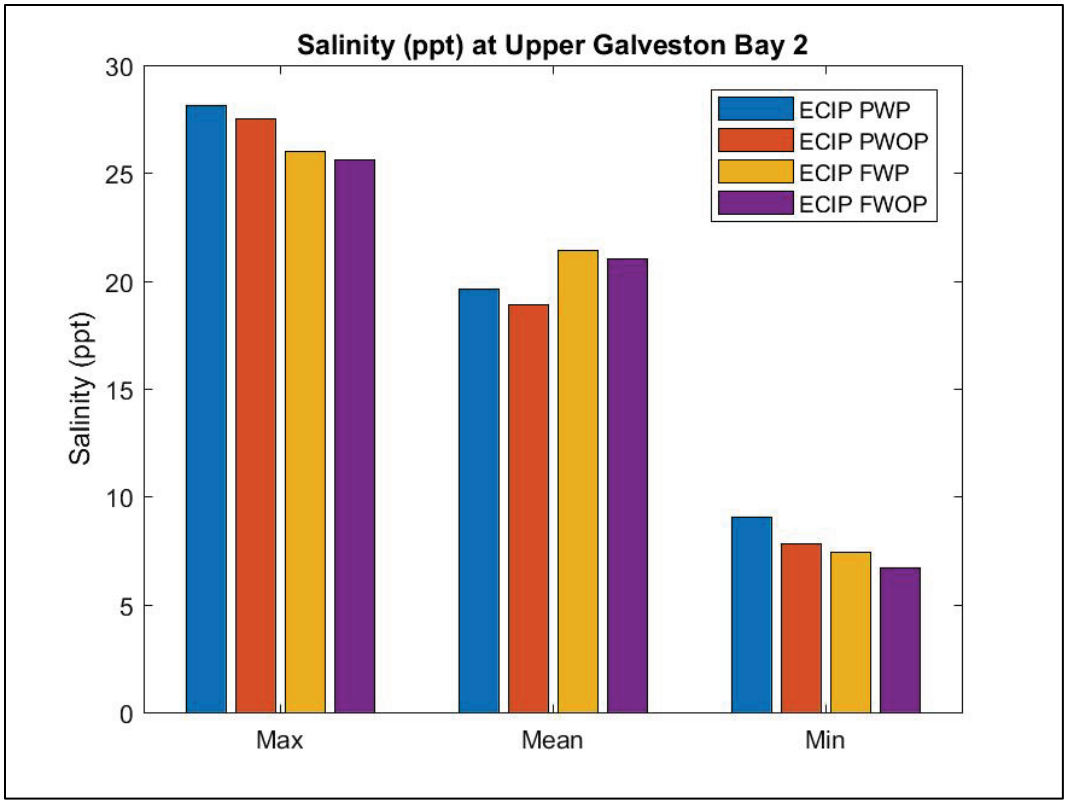

Salinity at Upper Galveston Bay 1
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

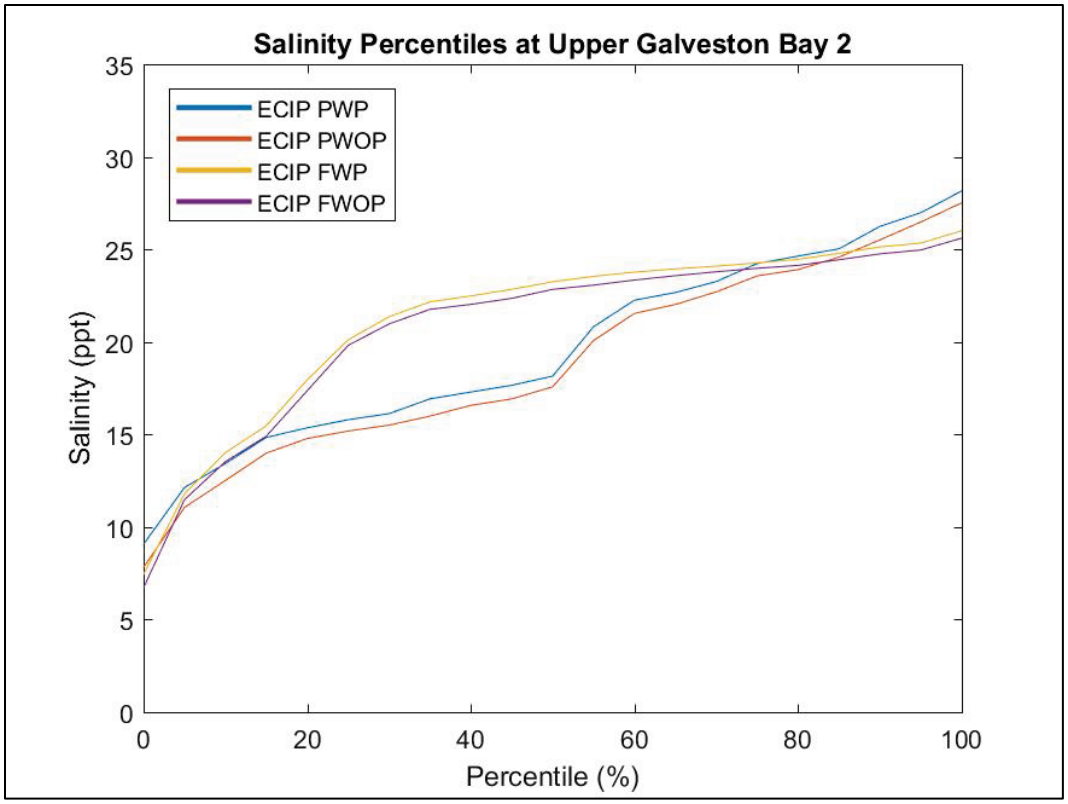

Salinity (ppt) at Upper Galveston Bay 1
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

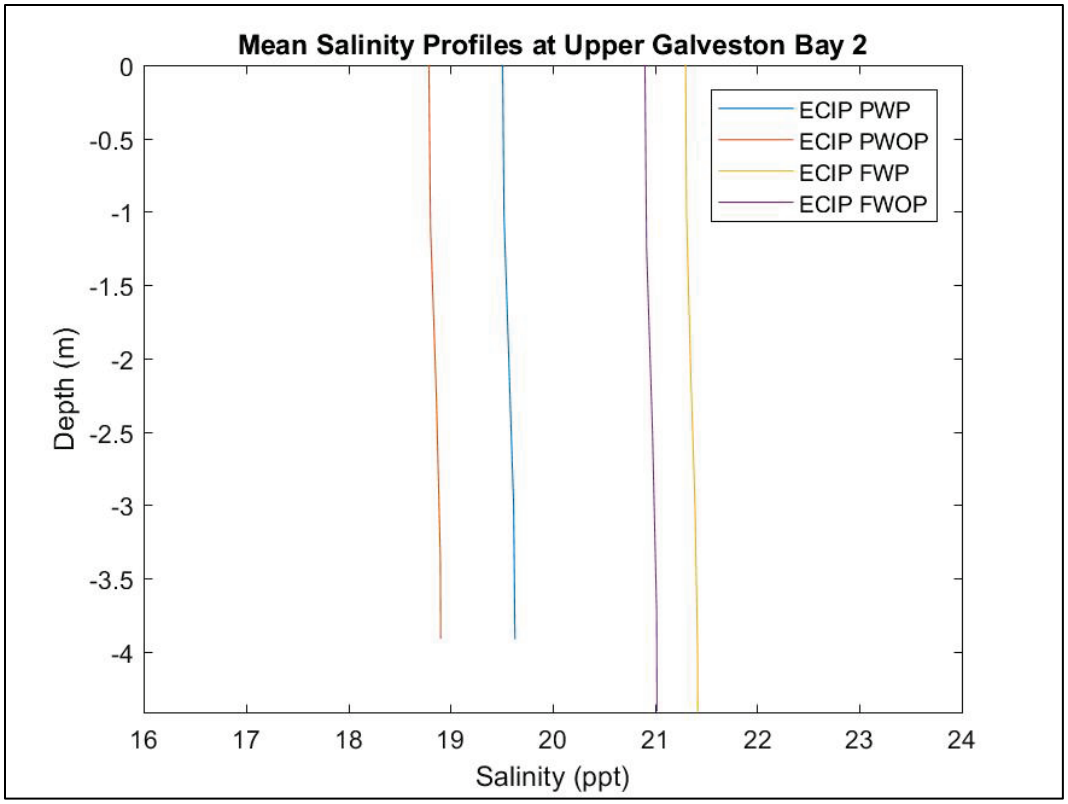

Salinity Percentiles at Upper Galveston Bay 1
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

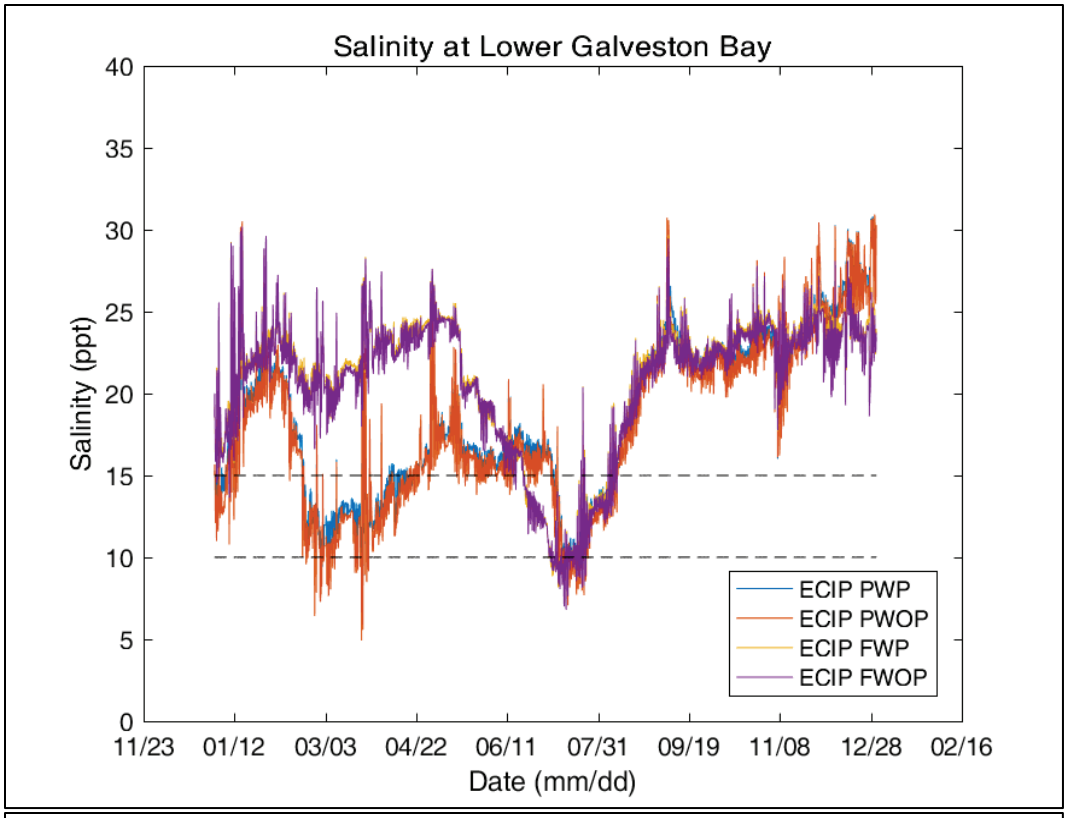

Mean Salinity Profiles at Upper Galveston Bay 1
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
15
16
17
18
19
20
21
22
23
24

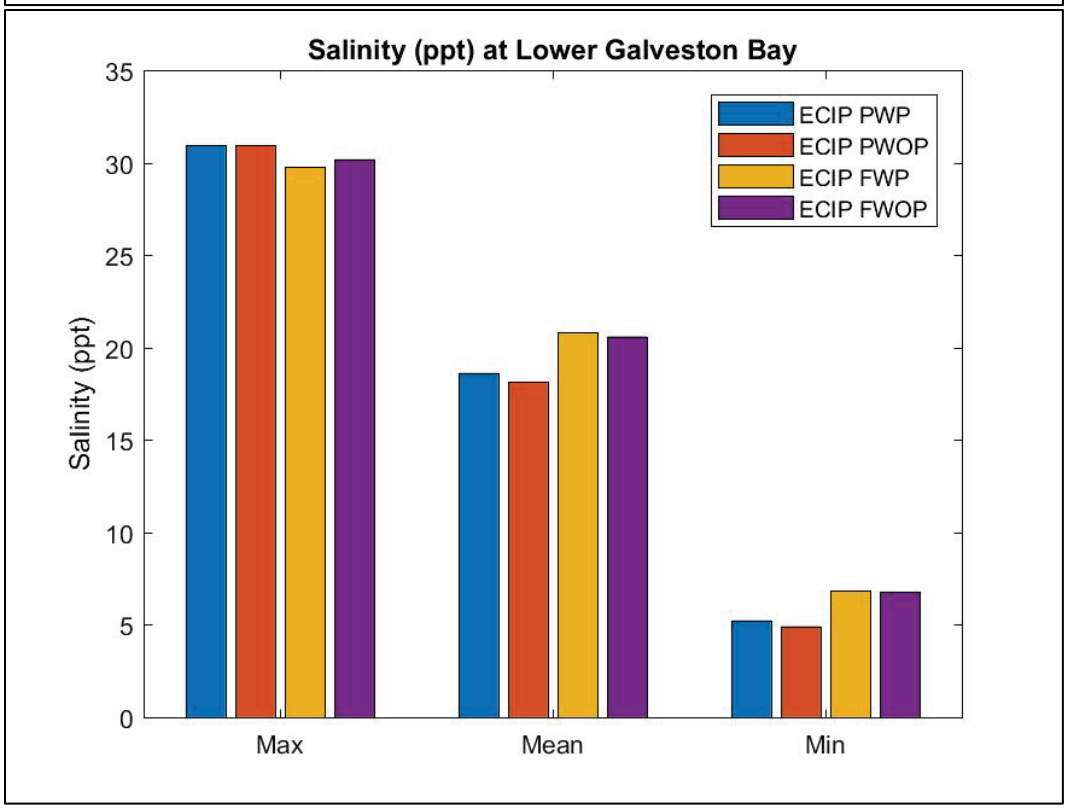

Salinity at Upper Galveston Bay 2
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

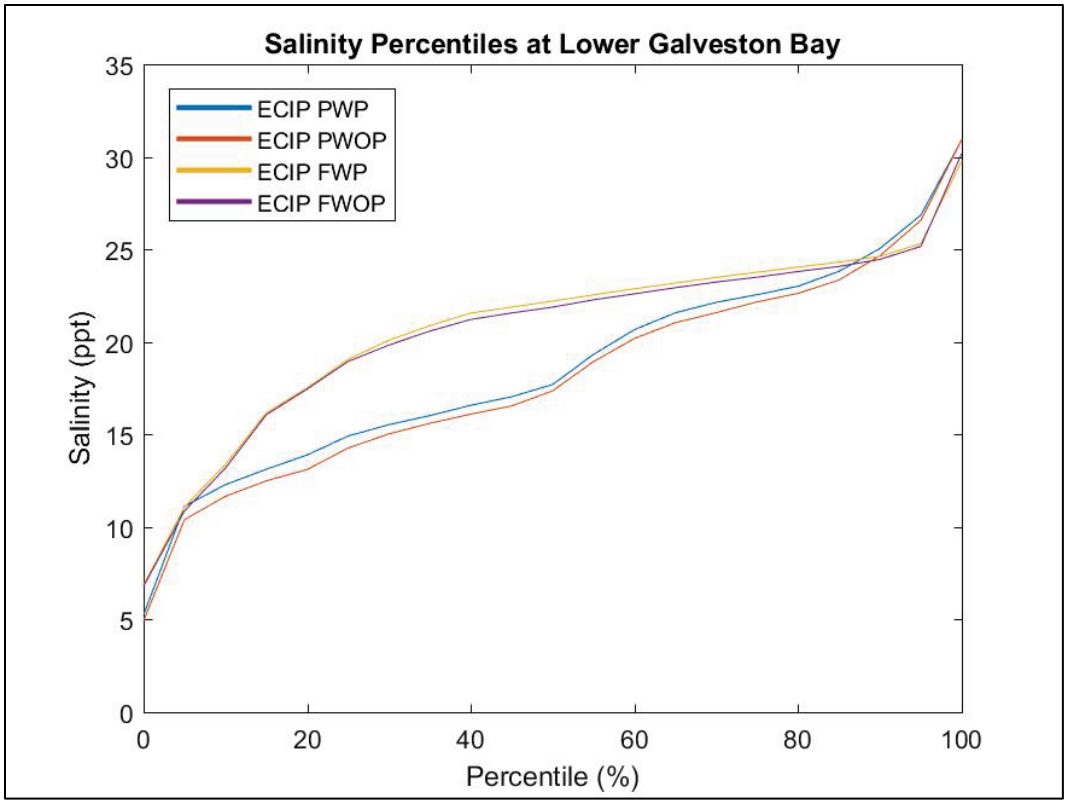

Salinity (ppt) at Upper Galveston Bay 2
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

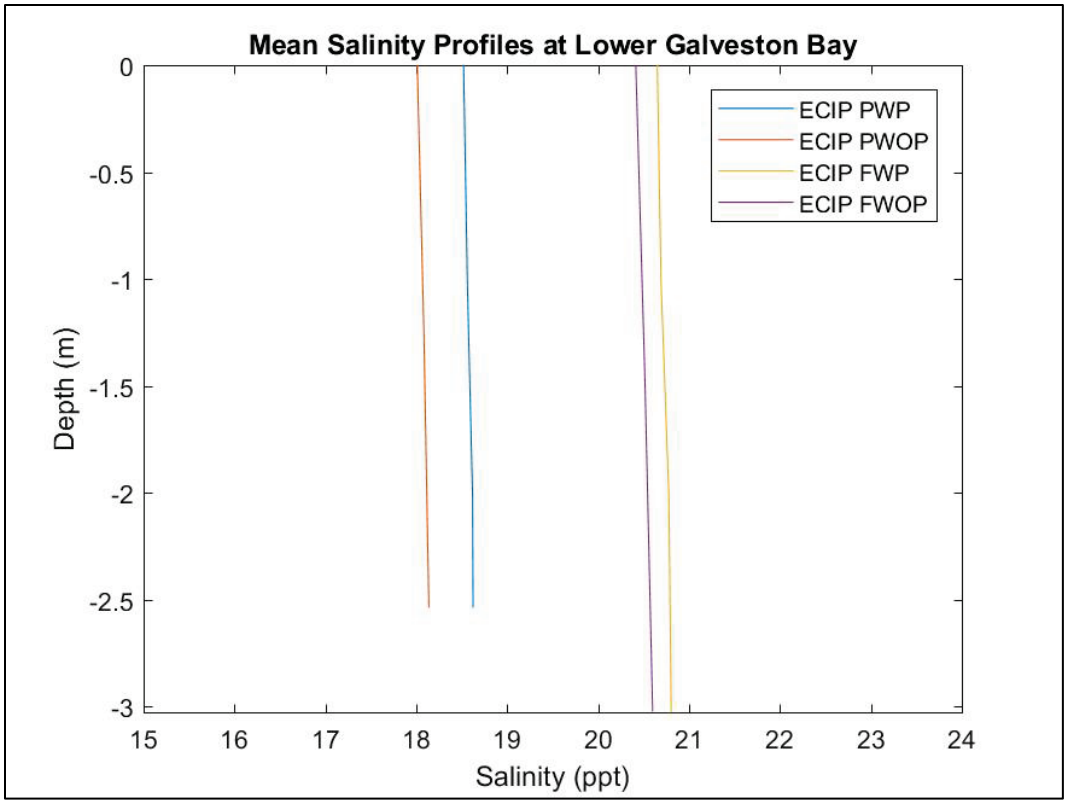

Salinity Percentiles at Upper Galveston Bay 2
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

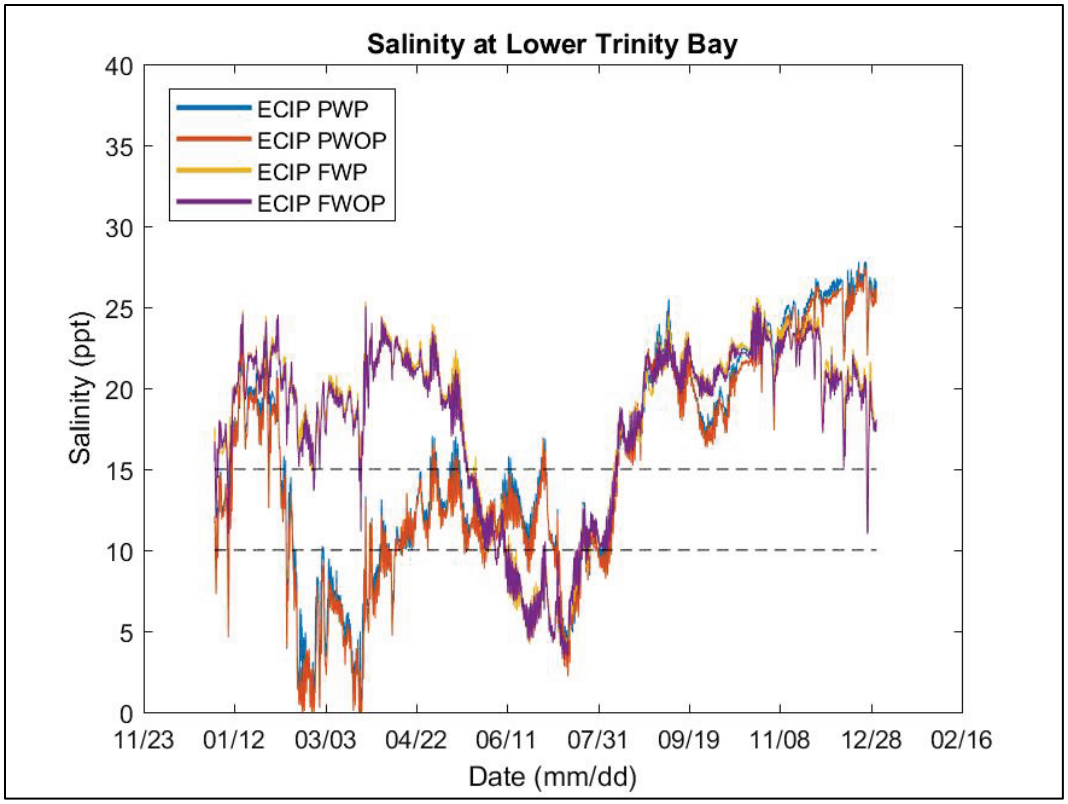

Mean Salinity Profiles at Upper Galveston Bay 2
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
16
17
18
19
20
21
22
23
24

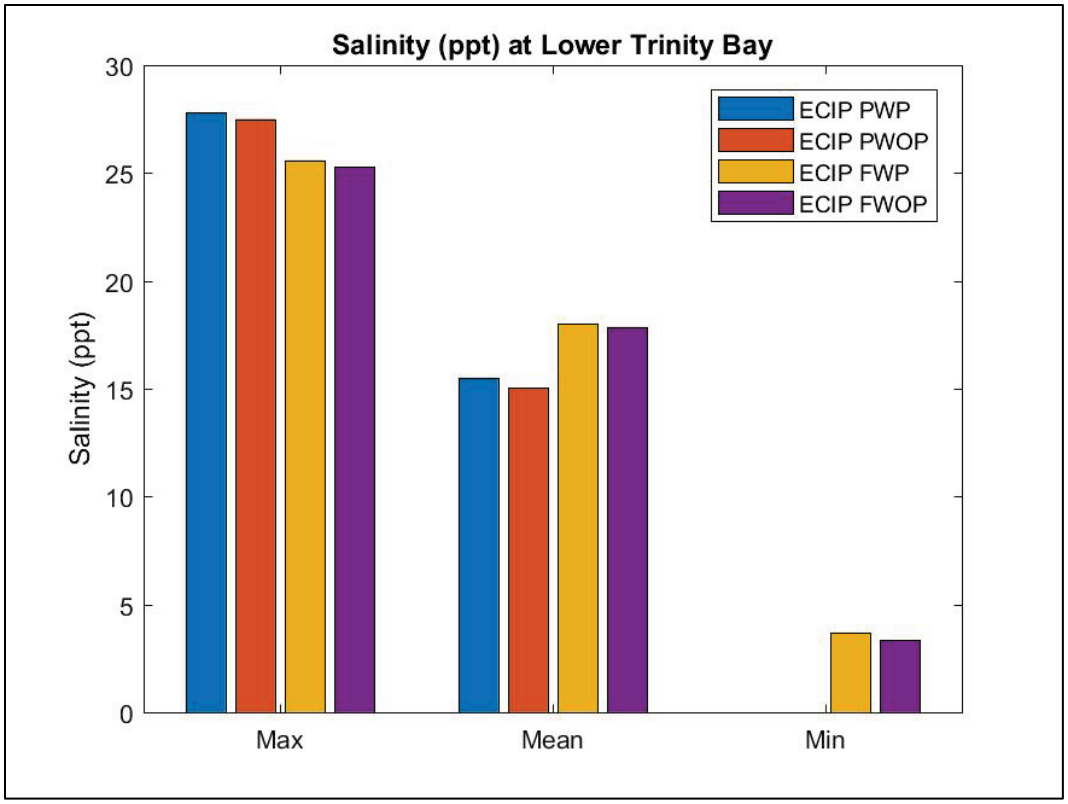

Salinity at Lower Galveston Bay
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

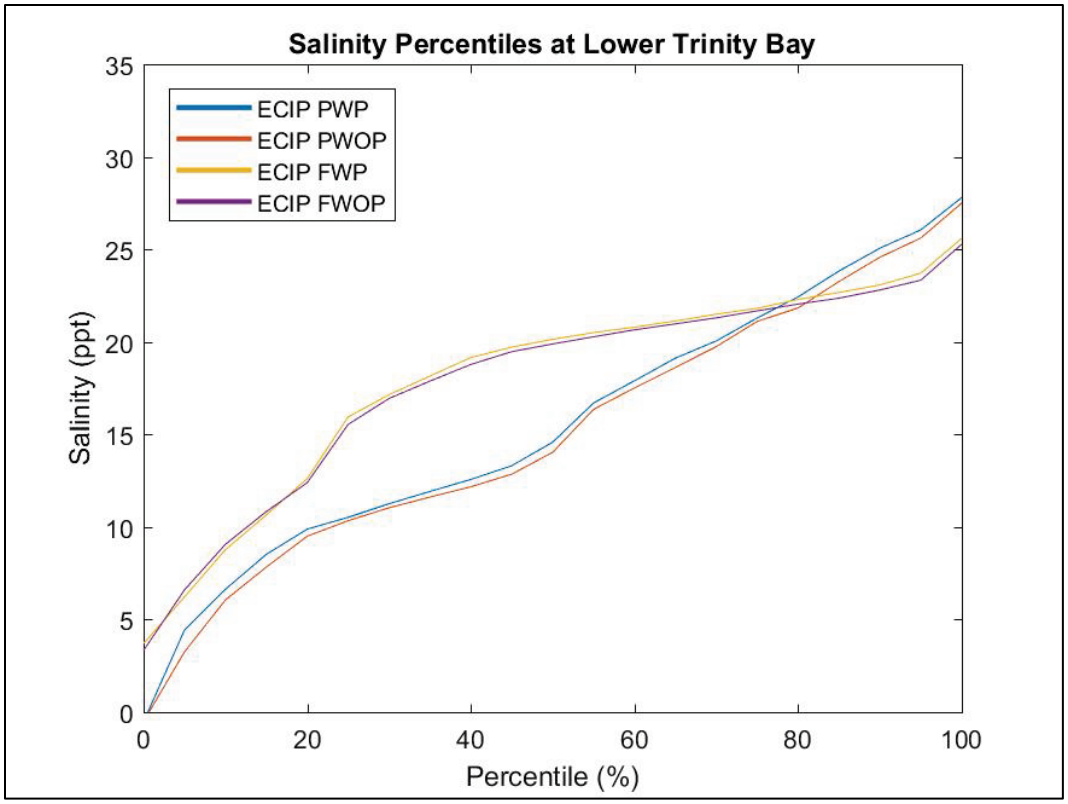

Salinity (ppt) at Lower Galveston Bay
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

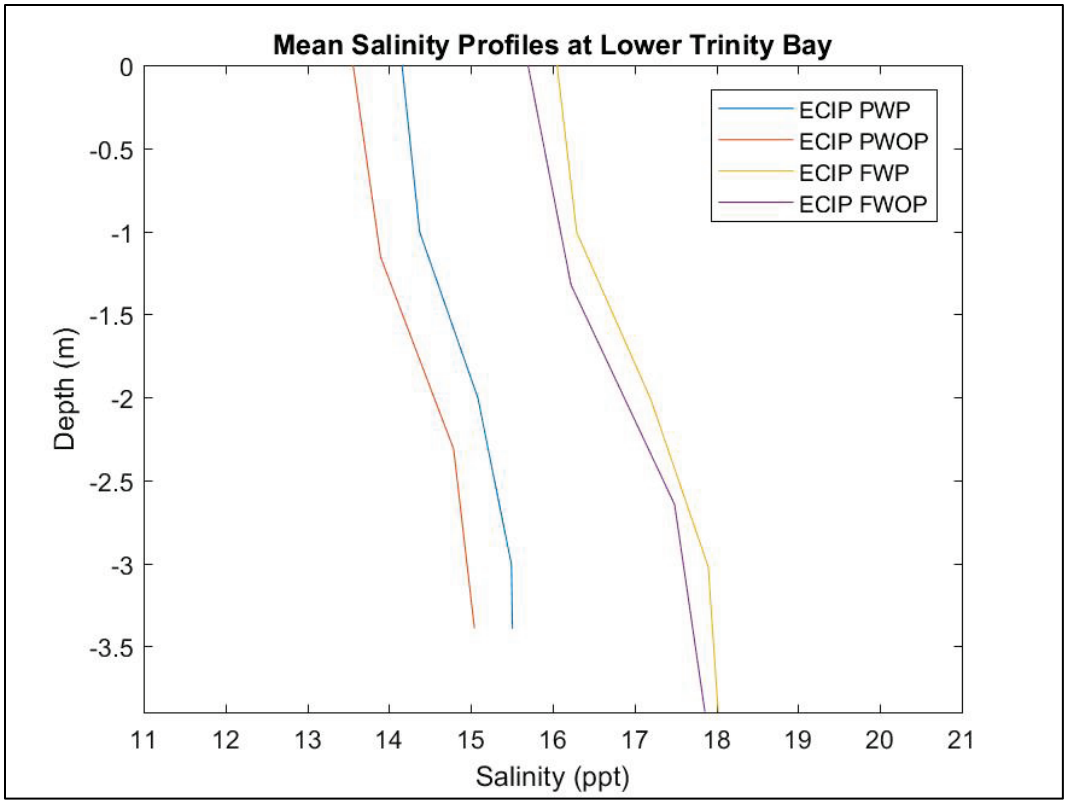

Salinity Percentiles at Lower Galveston Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

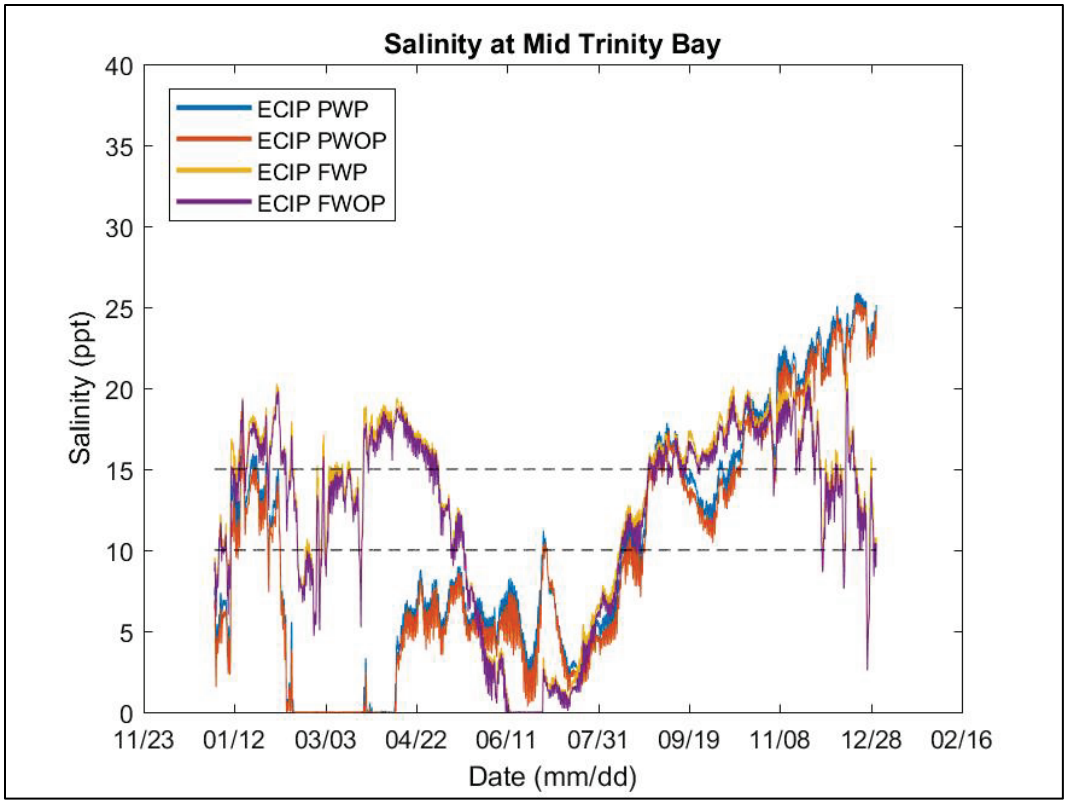

Mean Salinity Profiles at Lower Galveston Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
15
16
17
18
19
20
21
22
23
24

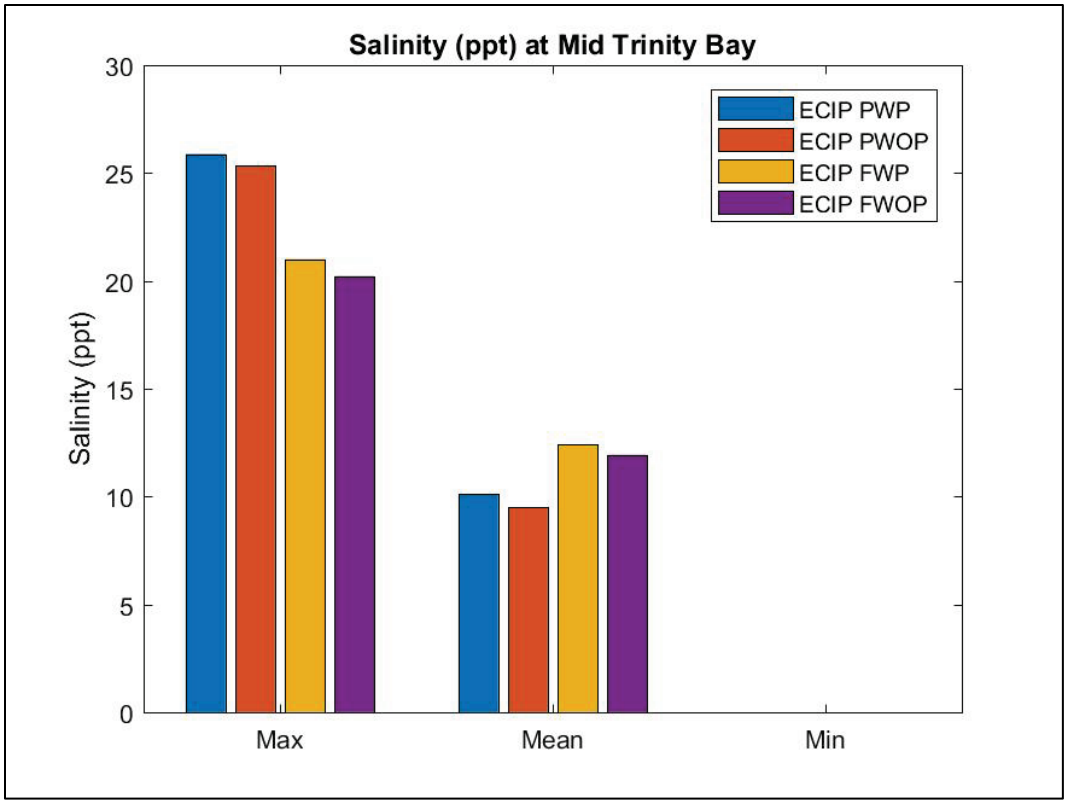

Salinity at Lower Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

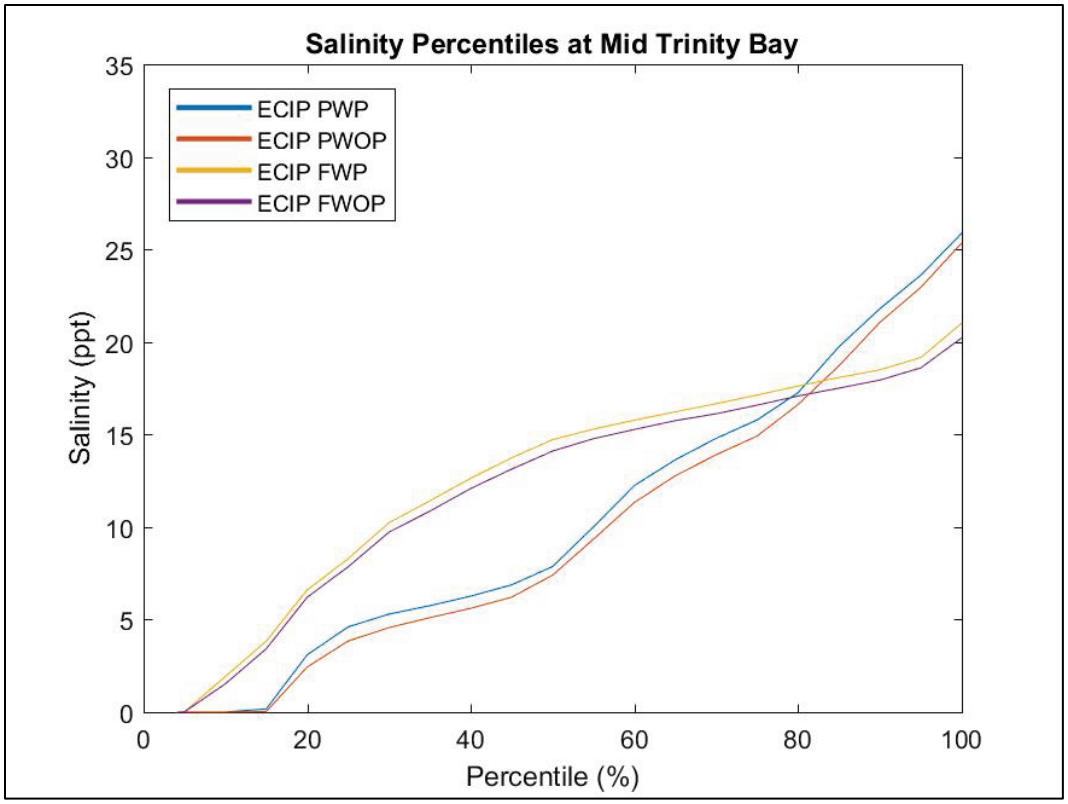

Salinity (ppt) at Lower Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

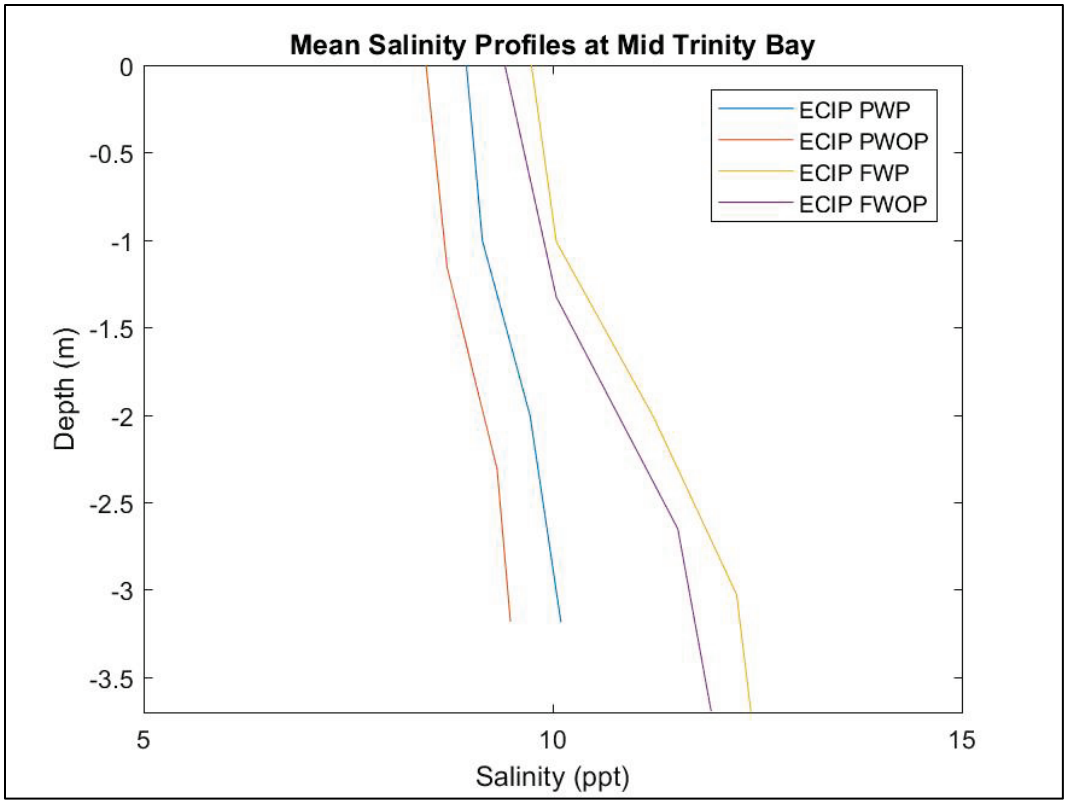

Salinity Percentiles at Lower Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

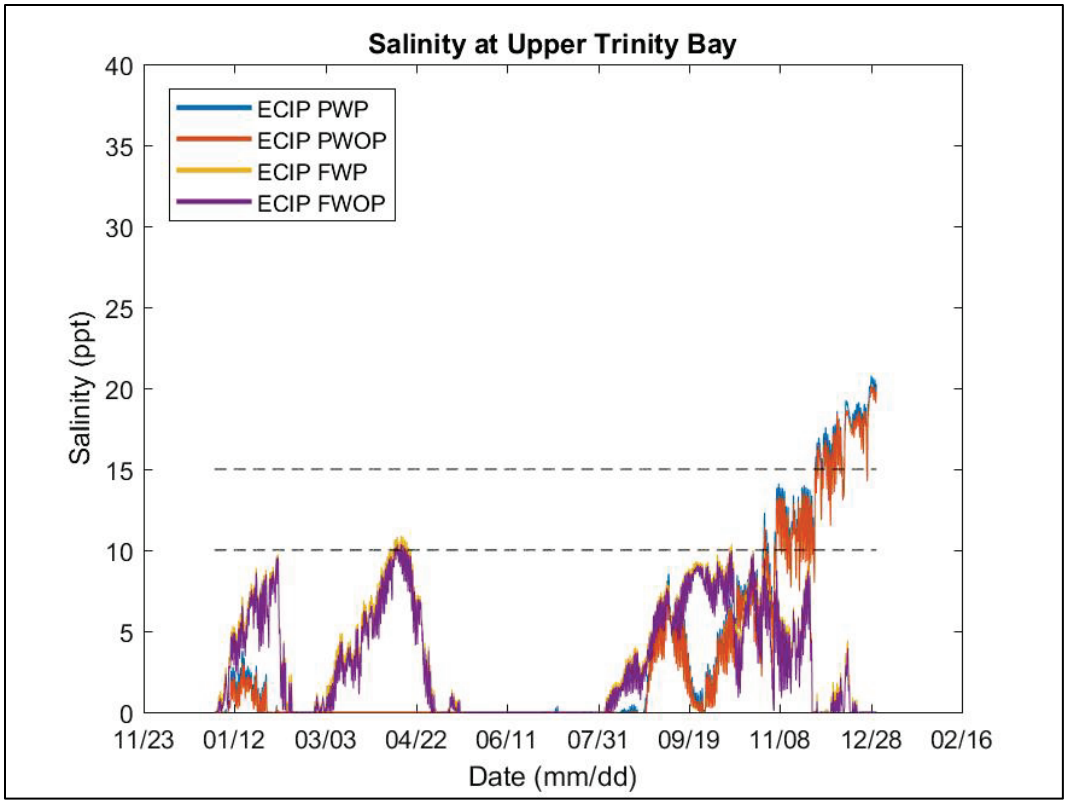

Mean Salinity Profiles at Lower Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
11
12
13
14
15
16
17
18
19
20
21

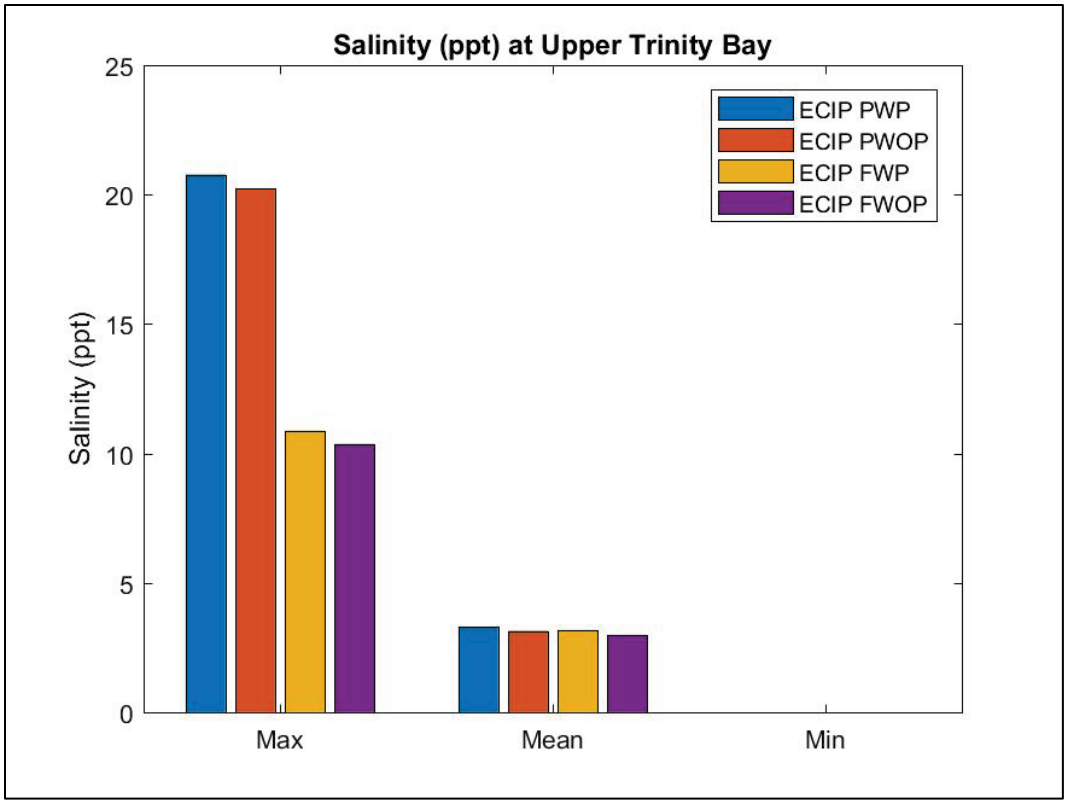

Salinity at Mid Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

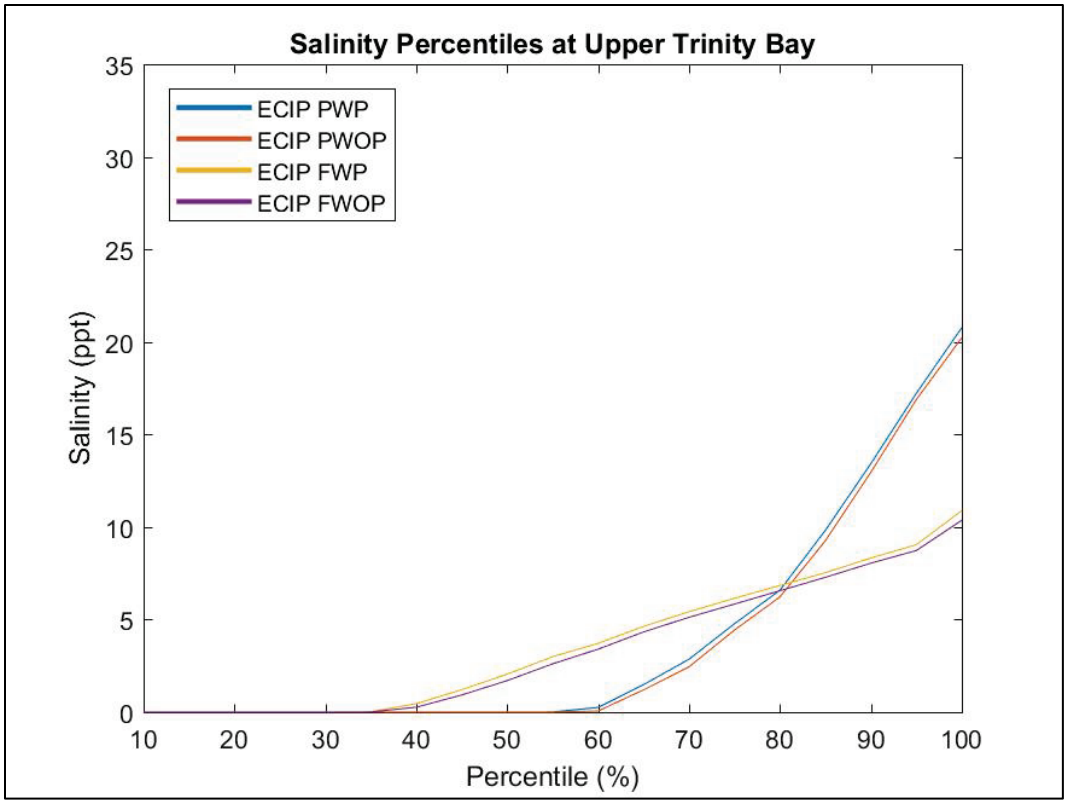

Salinity (ppt) at Mid Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min

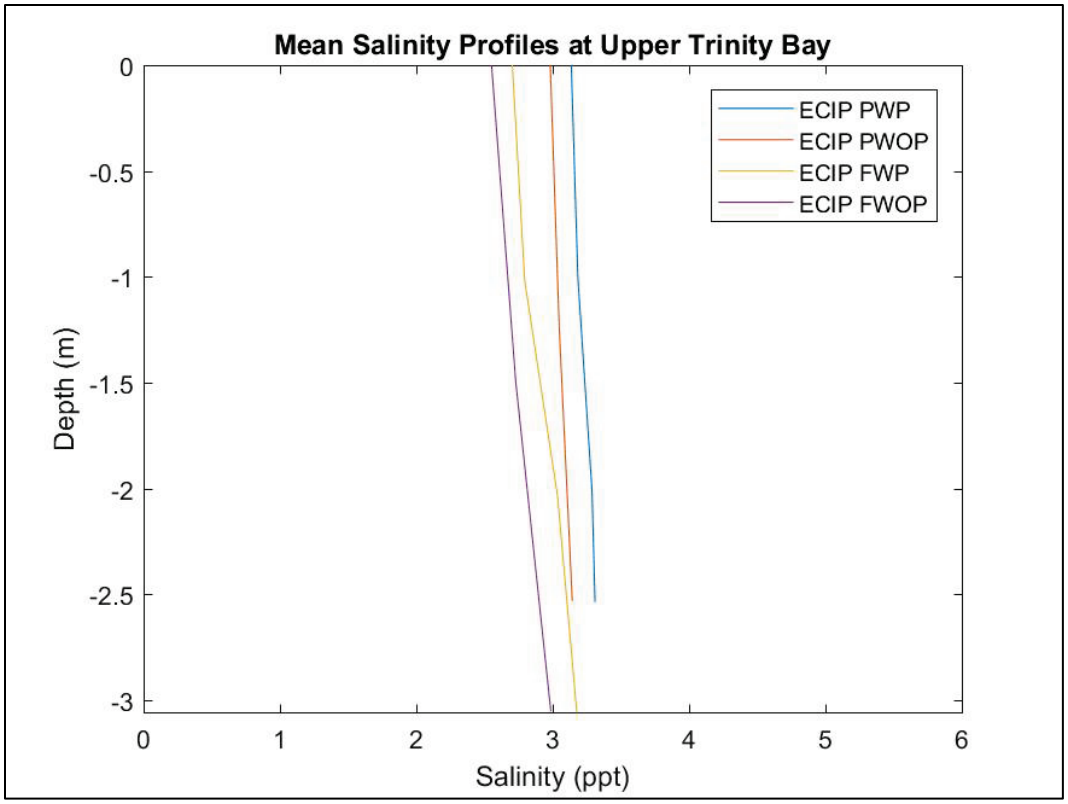

Salinity Percentiles at Mid Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

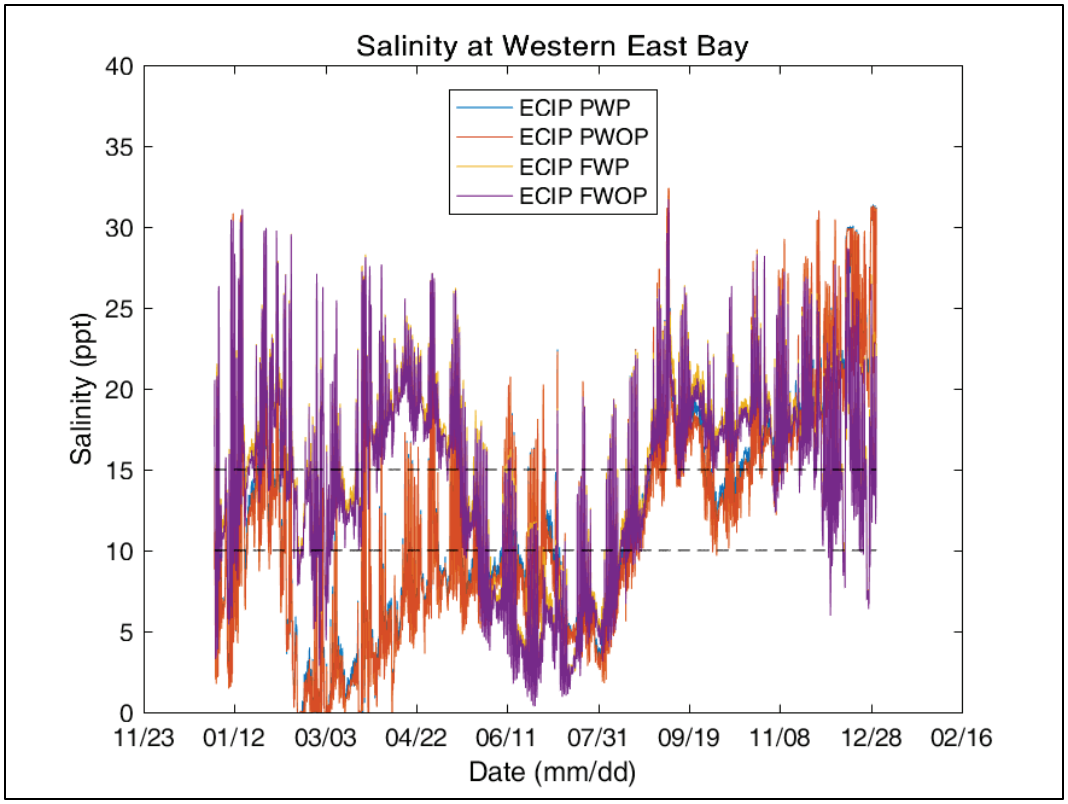

Mean Salinity Profiles at Mid Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
5
10
15

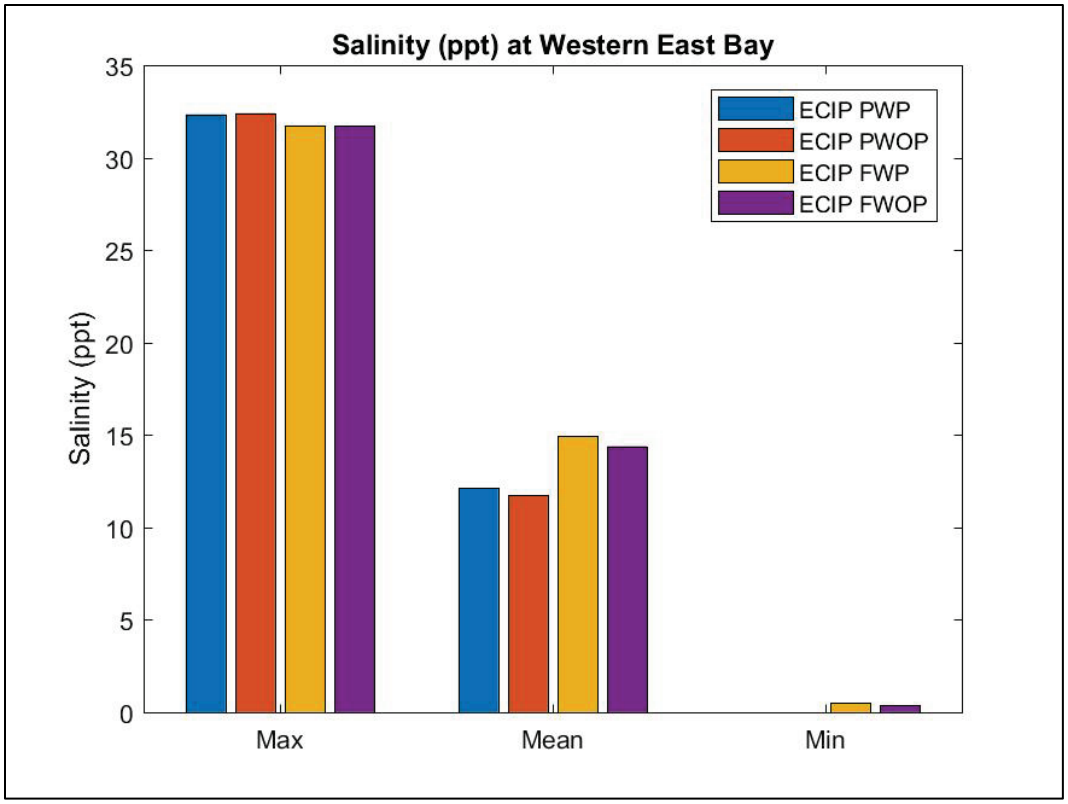

Salinity at Upper Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

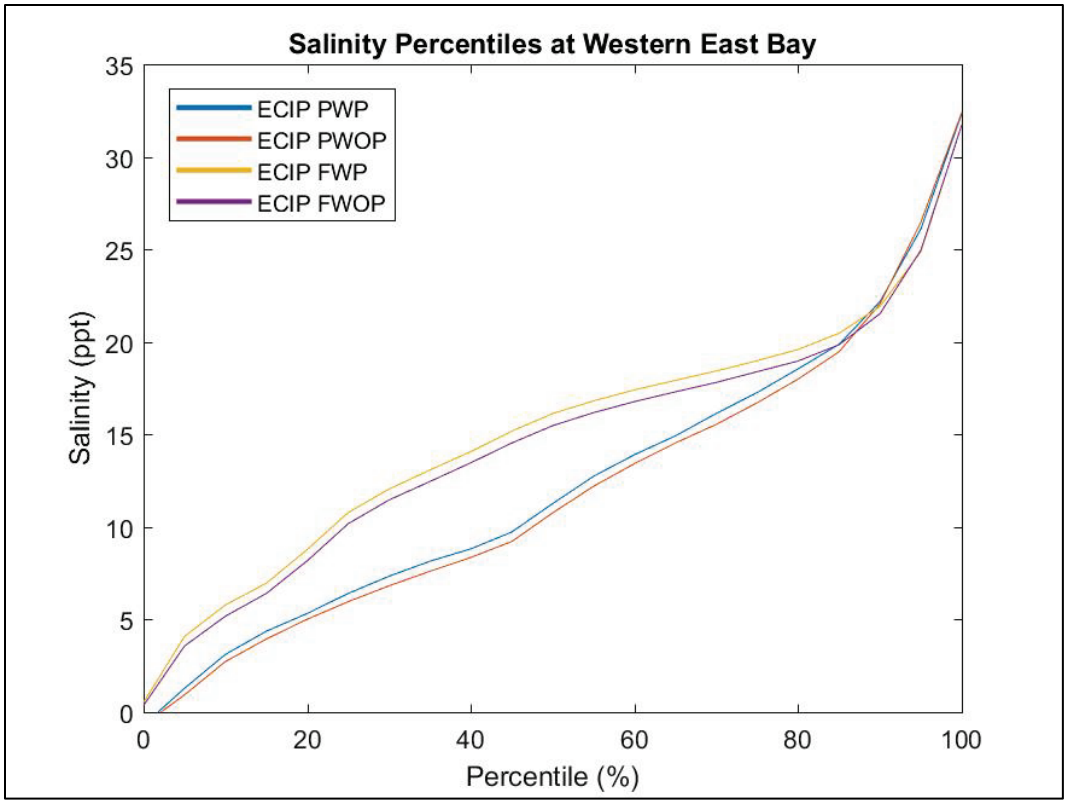

Salinity (ppt) at Upper Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
25
20
15
10
5
0
Max
Mean
Min

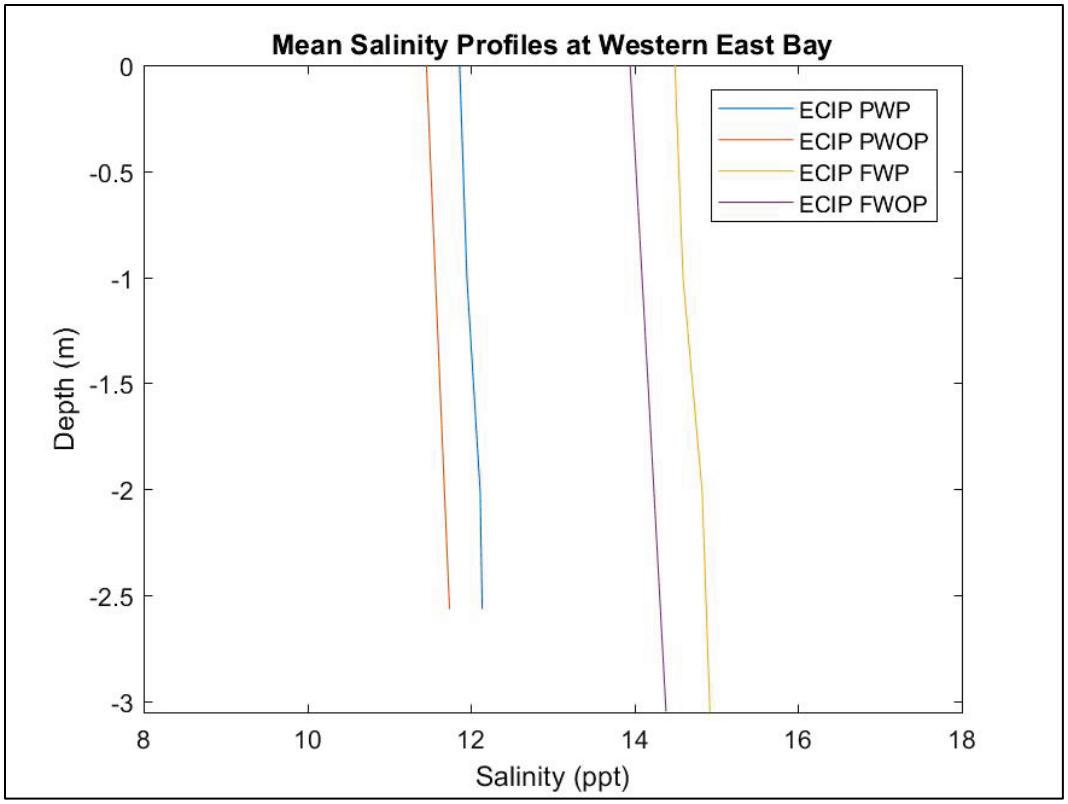

Salinity Percentiles at Upper Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
10
20
30
40
50
60
70
80
90
100

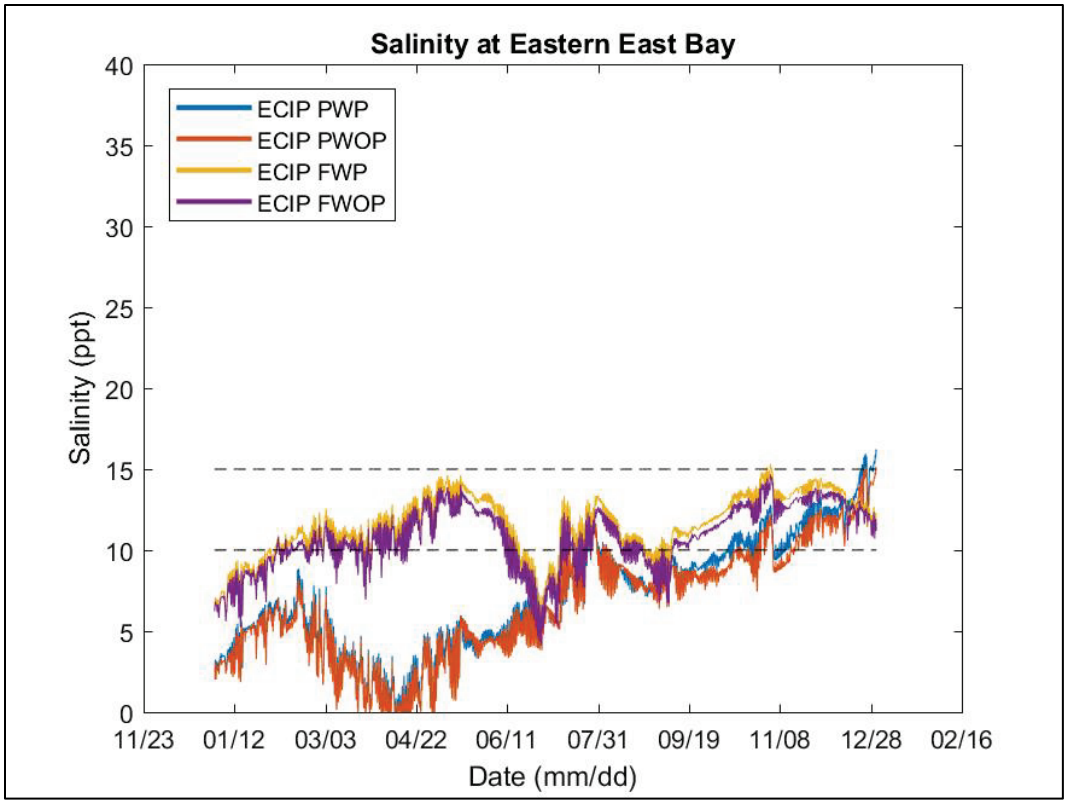

Mean Salinity Profiles at Upper Trinity Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
0
1
2
3
4
5
6

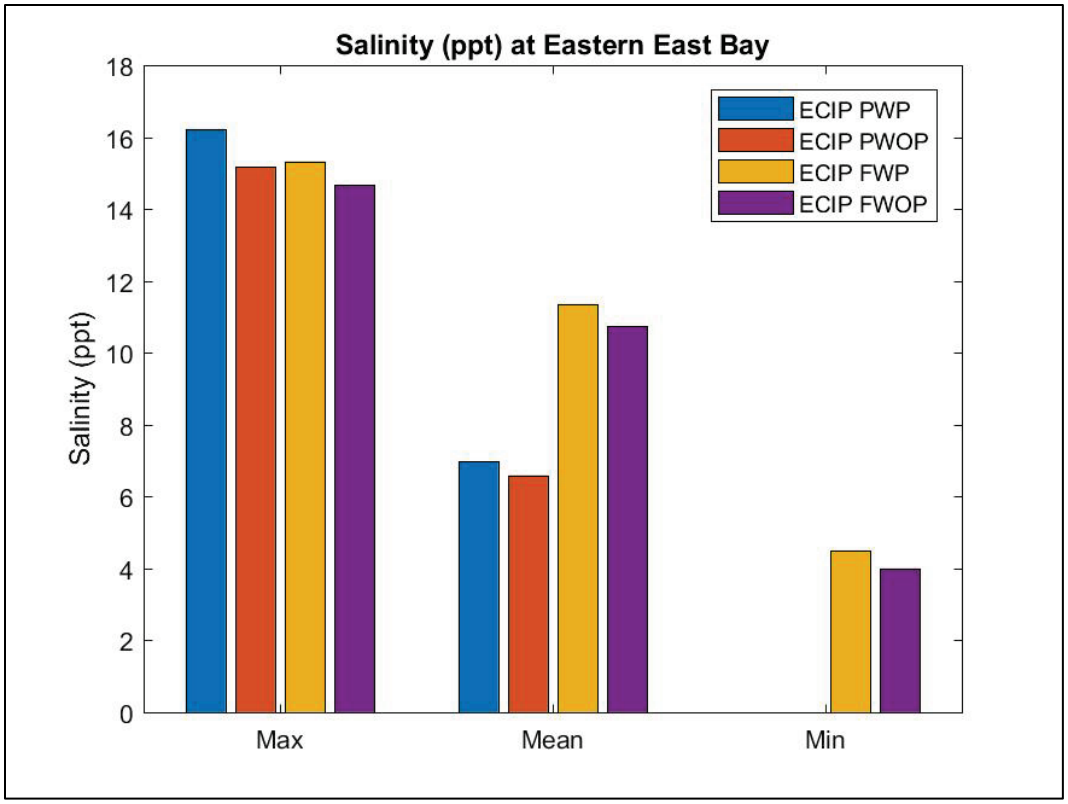

Salinity at Western East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

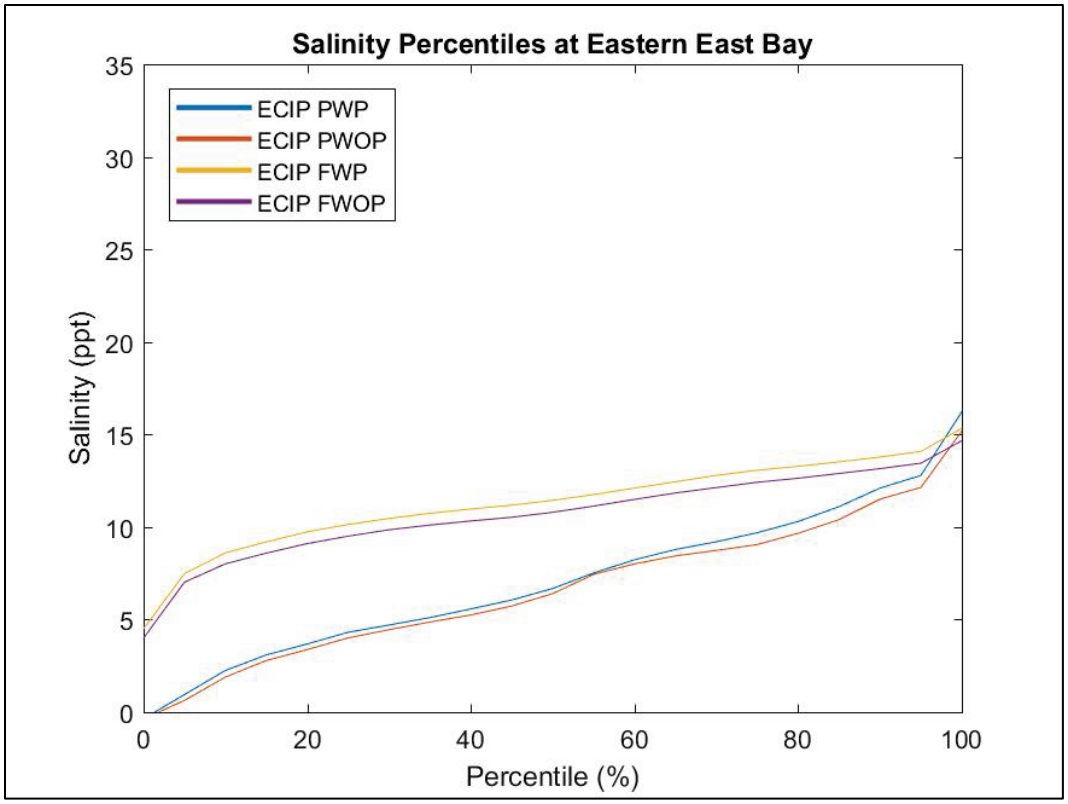

Salinity (ppt) at Western East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min

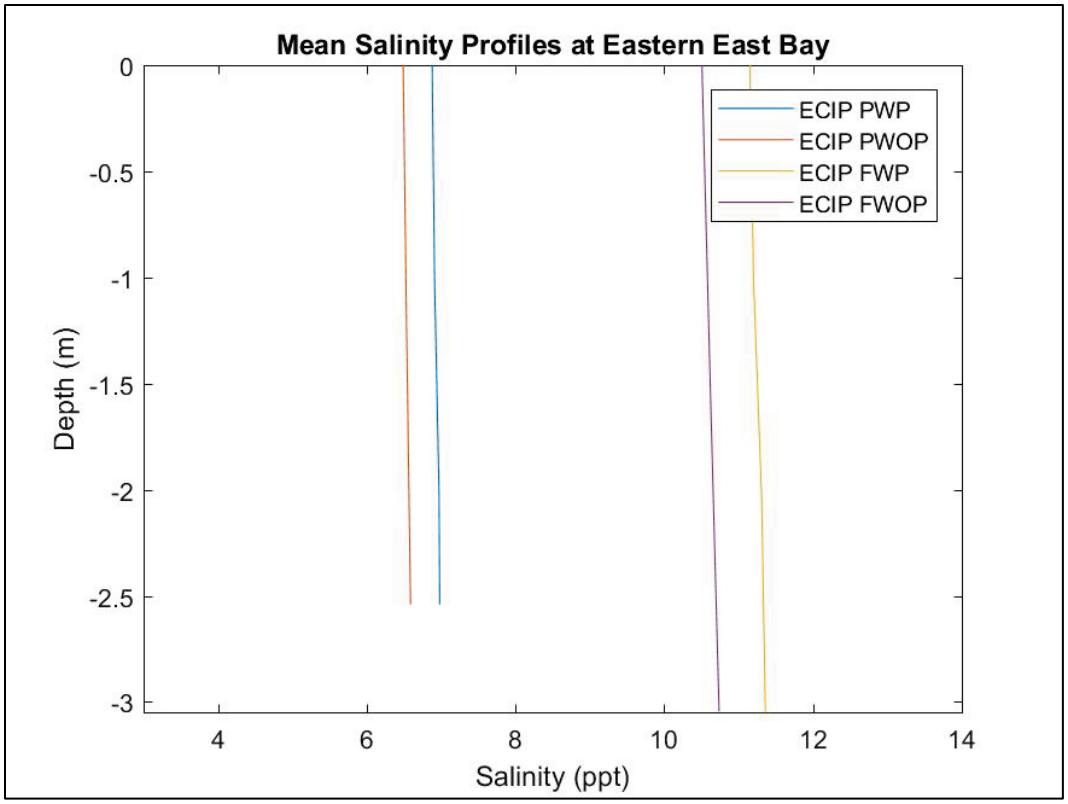

Salinity Percentiles at Western East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

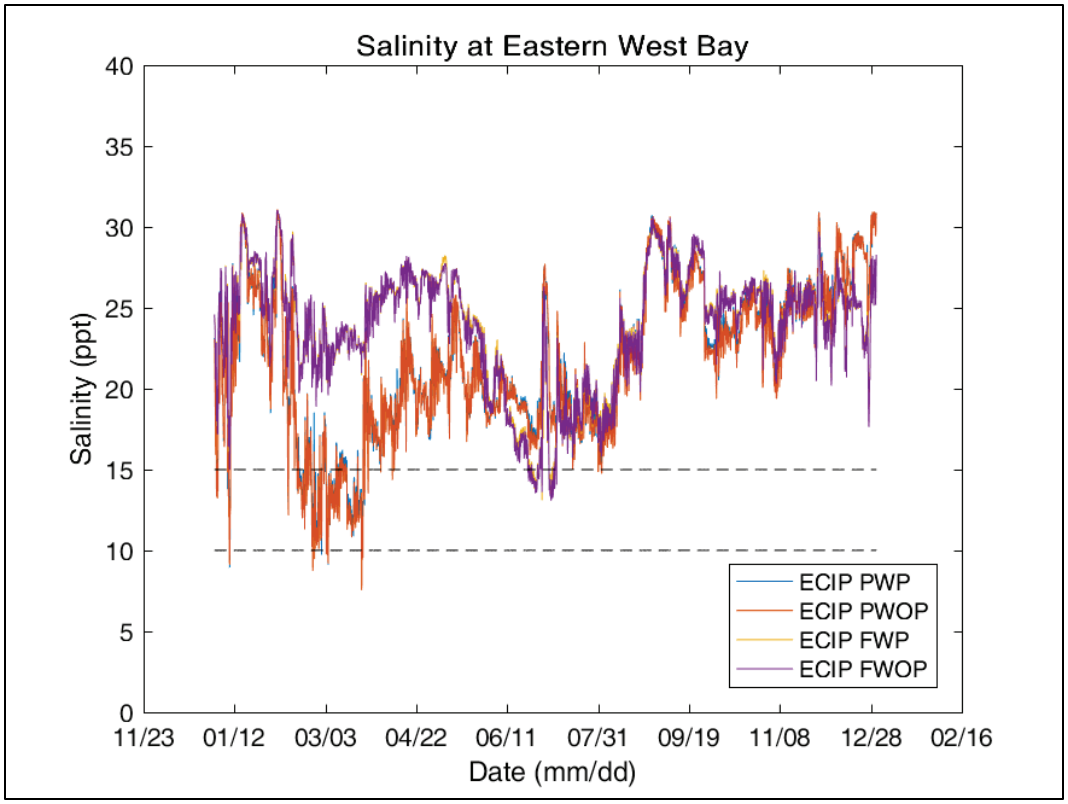

Mean Salinity Profiles at Western East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
8
10
12
14
16
18

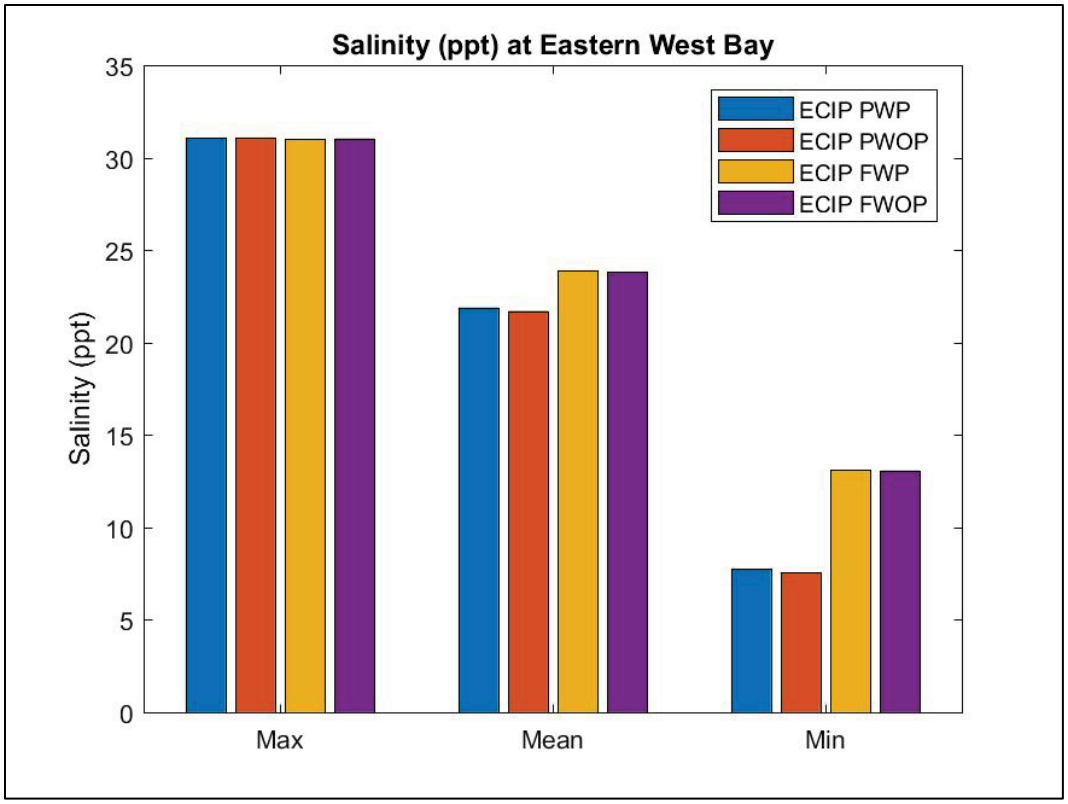

Salinity at Eastern East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

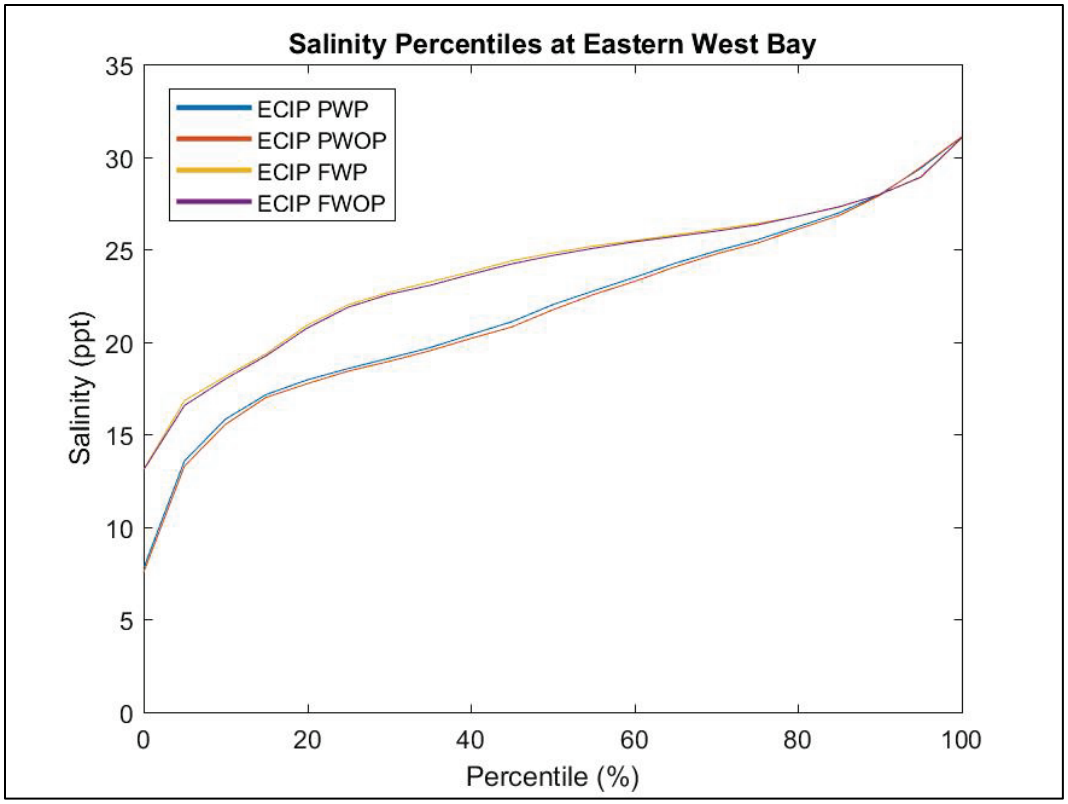

Salinity (ppt) at Eastern East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
18
16
14
12
10
8
6
4
2
0
Max
Mean
Min

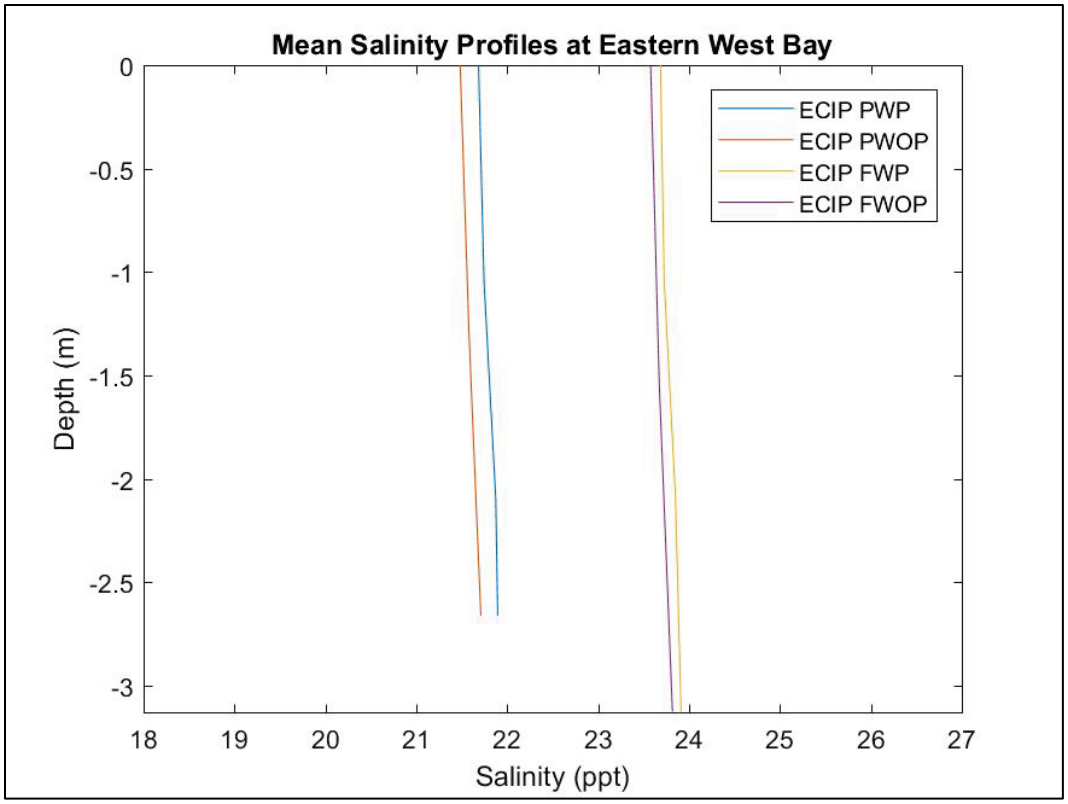

Salinity Percentiles at Eastern East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

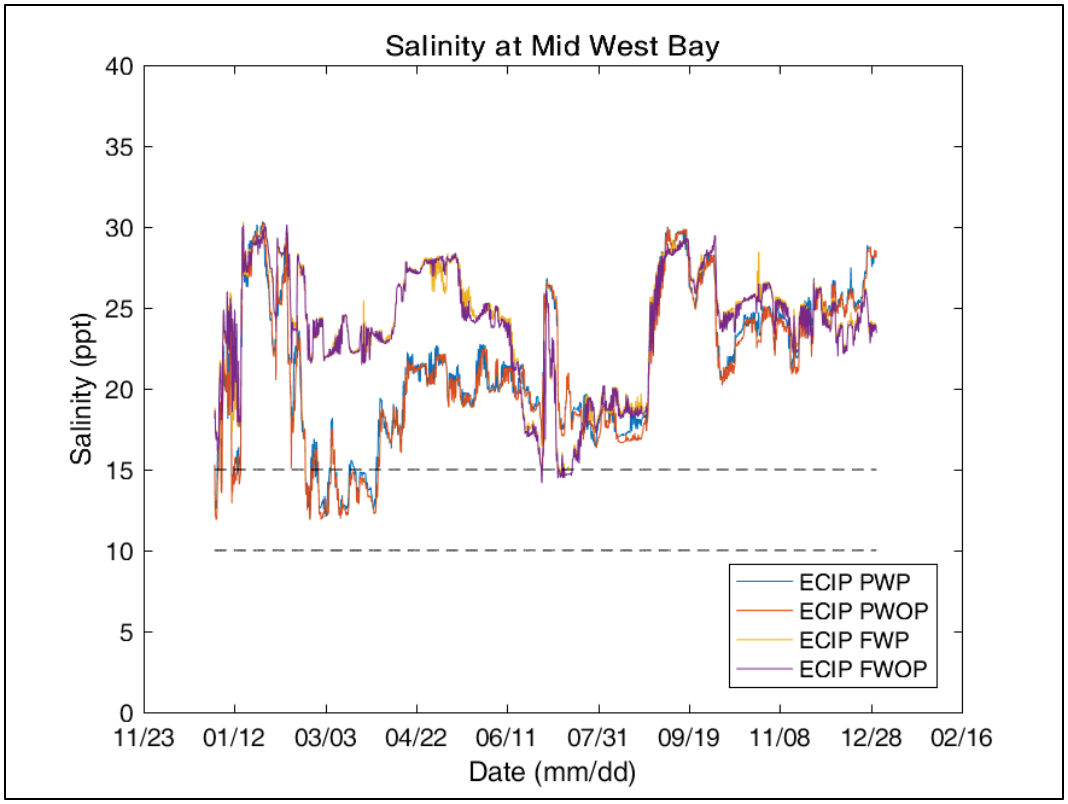

Mean Salinity Profiles at Eastern East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
4
6
8
10
12
14

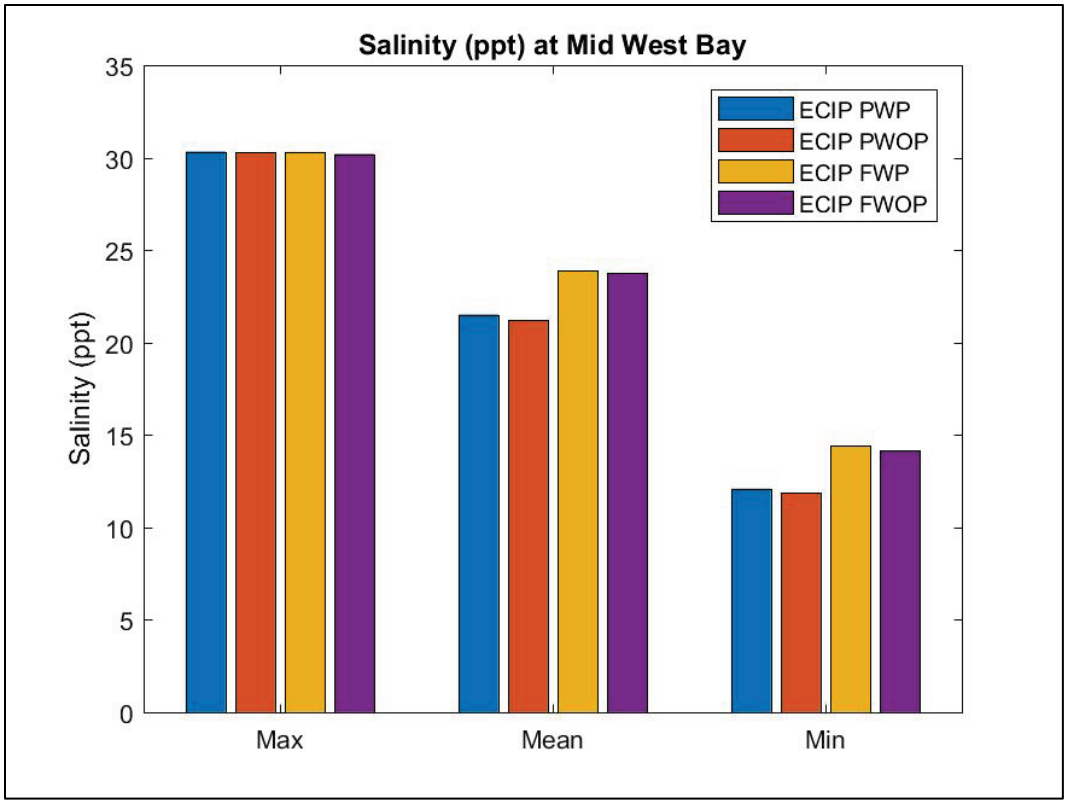

Salinity at Eastern West Bay
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

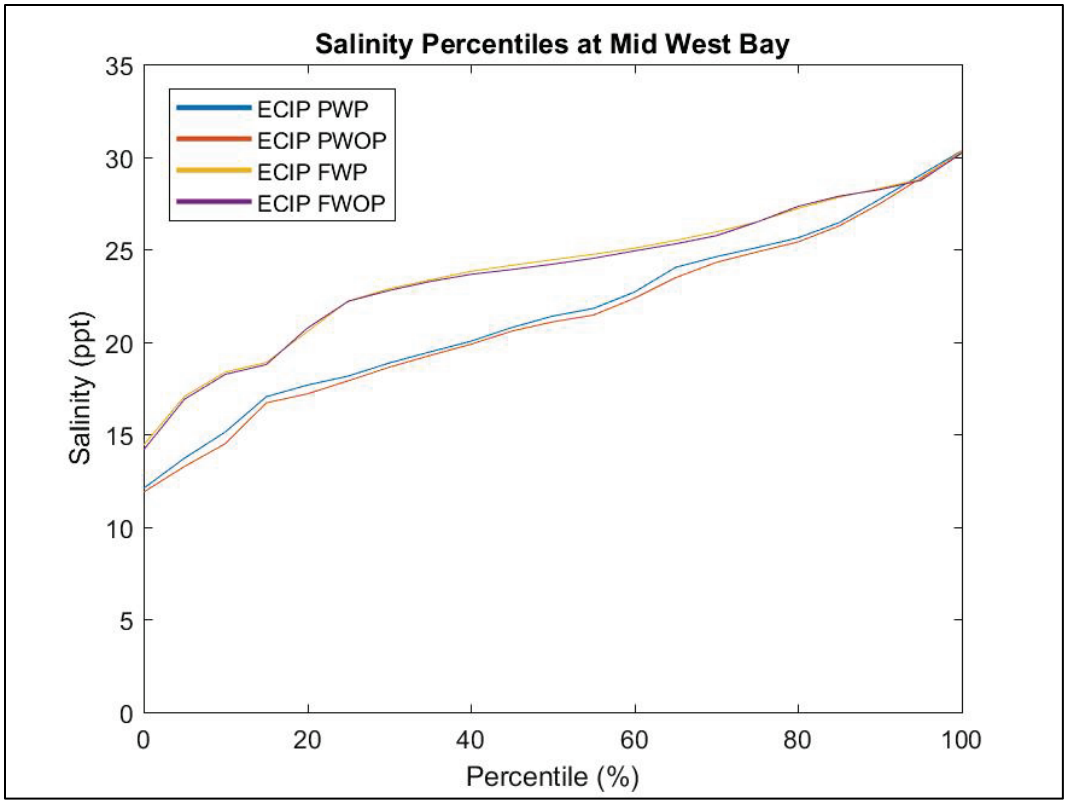

Salinity (ppt) at Eastern West Bay
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

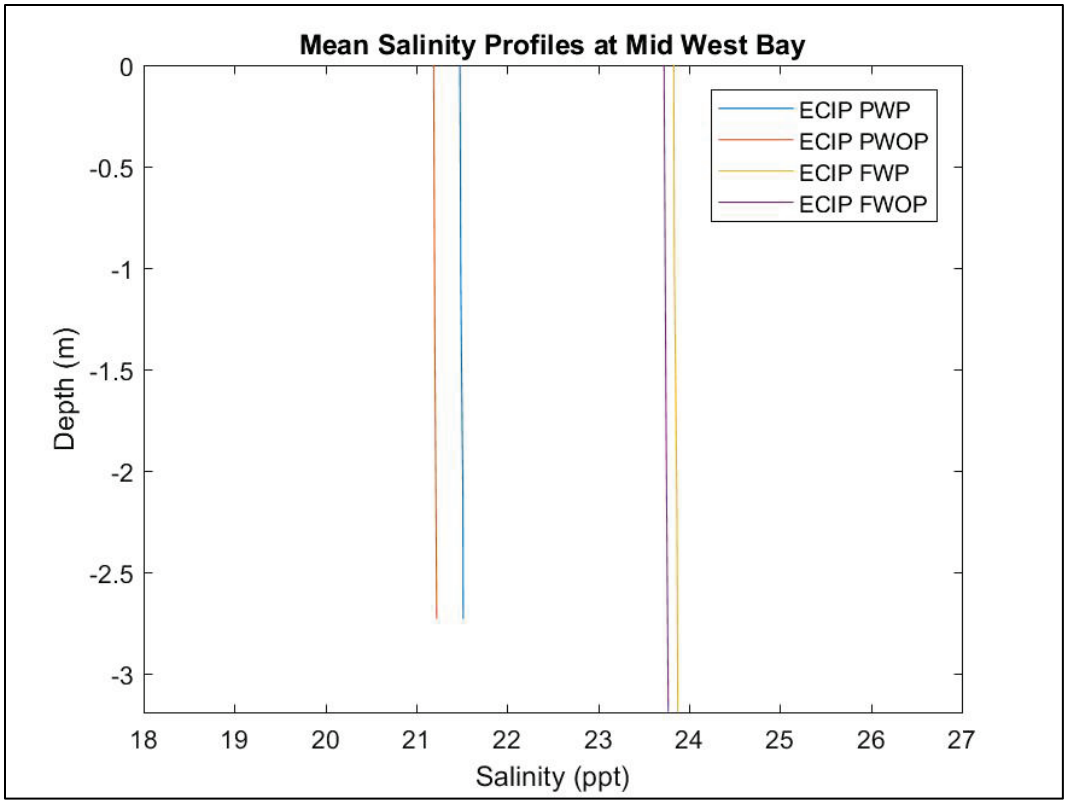

Salinity Percentiles at Eastern West Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

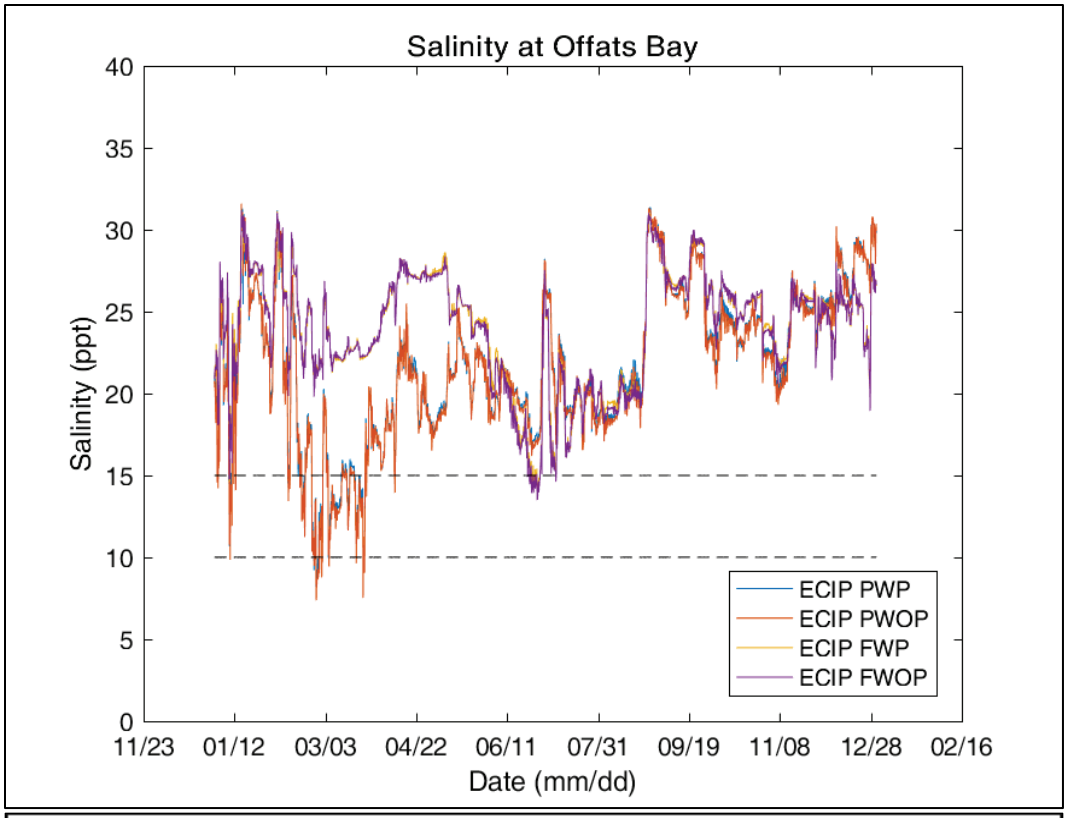

Mean Salinity Profiles at Eastern West Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
18
19
20
21
22
23
24
25
26
27

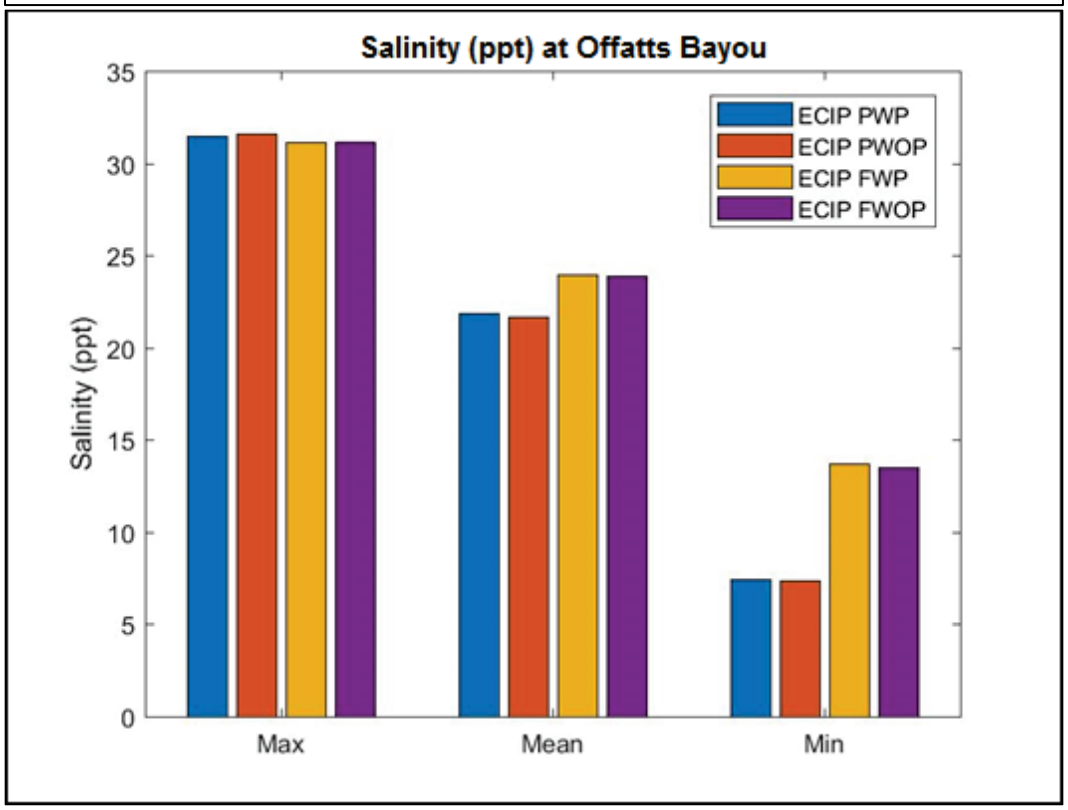

Salinity at Mid West Bay
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

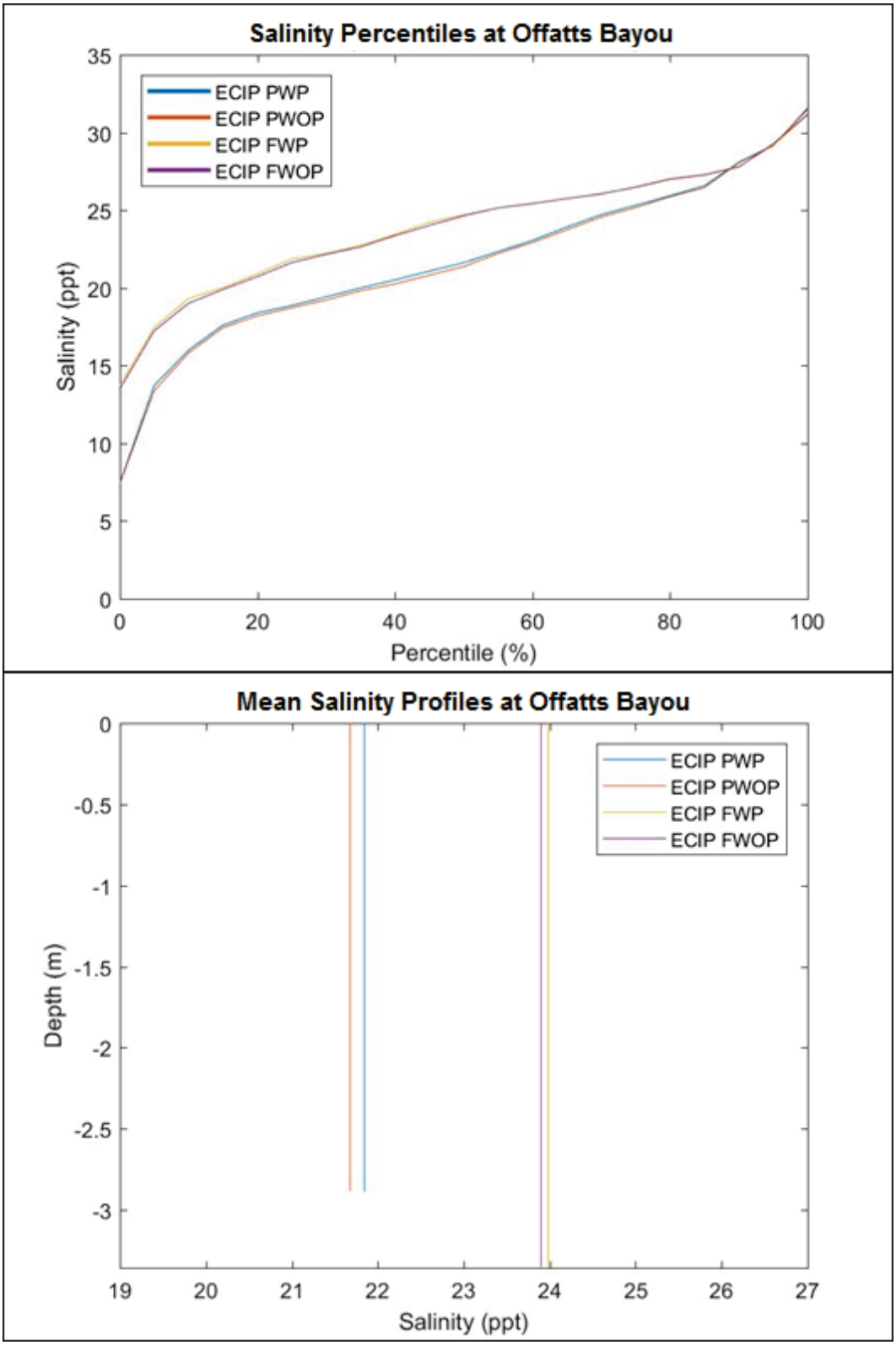

Salinity (ppt) at Mid West Bay
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

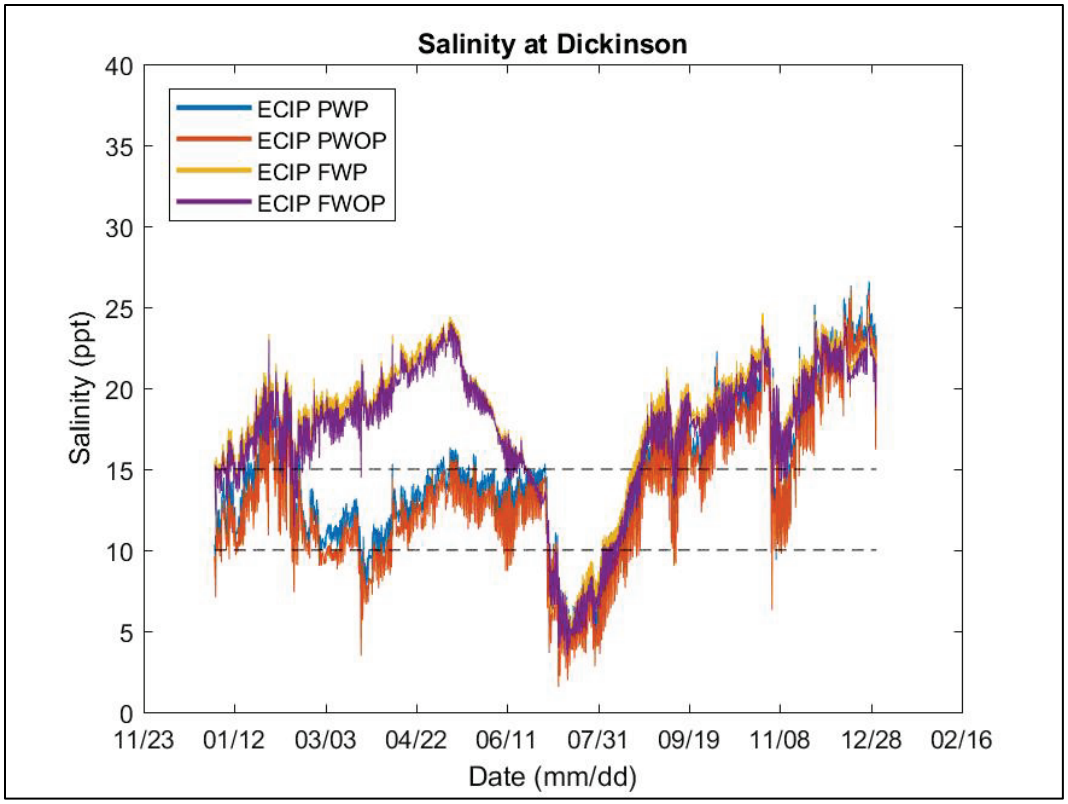

Salinity Percentiles at Mid West Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

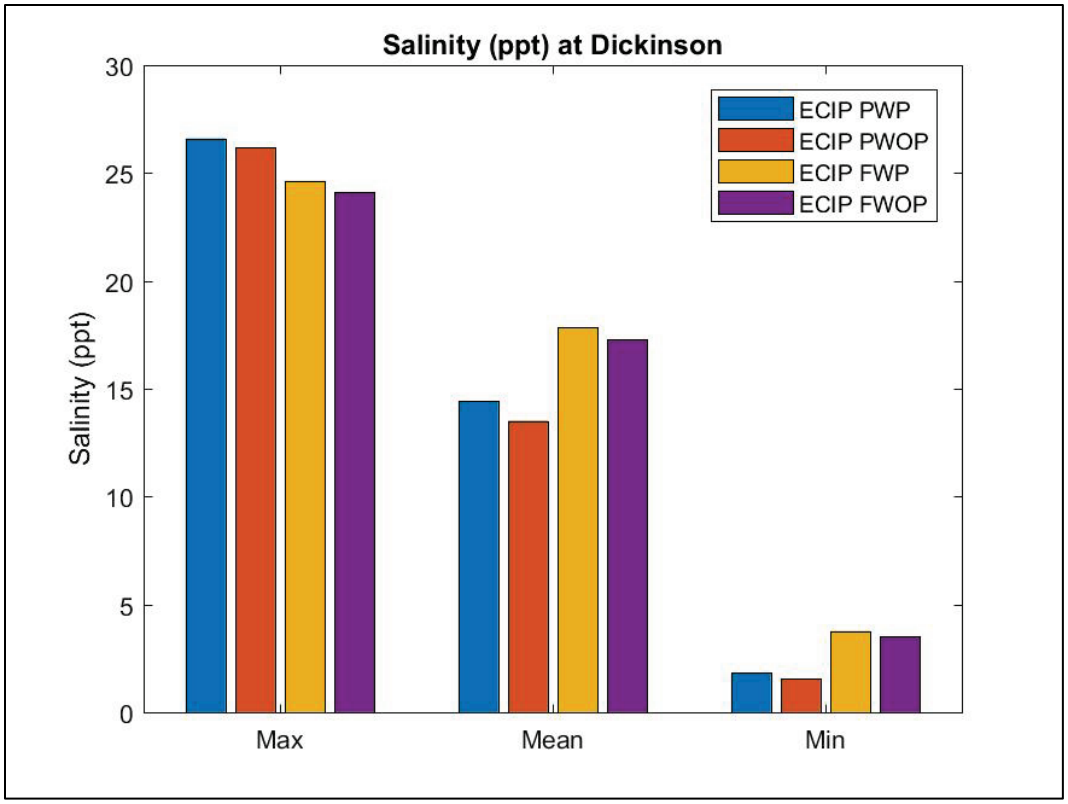

Mean Salinity Profiles at Mid West Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
18
19
20
21
22
23
24
25
26
27

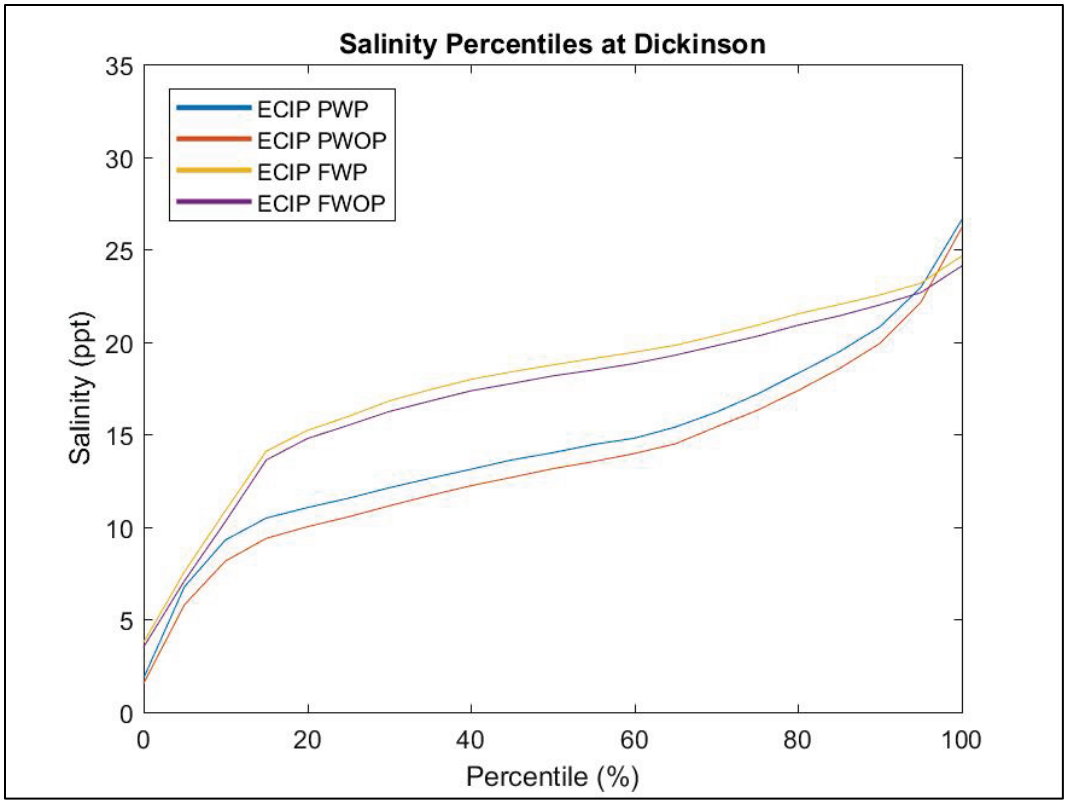

Salinity at Offats Bay
Salinity (ppt)
Date (mm/dd)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

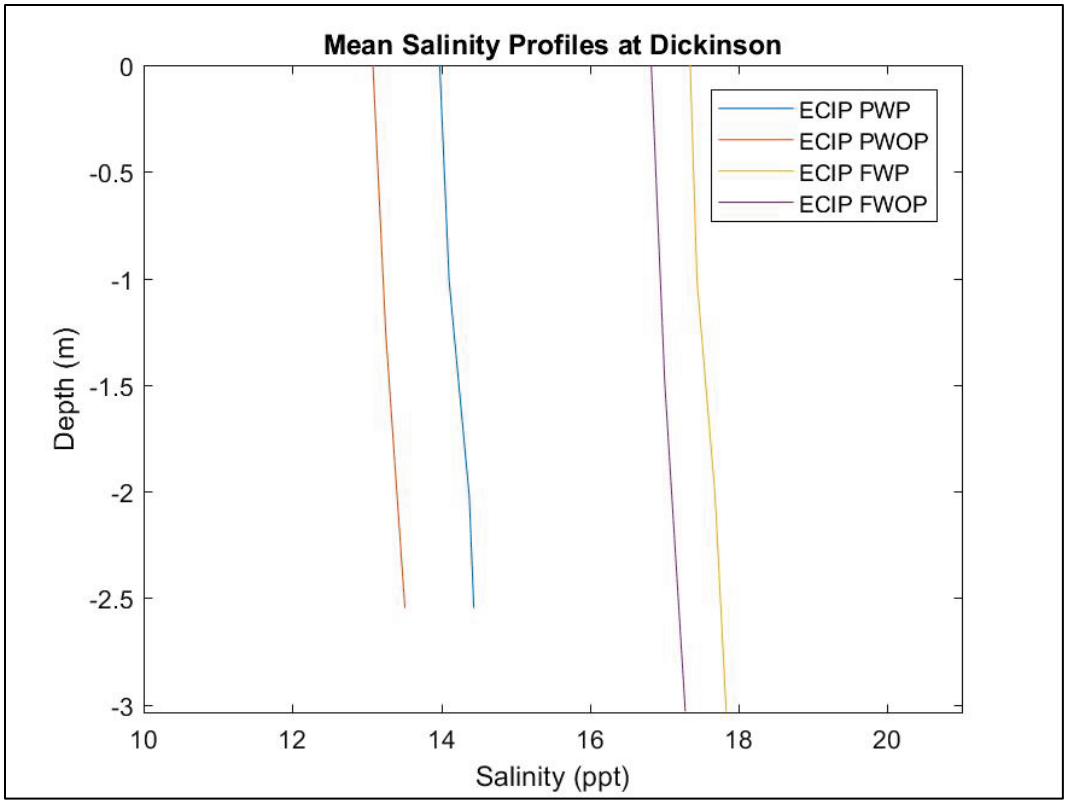

Salinity (ppt) at Offatts Bayou
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP

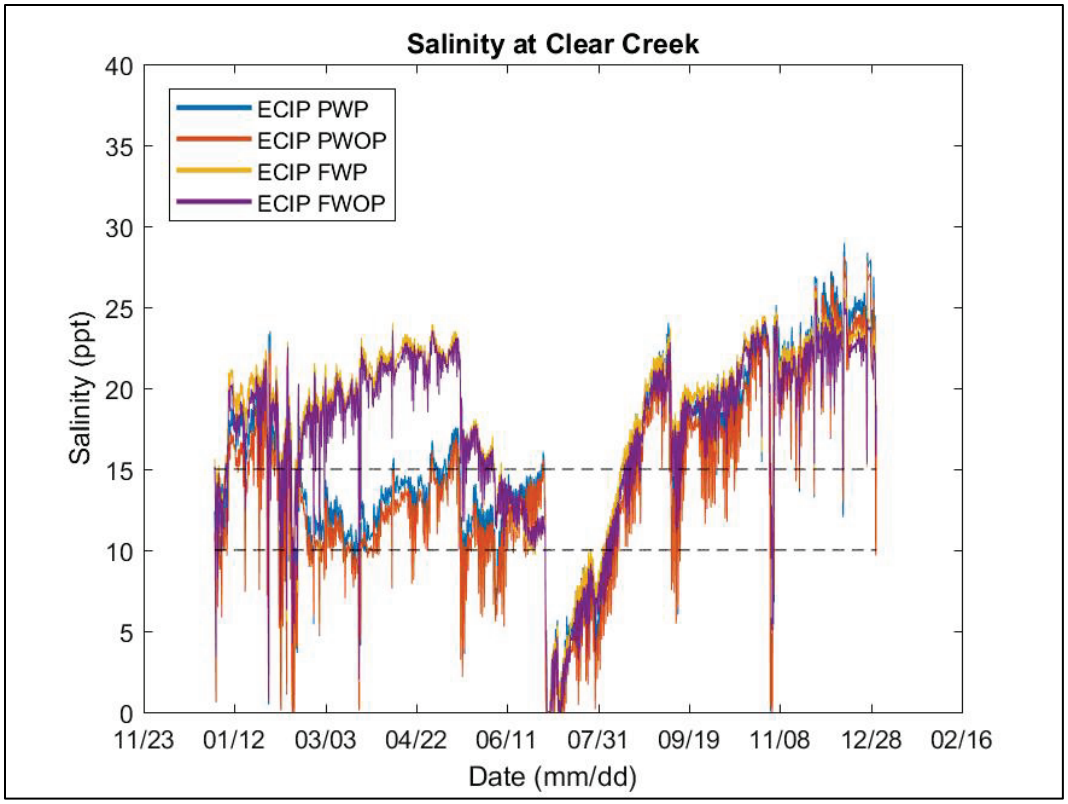

Salinity Percentiles at Offatts Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
Mean Salinity Profiles at Offatts Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
19
20
21
22
23
24
25
26
27

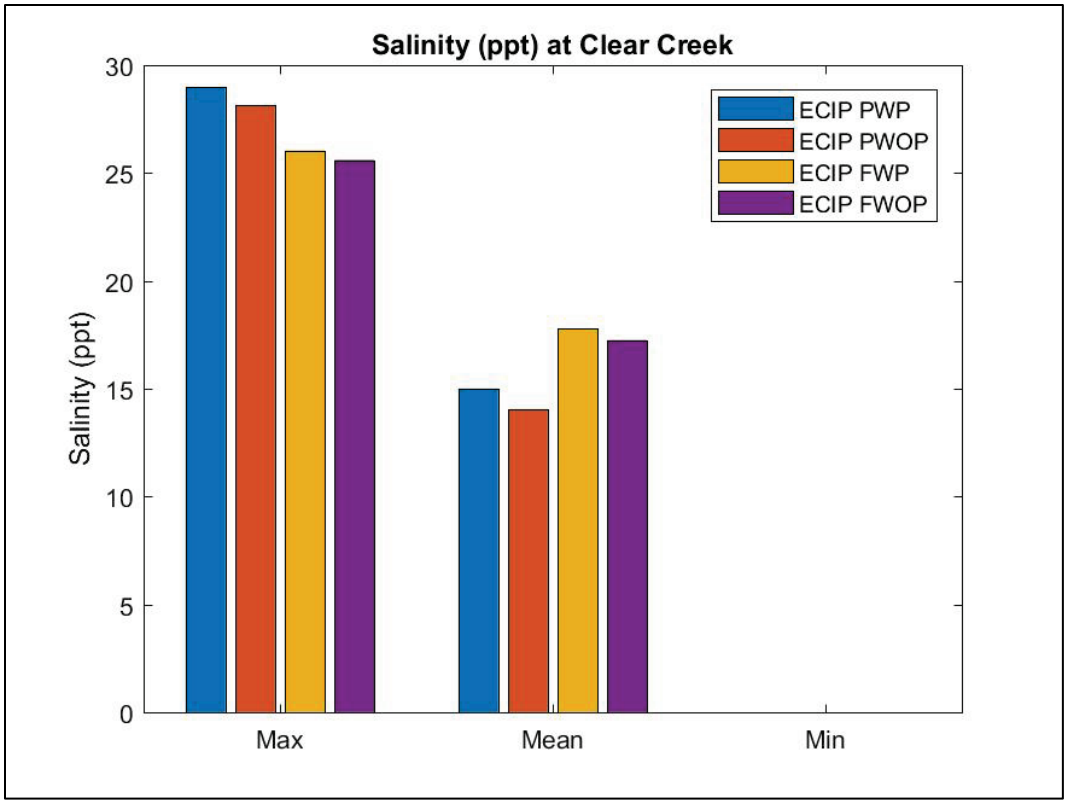

Salinity at Dickinson
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

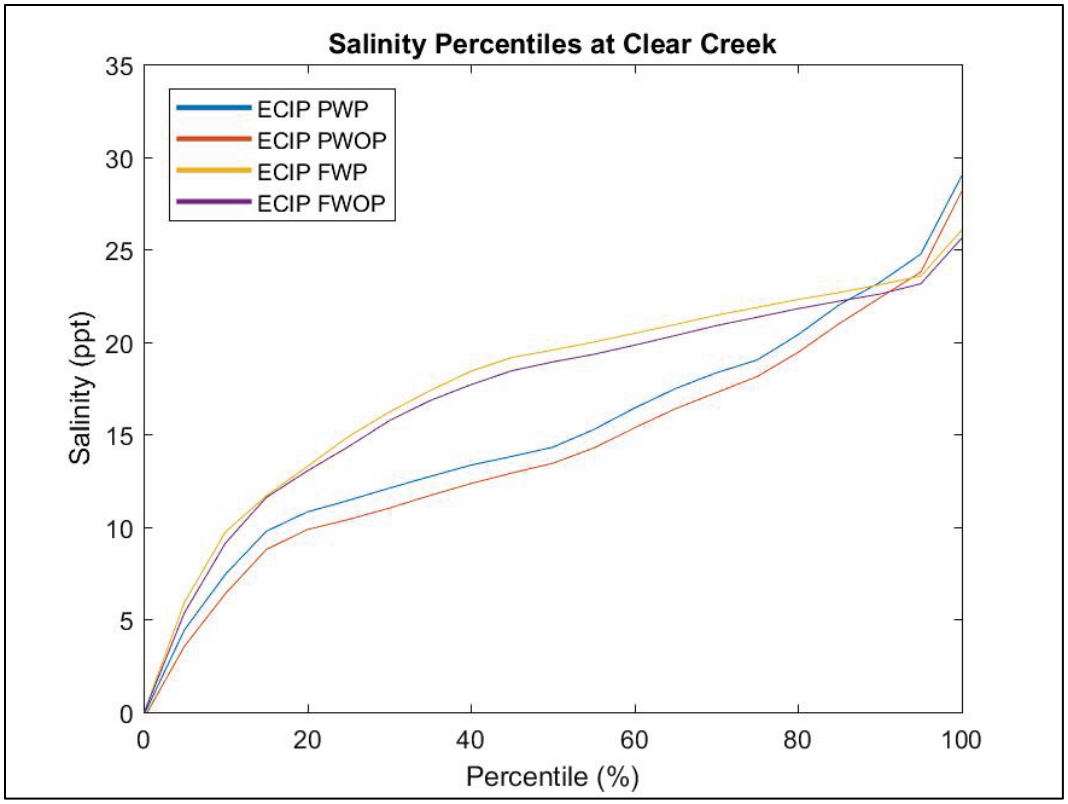

Salinity (ppt) at Dickinson
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

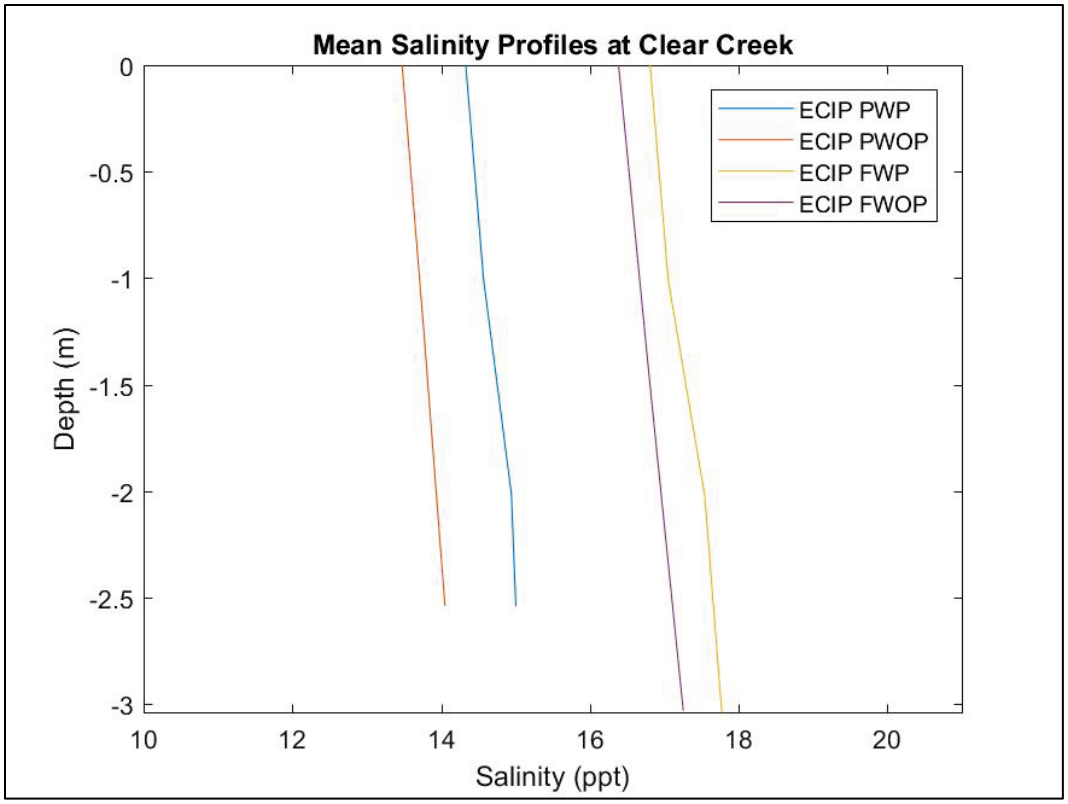

Salinity Percentiles at Dickinson
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

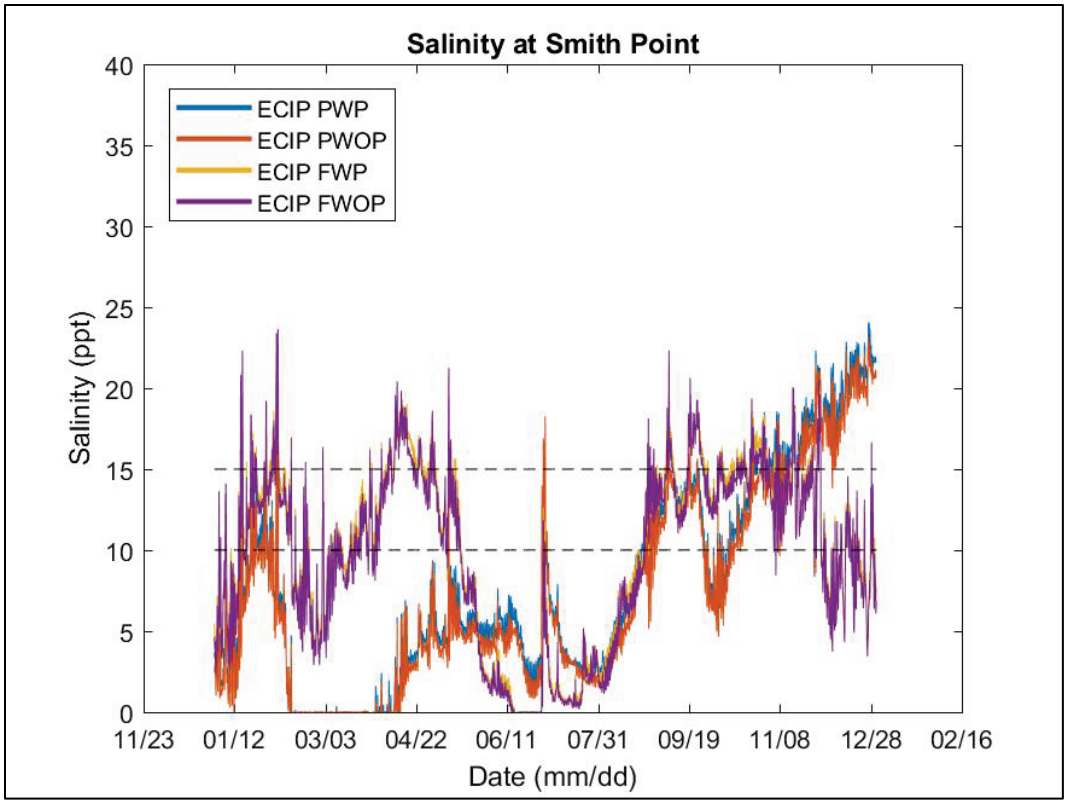

Mean Salinity Profiles at Dickinson
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
10
12
14
16
18
20

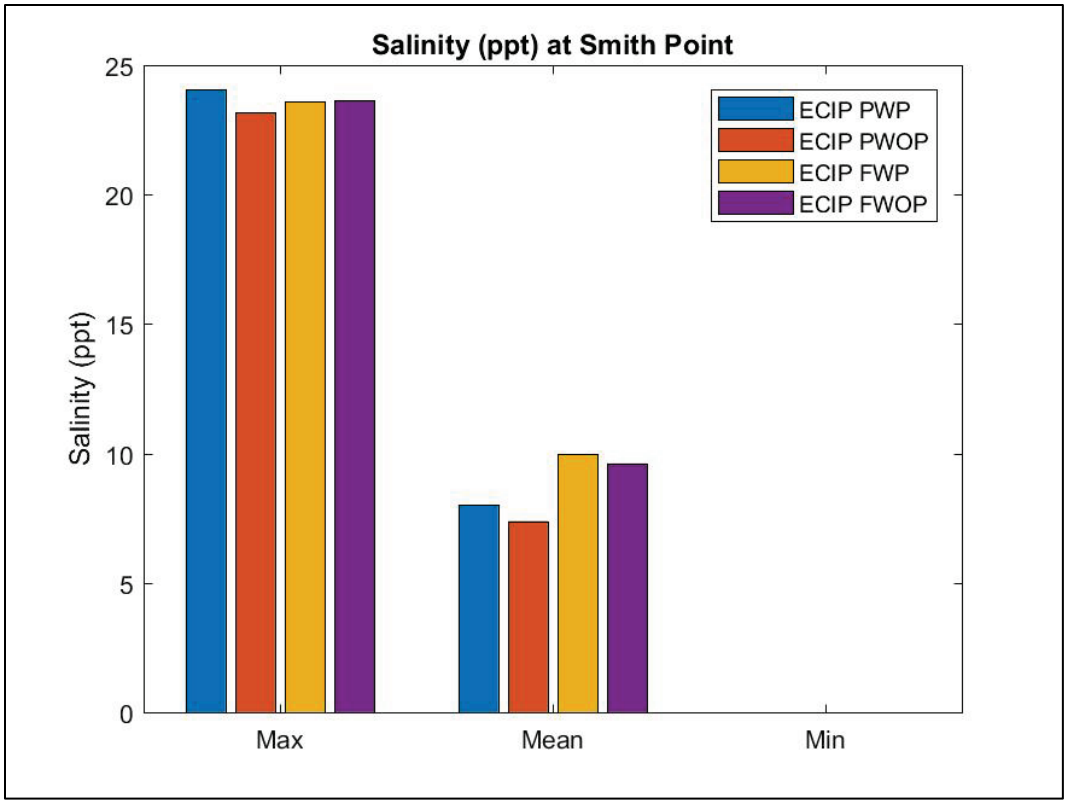

Salinity at Clear Creek
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

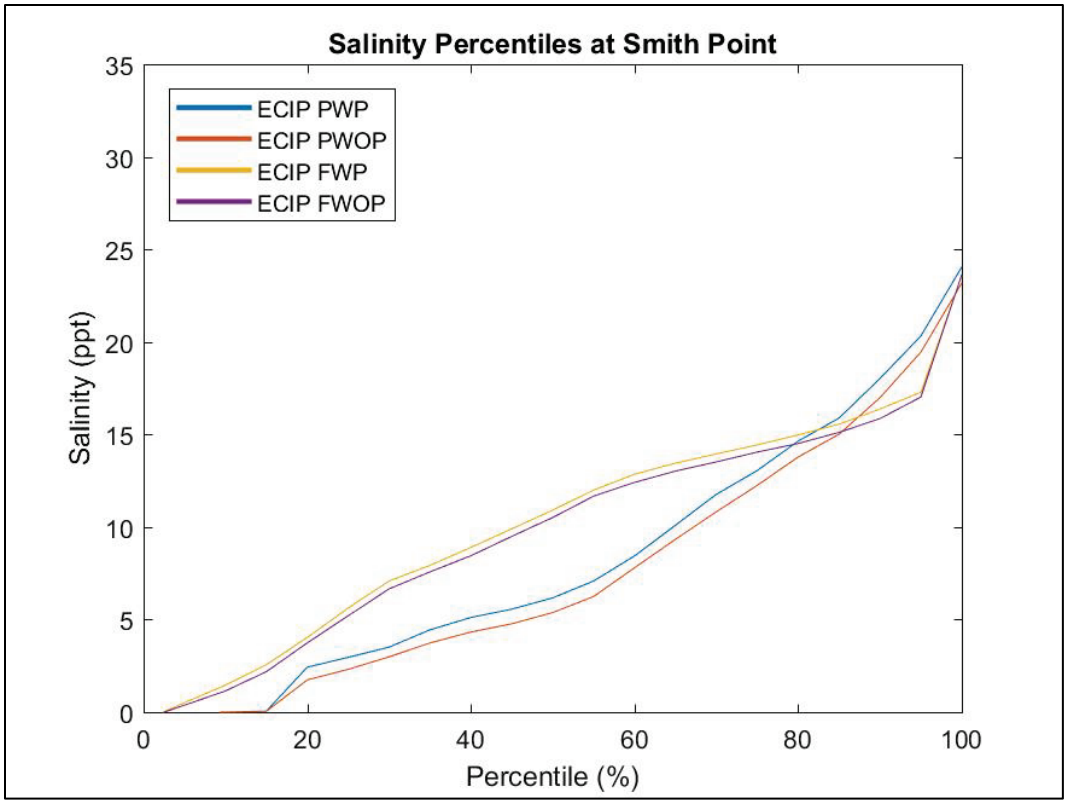

Salinity (ppt) at Clear Creek
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

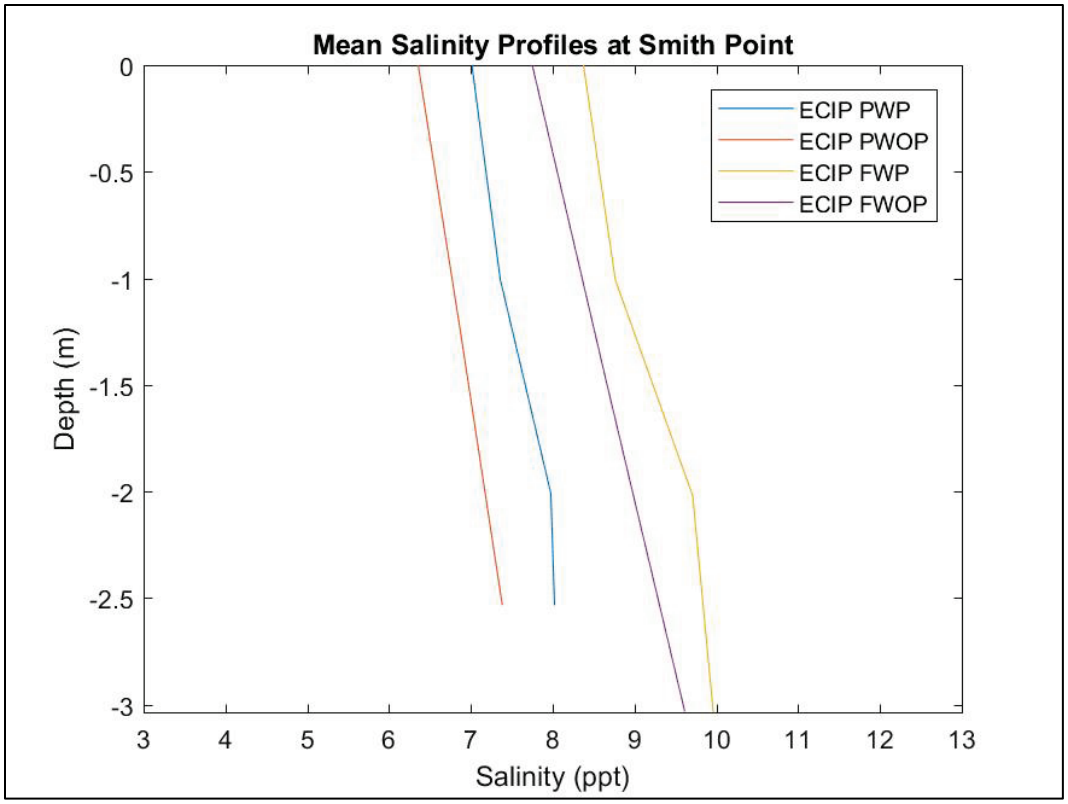

Salinity Percentiles at Clear Creek
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

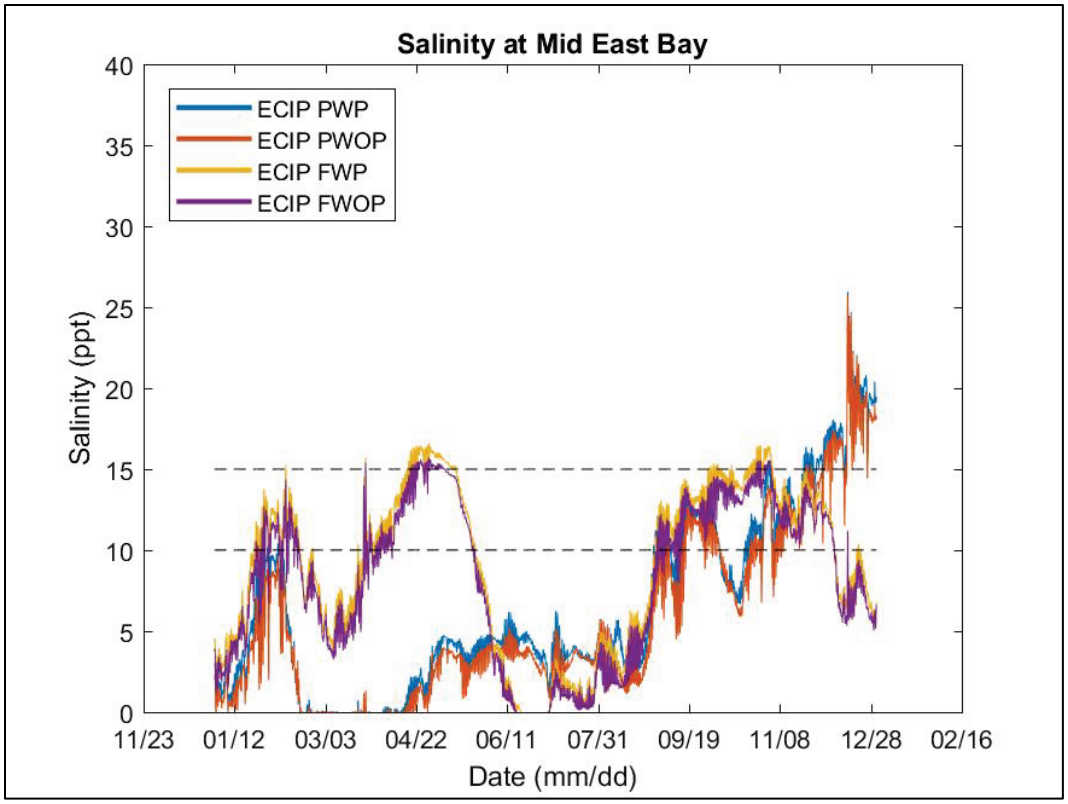

Mean Salinity Profiles at Clear Creek
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
10
12
14
16
18
20

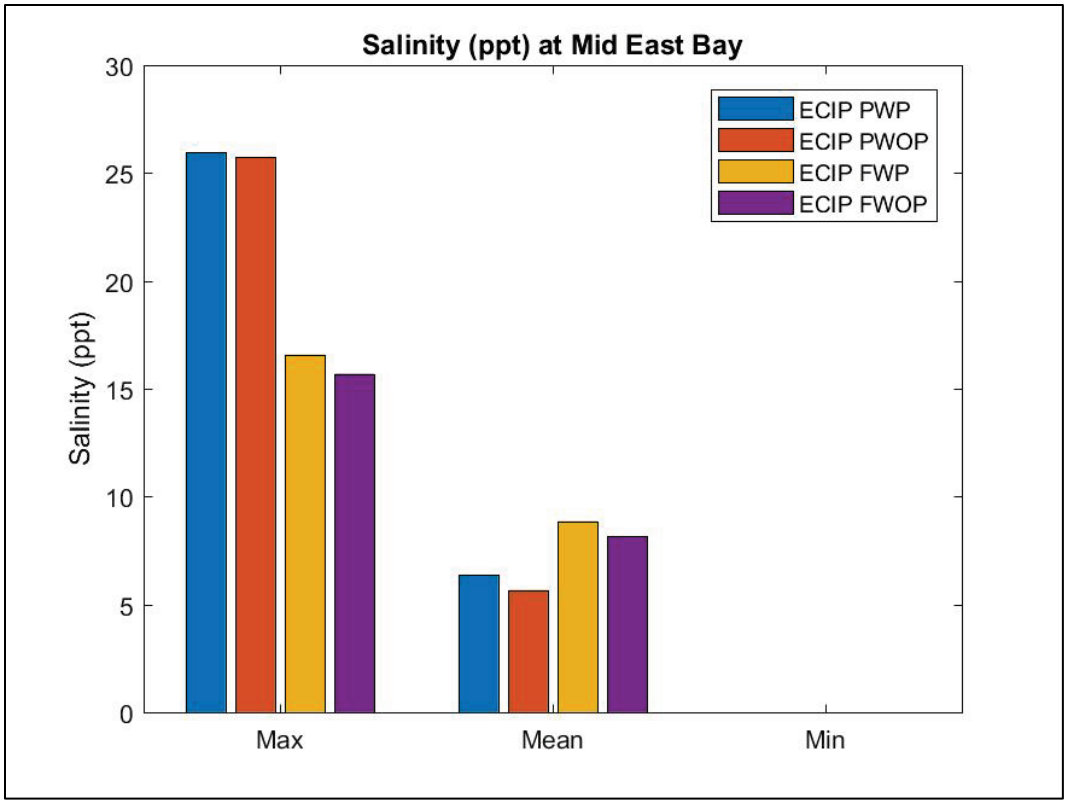

Salinity at Smith Point
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

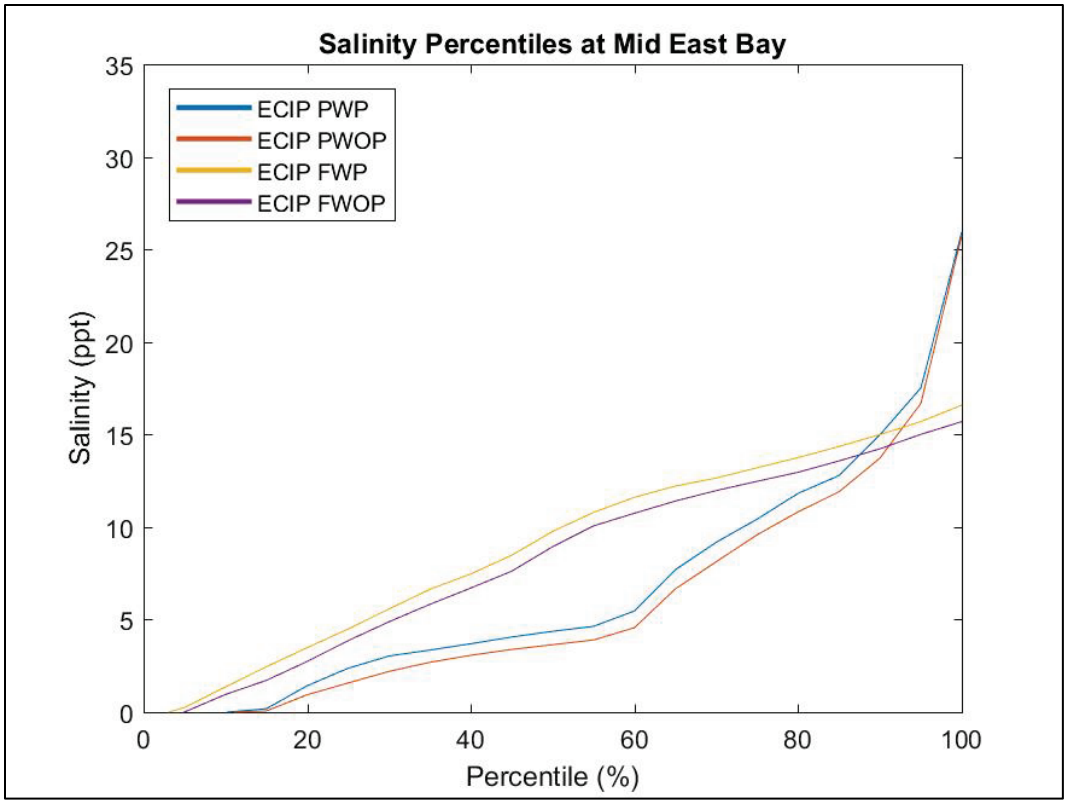

Salinity (ppt) at Smith Point
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
25
20
15
10
5
0
Max
Mean
Min

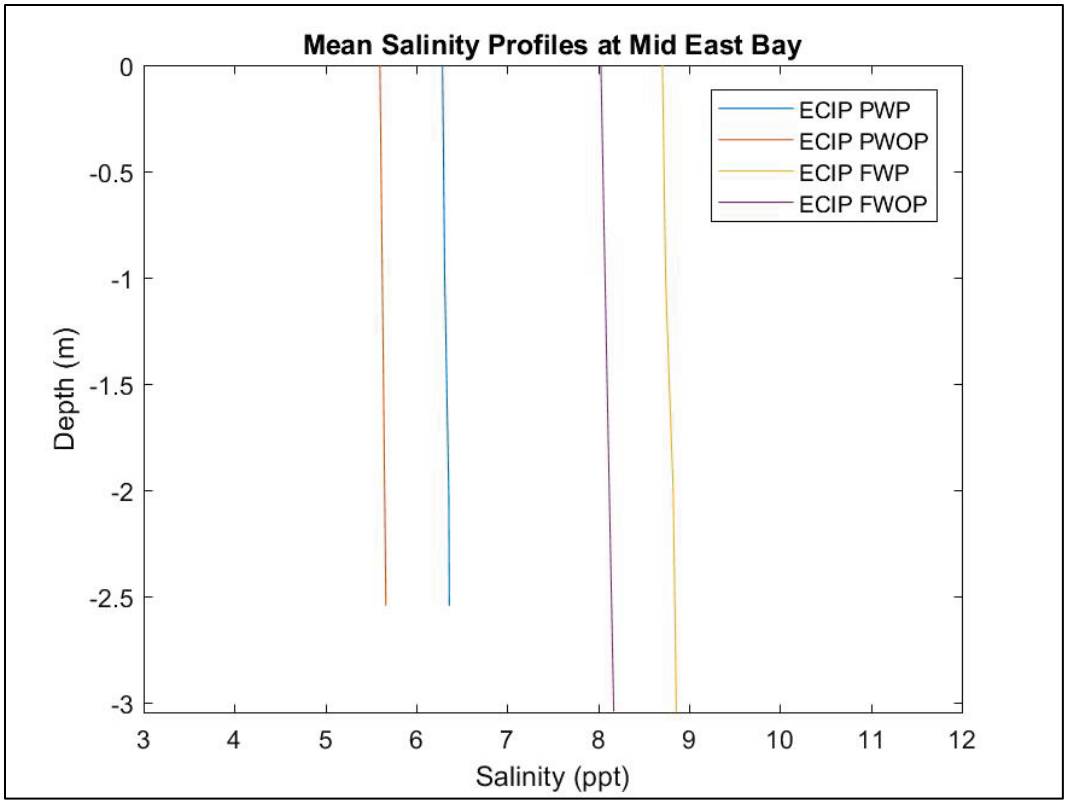

Salinity Percentiles at Smith Point
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

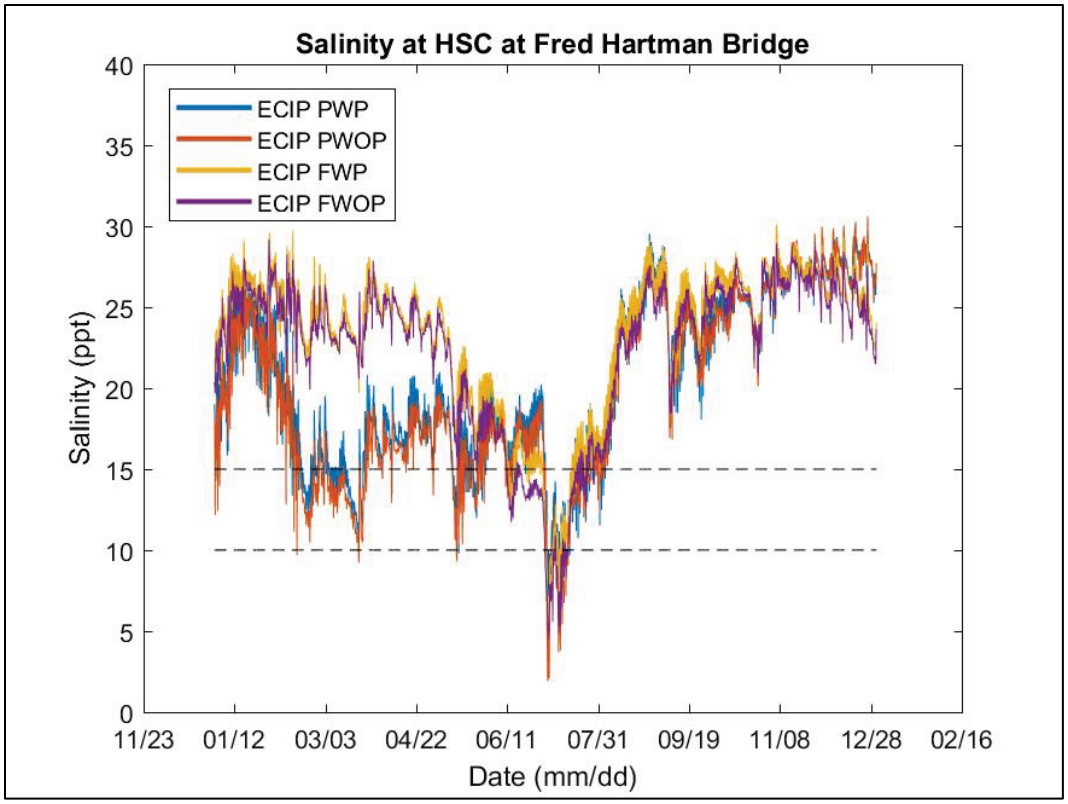

Mean Salinity Profiles at Smith Point
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
3
4
5
6
7
8
9
10
11
12
13

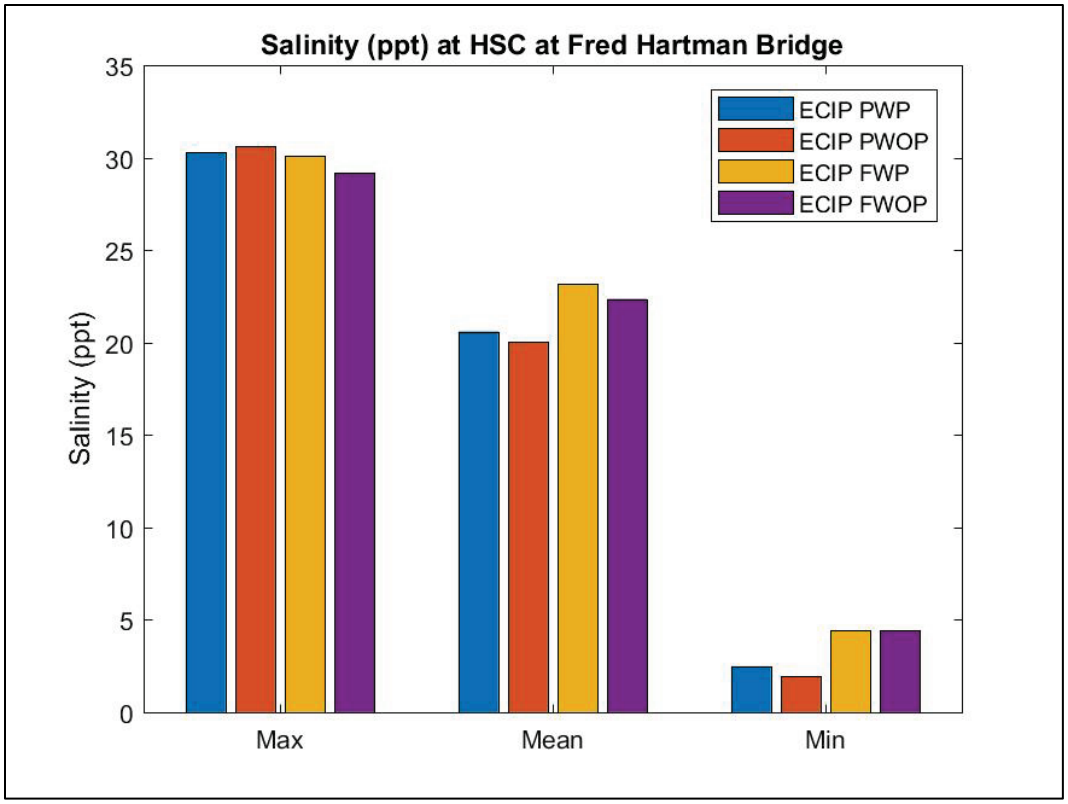

Salinity at Mid East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

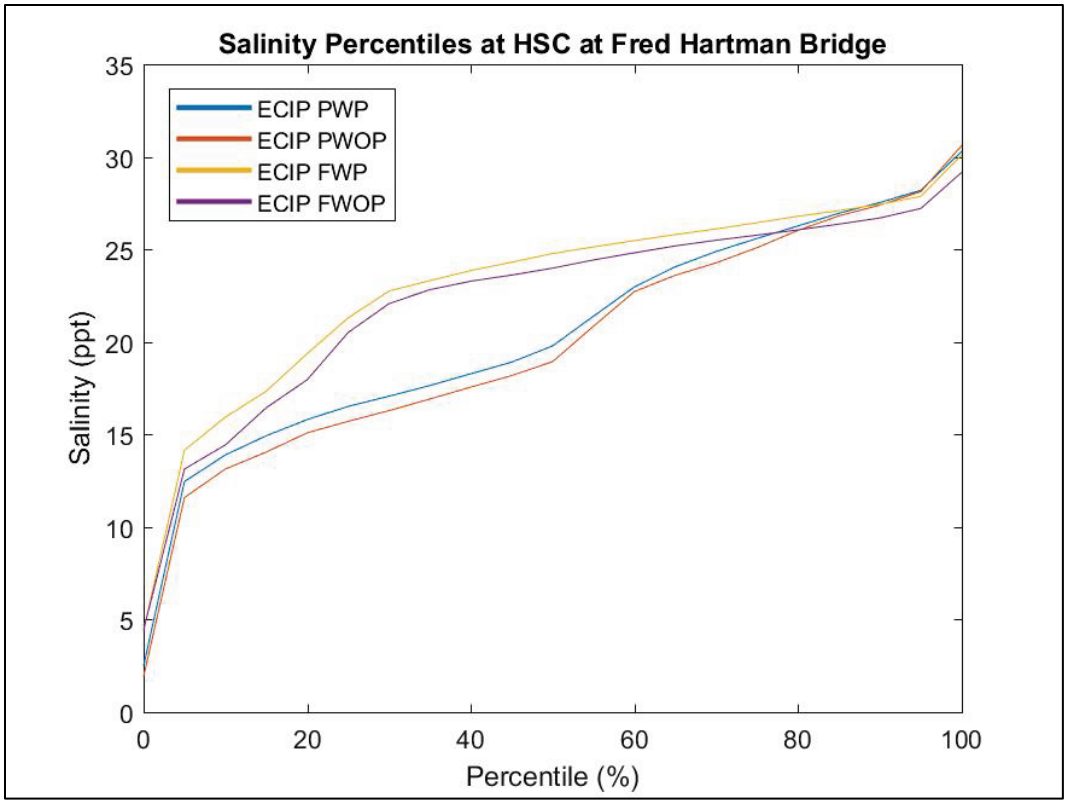

Salinity (ppt) at Mid East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

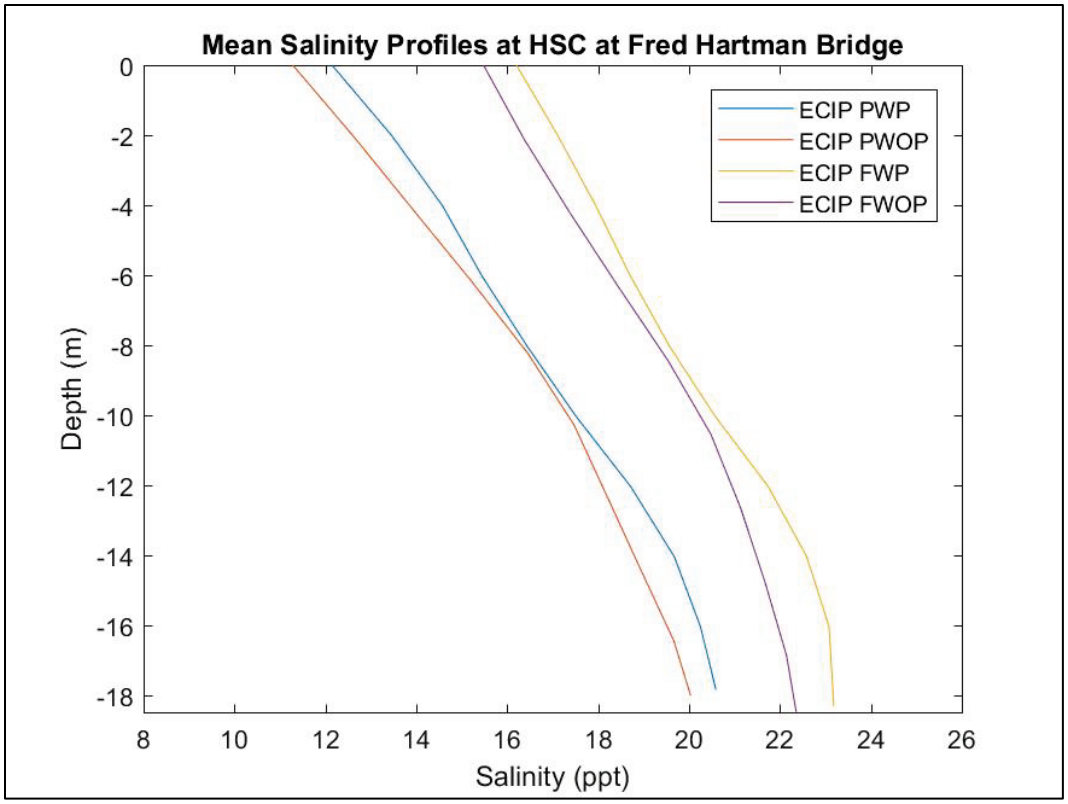

Salinity Percentiles at Mid East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

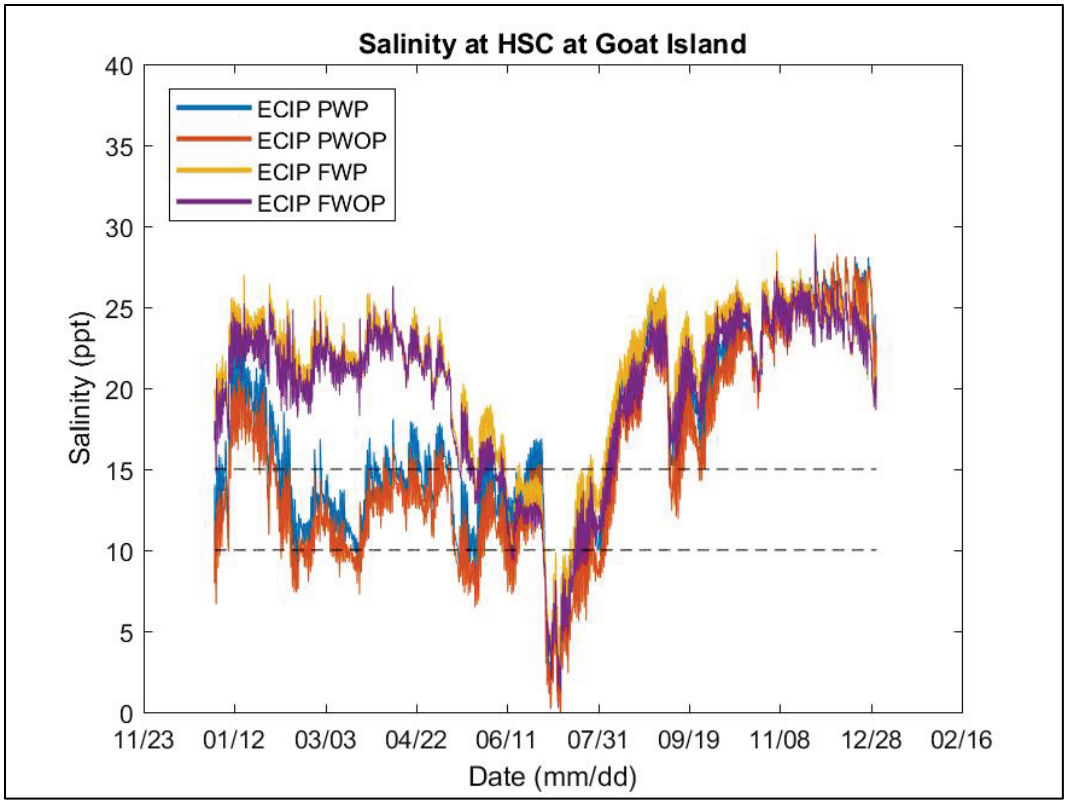

Mean Salinity Profiles at Mid East Bay
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
-3
3
4
5
6
7
8
9
10
11
12

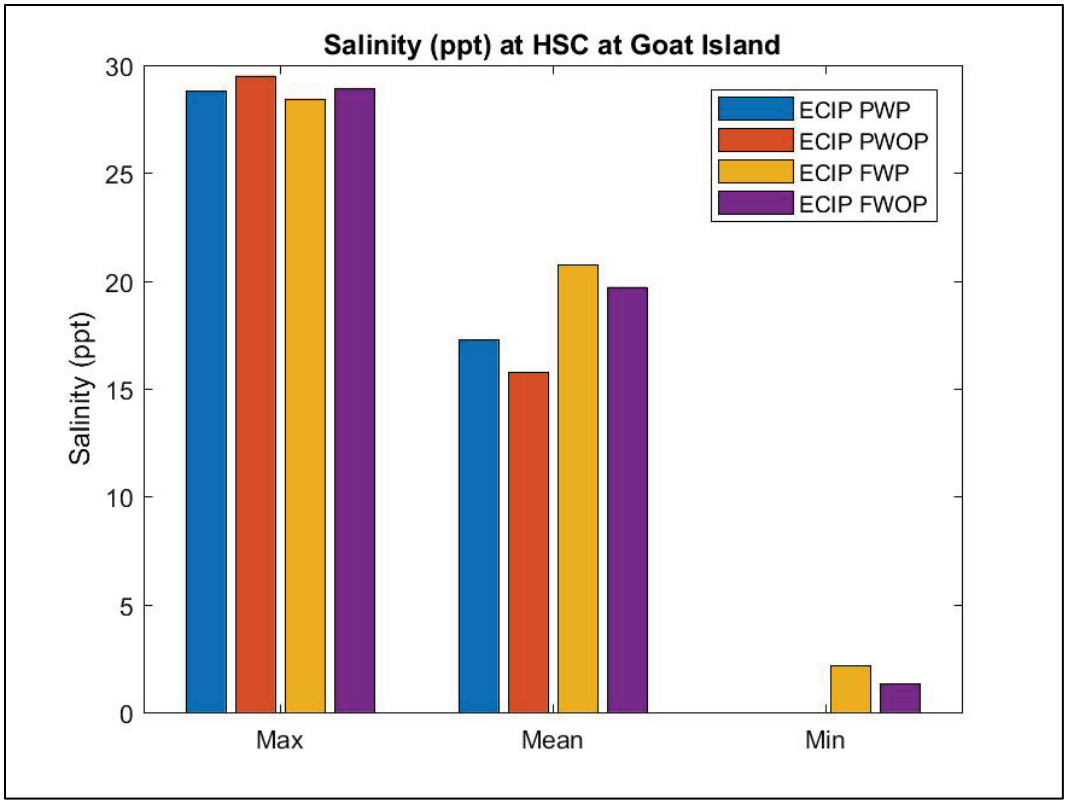

Salinity at HSC at Fred Hartman Bridge
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

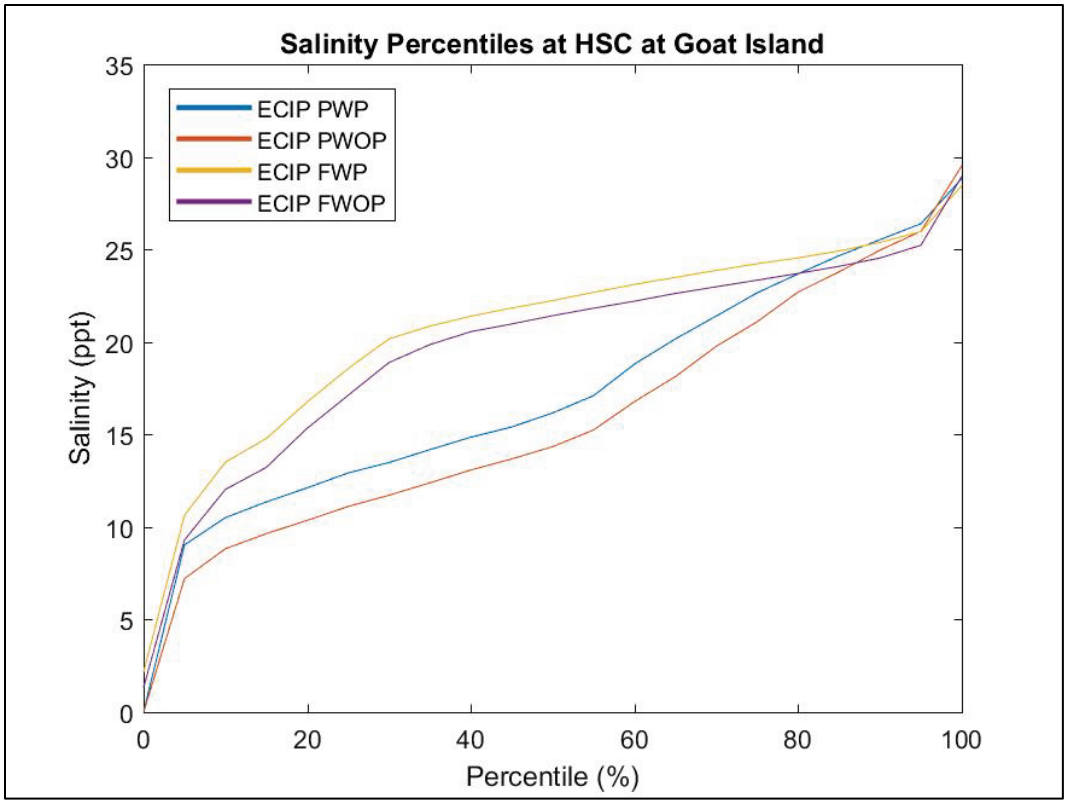

Salinity (ppt) at HSC at Fred Hartman Bridge
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min

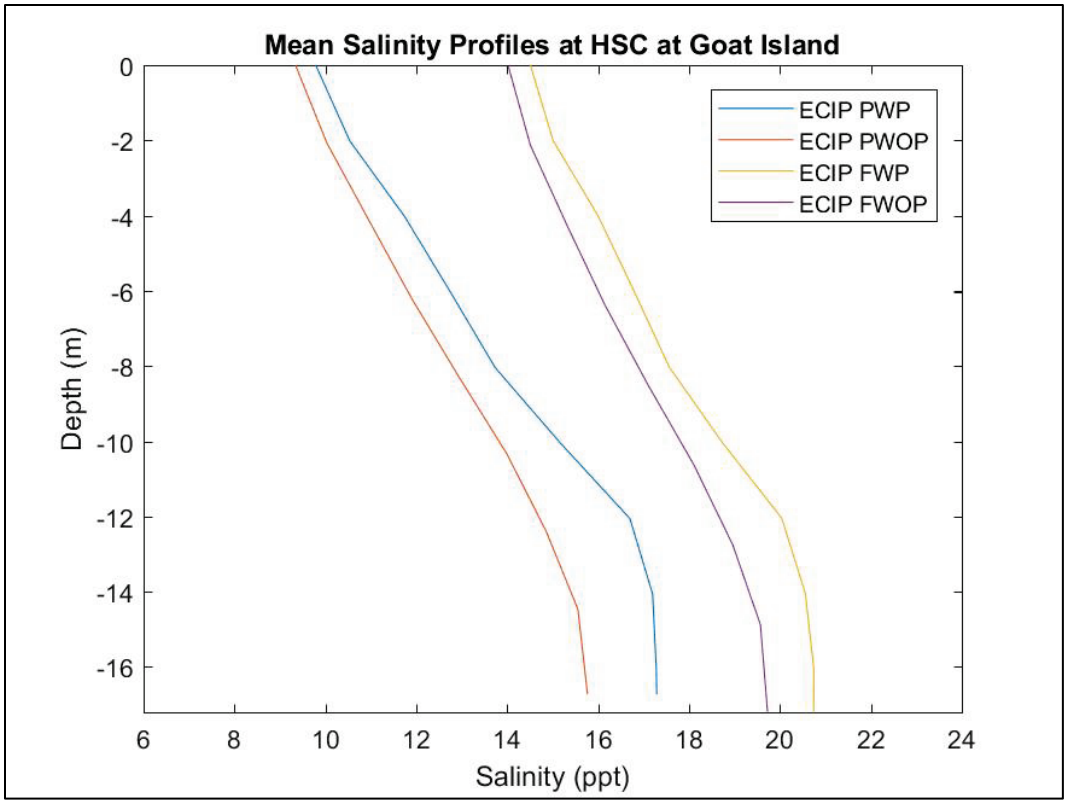

Salinity Percentiles at HSC at Fred Hartman Bridge
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

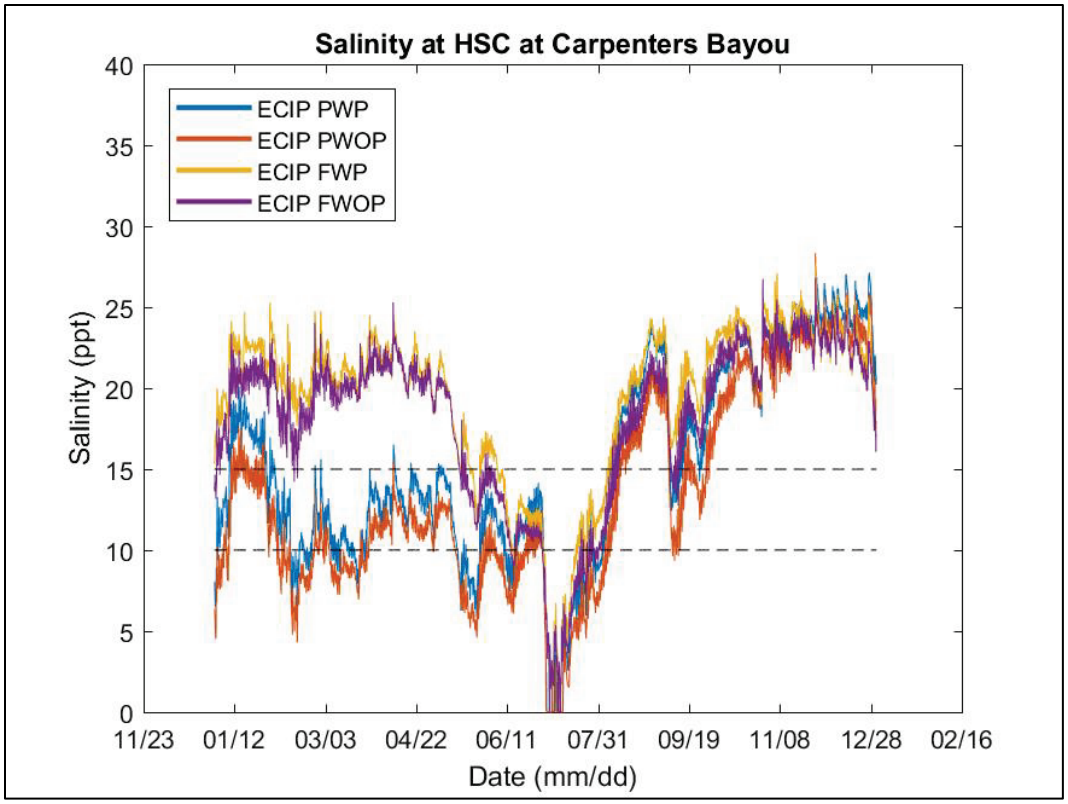

Mean Salinity Profiles at HSC at Fred Hartman Bridge
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
8
10
12
14
16
18
20
22
24
26

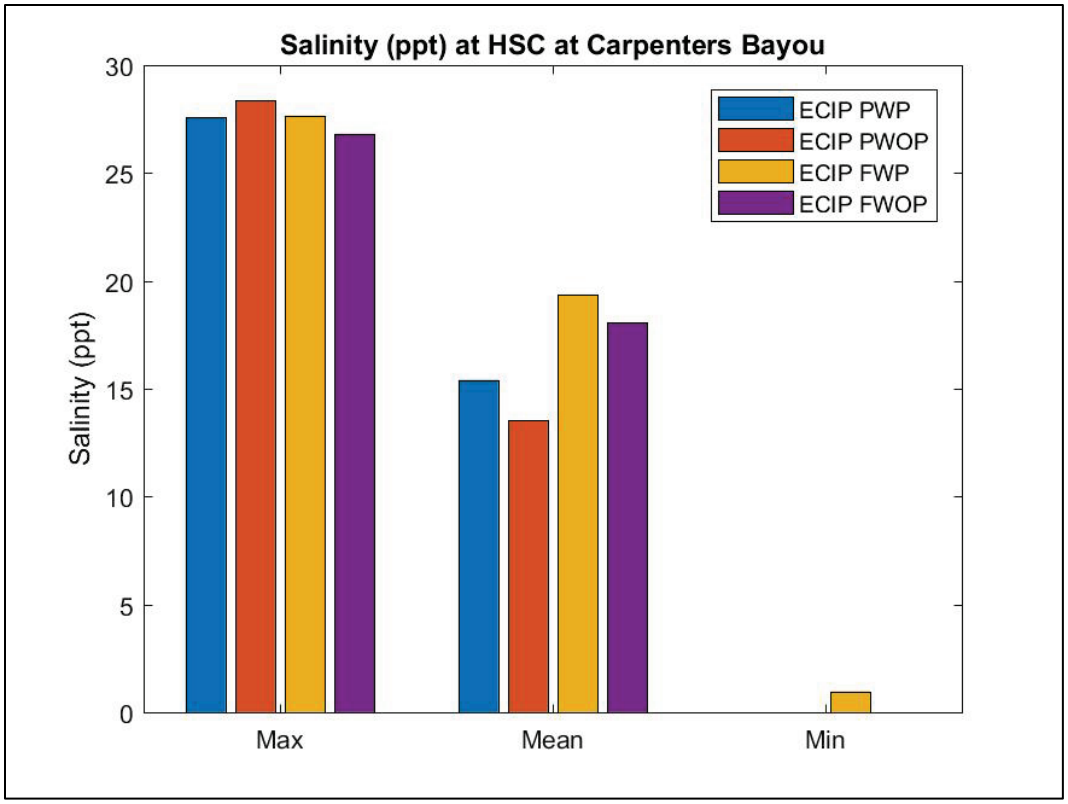

Salinity at HSC at Goat Island
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Date (mm/dd)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

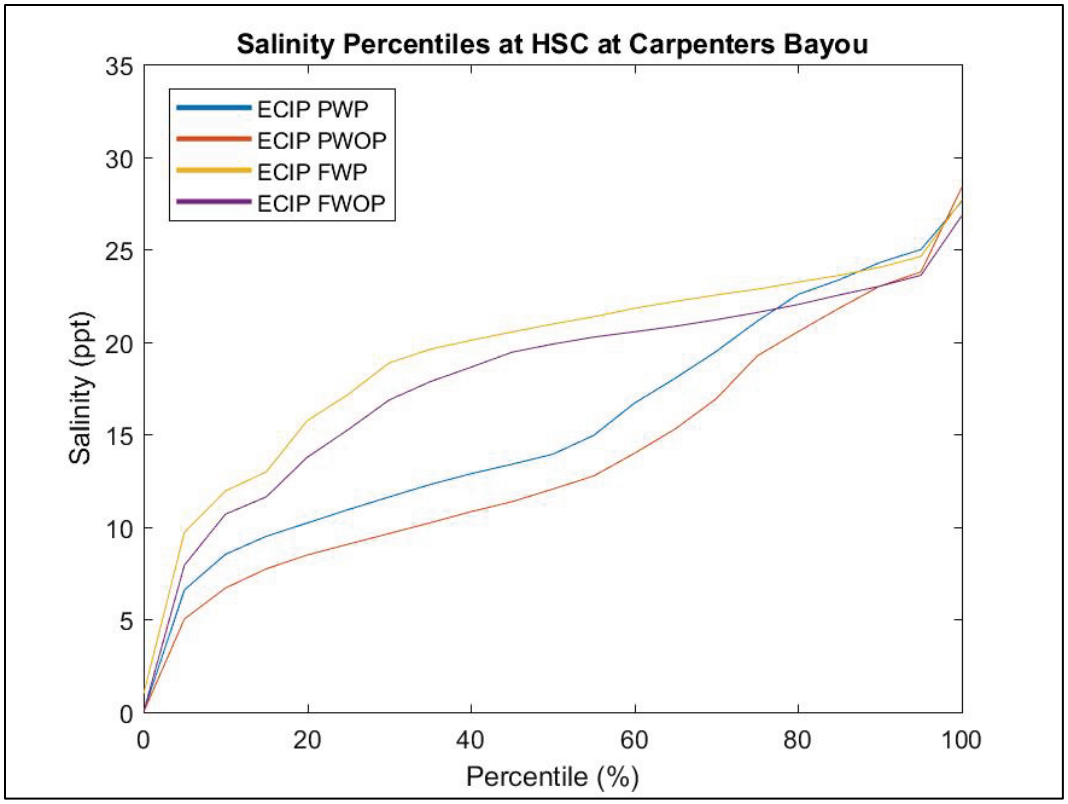

Salinity (ppt) at HSC at Goat Island
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

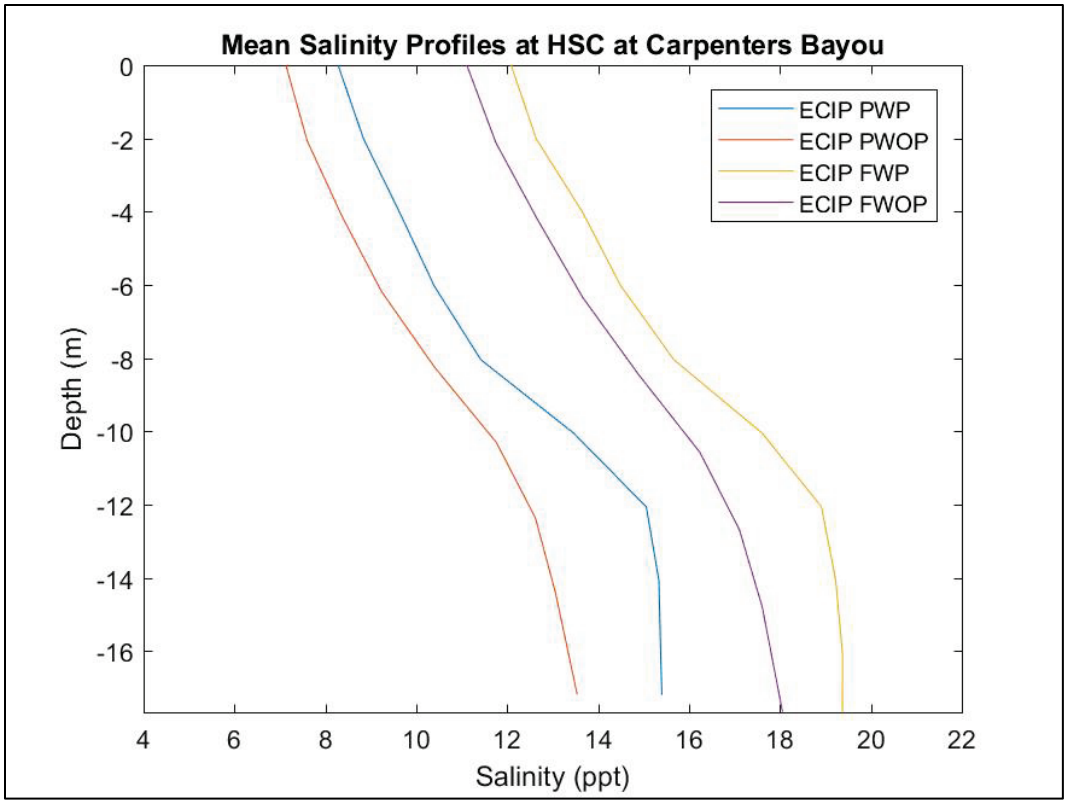

Salinity Percentiles at HSC at Goat Island
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

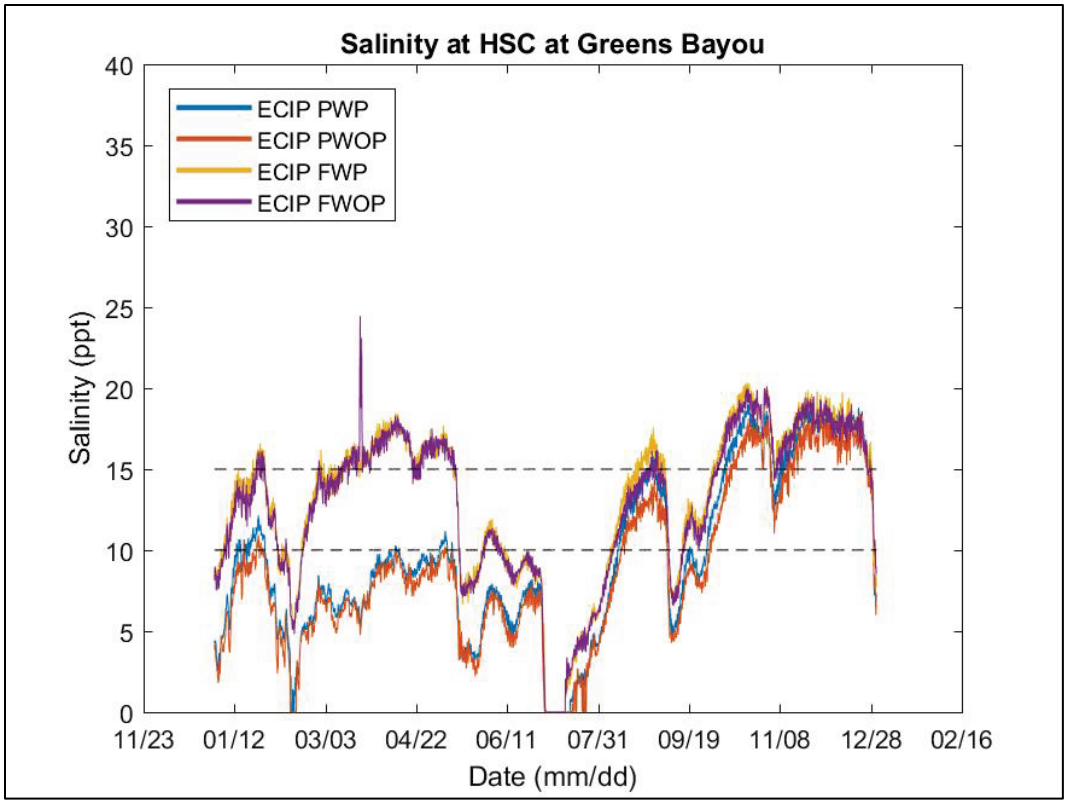

Mean Salinity Profiles at HSC at Goat Island
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
6
8
10
12
14
16
18
20
22
24

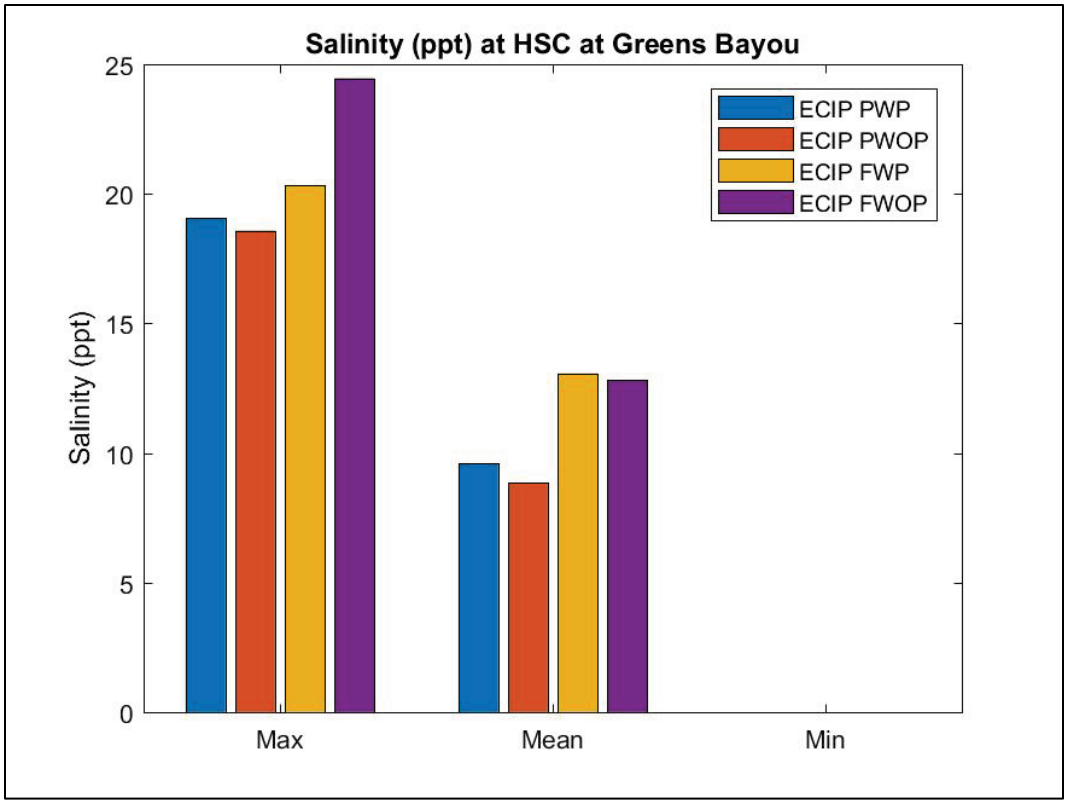

Salinity at HSC at Carpenters Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
35
40
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

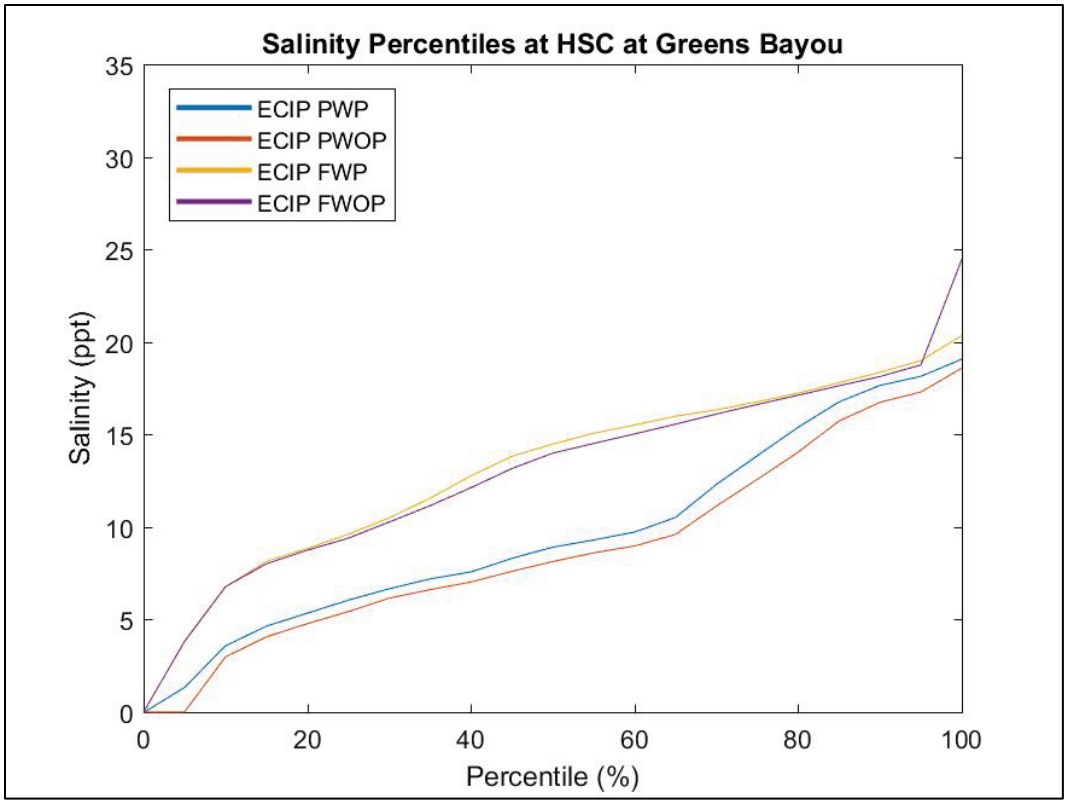

Salinity (ppt) at HSC at Carpenters Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min

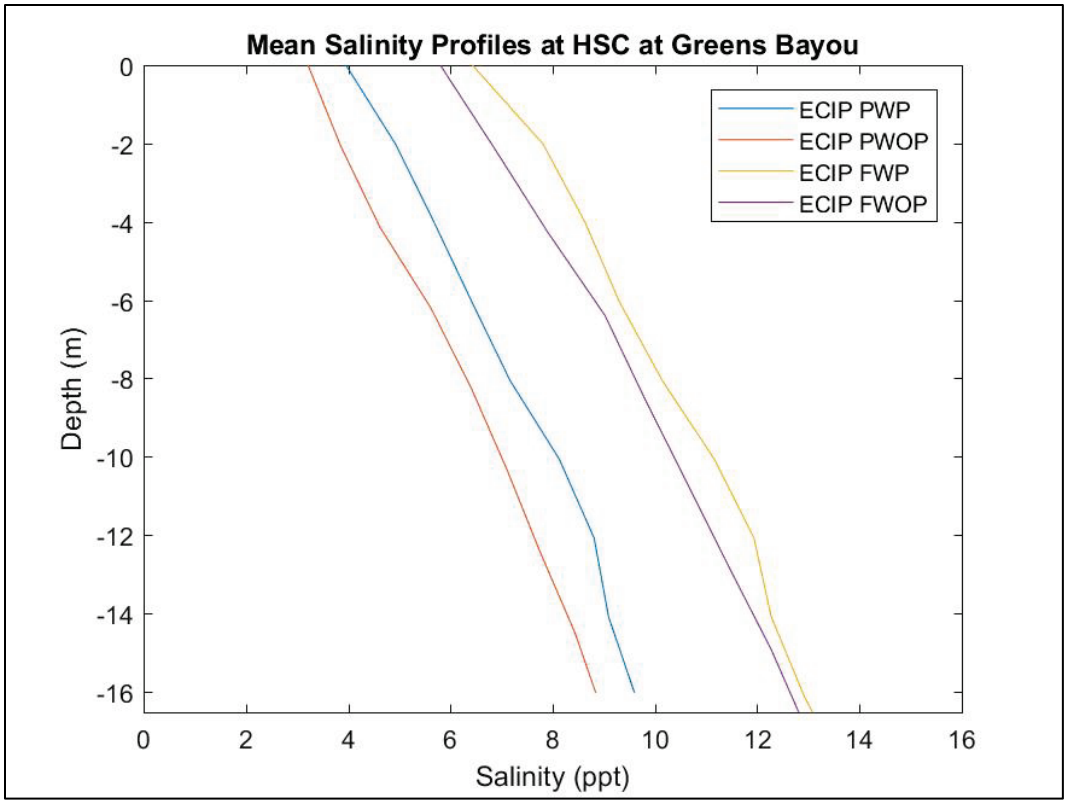

Salinity Percentiles at HSC at Carpenters Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

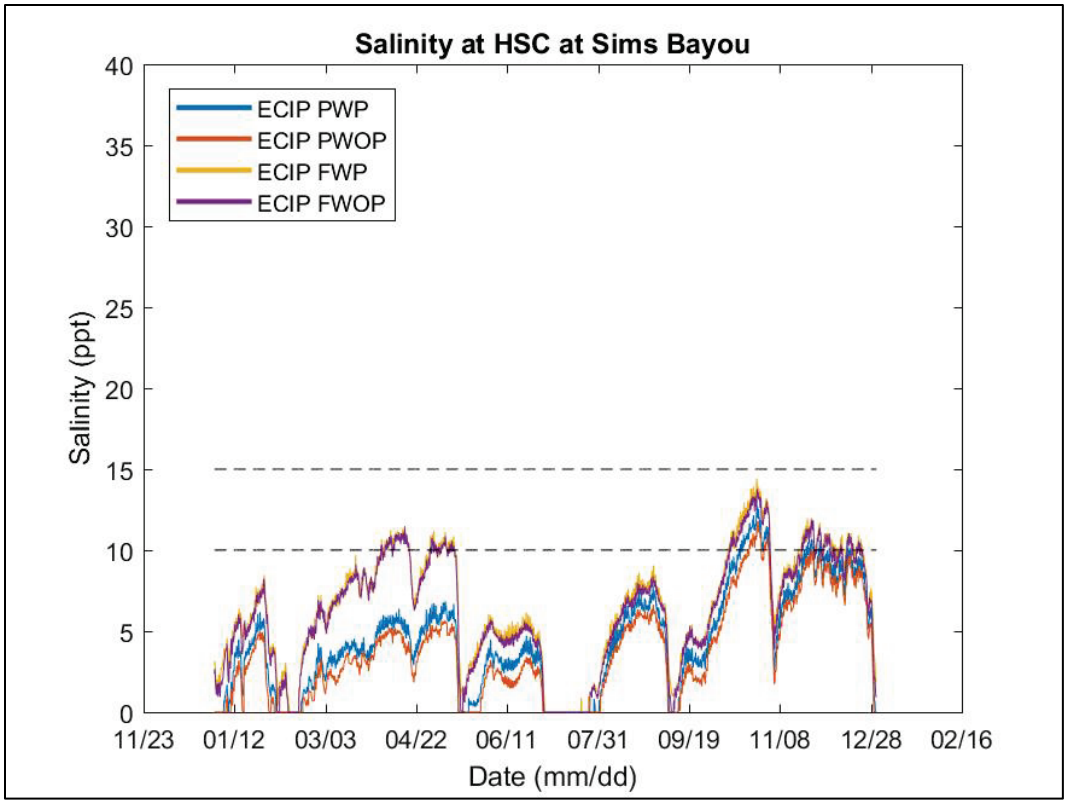

Mean Salinity Profiles at HSC at Carpenters Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
4
6
8
10
12
14
16
18
20
22

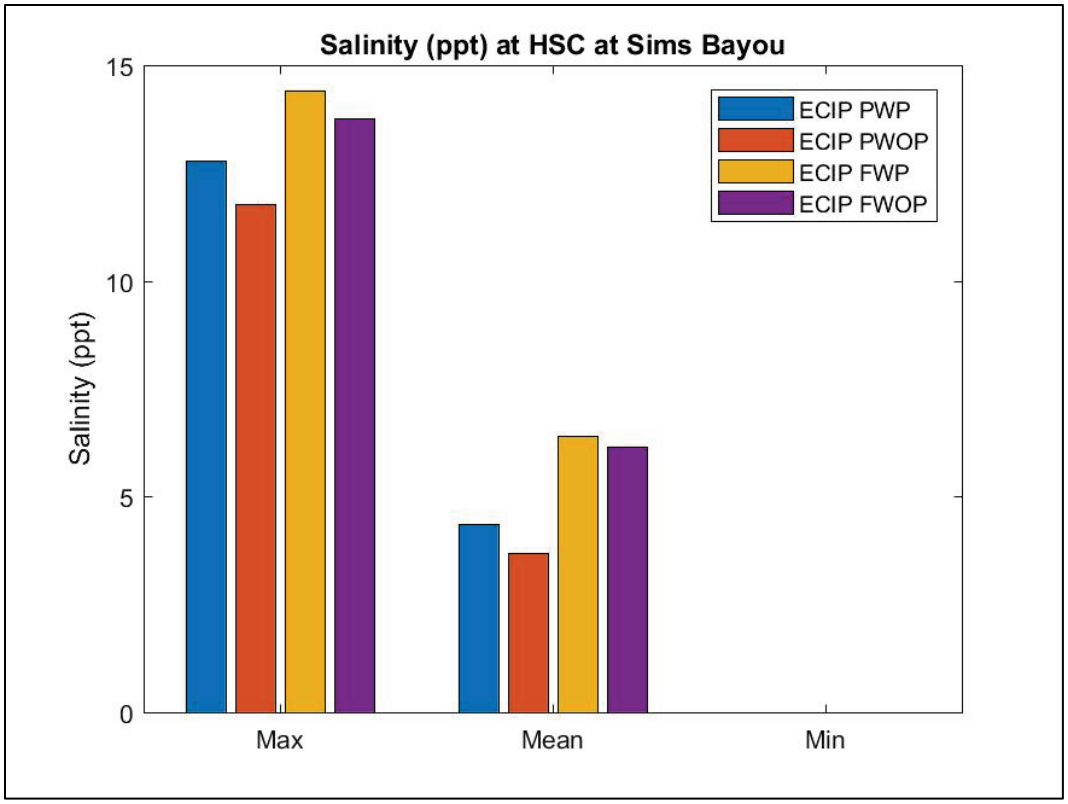

Salinity at HSC at Greens Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

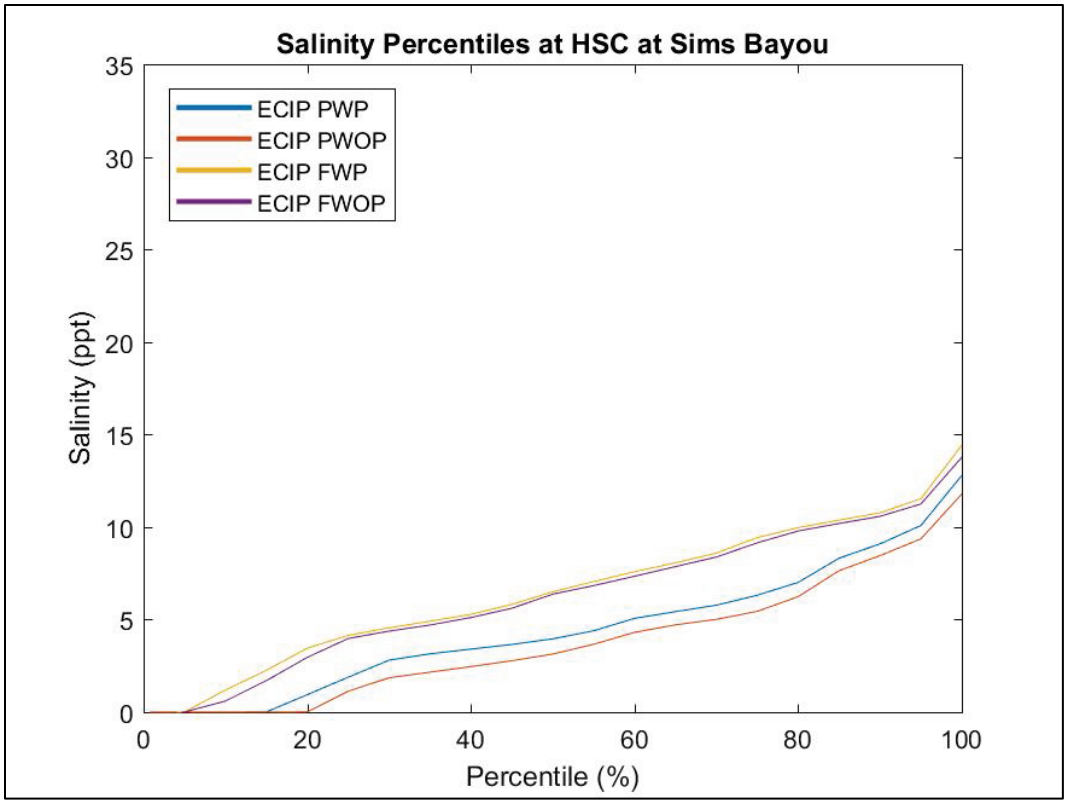

Salinity (ppt) at HSC at Greens Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
25
20
15
10
5
0
Max
Mean
Min

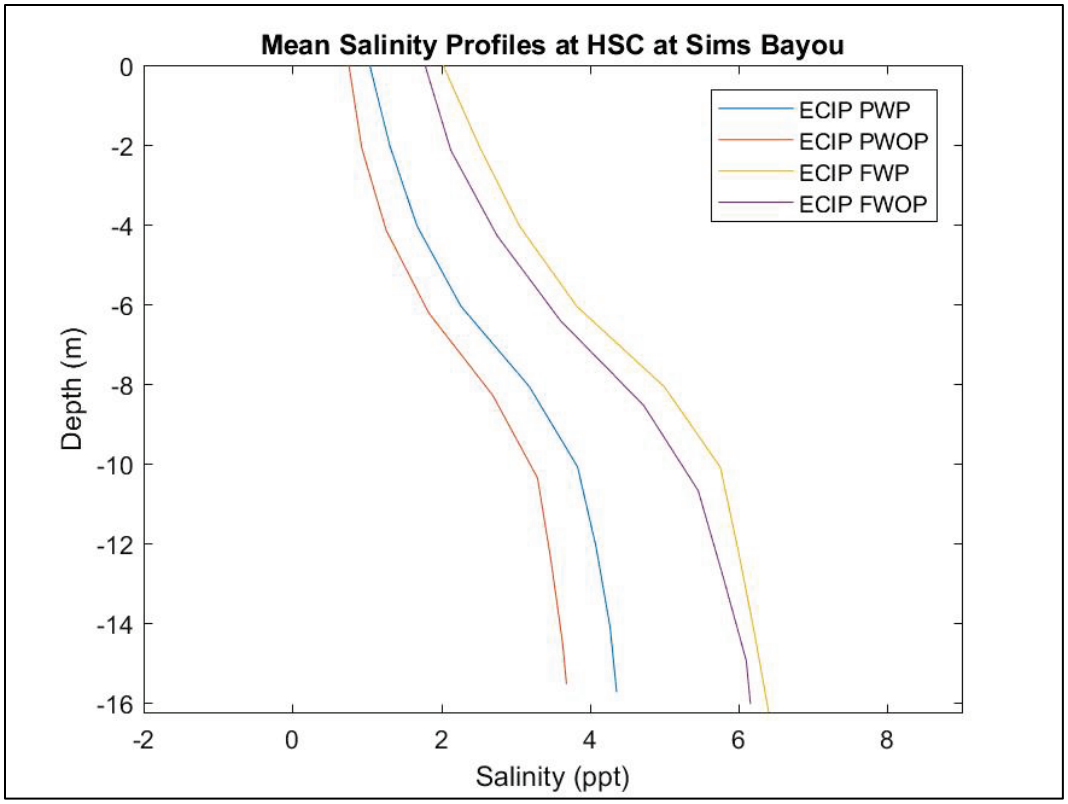

Salinity Percentiles at HSC at Greens Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100

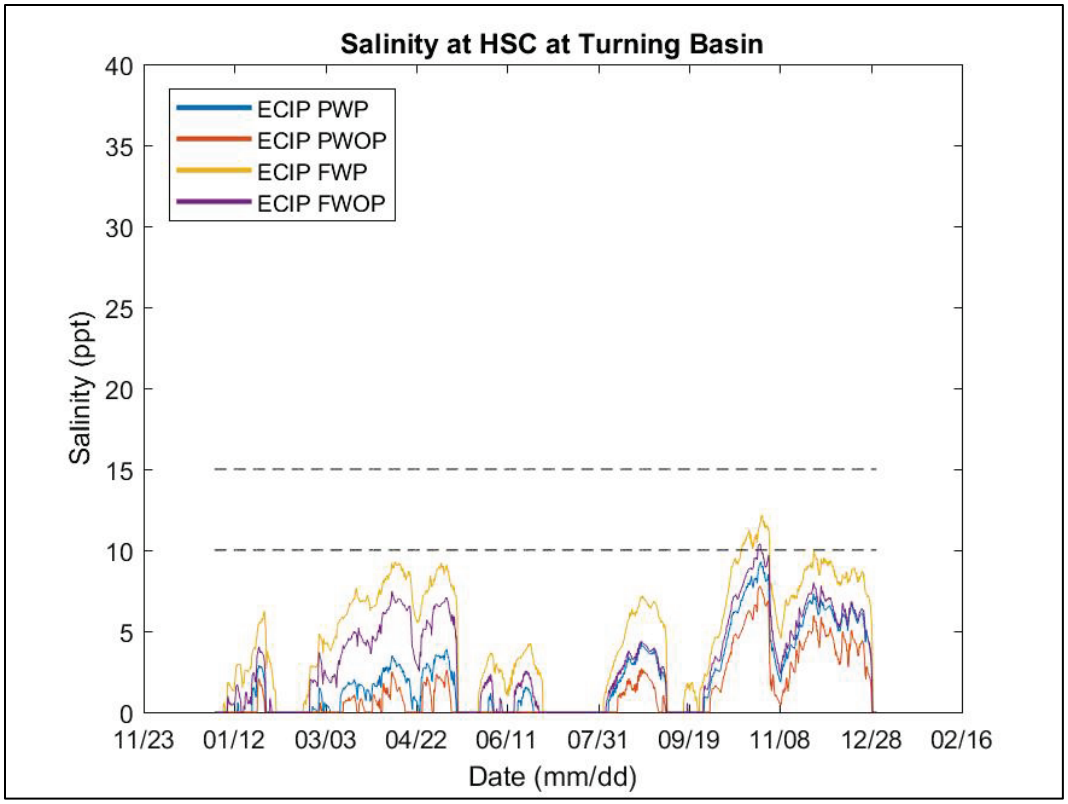

Mean Salinity Profiles at HSC at Greens Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
0
2
4
6
8
10
12
14
16

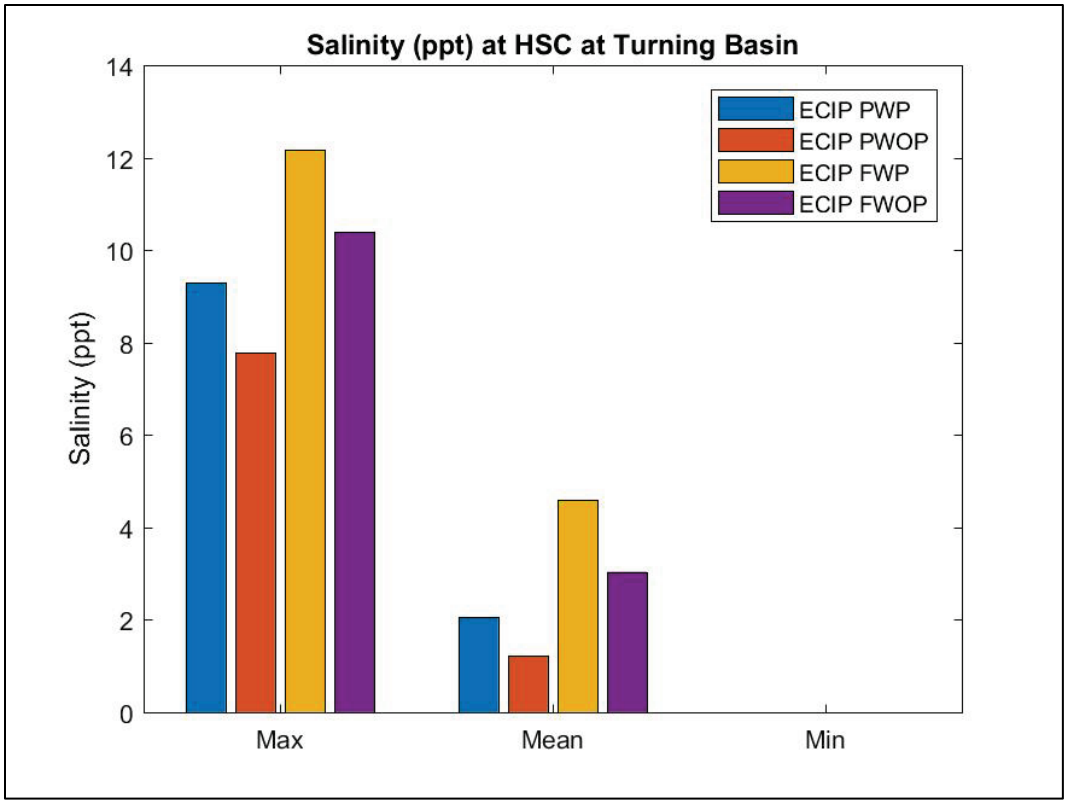

Salinity at HSC at Sims Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

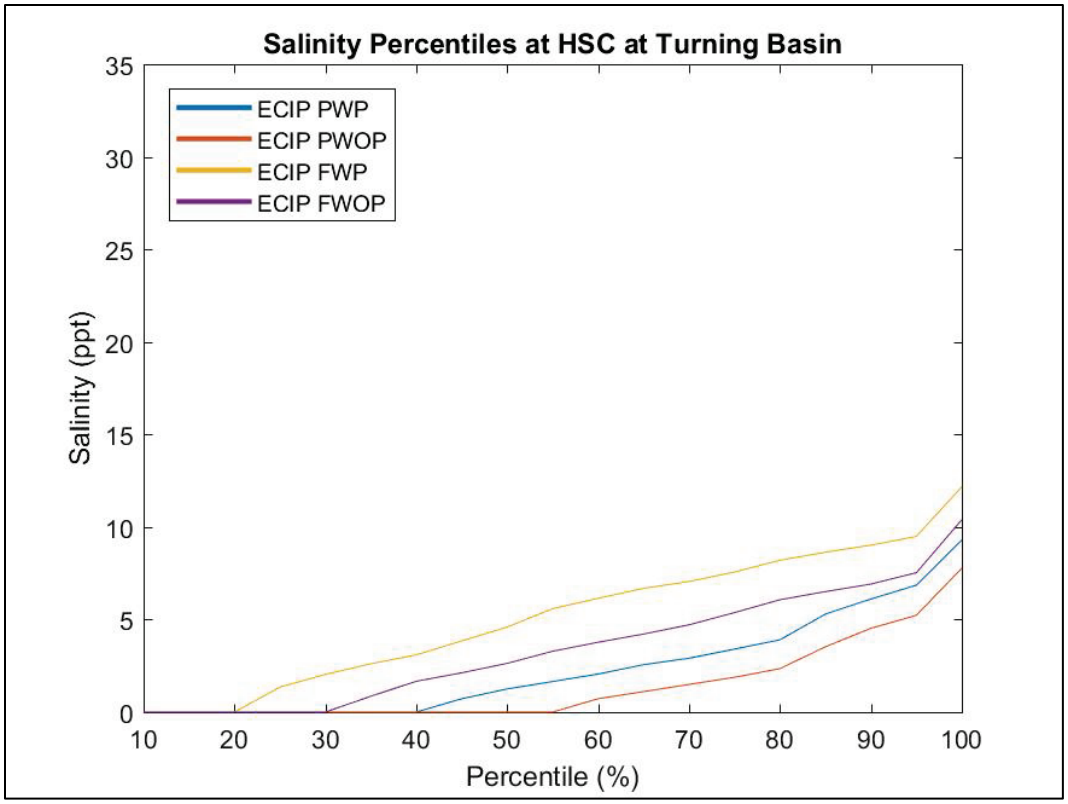

Salinity (ppt) at HSC at Sims Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
15
10
5
0
Max
Mean
Min

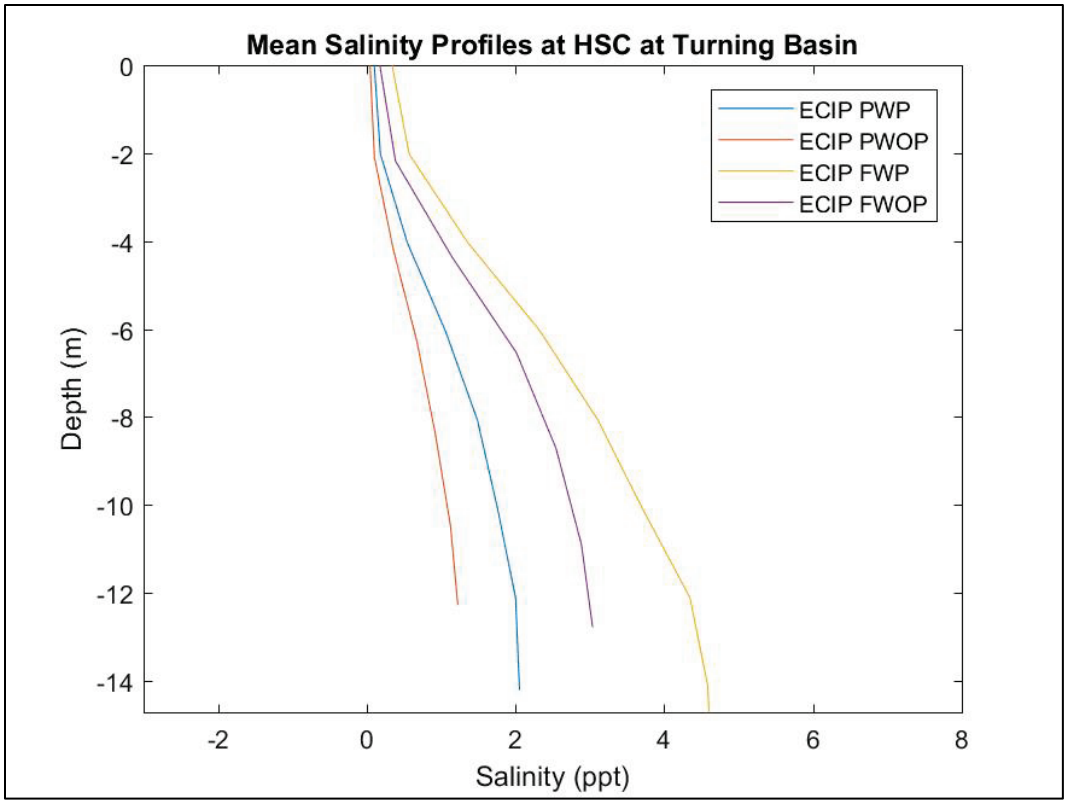

Salinity Percentiles at HSC at Sims Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
20
40
60
80
100


Mean Salinity Profiles at HSC at Sims Bayou
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
-2
0
2
4
6
8


Salinity at HSC at Turning Basin
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

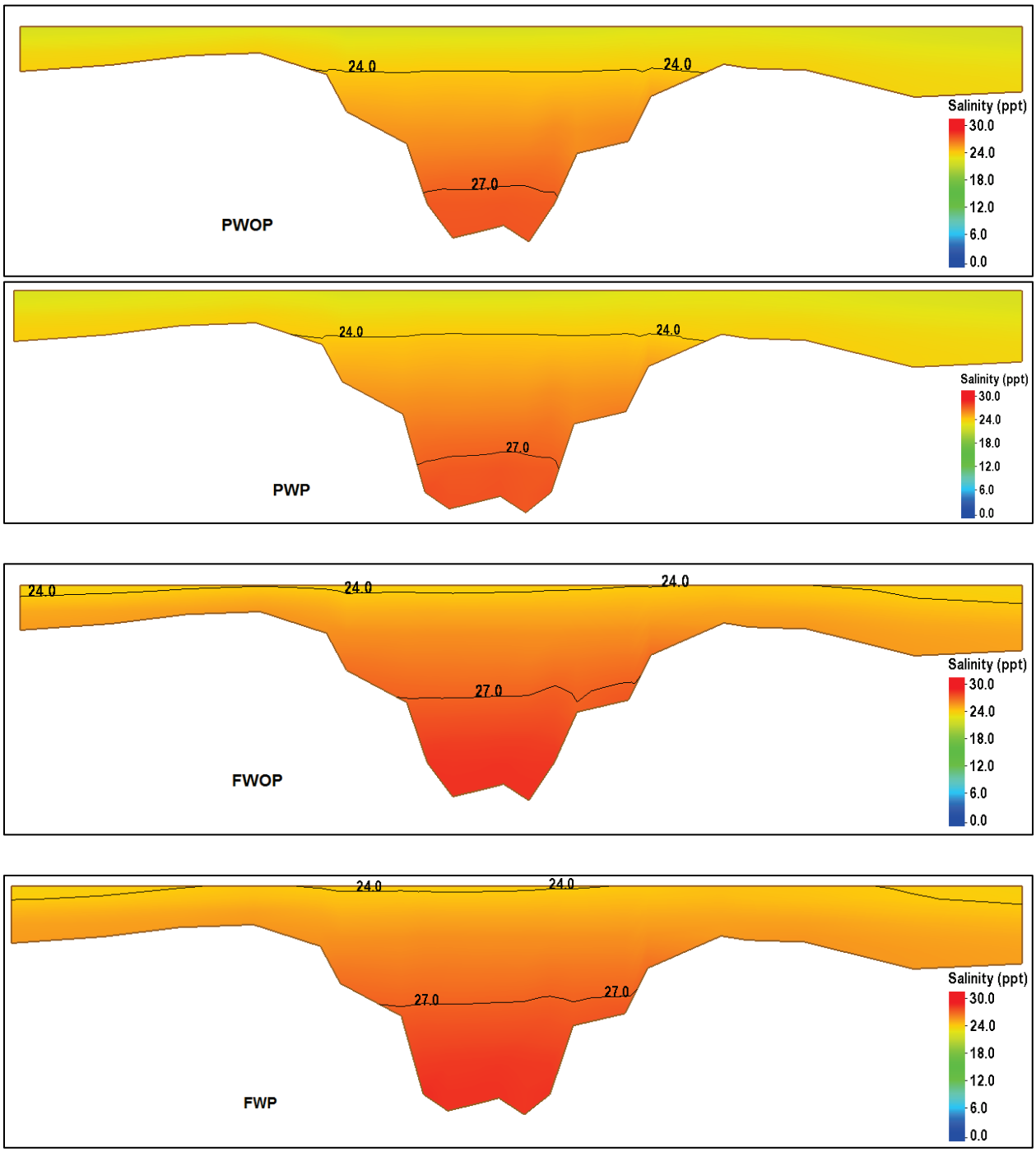

Salinity (ppt) at HSC at Turning Basin
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
14
12
10
8
6
4
2
0
Max
Mean
Min


Salinity Percentiles at HSC at Turning Basin
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
10
20
30
40
50
60
70
80
90
100

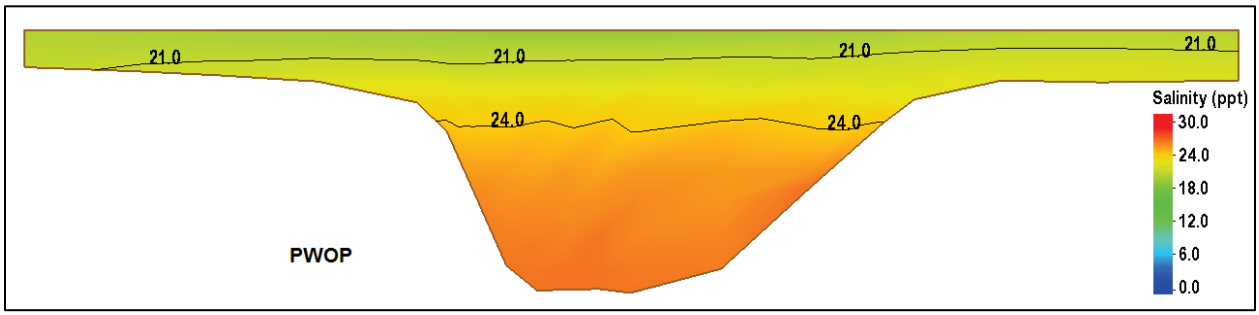

Mean Salinity Profiles at HSC at Turning Basin
ECIP PWP
ECIP PWOP
ECIP FWP
ECIP FWOP
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-2
0
2
4
6
8

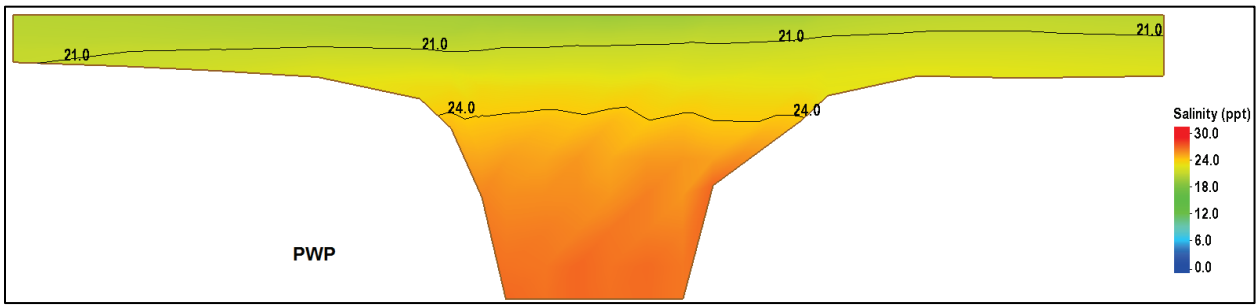
Cross-sectional salinity analysis

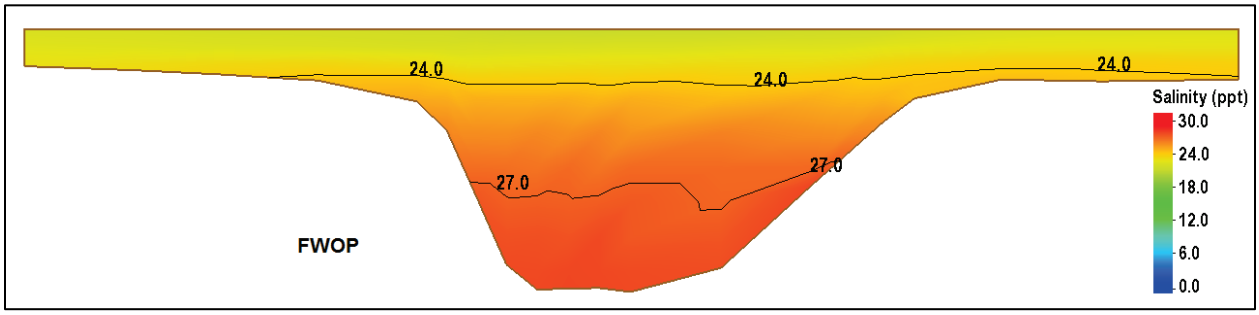
Cross section 1

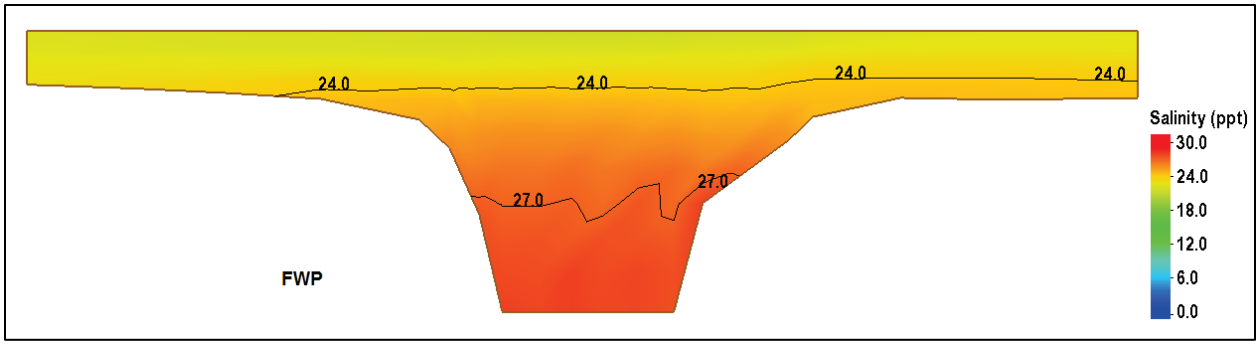


Cross section 2

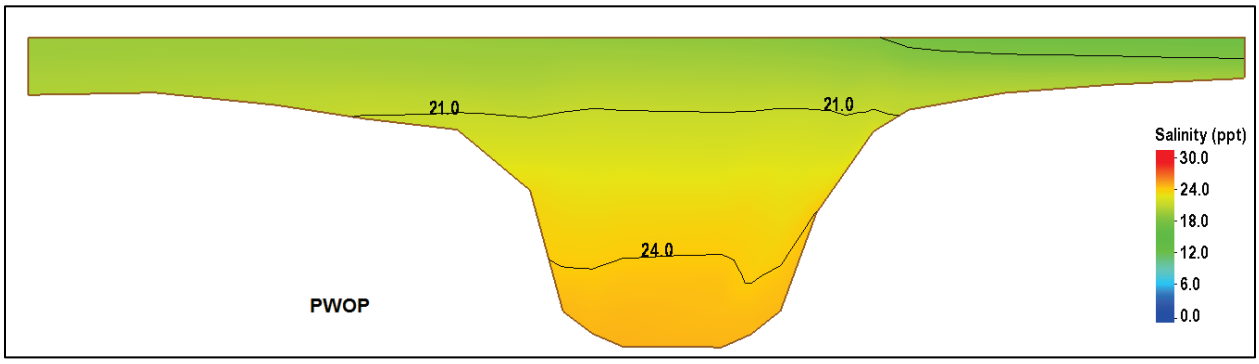


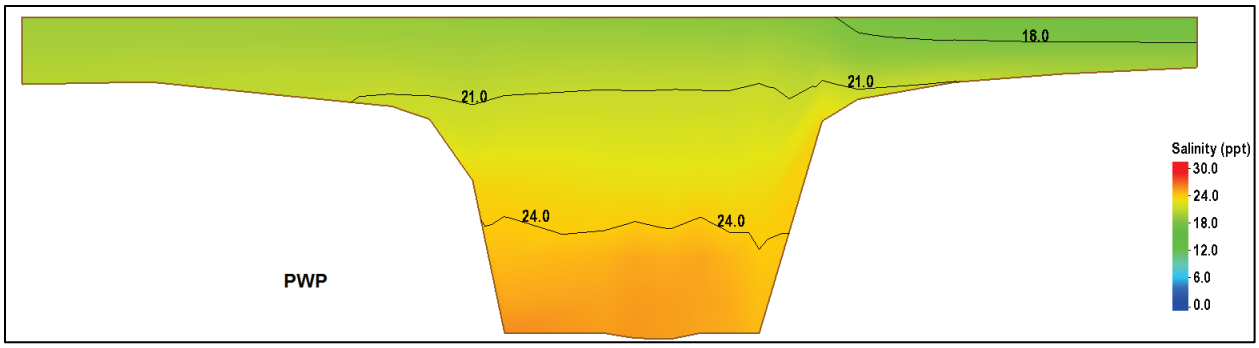


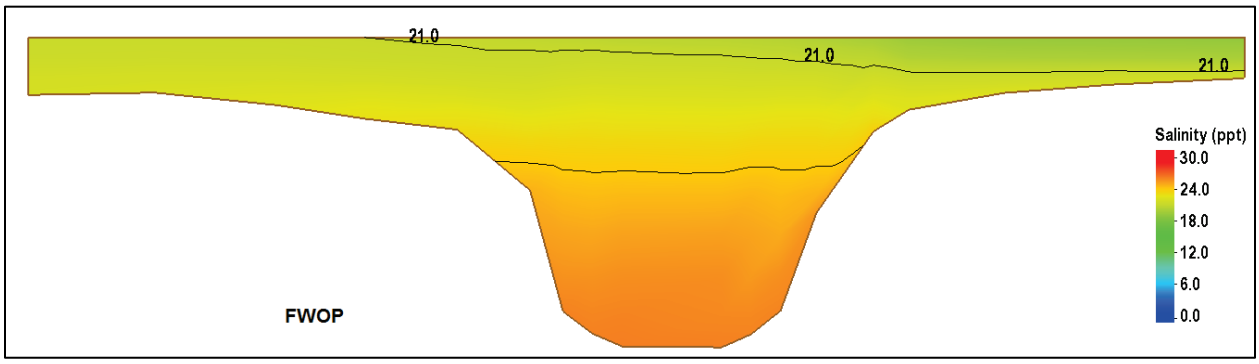


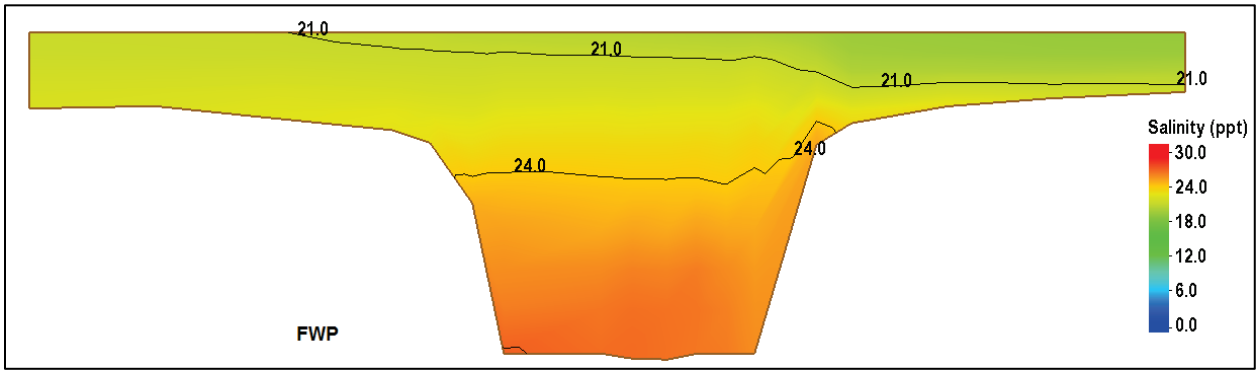


Cross section 3

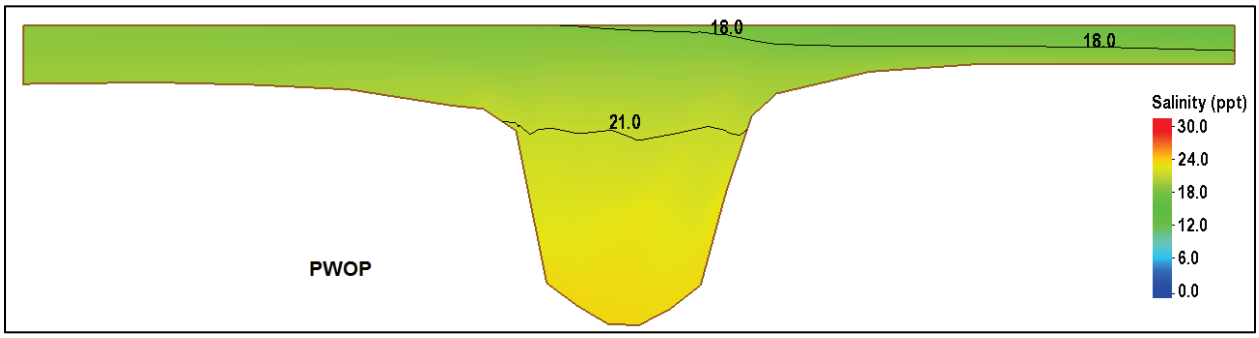


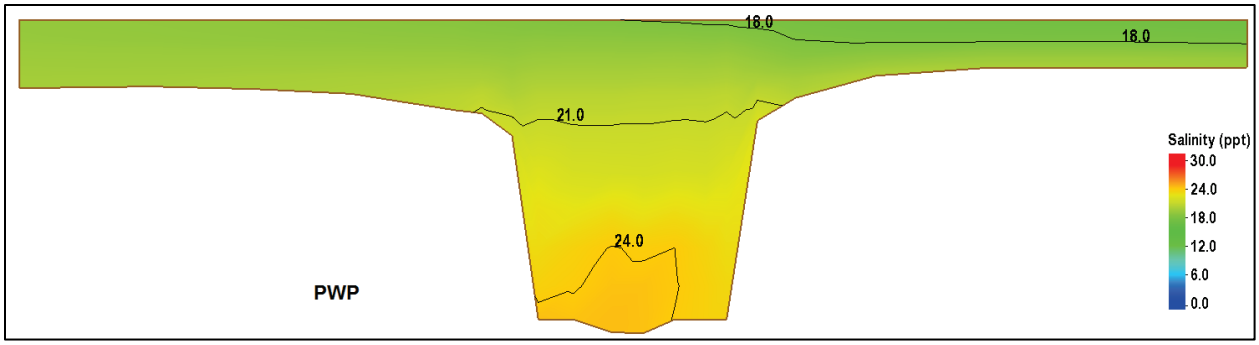


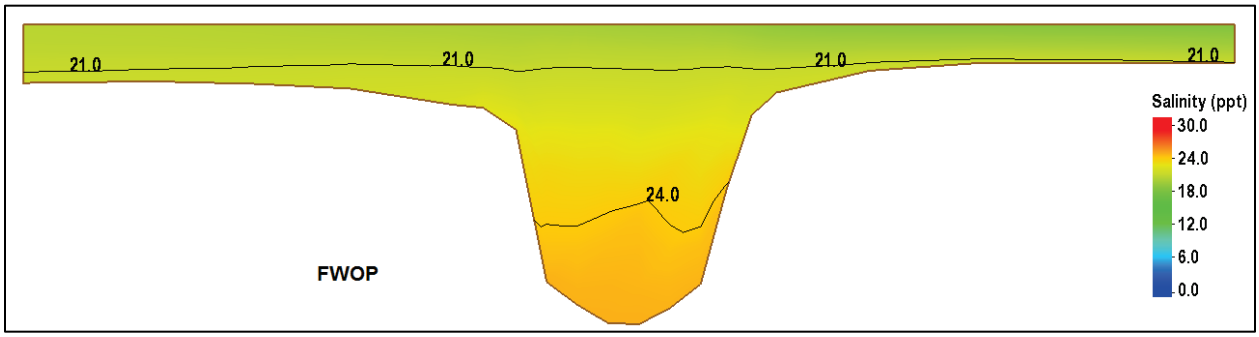


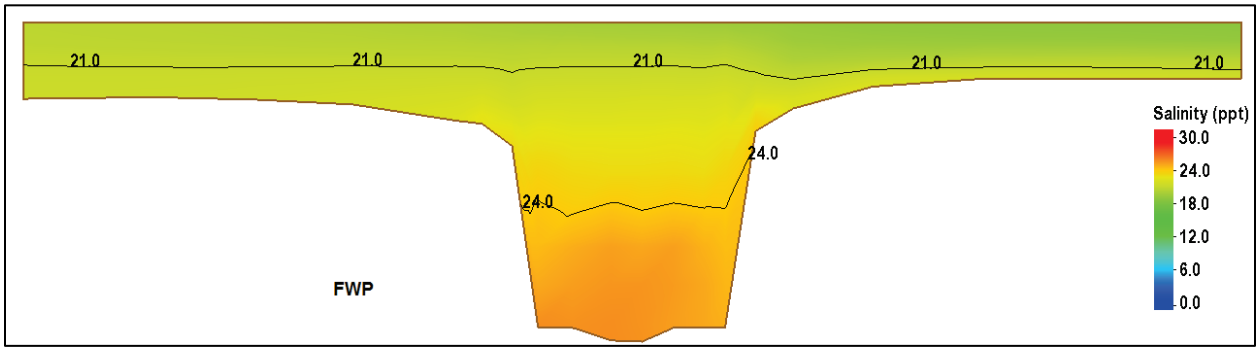


Cross section 4

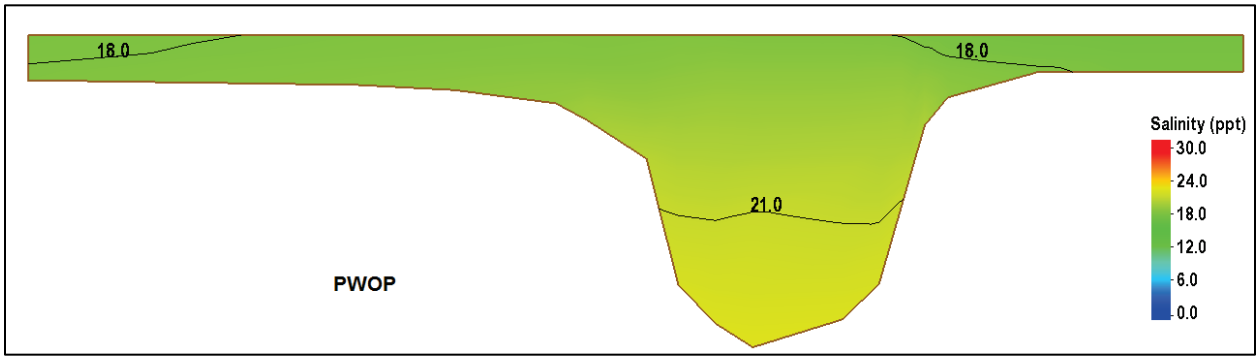


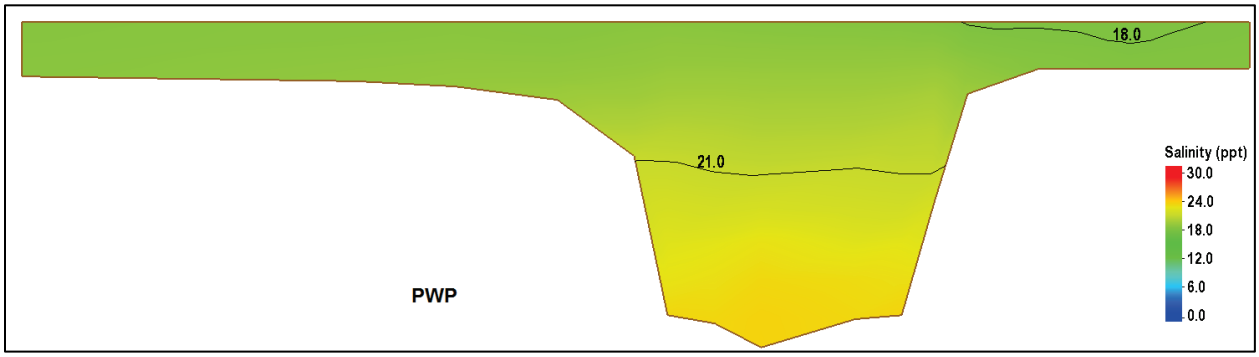


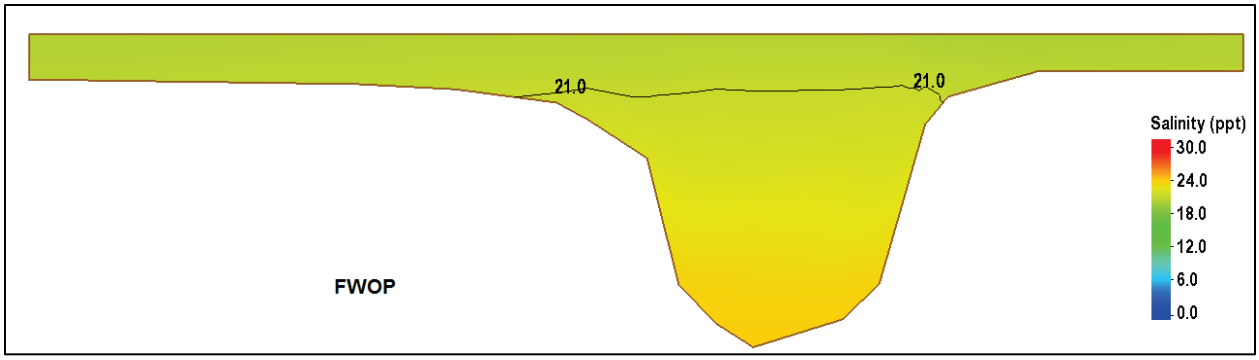


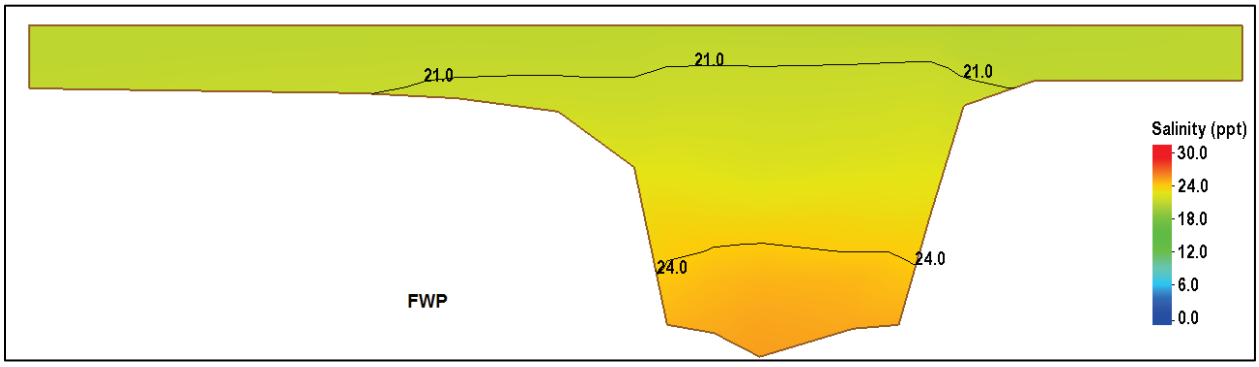


Cross section 5

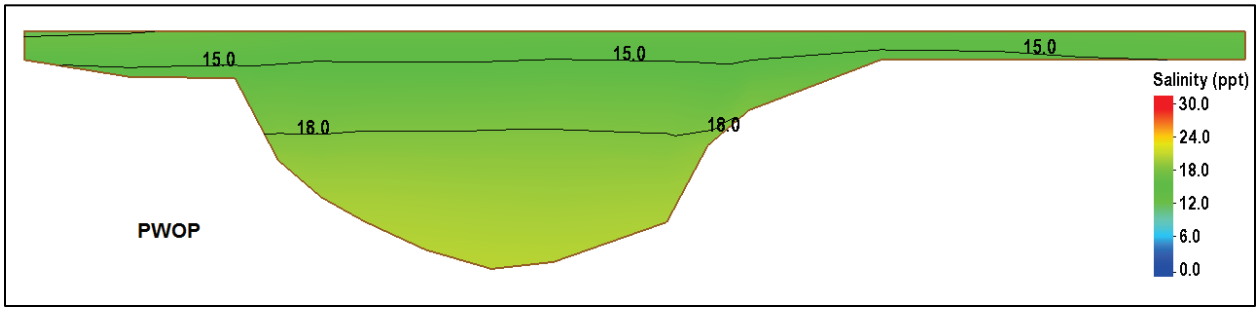


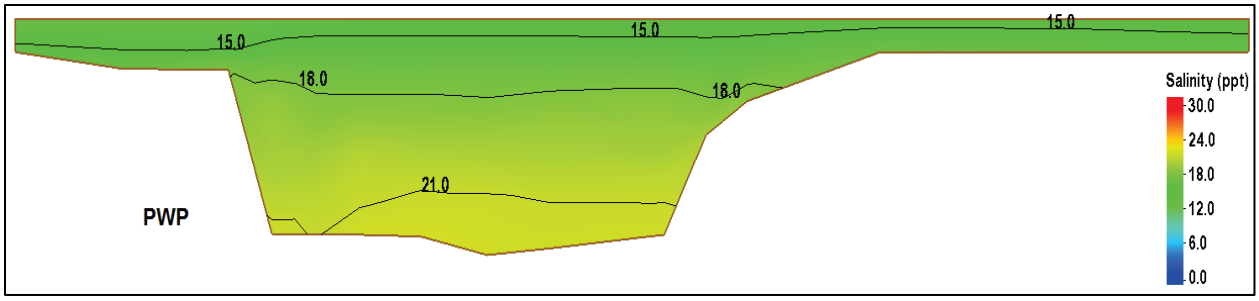


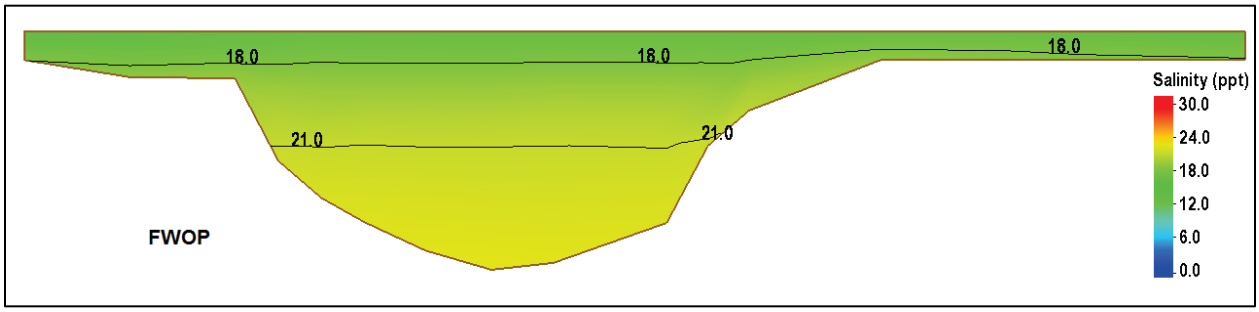


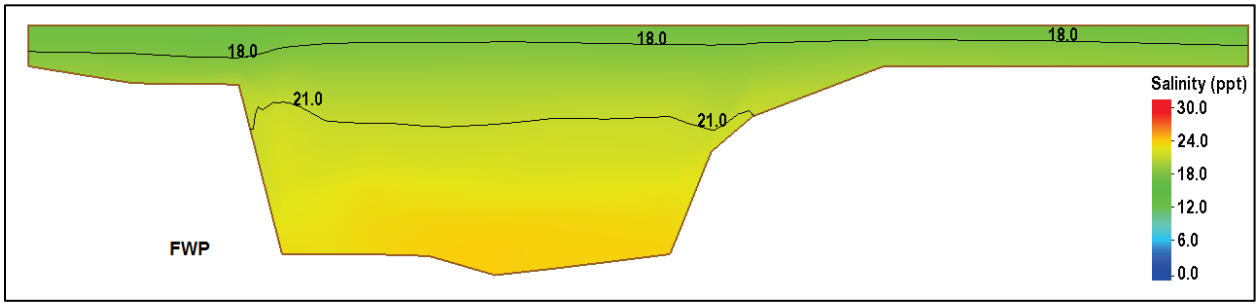


Cross section 6

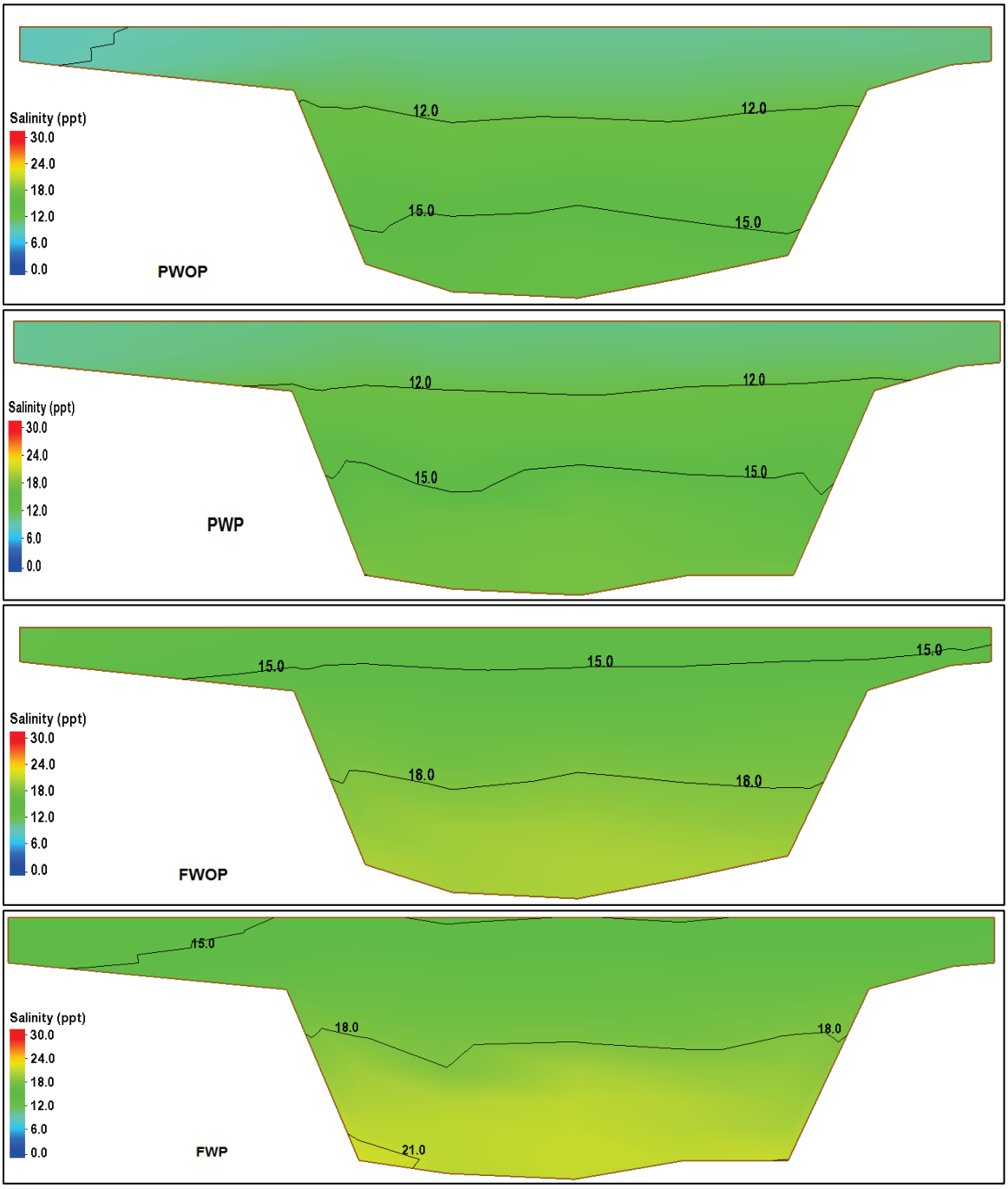








Cross section 7



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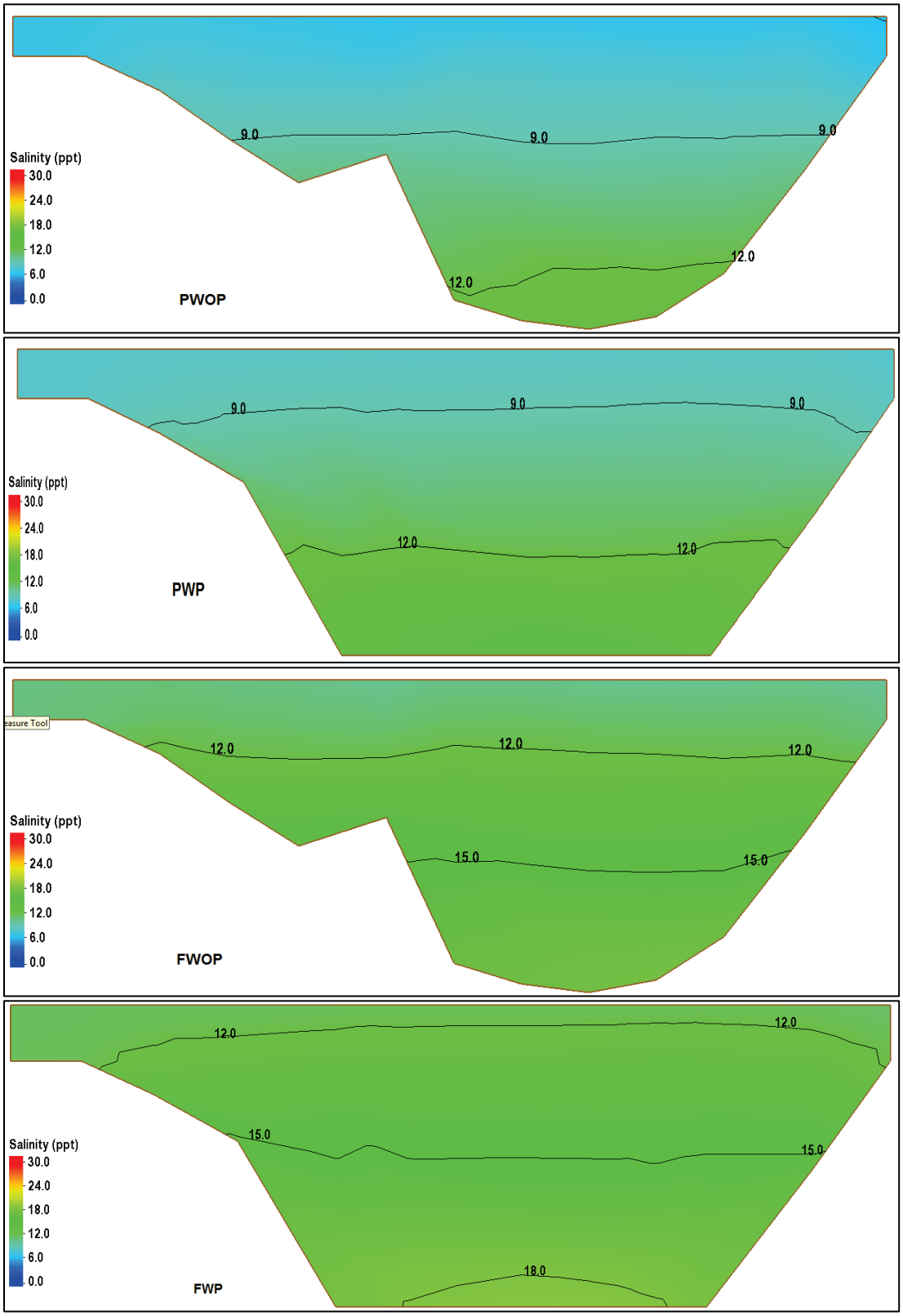

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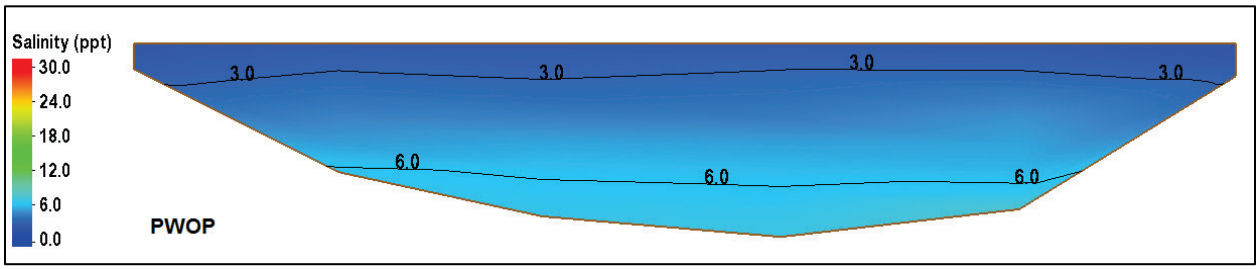

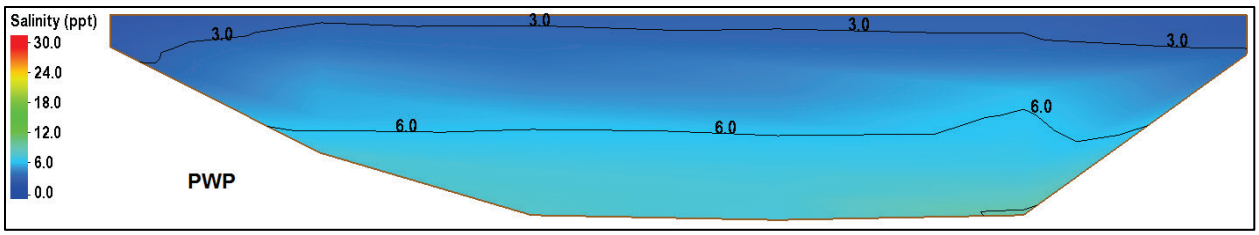

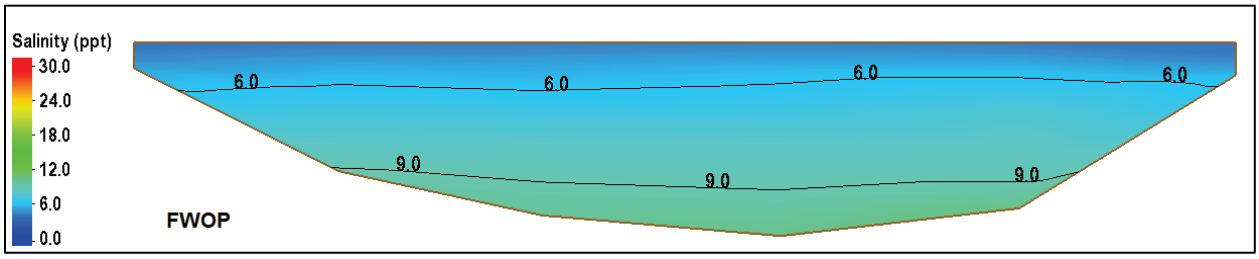

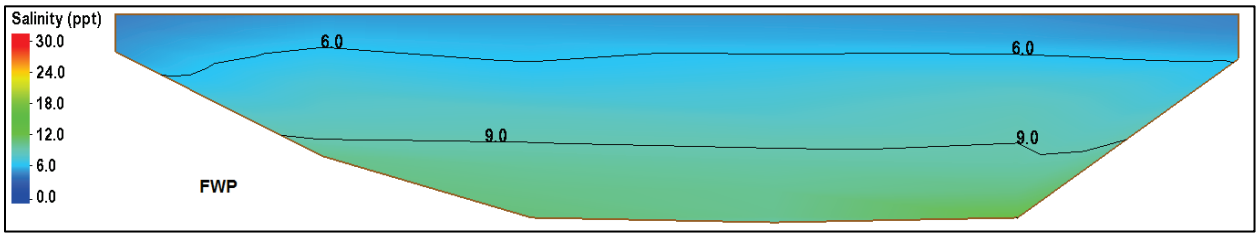

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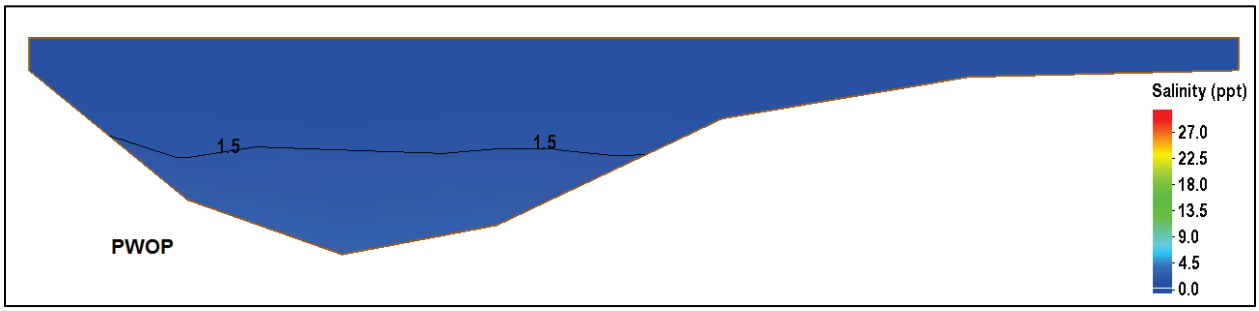

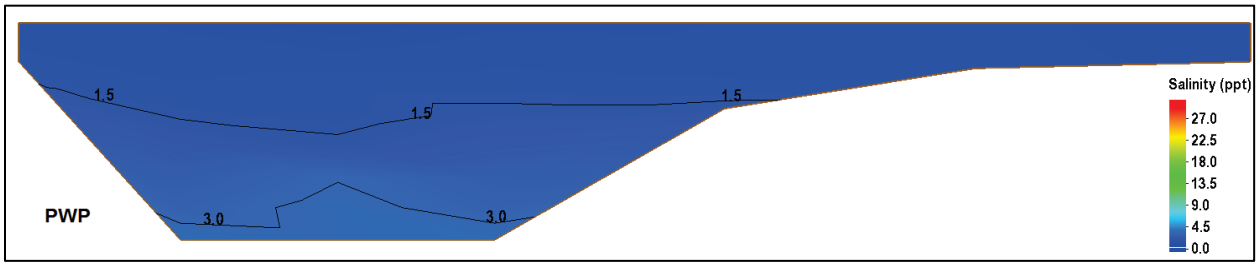

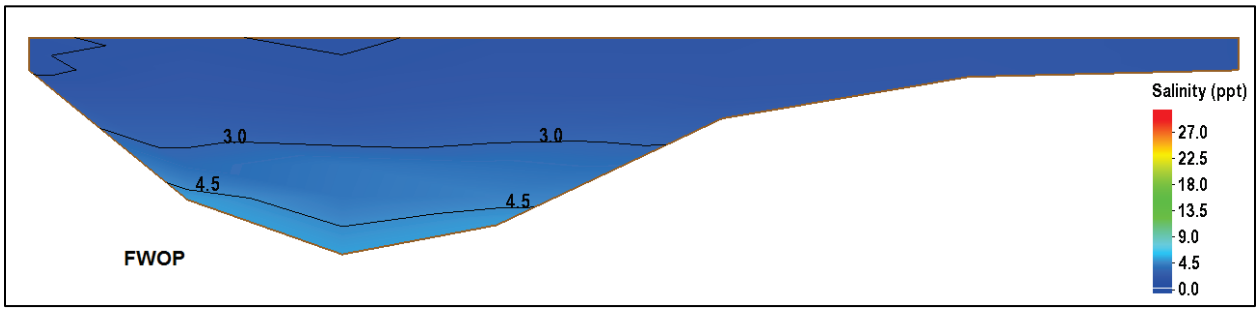

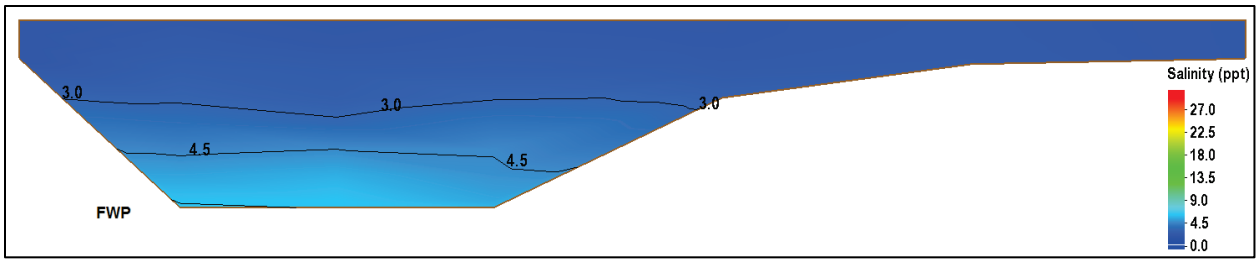

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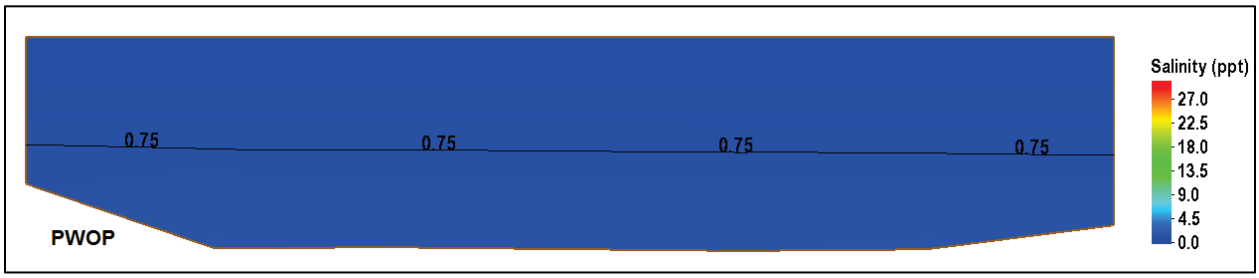

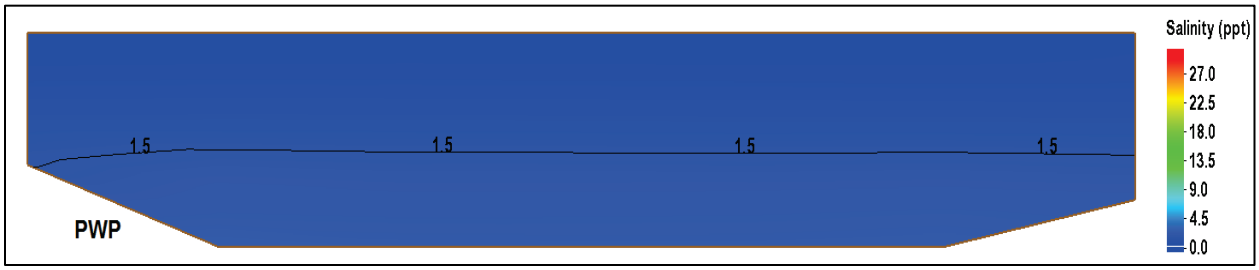

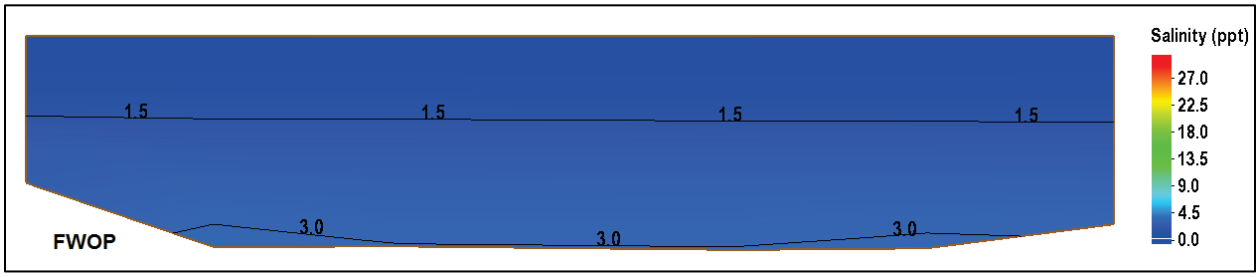

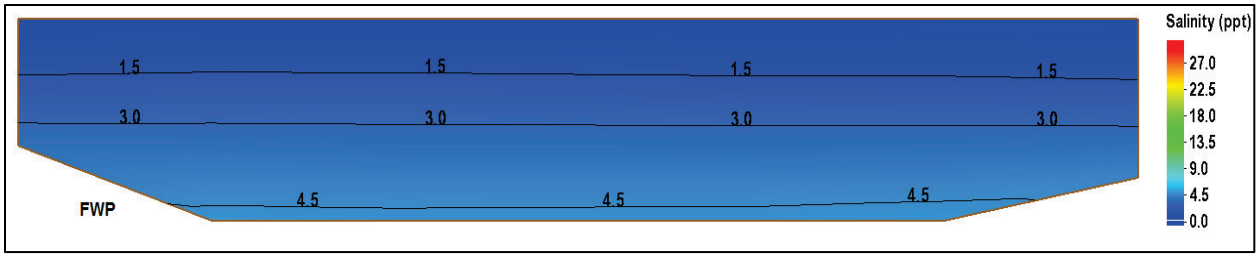

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic feet per second	0.02831685	cubic meters per second
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	0.0254	meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
square feet	0.09290304	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

List of Abbreviations

HSC	Houston Ship Channel
AdH	Adaptive Hydraulics
AM	Advanced Maintenance
AO	Allowable Overdepth
CSAT	Corps Shoaling Analysis Tool
ECIP	Expansion Channel Improvement Project
ERDC-CHL	Engineer Research and Development Center, Coastal and Hydraulics Laboratory
FWP	Future With Project
FWOP	Future Without Project
MLLW	Mean Lower Low Water
NOAA	National Oceanic and Atmospheric Administration
PWP	Present With Project
PWOP	Present Without Project
SLR	Sea Level Rise
SWG	US Army Engineer District, Galveston
TSP	Tentatively selected plan
TWDB	Texas Water Development Board
USACE	U.S. Army Corps of Engineers
WIS	Wave Information Studies
3D	Three-dimensional

List of Unit Abbreviations

ft	feet
m	meters
m^3	cubic meters
cms	cubic meters per second
m/s	meters per second
mg/l	milligrams per liter
ppt	parts per thousand

REPORT DOCUMENTATION PAGE

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14. ABSTRACT

The Houston Ship Channel is one of the busiest deep-draft navigation channels in the United States and must be able to accommodate larger vessel dimensions over time. The U.S. Army Engineer District, Galveston (SWG), requested the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, perform hydrodynamic and sediment modeling of proposed modifications along the Houston Ship Channel from its connection to the Gulf of Mexico to the Port of Houston. The modeling results are necessary to provide data for salinity and sediment transport analysis as well as ship simulation studies. SWG provided a project alternative that includes channel widening, deepening, and bend easing. The model is run for present year zero (2029) and future year 50 (2079) with and without project. The model shows that the salinity does not vary greatly with project. Changes to salinity are 2 parts per thousand or less. The tidal prism increases by less than 2% when the project is included, and the tidal amplitudes increase by no more than 0.01 meter. The residual velocity vectors do vary in and around areas where project modifications are made — along the Houston Ship Channel, Bayport Channel, and Barbours Cut Channel. The model also indicates an increase in the shoaling along the ship channel when compared to the without project results, the largest increases being in the Bayport channel and flare.

15. SUBJECT TERMS
Coastal engineering—Numerical analysis, Dredging, Houston Ship Channel (Tex.), Hydrodynamics, Inland navigation, Salinity, Sedimentation and deposition, Sediment transport

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