ERDC/CHL TR-21-2

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

# Houston Ship Channel Expansion Channel Improvement Project (ECIP) Numerical Modeling Report: Increased Channel Width Analysis

Jennifer McAlpin and Cassandra Ross

February 2021

ERDC/CHL TR-21-2
February 2021

# Houston Ship Channel Expansion Channel Improvement Project (ECIP) Numerical Modeling Report: Increased Channel Width Analysis

Jennifer McAlpin and Cassandra Ross

*Coastal and Hydraulics Laboratory*
*U.S. Army Engineer Research and Development Center*
*3909 Halls Ferry Road*
*Vicksburg, MS 39180-6199*

Final report

Approved for public release; distribution is unlimited

Prepared for Port of Houston Authority
Houston, TX 77029

Under Port of Houston Authority; Funding Account Code SA-2020-CHL-3562

# 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. 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. After initial analysis, two additional channel widths in the bay portion of the Houston Ship Channel were requested for testing. The results of these additional channel widths are presented in this report.

The model shows that the salinity does not vary significantly due to the channel modifications being considered for this project. Changes in 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.

# Contents

# Figures and Tables

## Figures

## Tables

# Preface

The model investigation presented in this report was authorized and funded by the Port of Houston Authority, Funding Account Code SA-2020-CHL-3562.

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 Dr. Ty V. Wamsley, 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. David May, Chief, River and Estuarine Engineering Branch.

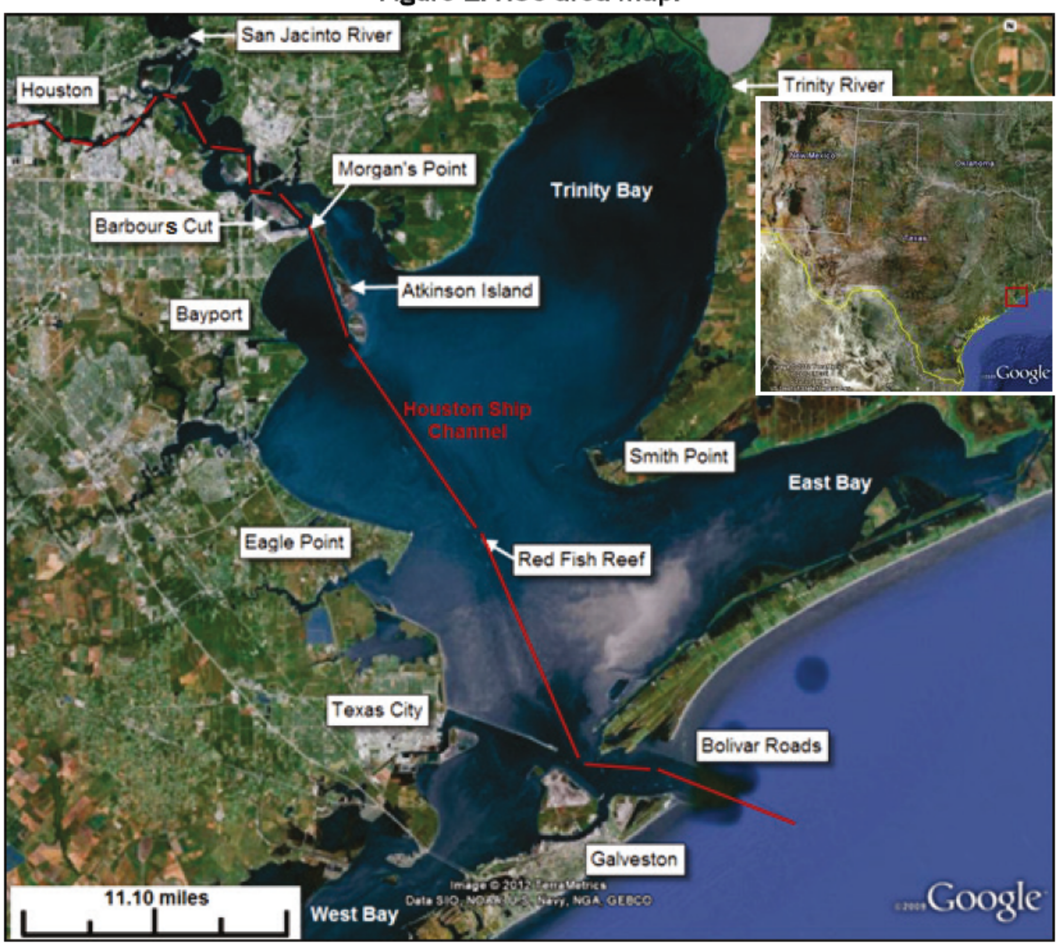
COL Schlosser was Commander of ERDC, and Dr. David Pittman was Director.

# 1 Introduction

## 1.1 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.



In 2005, The U.S. Army Corps of Engineers (USACE), Galveston District (SWG) enlarged the HSC from a 40 ft* depth by 400 ft width to a 45 ft depth by 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 denser 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 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, Atchafalaya, 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 (Berger et al. 1995a). A reduction in bay salinity is hypothesized to result in different suspended

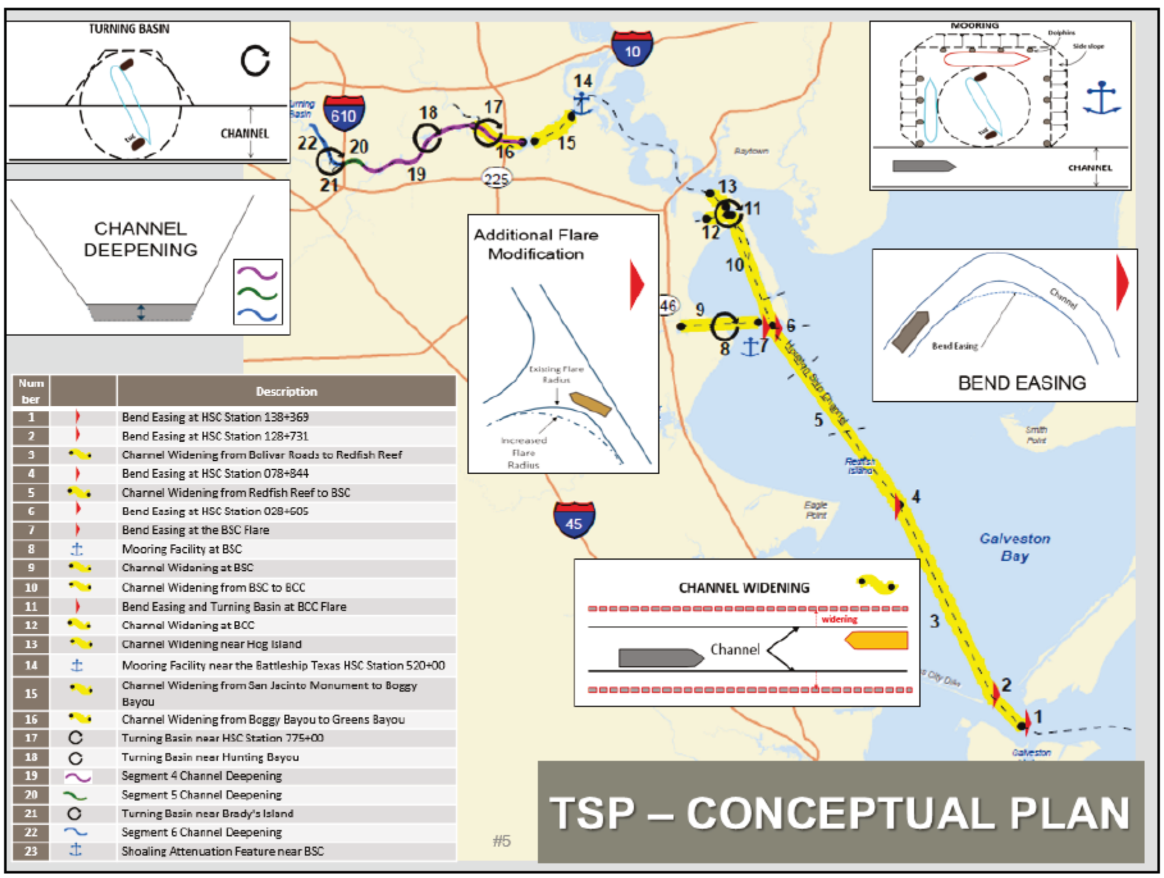
* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

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 late springtime period.

## 1.2 Objective

In 2016, SWG requested the ERDC-CHL perform hydrodynamic and sediment transport modeling of proposed modifications along the HSC from its connection at the Gulf of Mexico to the Port of Houston (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 navigation effects of the modifications. The model results of project year zero (2029) and project year 50 (2079) with and without project results were documented in McAlpin et al. (2019b).

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 |

In 2020, the Port of Houston Authority requested modeling for two additional channel widths in the bay portion of the HSC (HSC Stations 138+000 to 0+000, labeled from 1 to 13 in Figure 2). These widths are necessary for ship simulation such that an adequate channel width can be determined for safe navigation. Previously, a 650 ft channel width was simulated. This addendum includes channel widths of 700 ft and 750 ft.

## 1.3 Approach

Previously, a 3D Adaptive Hydraulics (AdH) model was developed and validated for simulation of hydrodynamics, salinity, and sediment transport (Savant and Berger 2015). The AdH code solves the shallow water equations to compute depth and velocity at node points defining the domain. AdH includes a linkage to the SEDLIB sediment transport library that computes cohesive and non-cohesive erosion and deposition that is then transported by the AdH code. Flocculation of sediment is not included in AdH but is somewhat accounted for by manipulation of sediment grain size and settling velocity. All models are limited by the data used to define them, and uncertainty in model boundary conditions must be considered when reviewing the model results and determining their applicability to the specific project.

The model was validated to available field data for all parameters (McAlpin et al. 2019a) and then utilized to test project alternatives for present and future conditions (McAlpin et al. 2019b). For all simulations the model was 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 was used for all analyses. The same method is used for simulation of these two additional channel widths.

The model development and boundary condition specification 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 were documented in McAlpin et al. (2019a). This addendum focuses on the model results for the 700 ft channel and the 750 ft channel for the bay section of the HSC deepening and widening alternative. These simulations are only made for the present boundary conditions) and all other proposed changes to the HSC are included. No future boundary condition simulations were performed in this study.

# 2 Plan Alternatives

Documentation of the plan alternatives includes the geometric modifications to the system, defined as "project," as well as the input conditions for the "present" project year zero (2029). Therefore, there will be four alternatives – present without project (PWOP), present with 650 ft width project (PWP650), present with 700 ft width project (PWP700), and present with 750 ft width project (PWP750). The PWOP and he PWP650 were simulated during the initial project (McAlpin et al. 2019b) but will be presented here with the additional width alternatives for purpose of comparison.

## 2.1 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 initially at 650 ft as requested by SWG. The Bolivar-to-Morgan's Point widening is now being modeled at the two additional channel widths – 700 ft and 750 ft. All other plan features remain unchanged in the project alternative.

**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 | 650/700/750 | | | | |
| Redfish Light 1 to Beacon 76 | 650/700/750 | | | | |
| Beacon 76 to Lower End Morgan's Point Cut | 650/700/750 | | | | |
| Morgan's Point to Exxon | 600 | | Station 153+06<br>Station 246+54 | | |
| Exxon to Carpenter's Bayou | | | | | |
| Carpenter's Bayou to Boggy Bayou | 530 | | | Station 520+00<br>41.5 | |
| Bayport Ship Channel | 455 | | Flare | | RoRo<br>46.5 |
| Barbours Cut Ship Channel | 455 | | Flare | | |
| Boggy Bayou to Greens Bayou | 530 | 46.5<br>+2 AM +1 AO | | | Station 775+00<br>46.5 |
| Greens Bayou to Sims Bayou | | 46.5<br>+2 AM +1 AO | | | Hunting<br>46.5 |
| Sims Bayou to I-610 Bridge | | 41.5<br>+2 AM +1 AO | | | |
| I-610 Bridge to End Main Turning Basin | | 41.5<br>+2 AM +1 AO | | | Brady 900<br>46.5 |

Figure 3. TSP location map.

## 2.2 Input conditions

Although most USACE design projects require a 50-year project life span, the modeling of these additional HSC channel widths will only be simulated at the year zero (2029) condition. For this project, the 2010 validation year was determined suitable by SWG as a base or starting point for the year zero (present, 2029) model inputs. The 2010 sea level was adjusted to account for sea level change to arrive at the 2029 sea level values. All other forcings were equivalent to 2010. (For details of the 2010 model boundary conditions, see McAlpin et al. [2019a]). 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 in the spin-up and analysis years.

### 2.2.1 Sea level rise

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 sea level rise at year zero (2029), guidance defined in USACE Engineering Circular 1165-2-212, *Sea-Level Change Considerations for Civil Works Programs*, was used. The 2010 data for the model validation were adjusted to 2017 utilizing the low sea level rise curve to obtain present conditions. The intermediate sea level rise 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, present, model scenario. The elevation shift was constant over the length of the model boundary and the time of the model simulation for each year.

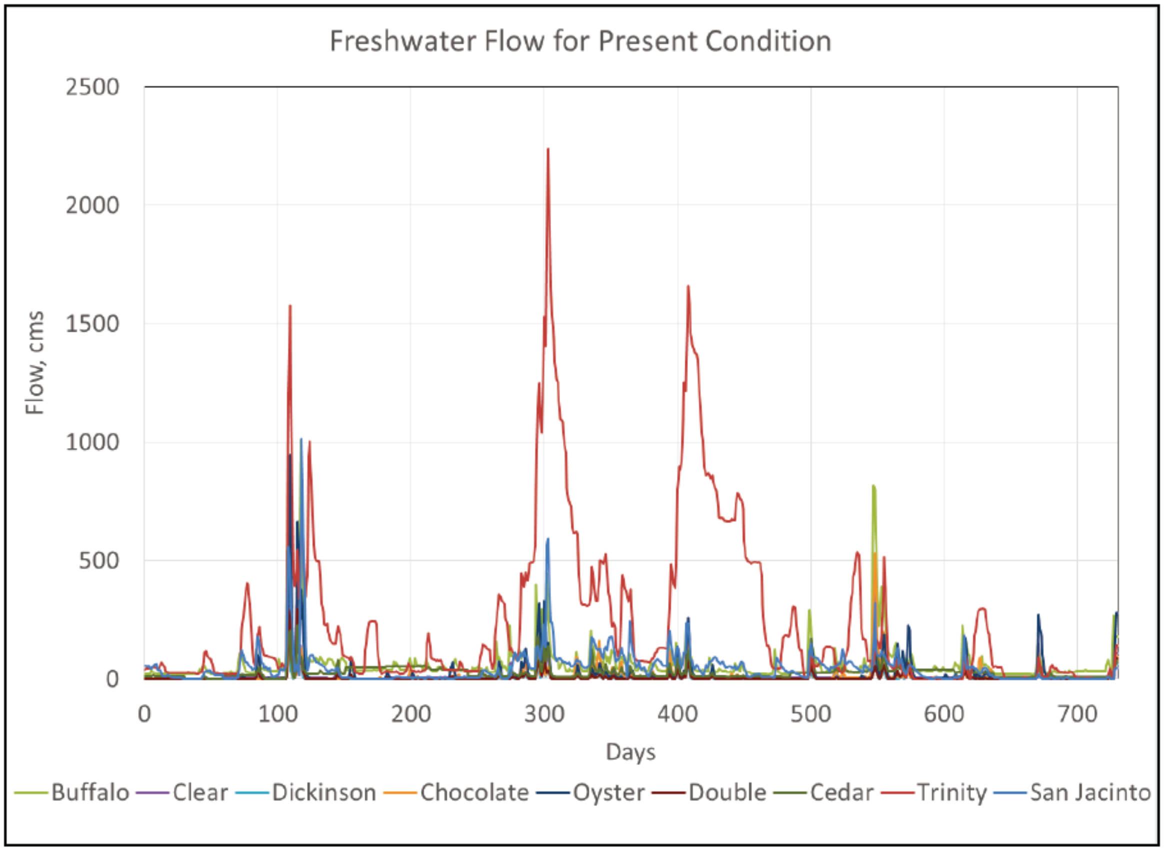
**Table 2. Sea level rise adjustment for model tidal boundary conditions.**

| Adjustment Period | Sea Level Rise Curve | Elevation Shift |
|---|---|---|
| 2010 to 2017 | Low | 0.148 ft (0.045 m) |
| 2017 to 2029 | Intermediate | 0.322 ft (0.098 m) |

### 2.2.2 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). For the 2029 spin-up and 2029 (present) conditions simulations, 2009 (spin-up year) and 2010 (analysis year) inflows are used for all freshwater inflow locations. Figure 4 shows the year 2029 (2009/2010) inflows.

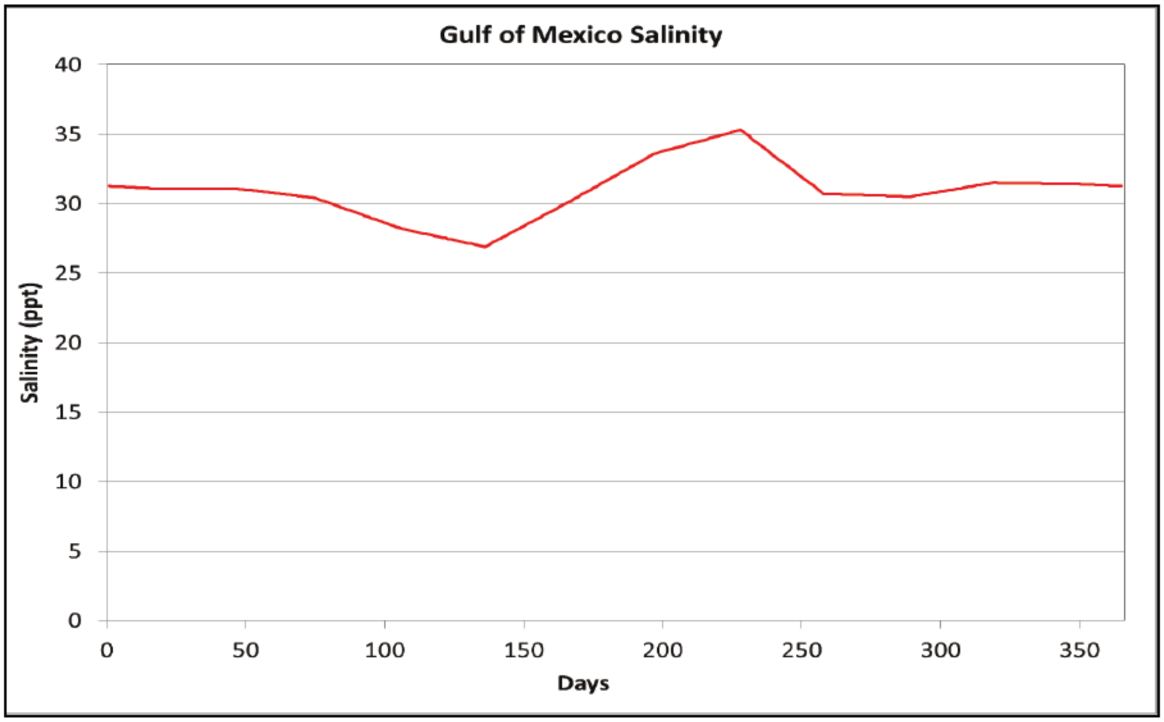
**Figure 4. Year 2029 (present) freshwater inflows (first 365 days were spin up and remaining 365 days were 2029 inflows).**



### 2.2.3 Salinity

The salinity input at the model's ocean boundary is unchanged from the model validation and shown in Figure 5 (McAlpin et al. 2019a). 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.

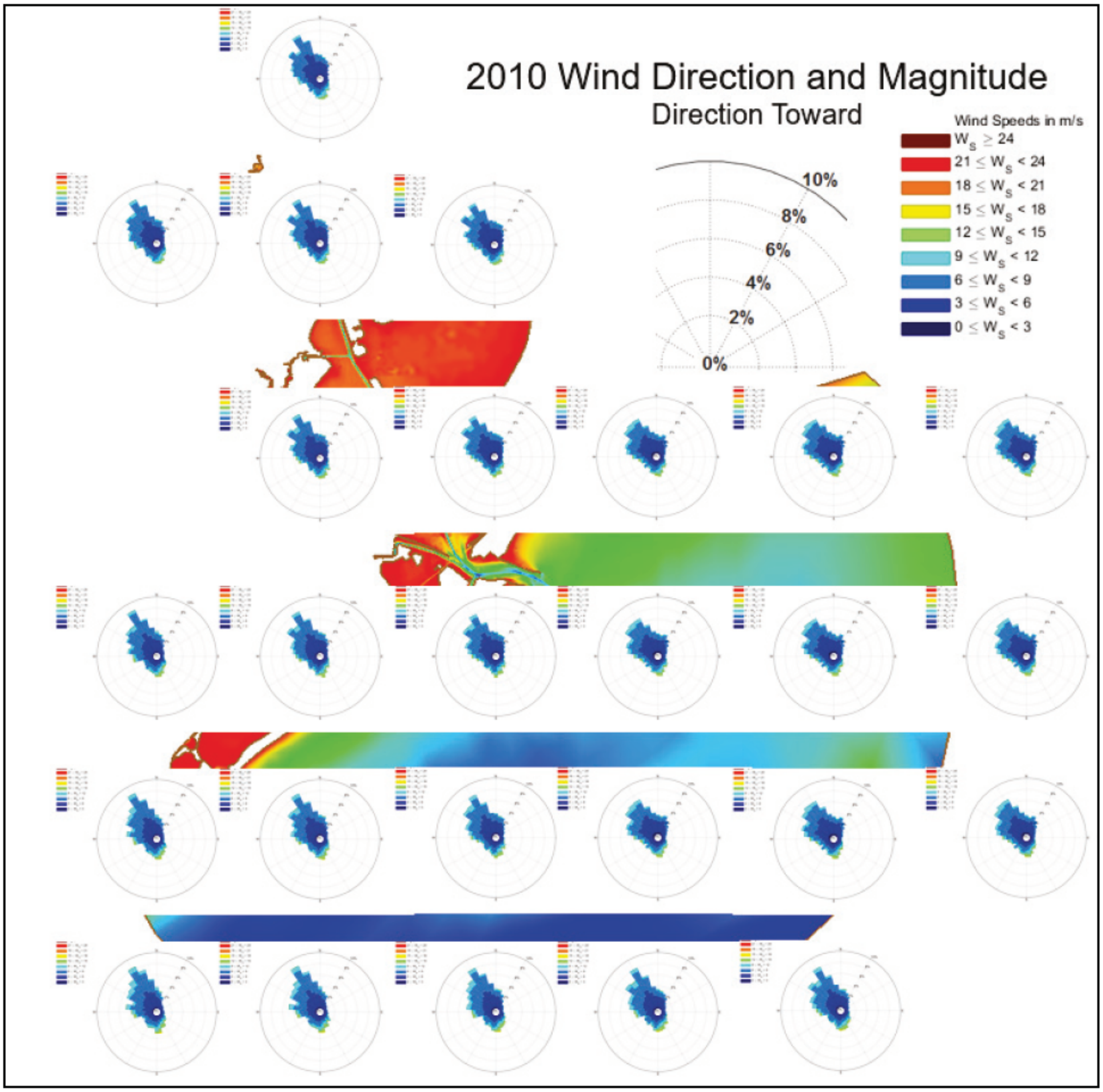
Figure 5. Salinity boundary condition for present condition.



### 2.2.4 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 et al. 2019a). This wind data set was unchanged and repeated for the spin-up and analysis years. Figure 6 shows the 2010 wind rose for all 26 computed wind series locations.

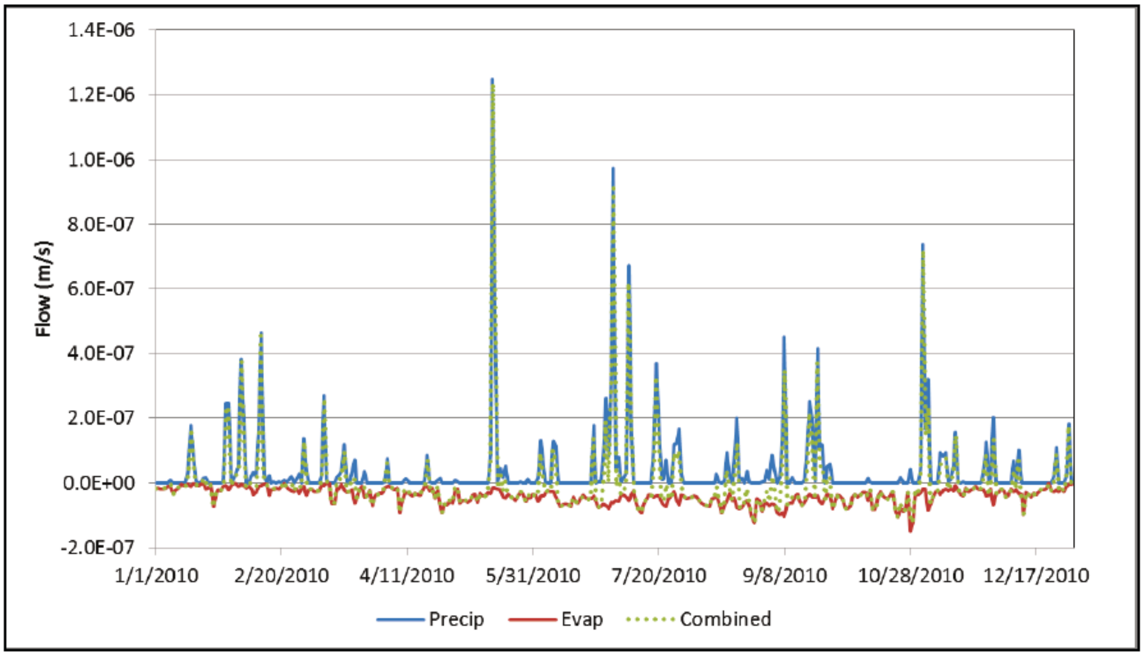
Figure 6. 2010 wind rose at all sites for 2029 (present) condition.



### 2.2.5 Meteorological conditions

Precipitation and evaporation were included in the model validation and alternative conditions simulations (McAlpin et al. 2019a). 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. Figure 7 shows the time series of the meteorological data.

Figure 7. 2010 meteorological conditions for 2029 (present) condition.



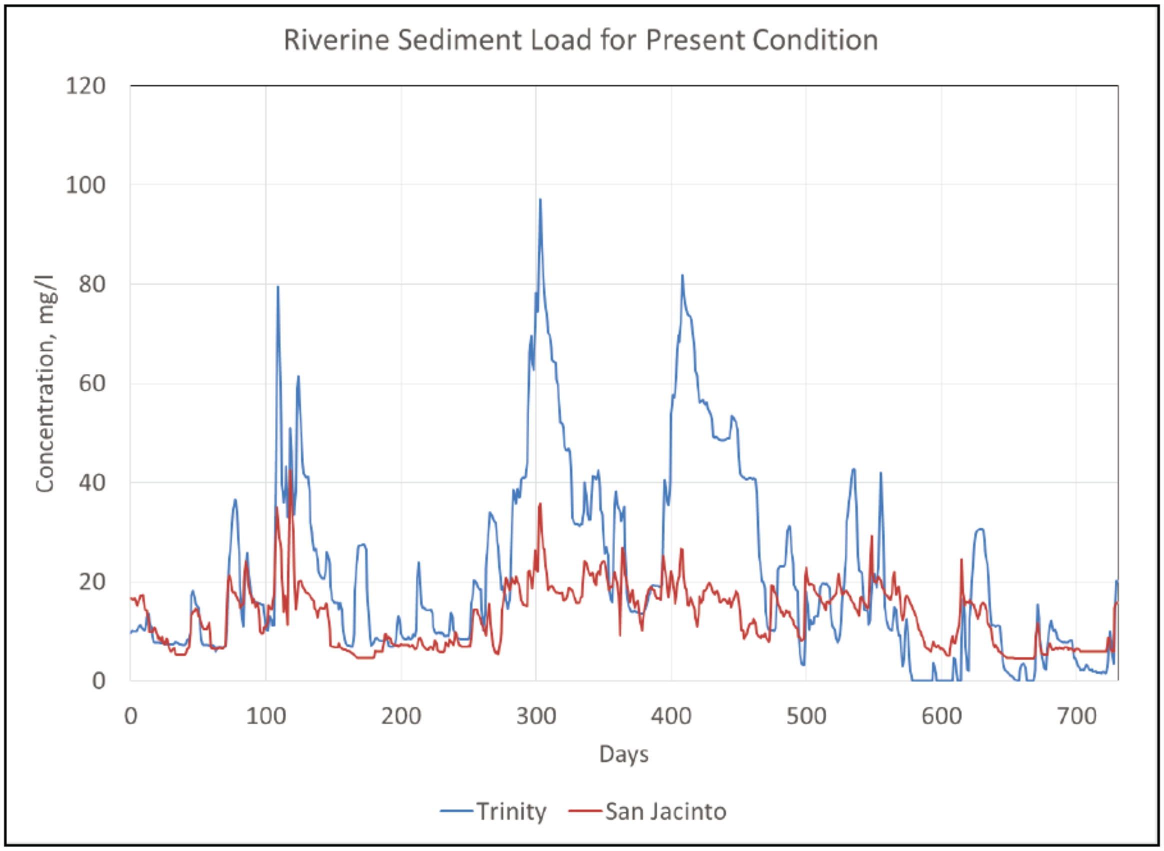

### 2.2.6 Sediment

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

Figure 8 shows the 2029 sediment loads, which are based on 2009 (2029 spin up) and 2010 (2029 simulations) 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 similar to the model validation.

The model validation (McAlpin et al. 2019a) 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 8. Year 2029 (present) total sediment load (first 365 days were spin up and remaining 365 days were 2029 sediment concentrations).**



# 3 Model Results and Discussion

The four alternatives – PWOP, PWP650, PWP700, and PWP750 – were simulated using 3D AdH as stated in the previous chapters. Present is considered the projected project completion in year 2029. No future condition beyond 2029 was simulated. 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 analyzed from the model results.

## 3.1 Salinity

### 3.1.1 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 by the points in Figure 9 and labeled in Table 3. A subset of these locations, circled in red in Figure 9 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 9. Point analysis locations. Circled locations discussed in this section.

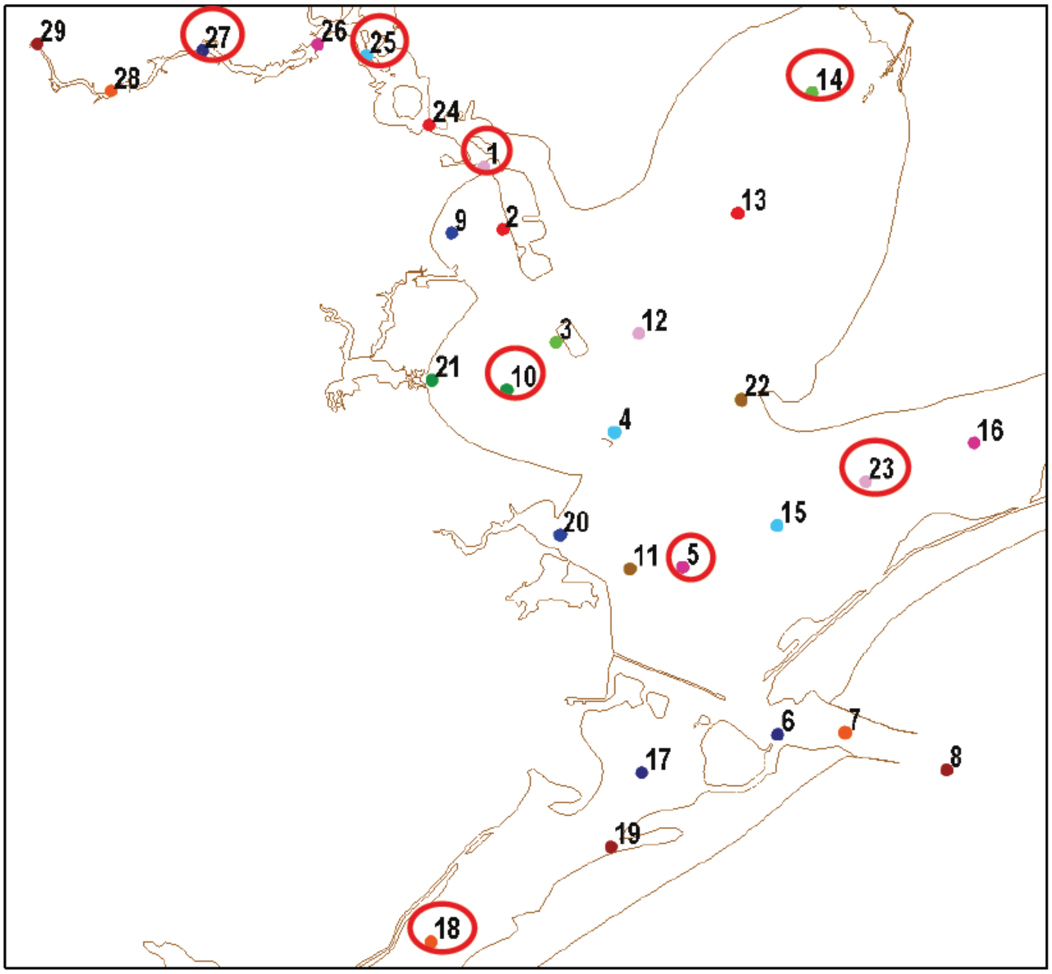



Table 3. Point analysis location names. Highlighted locations discussed in this section.

| Point # | Name | Point # | Name |
|---|---|---|---|
| 1 | HSC at Morgan's Point | 16 | Eastern East Bay |
| 2 | HSC at Atkinson Island | 17 | Eastern West Bay |
| 3 | HSC at Mid Bay Marsh | 18 | Mid West Bay |
| 4 | HSC at Red Fish Reef | 19 | Offatts Bayou |
| 5 | HSC at Lower Galveston Bay | 20 | Dickinson |
| 6 | HSC at Bolivar Roads | 21 | Clear Creek |
| 7 | HSC at Entrance | 22 | Smith Point |
| 8 | HSC at Gulf | 23 | Mid East Bay |
| 9 | Upper Galveston Bay 1 | 24 | HSC at Fred Hartman Bridge |
| 10 | Upper Galveston Bay 2 | 25 | HSC at Goat Island |
| 11 | Lower Galveston Bay | 26 | HSC at Carpenters Bayou |
| 12 | Lower Trinity Bay | 27 | HSC at Greens Bayou |

| | | | |
|---|---|---|---|
| 13 | Mid Trinity Bay | 28 | HSC at Sims Bayou |
| 14 | Upper Trinity Bay | 29 | HSC at Turning Basin |
| 15 | Western East Bay | | |

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 are 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, PWOP is blue, PWP650 is red, PWP700 is yellow, and PWP750 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 the salinity analysis points. Figure 10 through Figure 41 show the point salinity analysis (bottom) at the eight selected locations. The results (surface and bottom) for all 29 locations are provided in the appendix.

The variation in salinity between with and without project alternatives is quite small for most locations – generally less than 2 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.

Figure 10. Bottom salinity time history at HSC at Greens Bayou (Point 27).

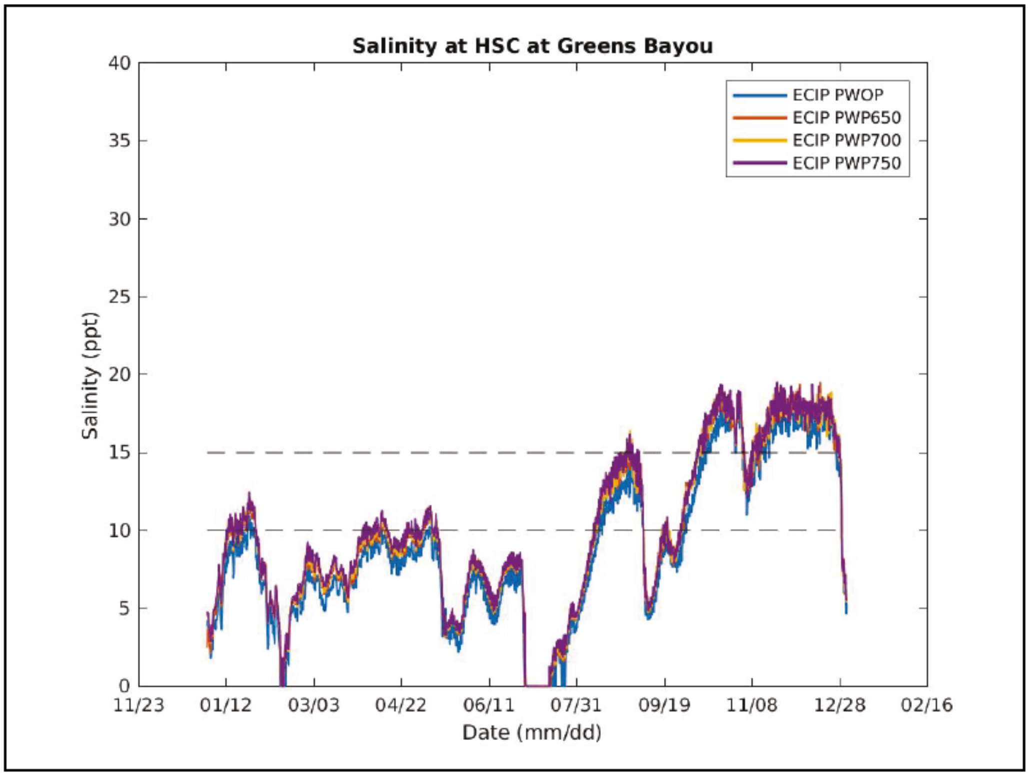



Figure 11. Maximum, minimum, and mean salinity at HSC at Greens Bayou (Point 27).

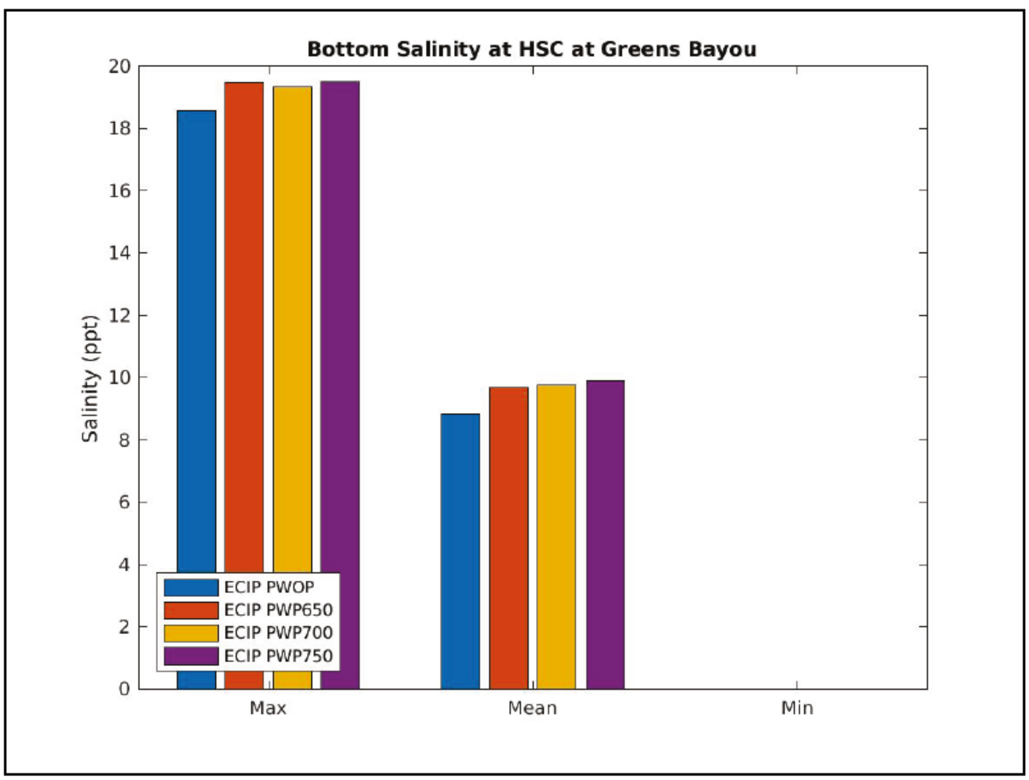


Figure 12. Percent less than salinity at HSC at Greens Bayou (Point 27).

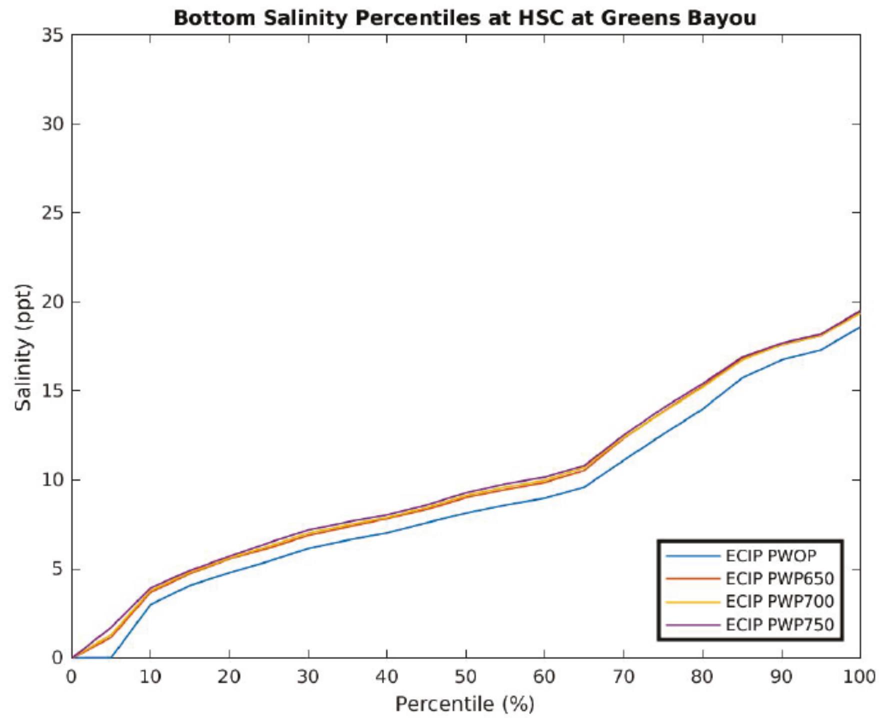



Figure 13. Vertical salinity profile at HSC at Greens Bayou (Point 27).

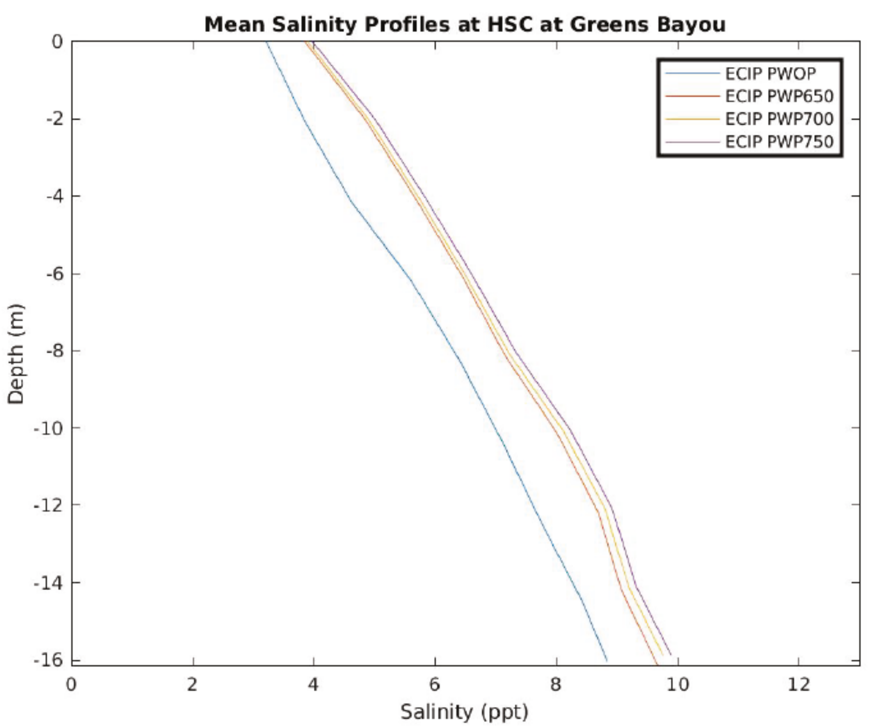


Figure 14. Bottom salinity time history at HSC at Goat Island (Point 25).

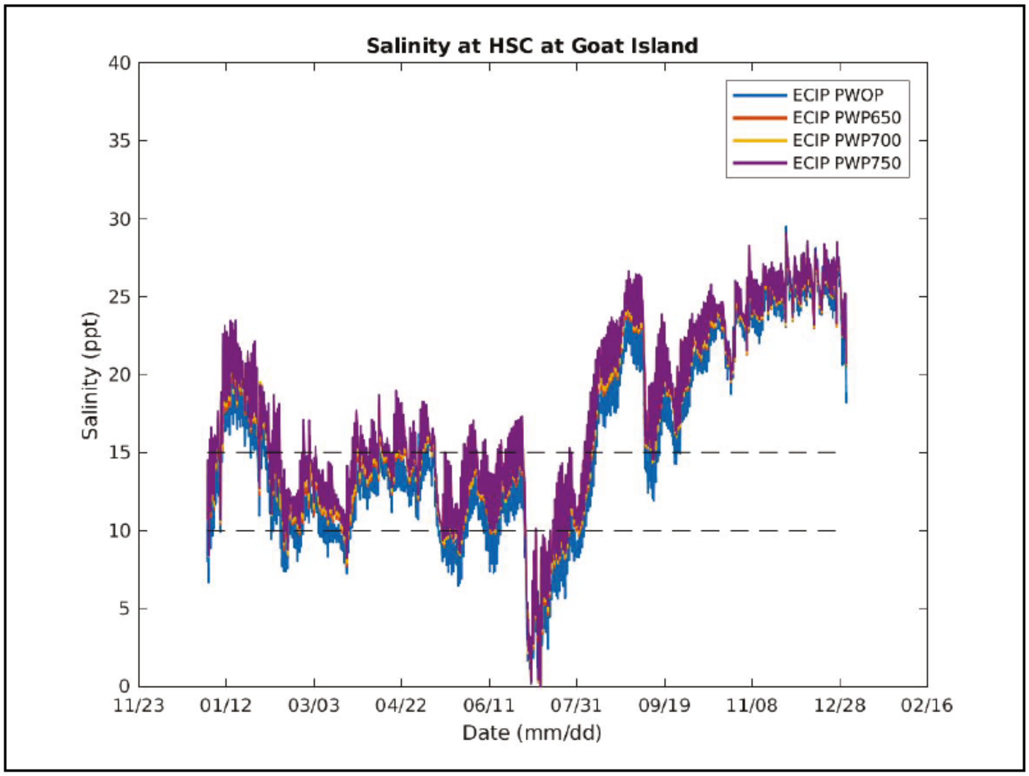



Figure 15. Maximum, minimum, and mean salinity at HSC at Goat Island (Point 25).

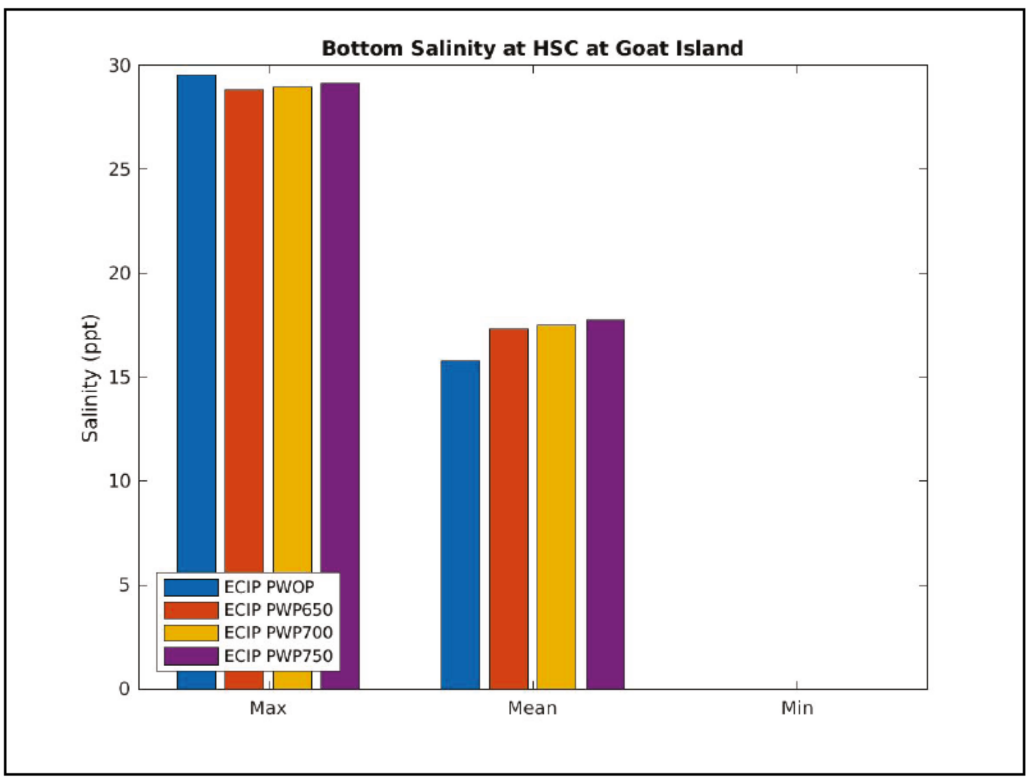


Figure 16. Percent less than salinity at HSC at Goat Island (Point 25).

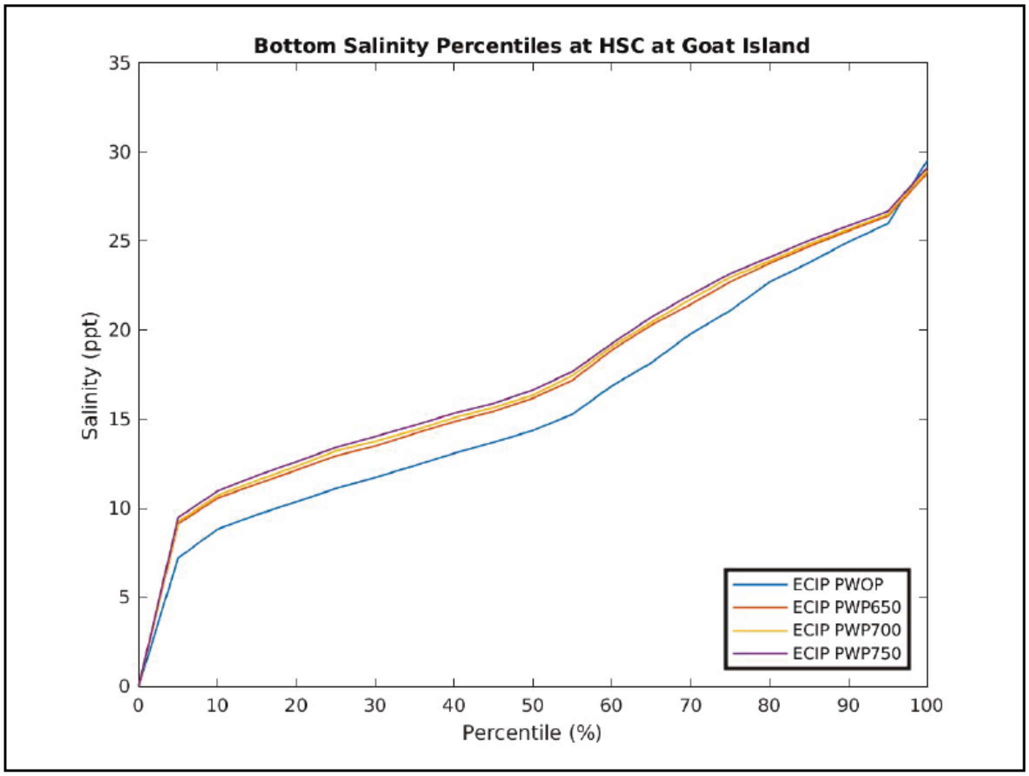



Figure 17. Vertical salinity profile at HSC at Goat Island (Point 25).

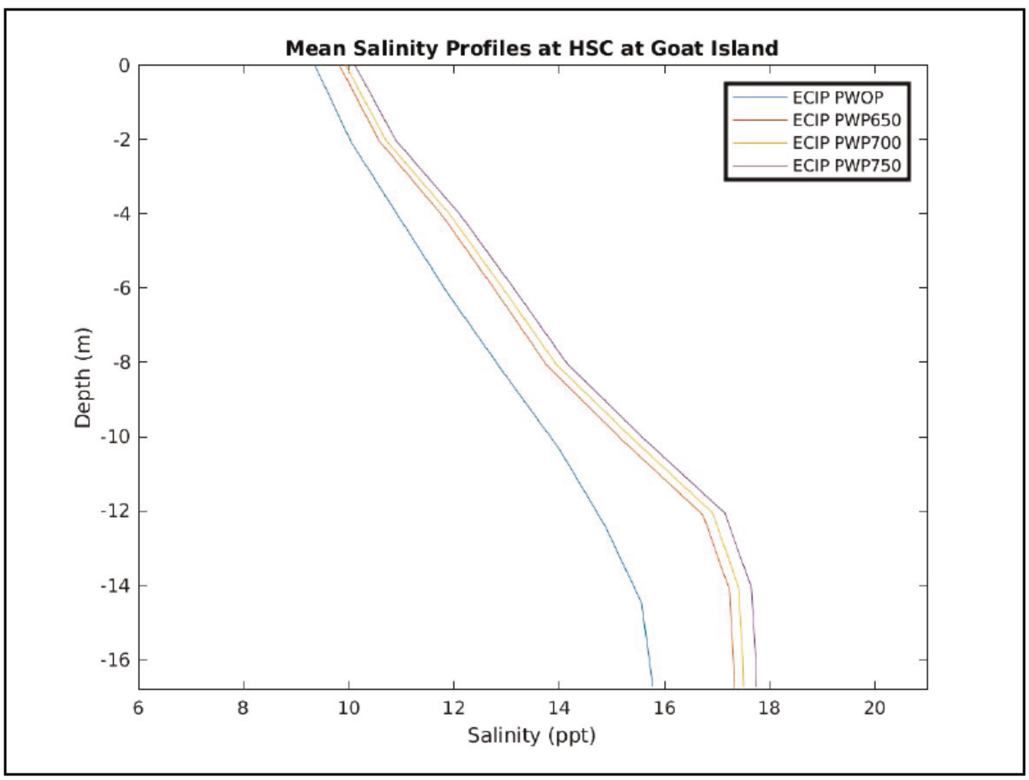


Figure 18. Bottom salinity time history at HSC at Morgan's Point (Point 1).

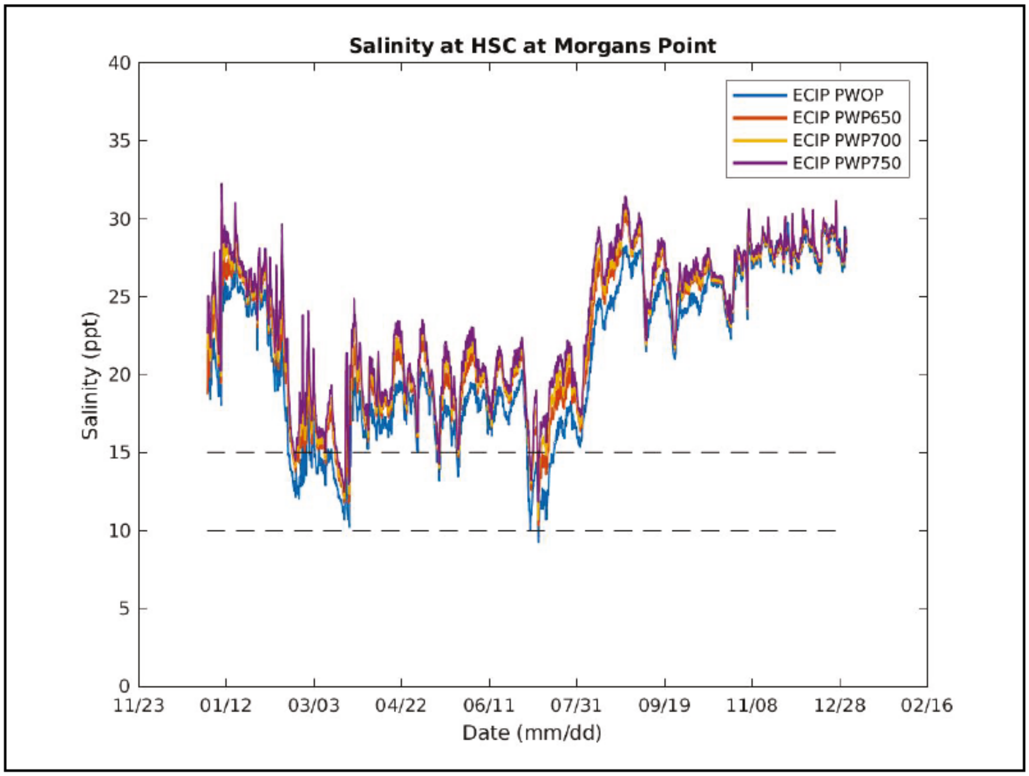



Figure 19. Maximum, minimum, and mean salinity at HSC at Morgan's Point (Point 1).

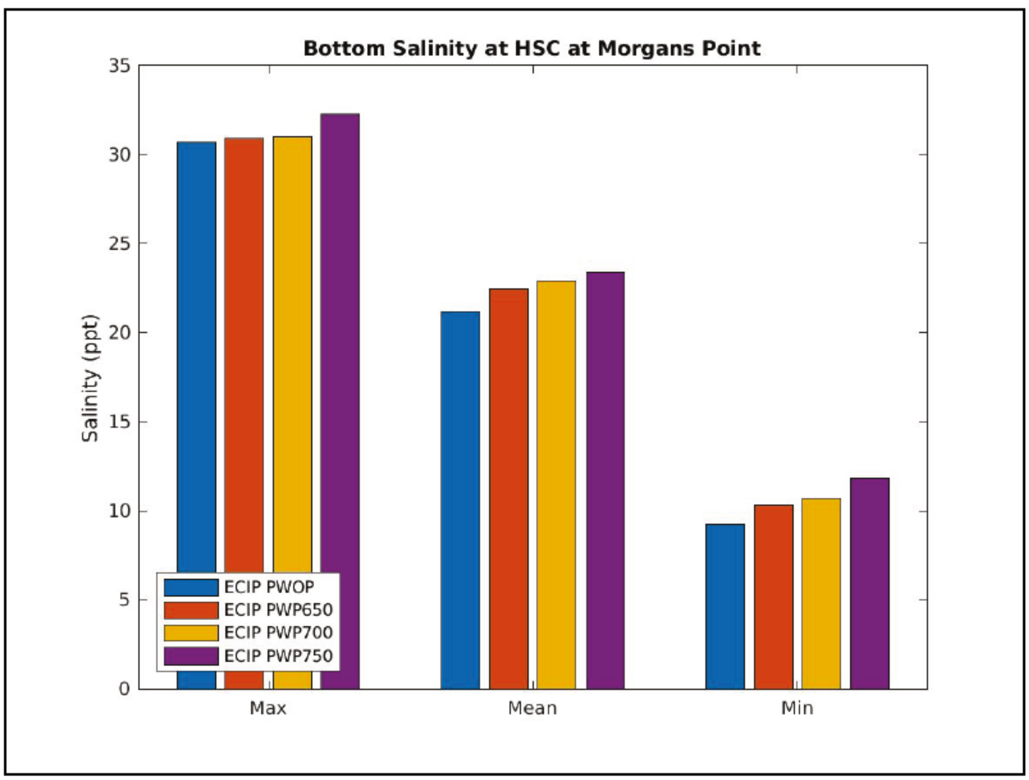


Figure 20. Percent less than salinity at HSC at Morgan's Point (Point 1).

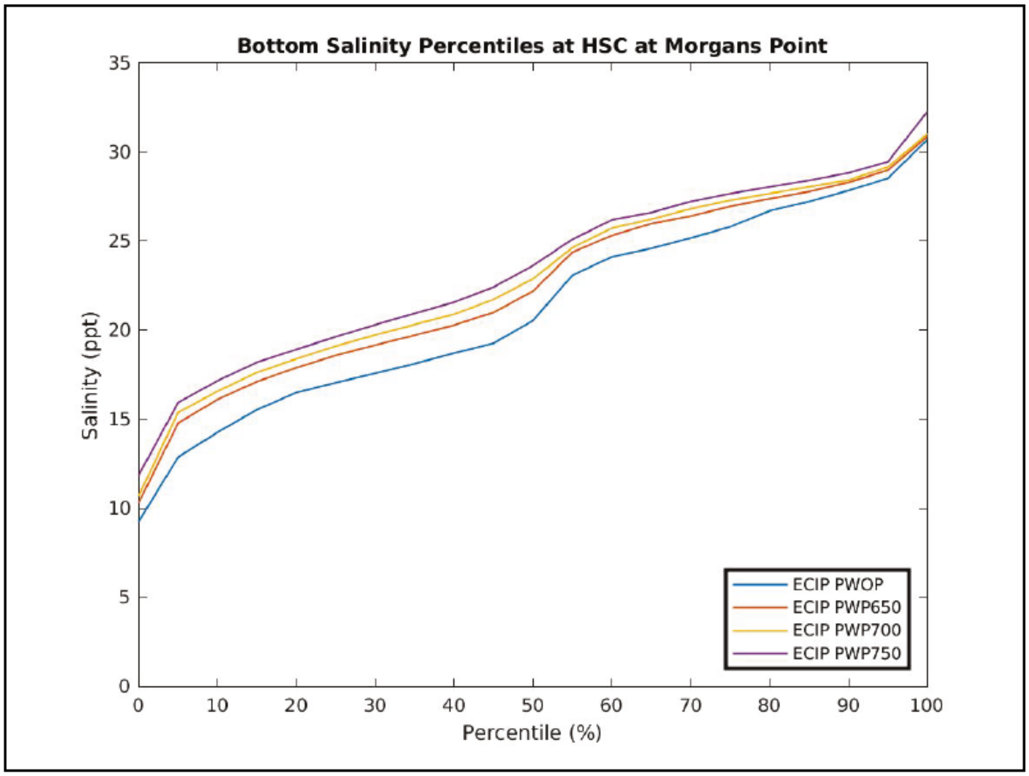



Figure 21. Vertical salinity profile at HSC at Morgan's Point (Point 1).

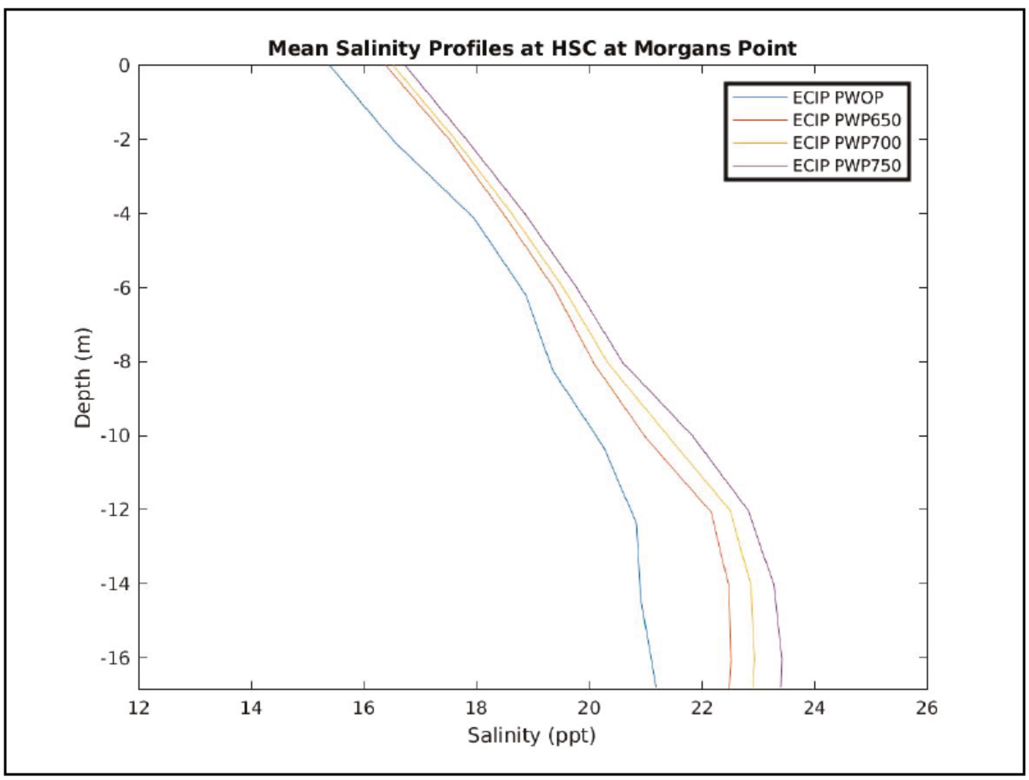


Figure 22. Bottom salinity time history at HSC at Lower Galveston Bay (Point 5).

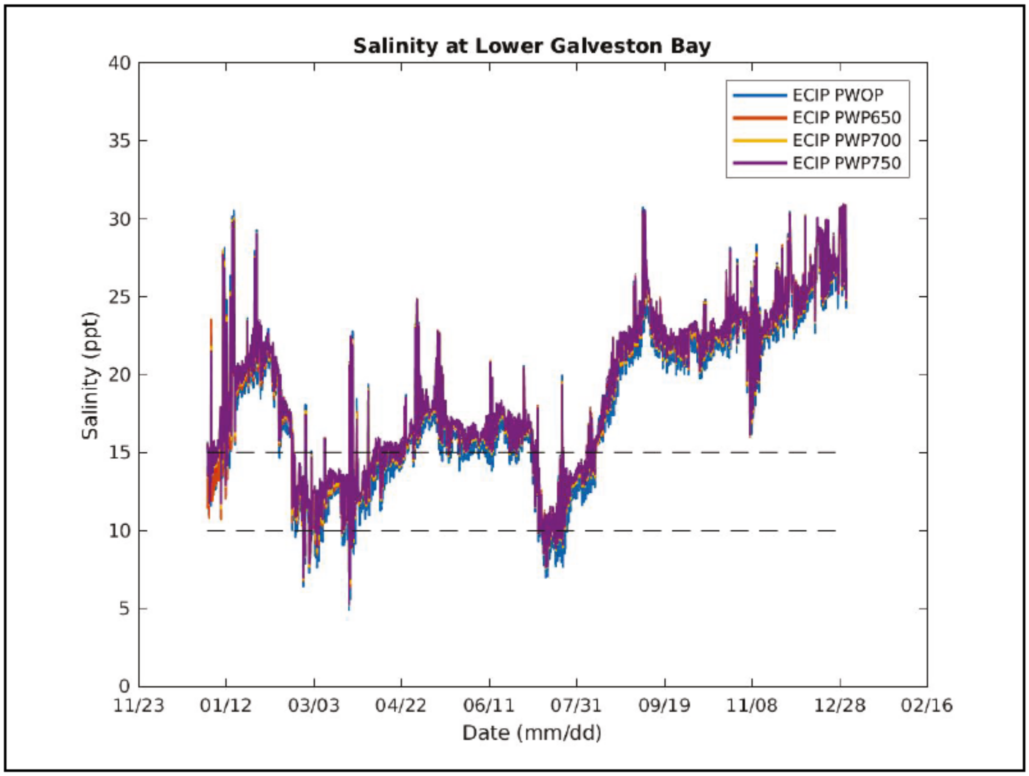



Figure 23. Maximum, minimum, and mean salinity at HSC at Lower Galveston Bay (Point 5).

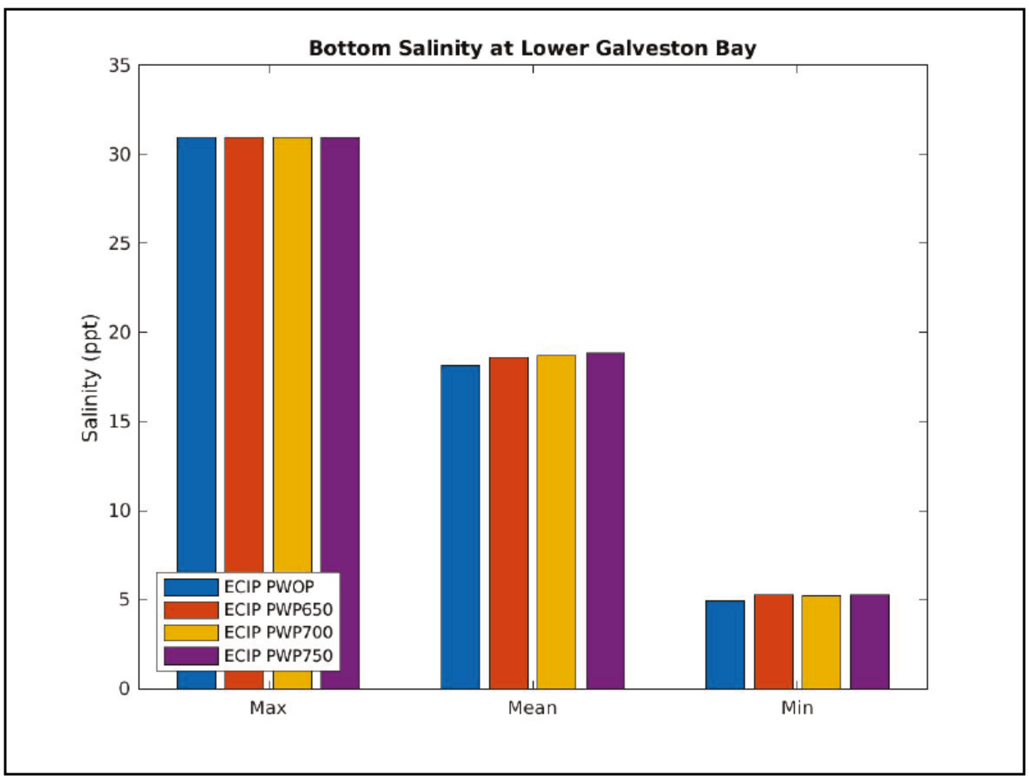


Figure 24. Percent less than salinity at HSC at Lower Galveston Bay (Point 5).

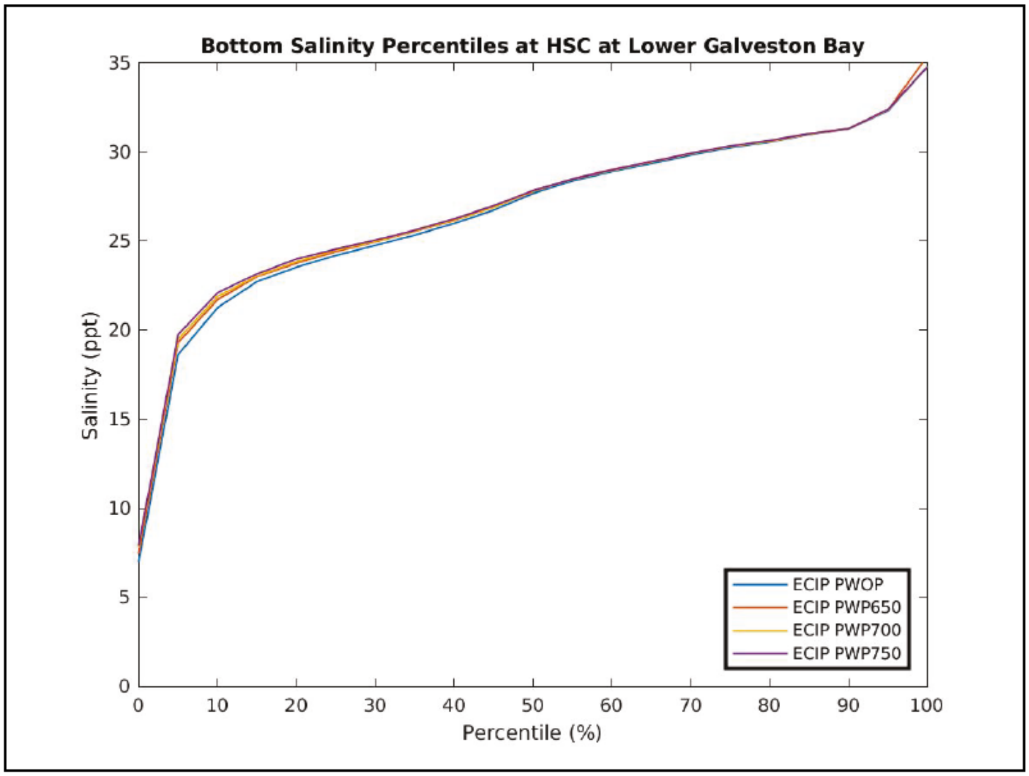



Figure 25. Vertical salinity profile at HSC at Lower Galveston Bay (Point 5).

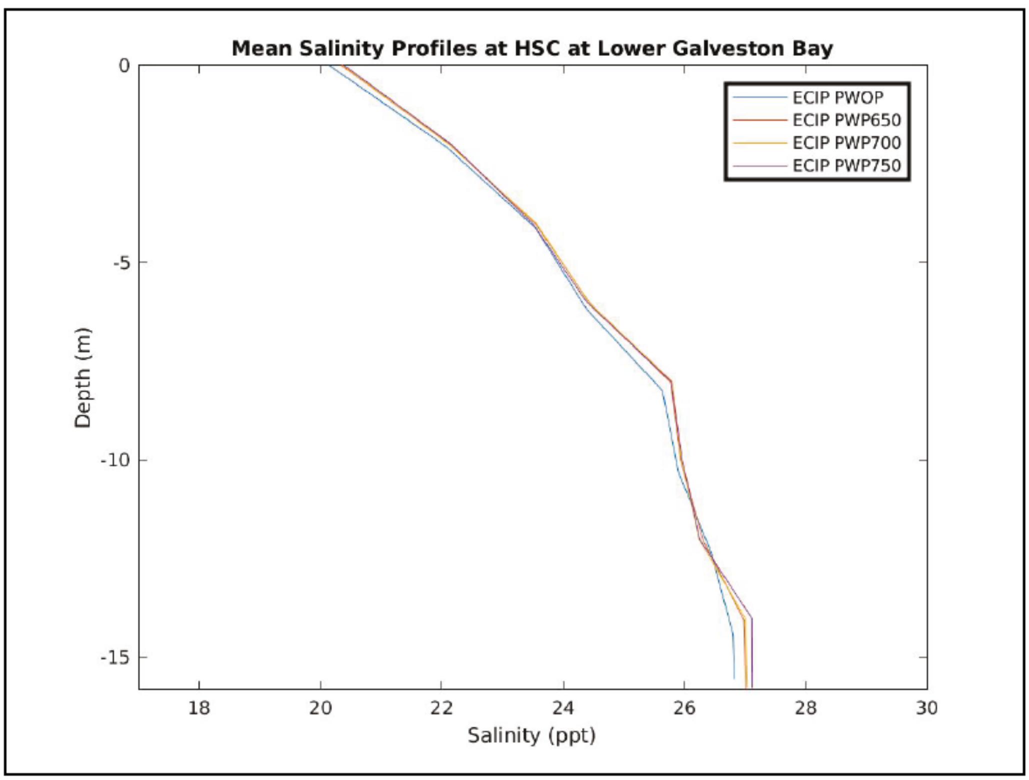


Figure 26. Bottom salinity time history at Upper Galveston Bay 2 (Point 10).

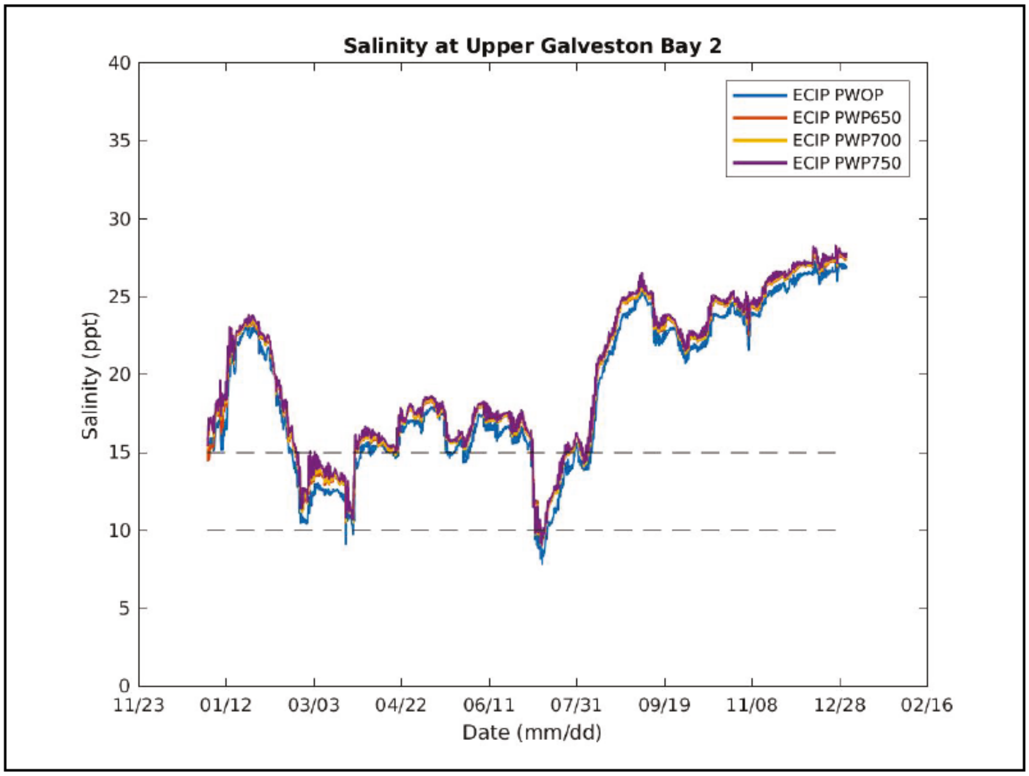



Figure 27. Maximum, minimum, and mean salinity at Upper Galveston Bay 2 (Point 10).

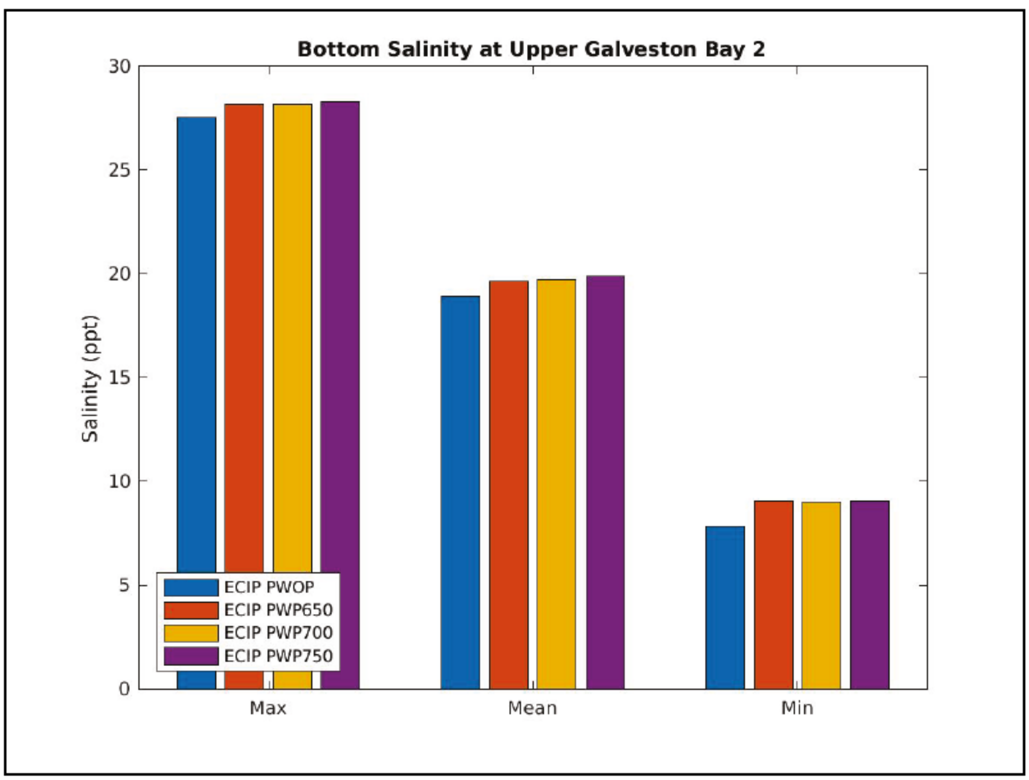


Figure 28. Percent less than salinity at Upper Galveston Bay 2 (Point 10).

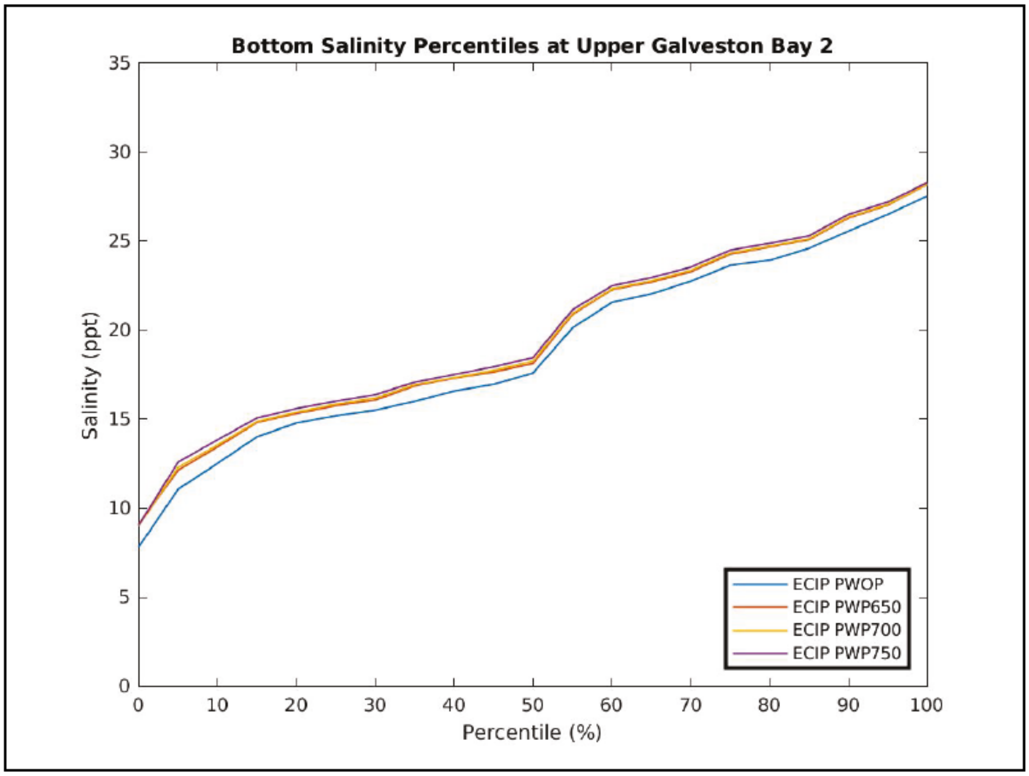



Figure 29. Vertical salinity profile at Upper Galveston Bay 2 (Point 10).

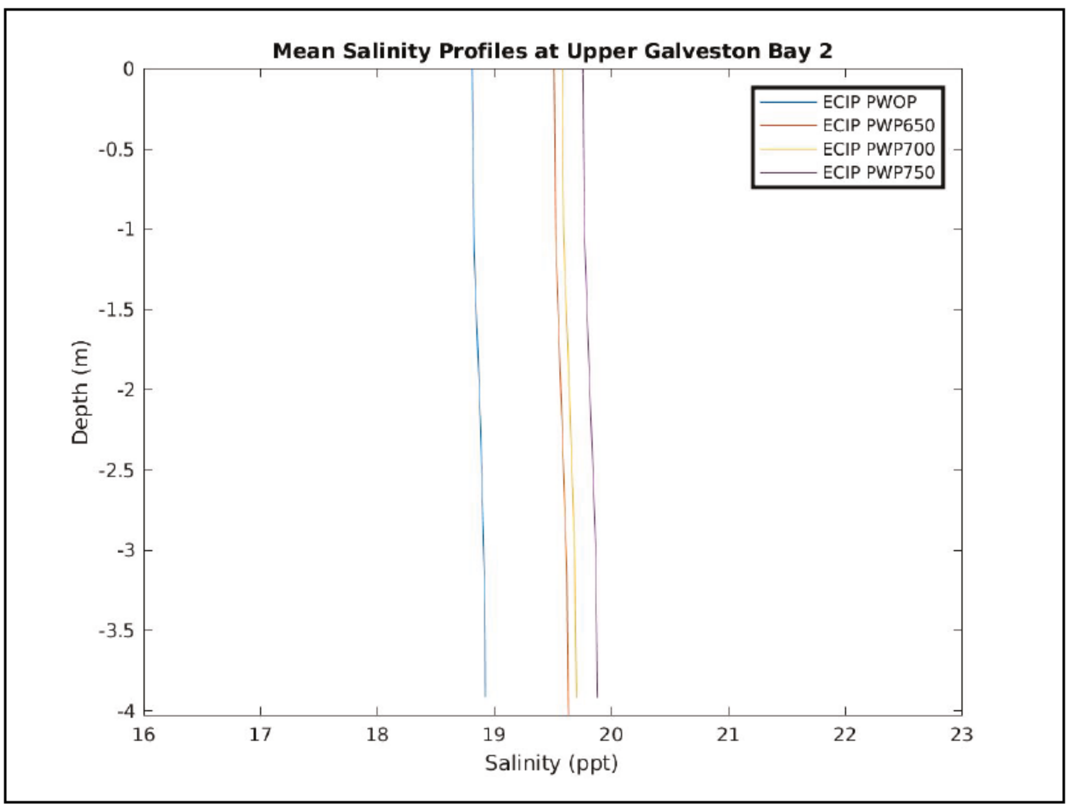


Figure 30. Bottom salinity time history at Upper Trinity Bay (Point 14).

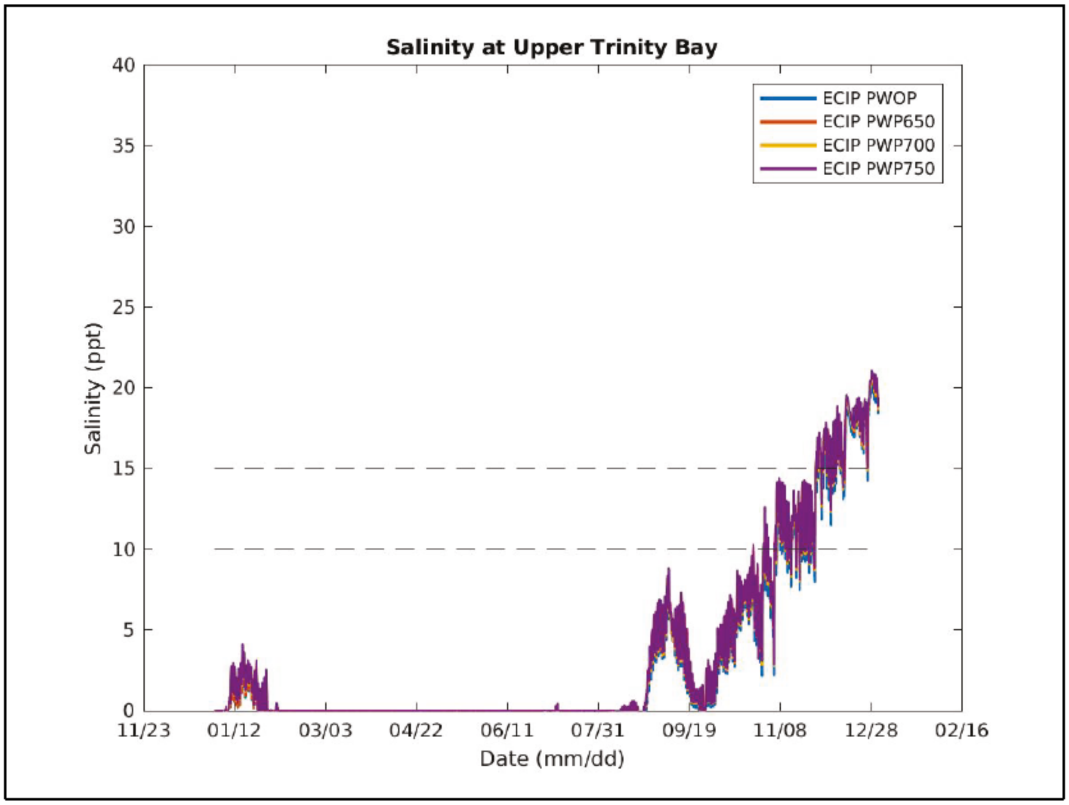



Figure 31. Maximum, minimum, and mean salinity at Upper Trinity Bay (Point 14).

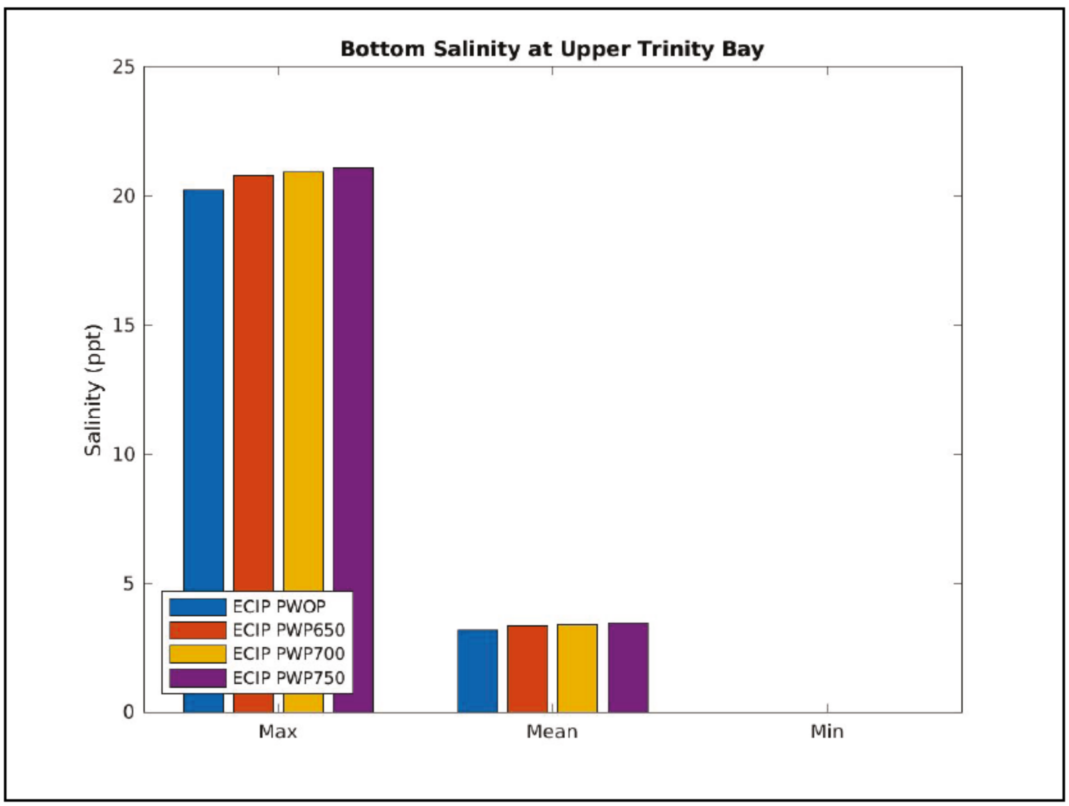


Figure 32. Percent less than salinity at Upper Trinity Bay (Point 14).

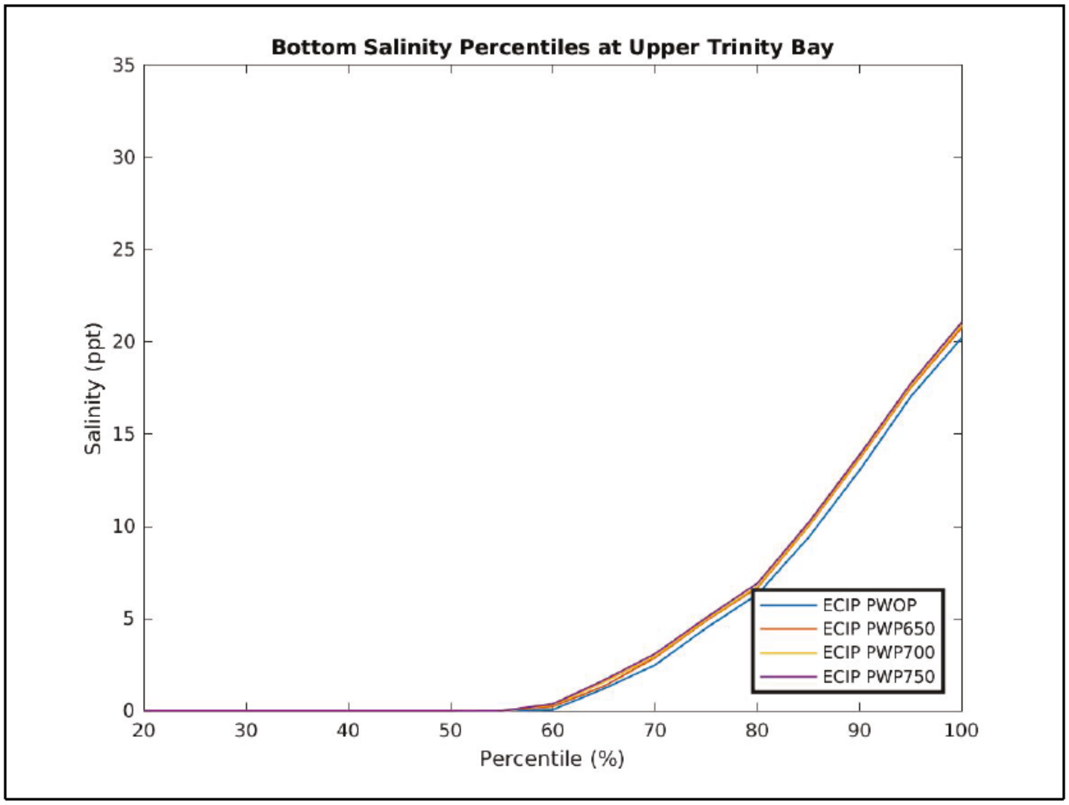



Figure 33. Vertical salinity profile at Upper Trinity Bay (Point 14).

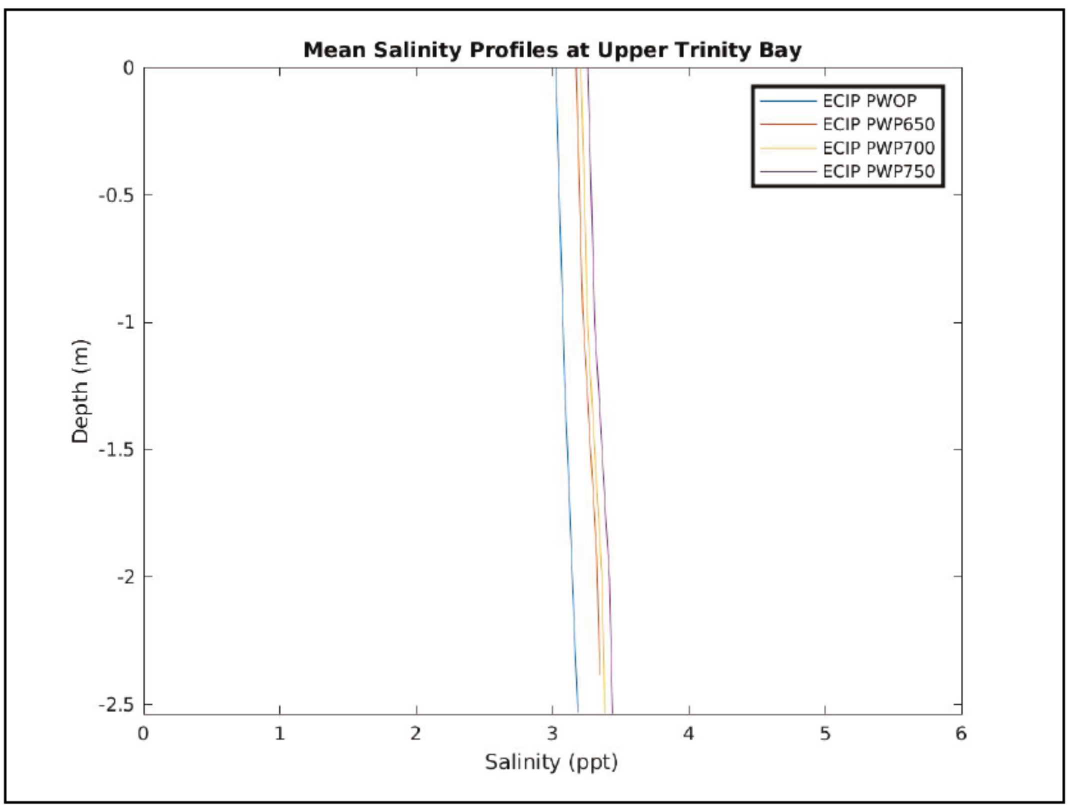


Figure 34. Bottom salinity time history at Mid West Bay (Point 18).

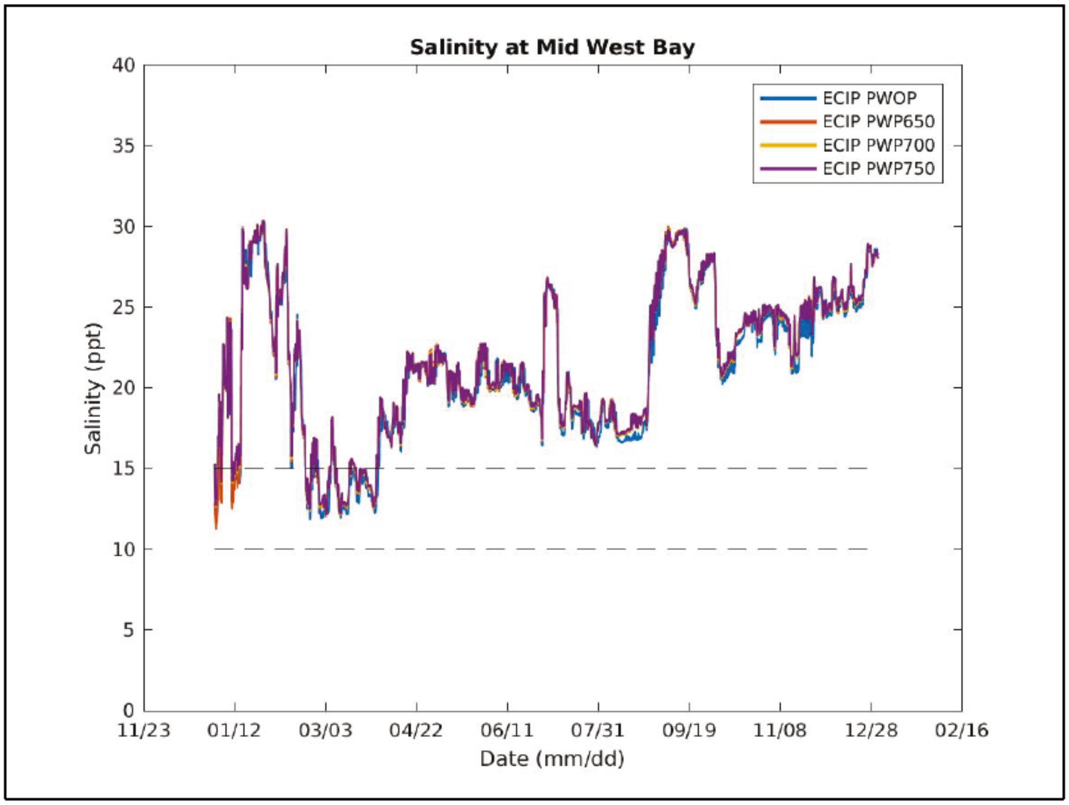



Figure 35. Maximum, minimum, and mean salinity at Mid West Bay (Point 18).

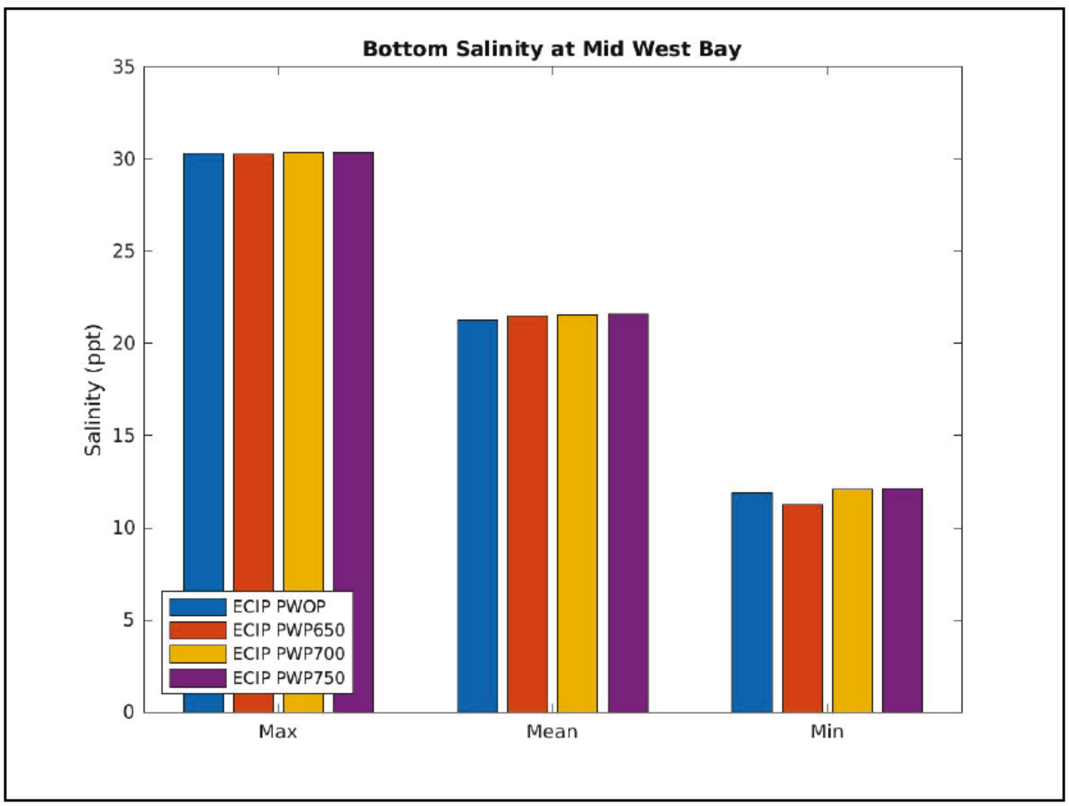


Figure 36. Percent less than salinity at Mid West Bay (Point 18).

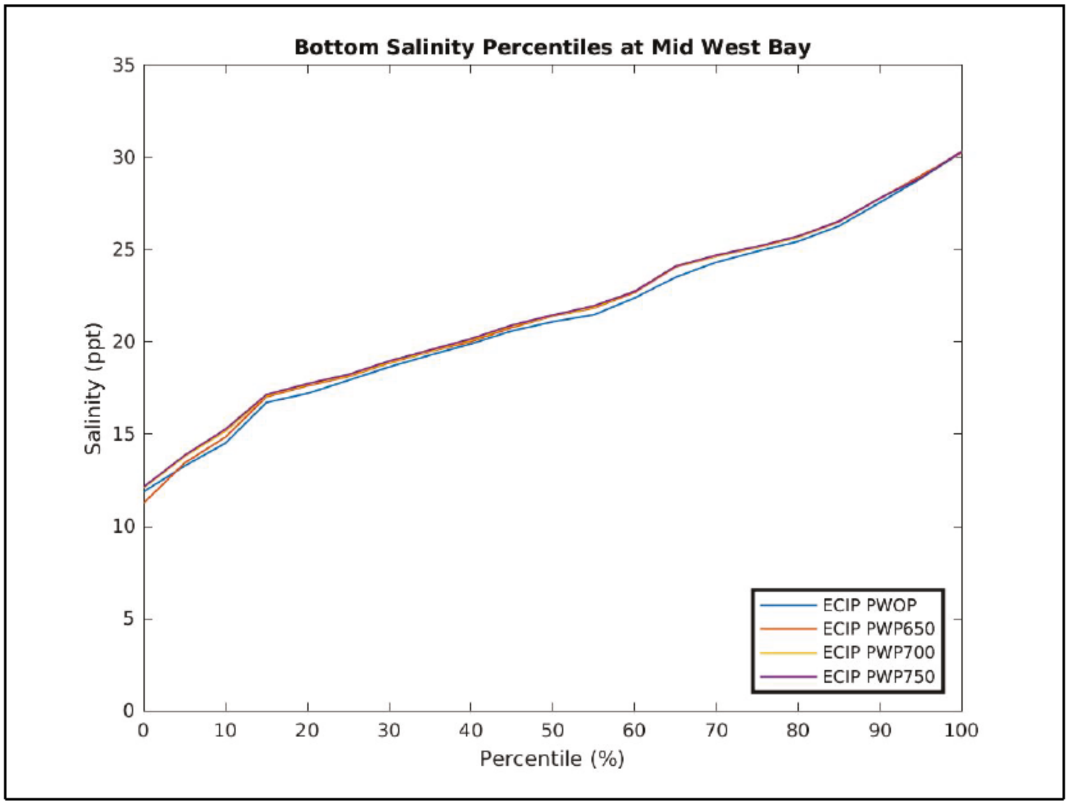



Figure 37. Vertical salinity profile at Mid West Bay (Point 18).

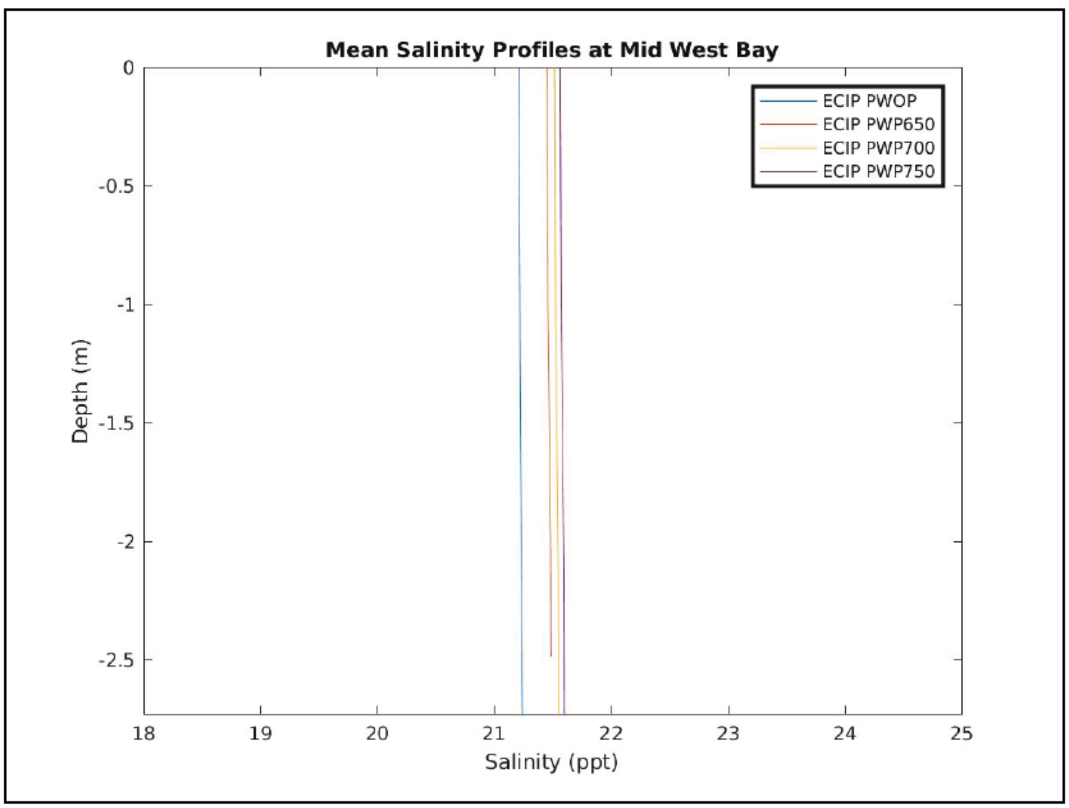


Figure 38. Bottom salinity time history at Mid East Bay (Point 23).

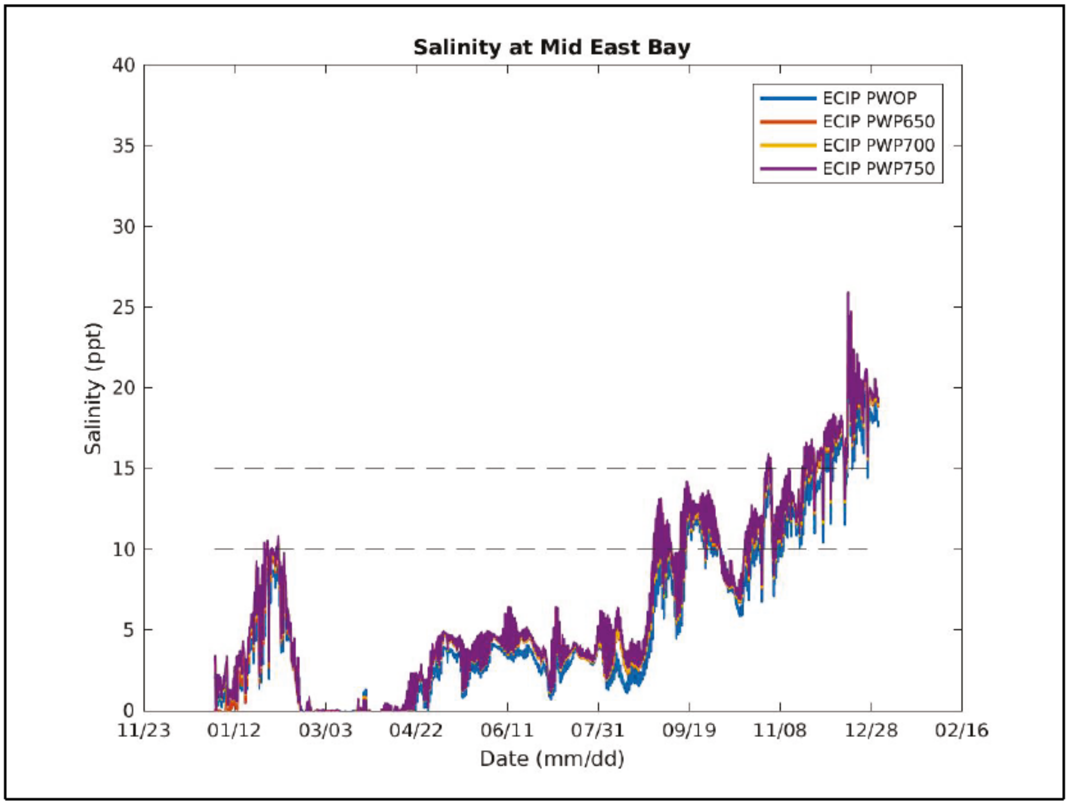



Figure 39. Maximum, minimum, and mean salinity at Mid East Bay (Point 23).

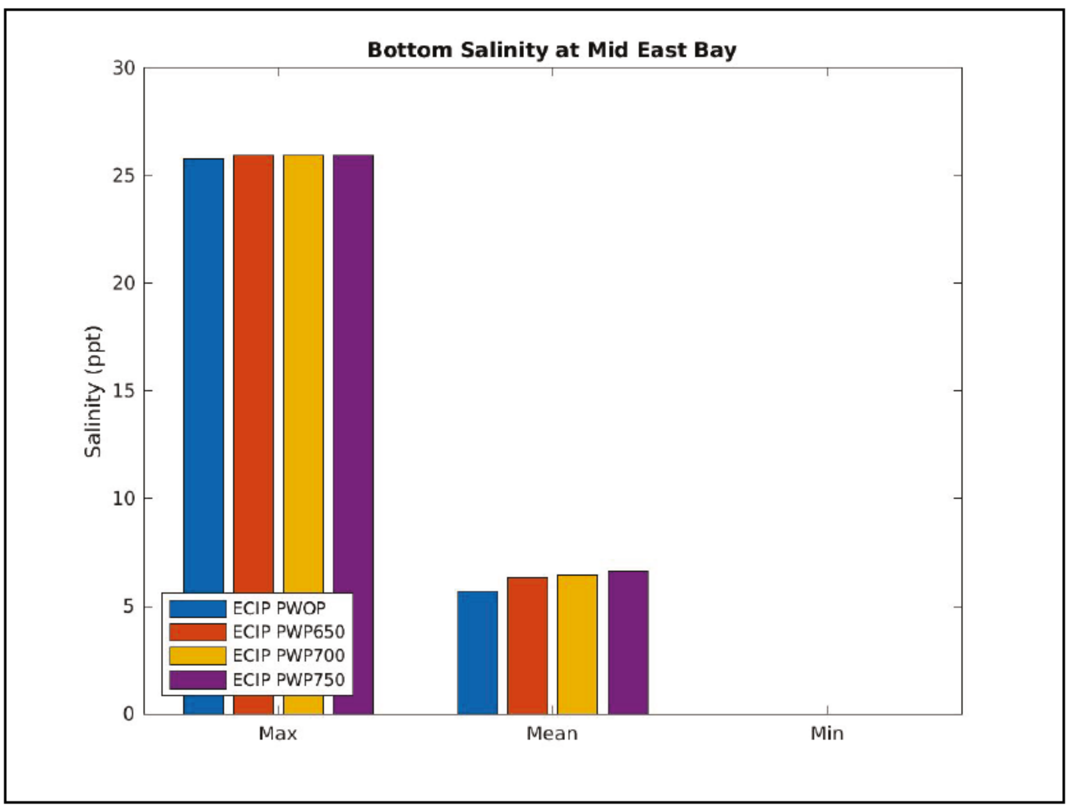


Figure 40. Percent less than salinity at Mid East Bay (Point 23).

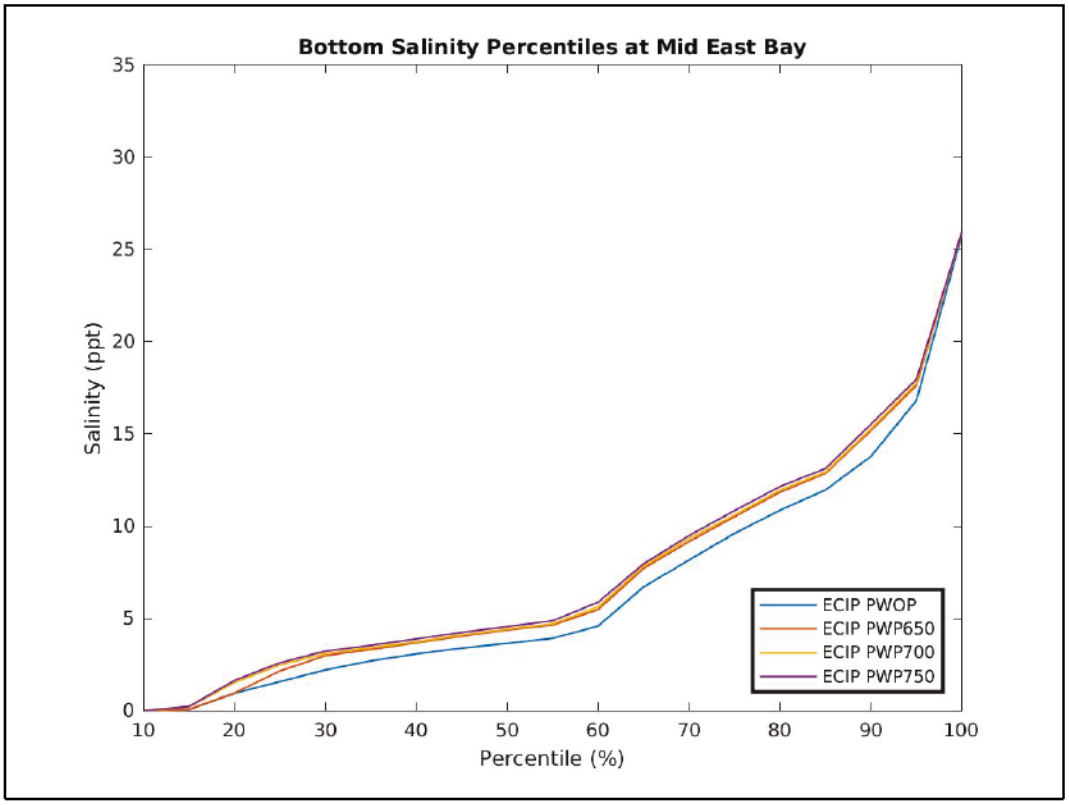
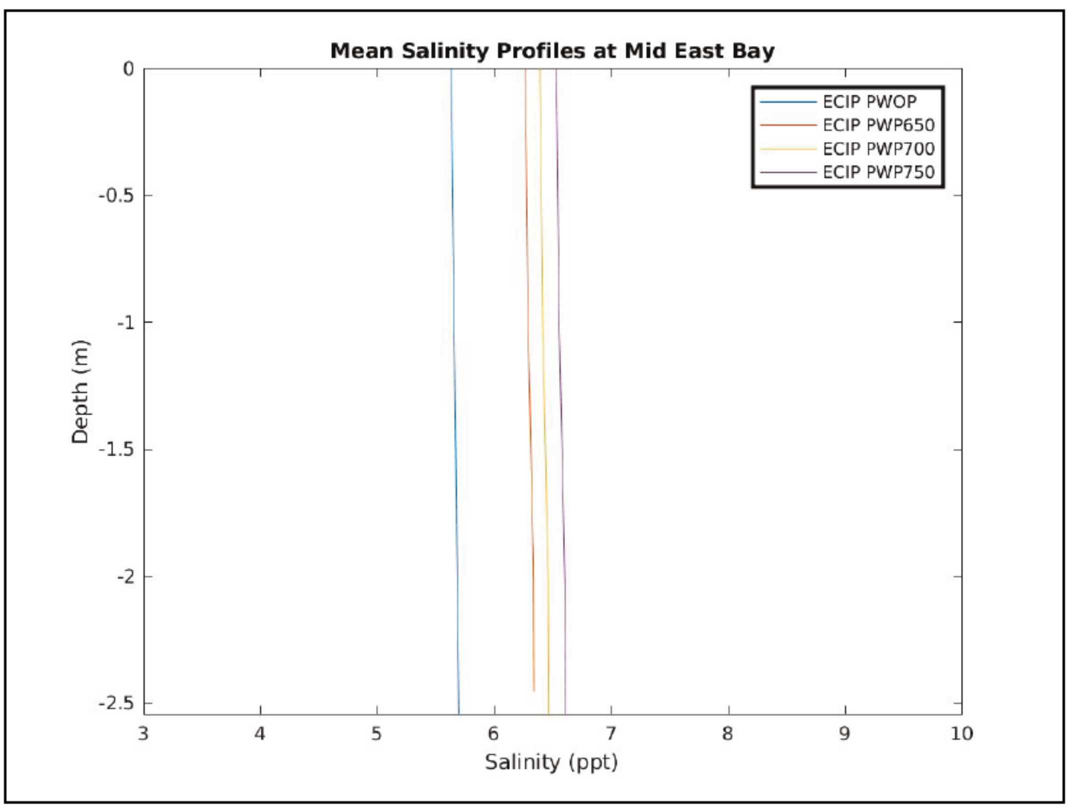



Figure 41. Vertical salinity profile at Mid East Bay (Point 23).



### 3.1.2 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 42 shows the location of these cross sections. Again, a subset of these cross sections – those circled in red in Figure 42 – are provided in the text (Figure 43 through Figure 45) with all locations included in the appendix. All cross-sections are defined looking upstream (i.e., left to right for cross-section 3 and bottom to top for cross-section 10).

Figure 42. HSC cross-sectional analysis locations. Circled locations discussed in this section.

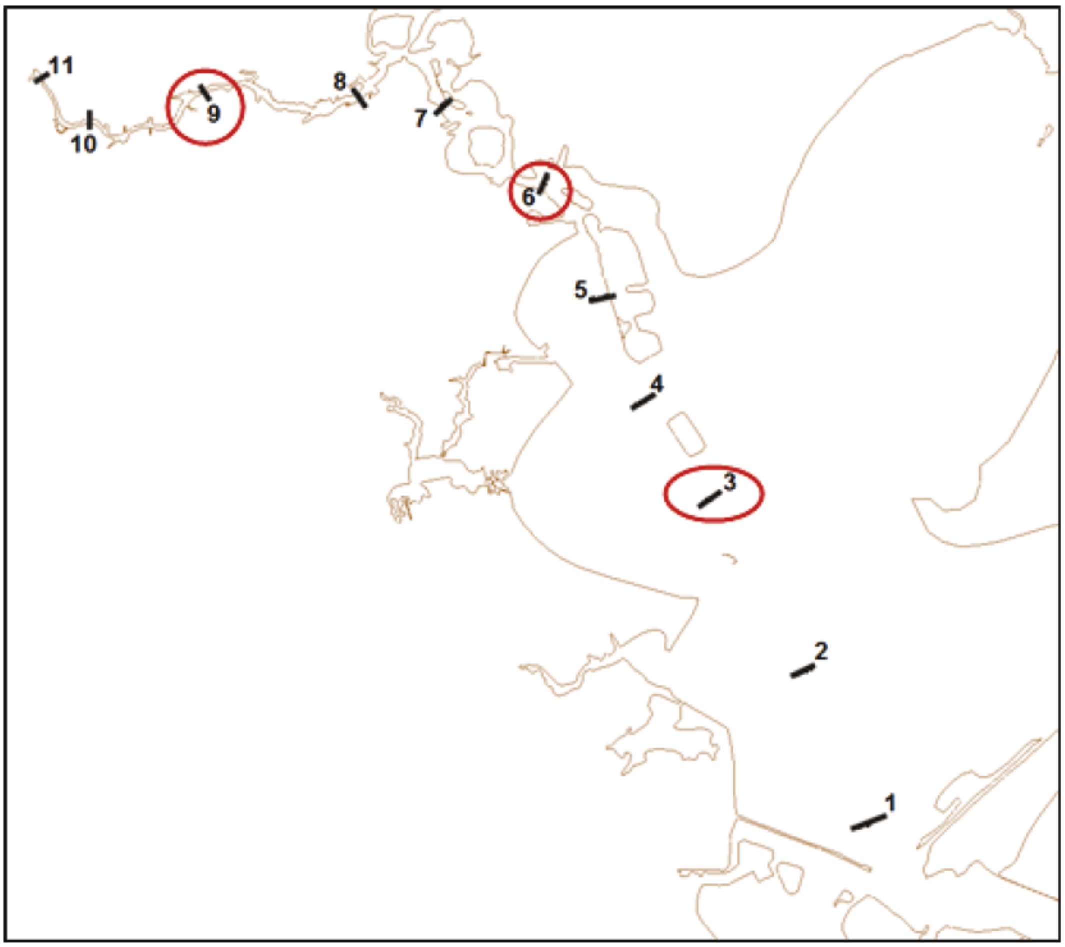


Figure 43. Cross section 3 mean salinity.

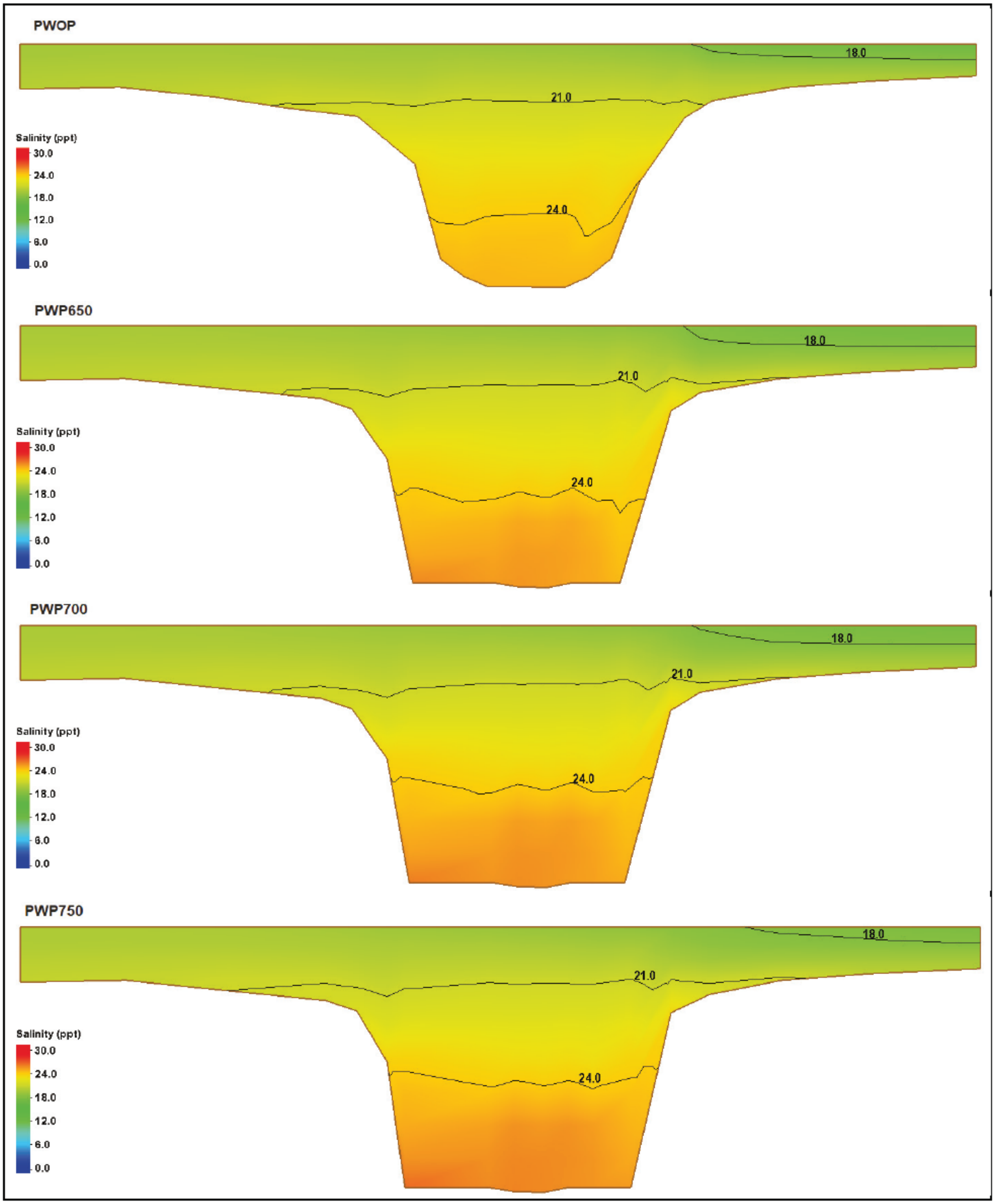


Figure 44. Cross section 6 mean salinity.

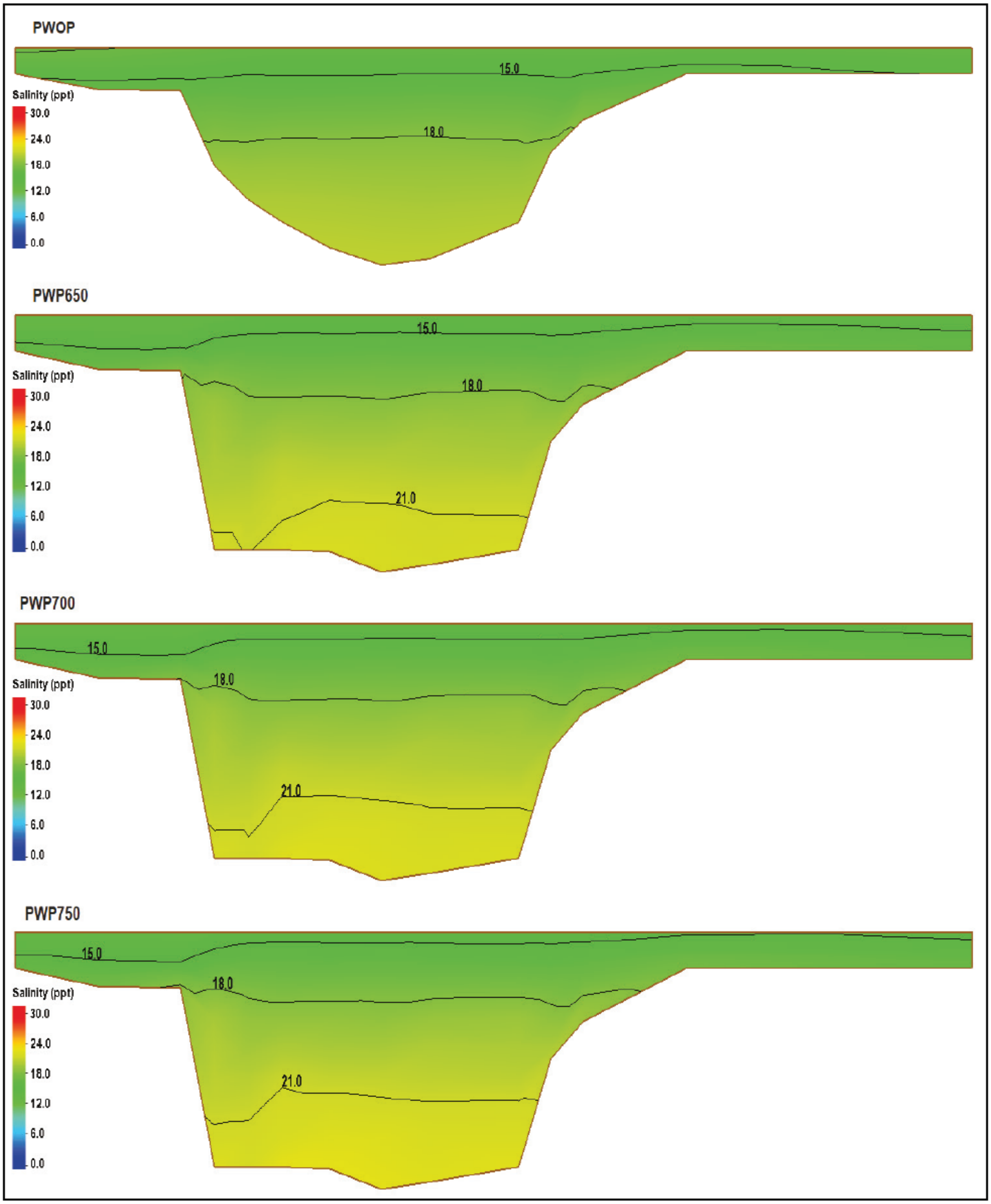
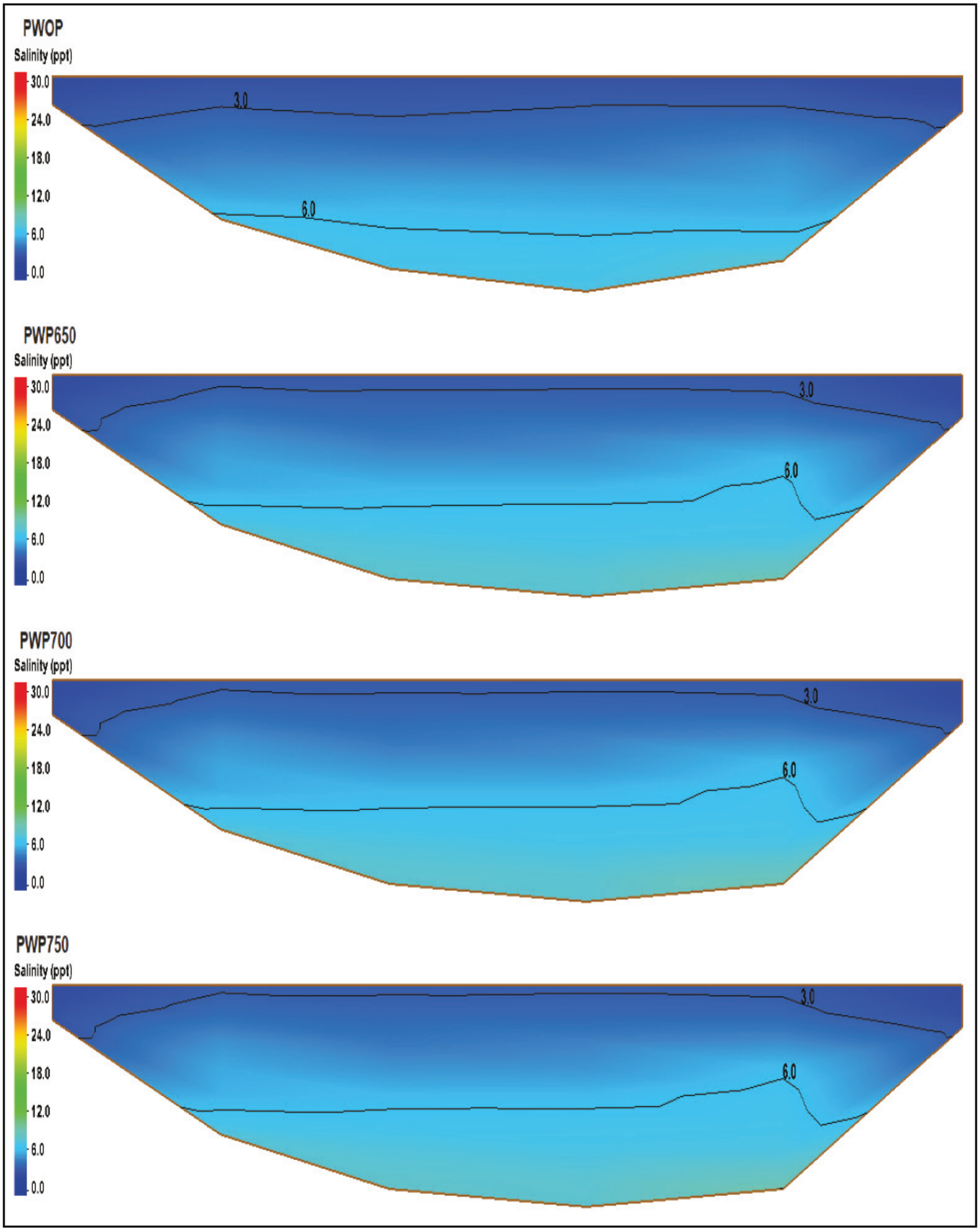


Figure 45. Cross section 9 mean salinity.



### 3.1.3 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 46 shows the location of key features along the HSC for reference (contours are irrelevant). Figure 47 shows the mean salinity along the HSC for all four conditions. The distance of salinity migration along the bottom of the ship channel is shown in Table 4. The salinity does migrate farther upstream for the wider channel alternatives; however, the shift in salinity in the upstream direction is greatest from PWOP to PWP650. The change in salinity wedge migration among the with project width alternatives is largest (approximately 2.8 miles for the 24 ppt contour) in the bay portion of the domain yet almost undetectable for contours farther upstream. The wider ship channel allows the high saline ocean water to push farther upstream until it is compressed in the along channel direction due to the fresh water entering the ship channel from the San Jacinto River and the Buffalo River. The mid-depth salinity actually increases in some locations due to this along channel compression, making the salinity wedge thicker and more stair-stepped in shape.

Figure 46. HSC slice analysis reference map (contours are irrelevant).

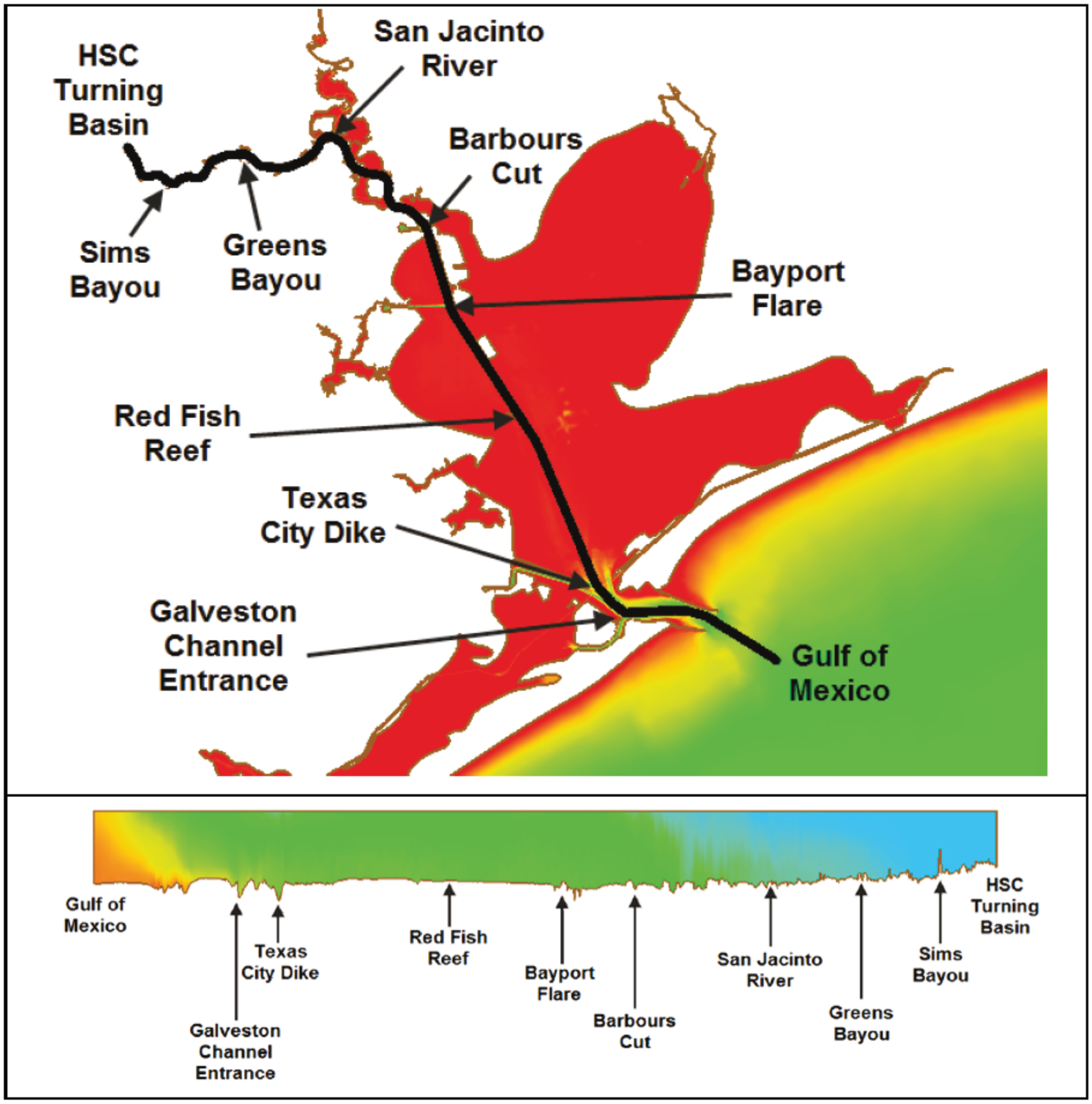


Figure 47. HSC average salinity slice results.

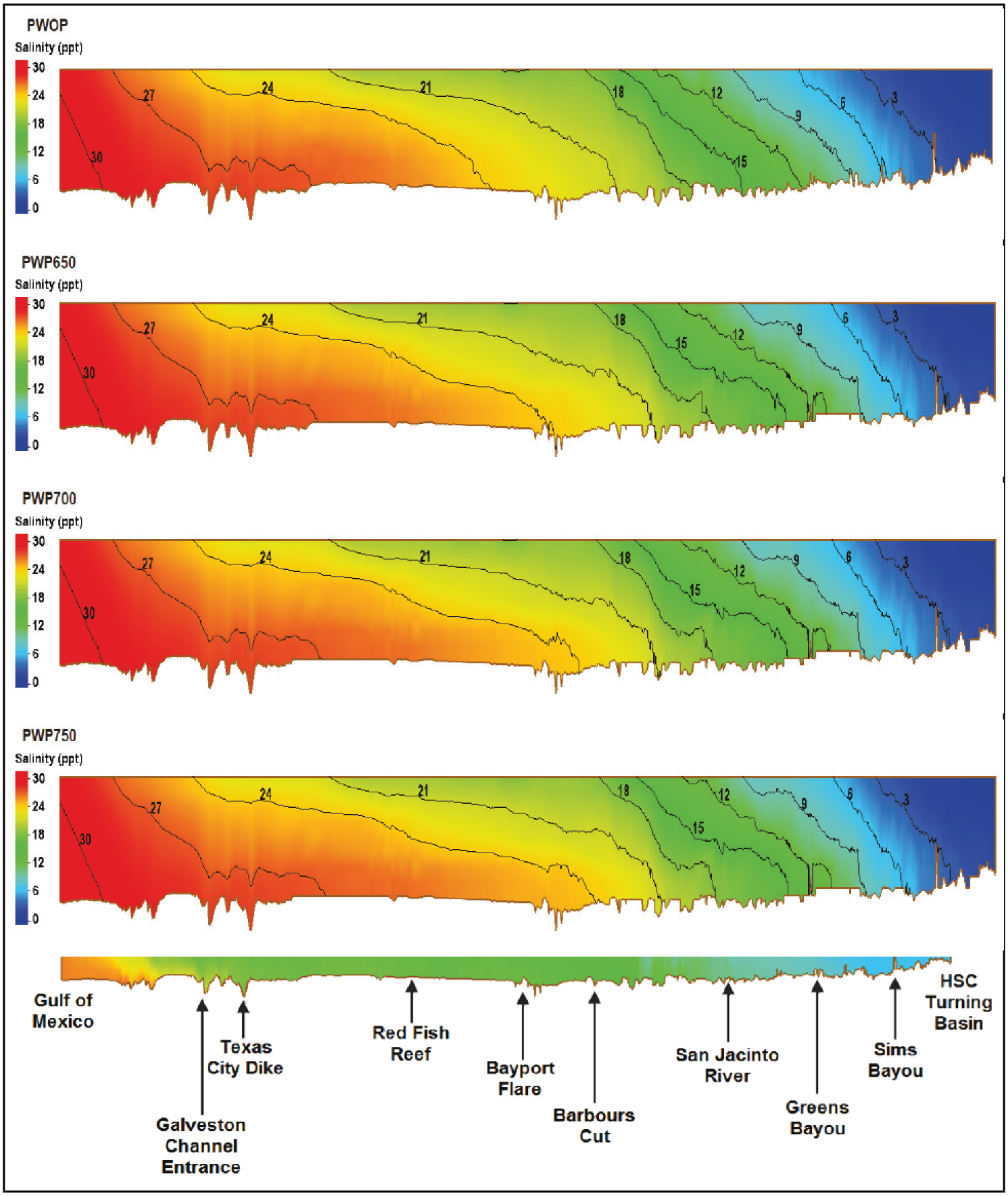


**Table 4. Salinity wedge migration from PWOP to with project alternatives.**

| Salinity contour (ppt) | PWP650 upstream shift (m) / (mi) | PWP700 upstream shift (m) / (mi) | PWP750 upstream shift (m) / (mi) |
|---|---|---|---|
| 24 | 6520 / 4.1 | 9170 / 5.7 | 11050 / 6.9 |
| 21 | 4150 / 2.6 | 4640 / 2.9 | 4750 / 3.0 |
| 15 | 4680 / 2.9 | 4780 / 3.0 | 4810 / 3.0 |
| 9 | 1170 / 0.7 | 1200 / 0.7 | 1290 / 0.8 |
| 3 | 1290 / 0.8 | 1330 / 0.8 | 1390 / 0.9 |

## 3.2 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 is computed for all tides over the analysis year, and the average tidal prism is determined. Table 5 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. There is a steady increase in the percentage change from PWOP for each with project width alternative. The change is less than 1.5%, which indicates that the modifications to the HSC do not greatly impact the volume of water entering and leaving the system.

**Table 5. Average tidal prism volume for analysis year and percent change of the with project alternatives from the without project alternative.**

| | PWOP (1000 $m^3$) | PWP650 (1000 $m^3$) | PWP650 % change from PWOP | PWP700 (1000 $m^3$) | PWP700 % change from PWOP | PWP750 (1000 $m^3$) | PWP750 % change from PWOP |
|---|---|---|---|---|---|---|---|
| Average | 527,609 | 531,148 | 0.67 | 532,965 | 1.02 | 534,451 | 1.30 |

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 6 shows the percentage change between PWOP and with project width alternatives. All locations see less than a 2%

increase or decrease in the tidal amplitude when the project modifications are included. Figure 48 and Figure 49 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 with project conditions are compared to the without project conditions – less than 0.01 m at any location with the largest variations found among the points in the lower portion of the model.

**Table 6. Percent change in tidal amplitude of the with project alternatives from the without project alternative.**

| | PWP650 % change from PWOP | PWP700 % change from PWOP | PWP750 % change from PWOP |
|---|---|---|---|
| HSC at Morgans Point | -0.82 | -0.93 | -0.95 |
| HSC at Atkinson Island | -0.77 | -0.89 | -1.68 |
| HSC at Mid Bay Marsh | -1.23 | -1.35 | -1.41 |
| HSC at Red Fish Reef | -1.14 | -1.25 | -1.37 |
| HSC at Lower Galveston Bay | -1.09 | -1.26 | -1.38 |
| HSC at Bolivar Roads | -0.63 | -0.81 | -0.92 |
| HSC at Entrance | -0.86 | -0.79 | -0.89 |
| HSC at Gulf | -0.76 | -0.84 | -1.20 |
| Upper Galveston Bay 1 | -1.29 | -1.29 | -1.52 |
| Upper Galveston Bay 2 | -0.93 | -1.19 | -1.74 |
| Lower Galveston Bay | -0.92 | -1.05 | -1.76 |
| Lower Trinity Bay | -0.80 | -0.93 | -1.40 |
| Mid Trinity Bay | -0.82 | -0.96 | -0.96 |
| Upper Trinity Bay | -0.65 | -0.79 | -0.78 |
| Western East Bay | -0.41 | -0.54 | -0.54 |
| Eastern East Bay | 0.13 | 0.00 | -0.01 |
| Eastern West Bay | -0.28 | -0.42 | -0.22 |
| Mid West Bay | 0.79 | 0.85 | 0.85 |
| Offatts Bayou | 0.31 | 0.18 | -0.01 |
| Dickinson | 0.80 | 0.67 | 0.49 |
| Clear Creek | 0.54 | 0.40 | 0.42 |
| Smith Point | 0.21 | 0.07 | 0.08 |
| Mid East Bay | 0.15 | 0.00 | 0.02 |

| | PWP650 % change from PWOP | PWP700 % change from PWOP | PWP750 % change from PWOP |
|---|---|---|---|
| HSC at Fred Hartman Bridge | 0.12 | 0.11 | 0.09 |
| HSC at Goat Island | 0.14 | 0.00 | 0.02 |
| HSC at Carpenters Bayou | 0.00 | 0.04 | -0.12 |
| HSC at Greens Bayou | -0.19 | -0.02 | -0.31 |
| HSC at Sims Bayou | -0.23 | -0.05 | -0.31 |
| HSC at Turning Basin | 0.07 | 0.19 | -0.18 |

Figure 48. Tidal amplitude comparison at HSC points for all alternatives.

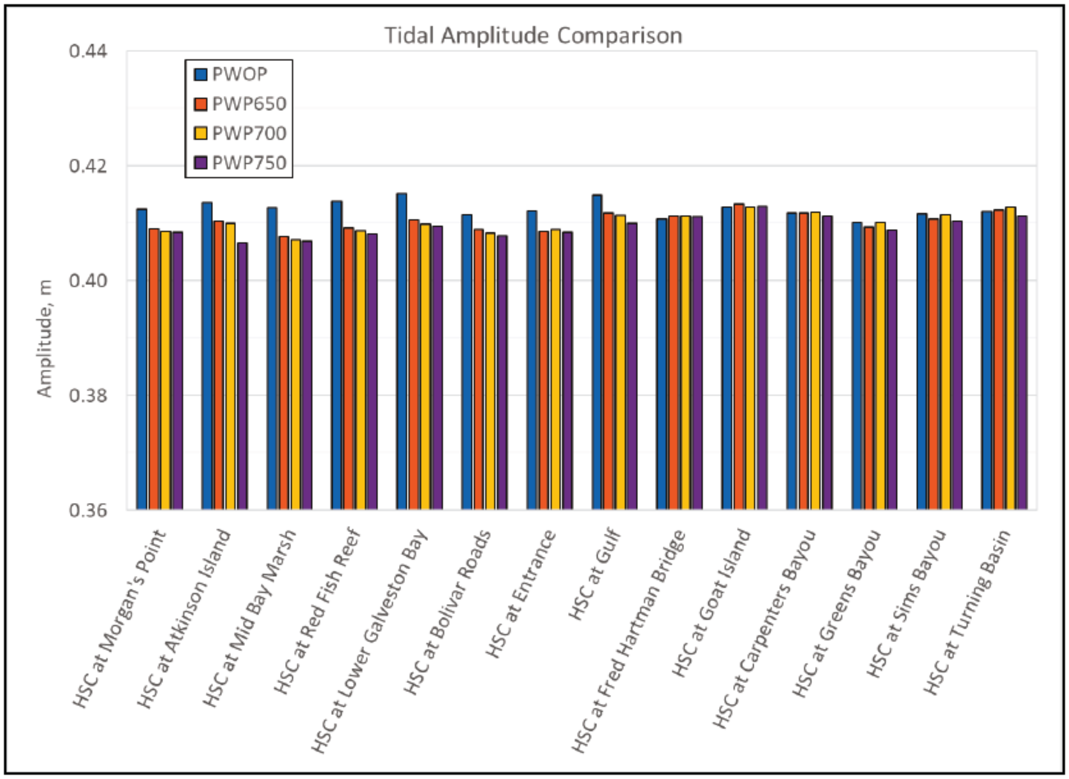
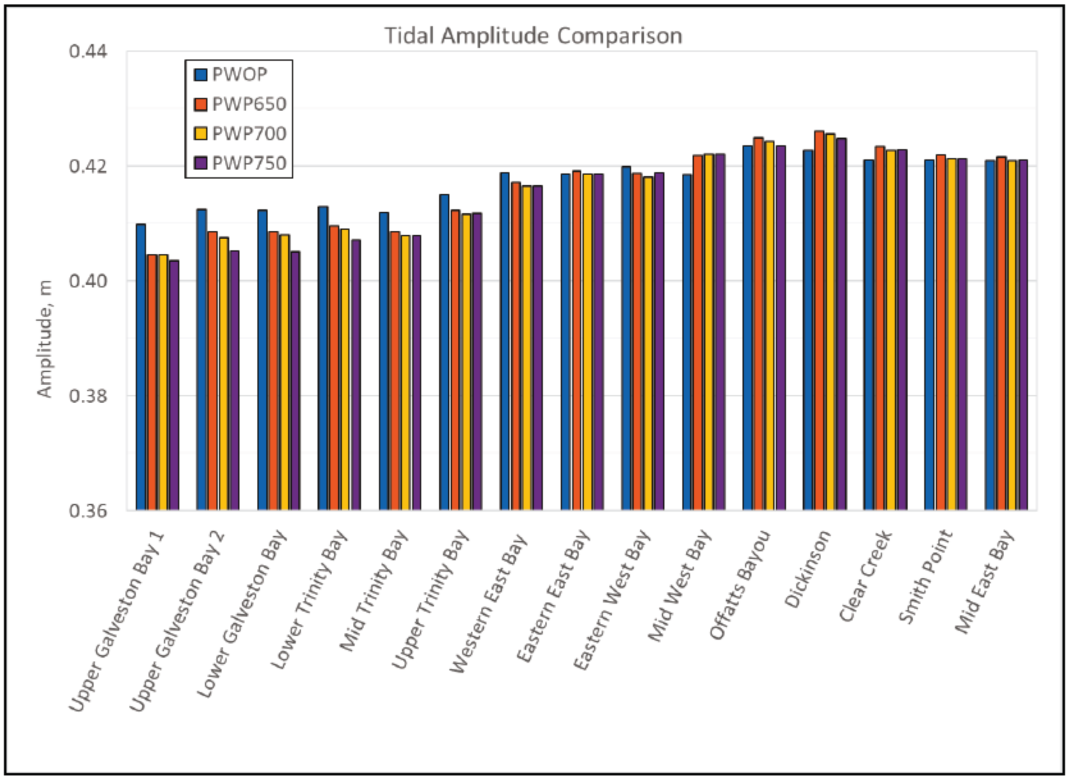


Figure 49. Tidal amplitude comparison at bay points for all alternatives.




## 3.3 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 the with project alternatives are shown in Figure 50 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 bottom velocity is a near-bed velocity and can be assumed to be at 5% of the depth above the bed.

The comparisons show that the residual vector directions are very similar for the with and without project alternatives, especially in Trinity Bay. There are locations where the residual vector directions vary but the general flow patterns are similar. The area with 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 same variations are shown in both the surface and bottom residual velocities. The further increase in the bay section channel width, as with the alternatives presented here, does not create additional changes in the residual velocity patterns. The change in the residual velocity magnitudes from the without project condition are a maximum of approximately 0.05 m/s.

Figure 50. Surface average residual velocity comparison for PWP650 conditions. (Red vectors – with project; Black vectors – without project)

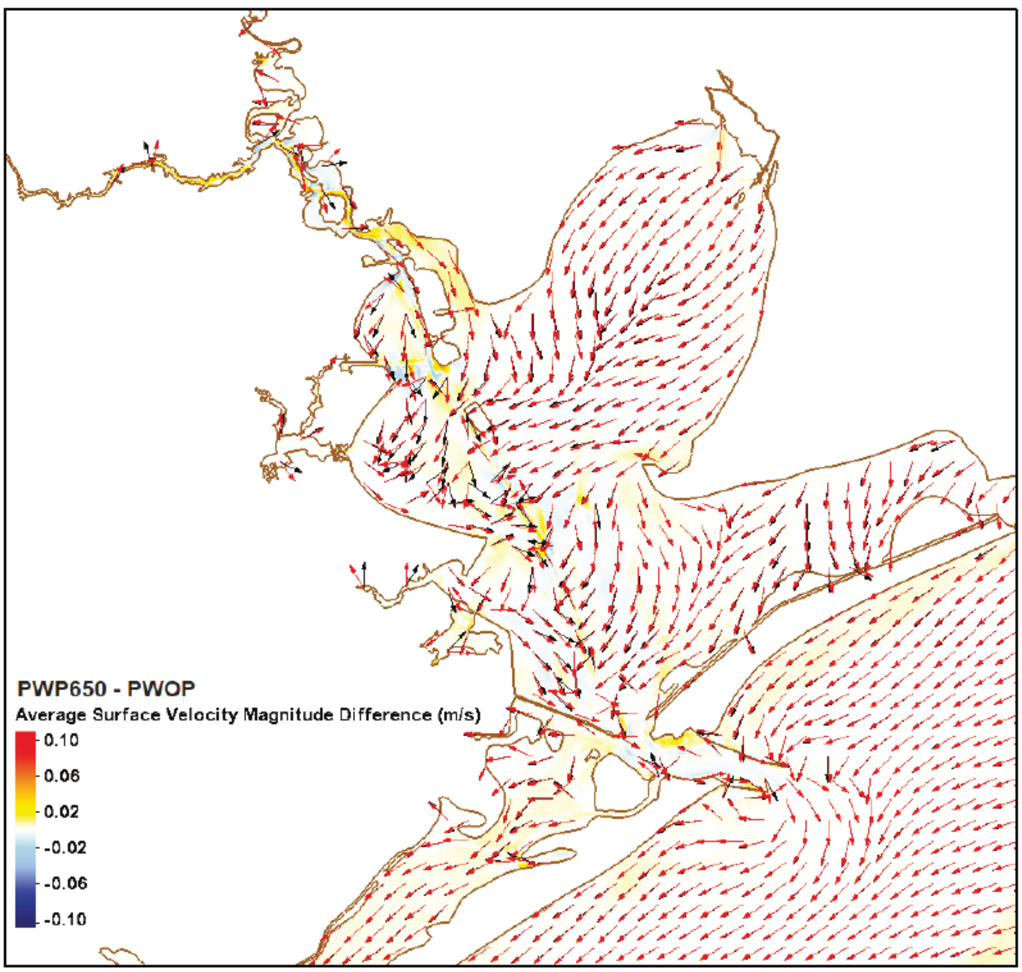


Figure 51. Bottom average residual velocity comparison for PWP650 conditions. (Red vectors – with project; Black vectors – without project)

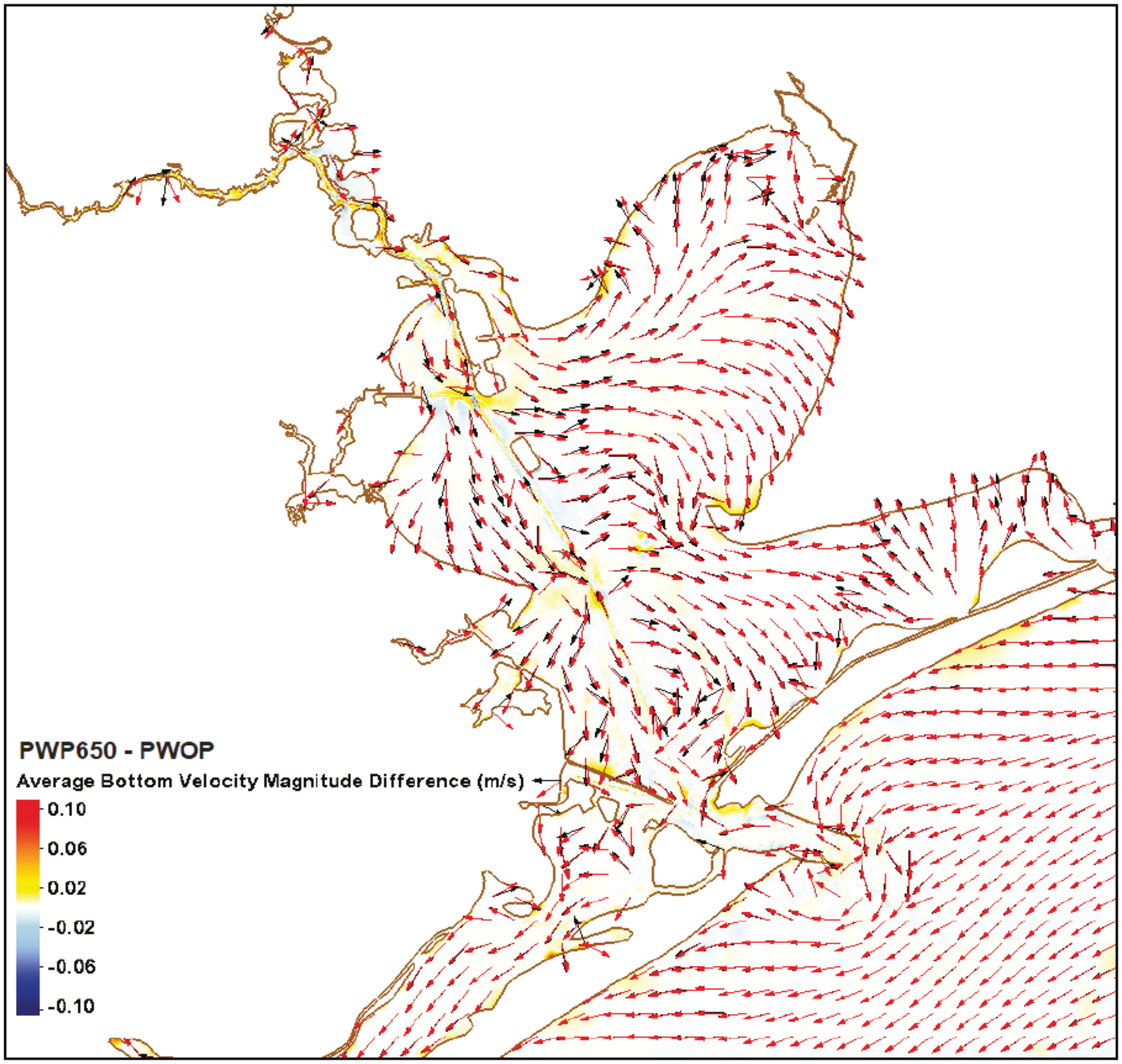


Figure 52. Surface average residual velocity comparison for PWP700 conditions. (Red vectors – with project; Black vectors – without project)

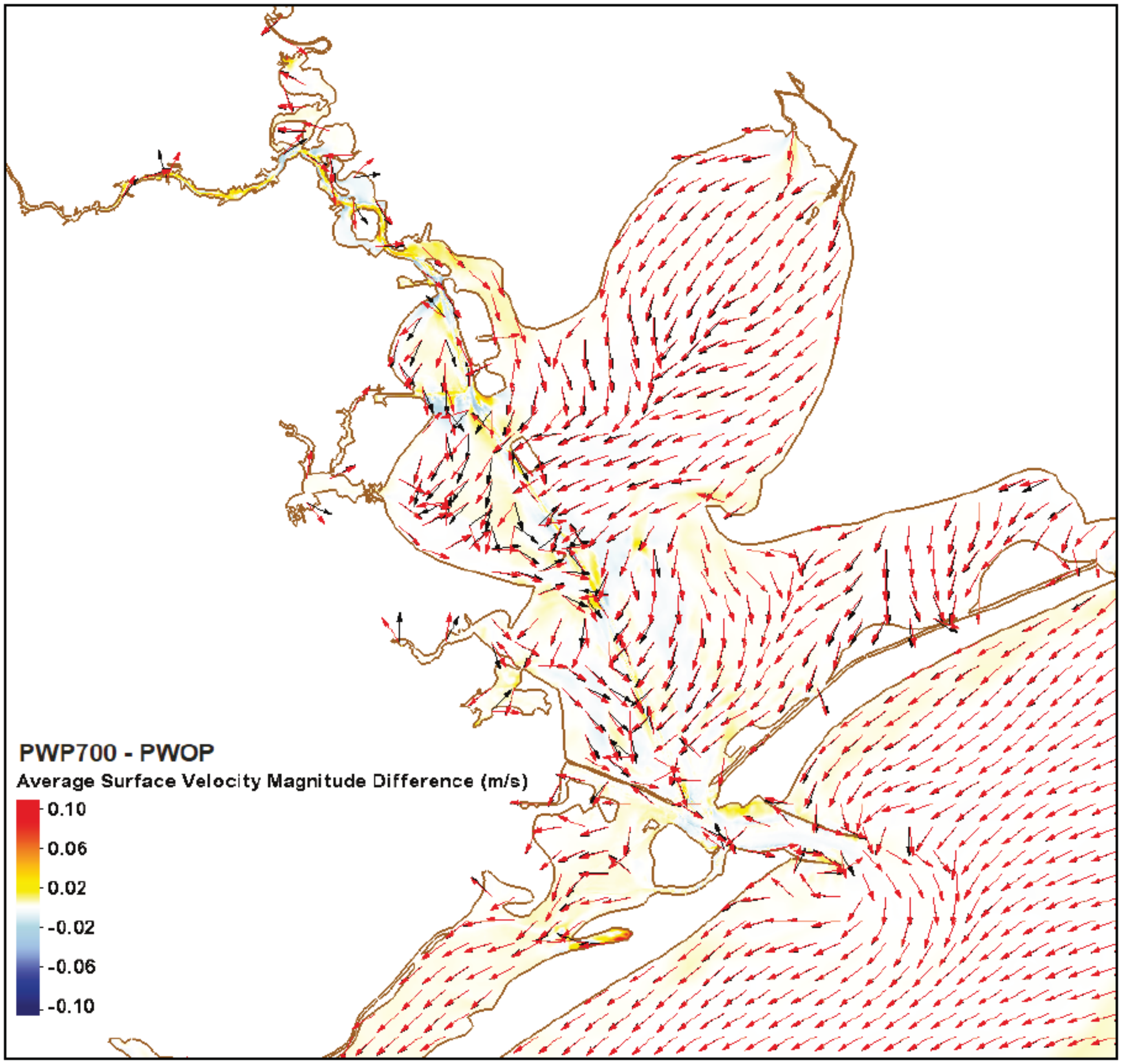


Figure 53. Bottom average residual velocity comparison for PWP700 conditions. (Red vectors – with project; Black vectors – without project)

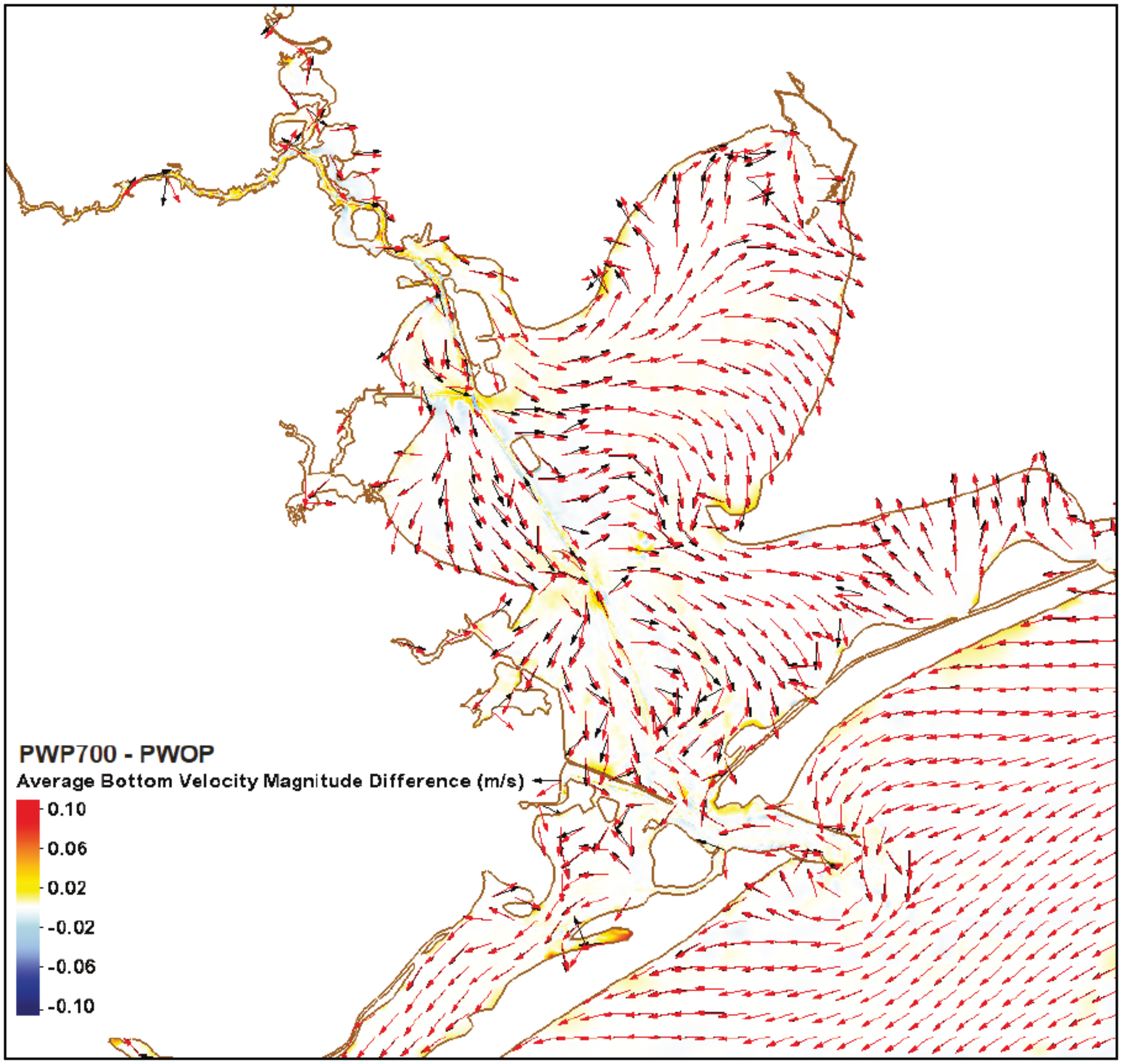


Figure 54. Surface average residual velocity comparison for PWP750 conditions. (Red vectors – with project; Black vectors – without project)

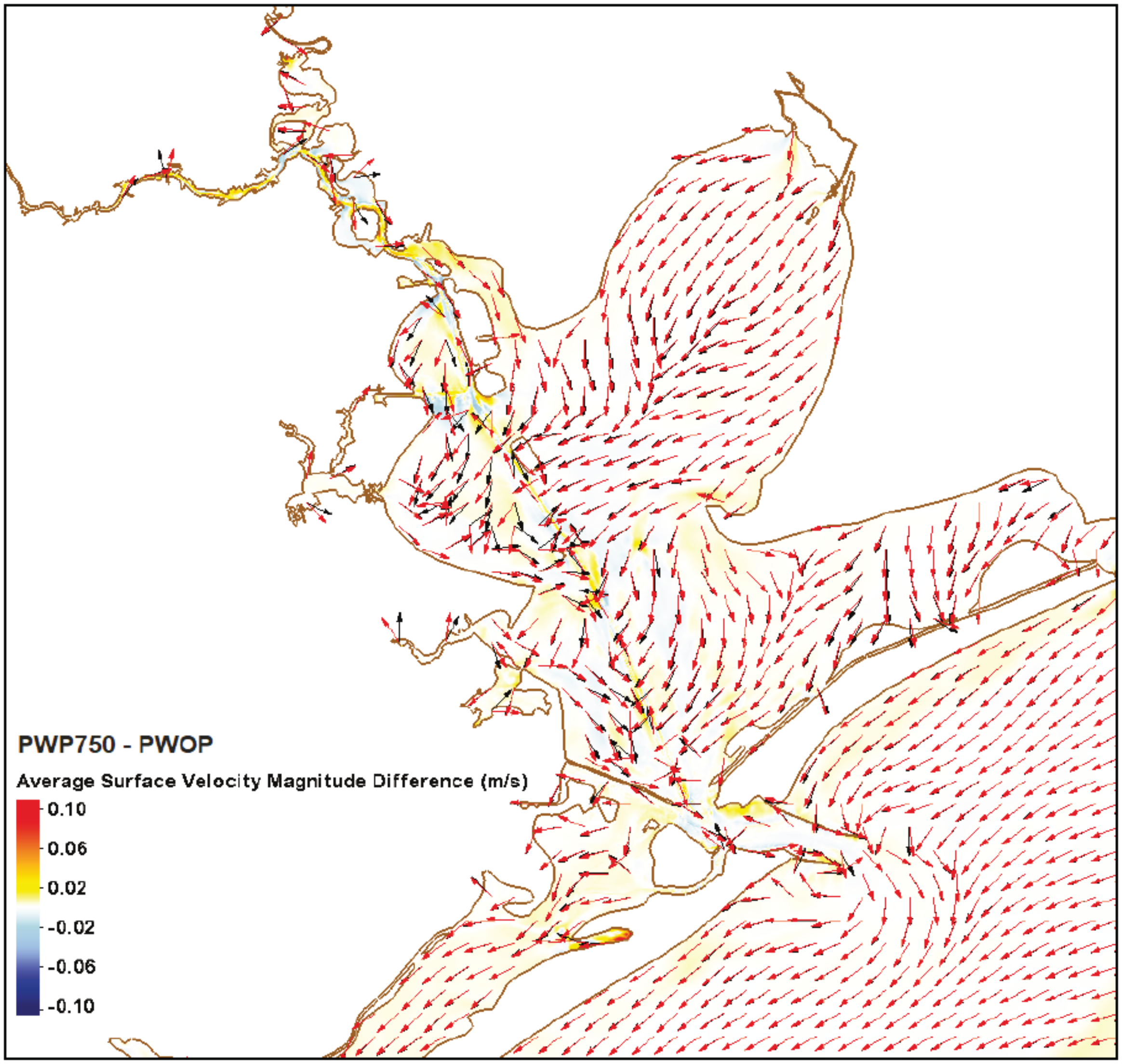
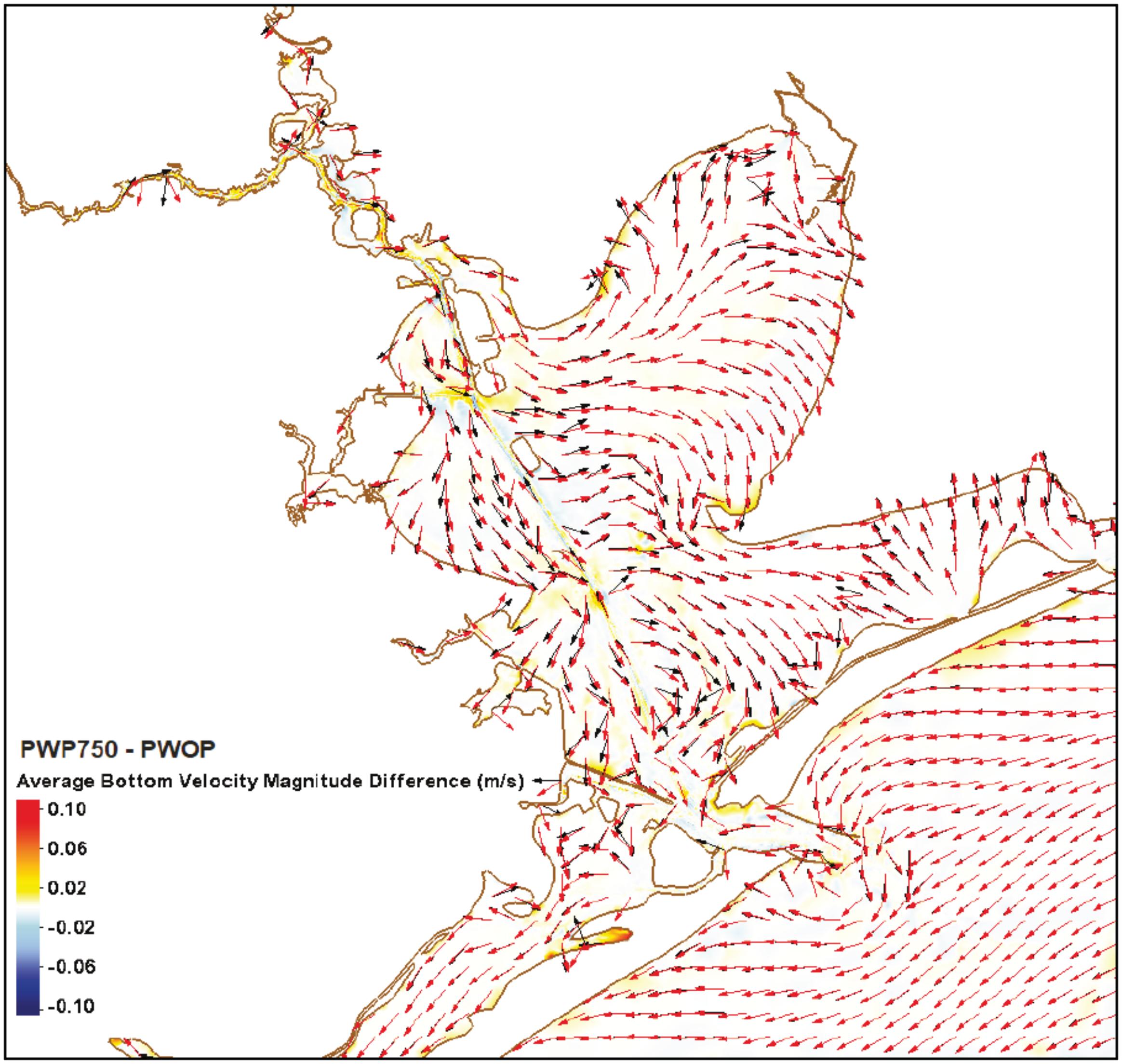


Figure 55. Bottom average residual velocity comparison for PWP750 conditions. (Red vectors – with project; Black vectors – without project)




## 3.4 Shoaling

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

Figure 56. HSC dredge template for shoaling analysis.

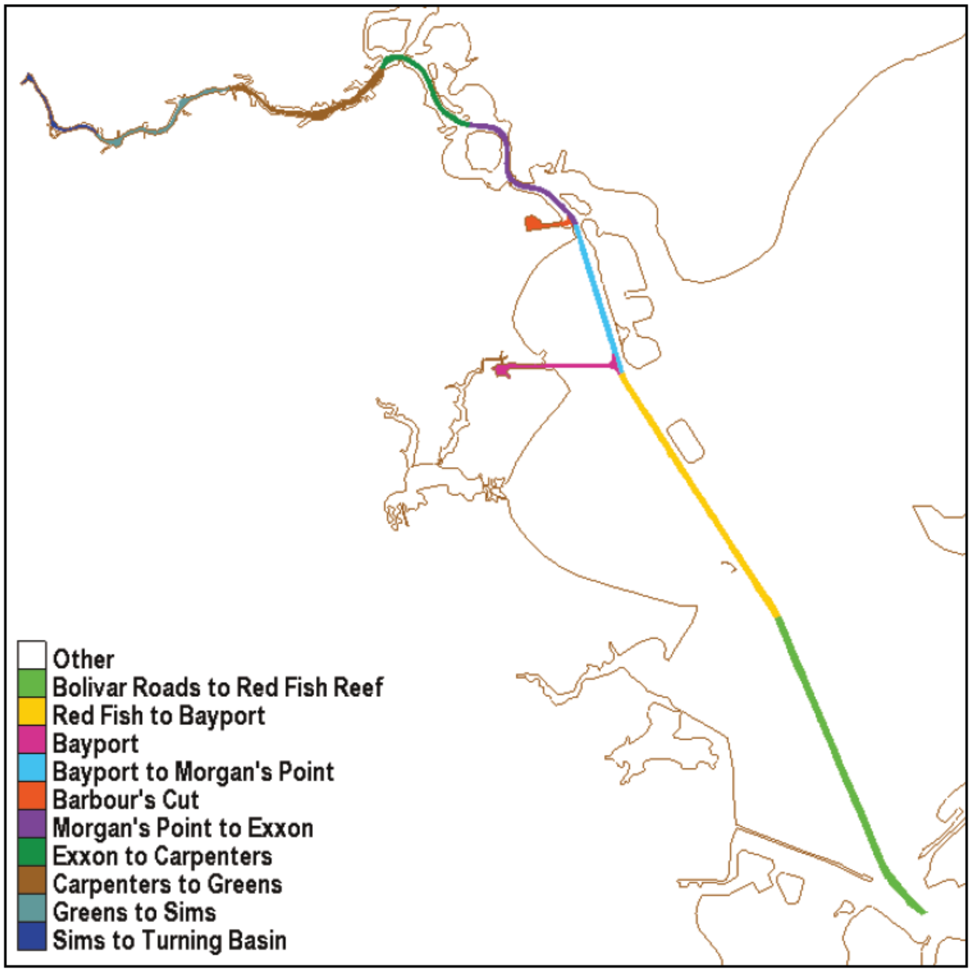



Figure 57 shows the scaled shoaling volume (McAlpin et al. 2019a) within each segment for the 2010 base condition and all four alternatives – PWOP, PWP650, PWP700, and PWP750. The with project shoaling is larger for all segments except at the farthest downstream segment. Bolivar Roads to Red Fish Reef 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 the bend easing further increase the footprint and therefore the tendency to trap sediment. Although the channel width increases in the project alternatives further increase the shoaling in the Bayport Flare, the largest impact is seen with the initial implementation of the plan conditions (PWP650).

Figure 57. Shoaling results by reach for all alternatives over the analysis year.

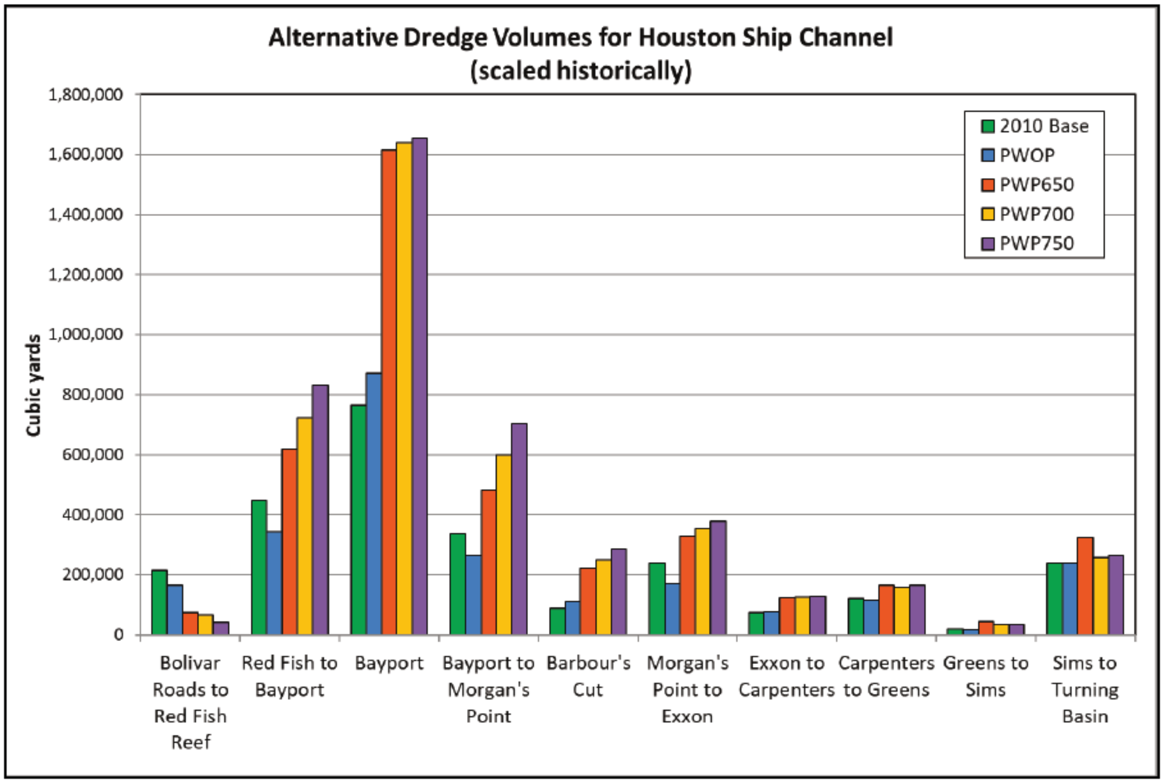
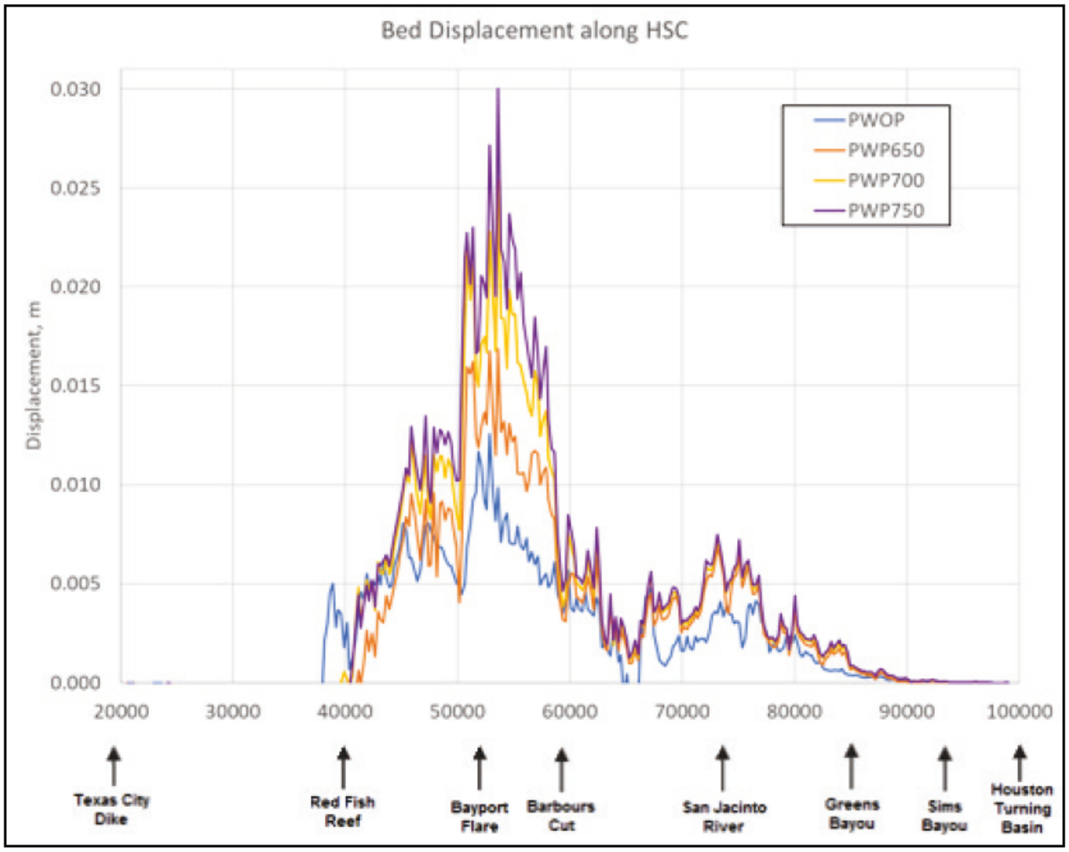



Figure 58 shows the model computed, unscaled bed displacement along the HSC from the Texas City Dike to the Houston Turning Basin. These results show a similar pattern to those in Figure 57, although no scaling has been done to ensure a correlation to historical data as in the shoaling volume plot. However, 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 to areas upstream of Red Fish Reef and upstream of Bayport in the peak shoaling locations for the with project alternatives. 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.

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




The widened ship channel in the bay section shows definite increases in shoaling volume as well as shoaling depth (bed displacement) along the HSC with each increase in width, especially in the Bayport Flare area. Based on survey data, vessel traffic will continuously erode the navigation channel centerline and may actually reduce these modeled shoaling depth projections (vessel impacts are included in the historical shoaling factor applied to the modeled reach volumes). However, vessels can transit at higher speeds in wider channels, which, in turn, can cause more erosion in the bays, providing a sediment source easily transported into the channel.

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 wedge moving further 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.

# 4 Conclusions

Overall, the proposed alternatives and various bay channel widths have little effect on salinity, but they do generate larger shoaling and localized changes in velocity patterns.

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 tend to migrate farther upstream due to the channel widening and deepening. That distance is on the order of 0.5 to almost 7 miles depending on the salinity value being tracked. However, once upstream of Morgan's Point, the salinity contours compress together, and the upstream migration due to the geometry changes in the ship channel lessens. Although the distance of the salinity wedge migration is several miles at the bed, the variation in the salinity at any given point remains on the order of 2 ppt for the with project conditions. The increase in the bay channel width does allow for a small amount of additional upstream migration of the salinity wedge but the primary increase is due to the initial channel widening and additional channel modifications.

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 1.5% for all project 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 residual velocity 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 0.05 m/s. Changes due to further increases in bay channel width are extremely small and do not impact the residual velocity much beyond the original channel modifications. There are impacts to velocity magnitude in the bay areas, but they are much smaller than the impacts at the locations of the modifications.

The alternative conditions do 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 width at the location of the flare. Additionally, it is in this area where the salinity wedge shows the largest migration (on average), which will also impact the tendency for sediment to fall to the bed in the area of the flare. It should be expected that the shoaling volume at the Bayport Flare will exceed the volume change due to the increased channel dimensions. Further increases in shoaling are observed in the model results with each bay channel width increase. Upstream of Morgan's Point, this shoaling increase is on the order of the increase in channel size. However, as noted previously, sediment loads from bayous entering the ship channel in this area are not included in the model. 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 if shoal height is reduced. In addition, a deeper/wider channel tends to result in increased sizes and speeds for the ships navigating the channel. In general, this will result in larger resuspension of sediment and could result in increased deposition in the ship channel beyond those predicted in this model study.

# References


Berger, R. C., R. T. McAdory, W. D. Martin, and J. H. Schmidt. 1995a. *Houston-Galveston Navigation Channels, Texas Project, Report 3, Three-dimensional Hydrodynamic Model Verification*. Technical Report HL-92-7. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Berger, R. C., Robert T. McAdory, Joseph H. Schmidt, and William D. Martin. 1995b. *Houston-Galveston Navigation Channels, Texas Project, Report 4, Three-dimensional Numerical Modeling of hydrodynamics and Salinity*. Technical Report HL-92-7. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Carrillo, A. R., M. S. Sarruff, and R. C. Berger. 2002. *Effects of adding barge lanes along Houston Ship Channel through Galveston Bay, Texas*. ERDC/CHL TR-02-23. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Galveston Bay Estuary Program. 2002. *The state of the bay: A characterization of the Galveston Bay ecosystem*, 2nd Ed. Edited by J. Lester and L. Gonzalez. Austin, TX: Texas Commission on Environmental Quality.

McAlpin, Jennifer N., Cassandra G. Ross, and C. Jared McKnight. 2019a. *Houston Ship Channel 3D Adaptive Hydraulics (AdH) Numerical Model Validation Report*. ERDC/CHL TR-19-10. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

McAlpin, Jennifer N., C. Jared McKnight, and Cassandra G. Ross. 2019b. *Houston Ship Channel Expansion Channel Improvement Project (ECIP) Numerical Modeling Report*. ERDC/CHL TR-19-12. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Savant, Gaurav, and R. Charlie Berger. 2015. *Three-Dimensional Shallow Water Adaptive Hydraulics (AdH-SW3) Validation: Galveston Bay Hydrodynamics and Salinity Transport*. ERDC/CHL TR-15-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Schoenbaechler, Caimee, and Carla G. Guthrie. 2012. *Coastal Hydrology for the Trinity-San Jacinto Estuary*. Austin, TX: Texas Water Development Board.

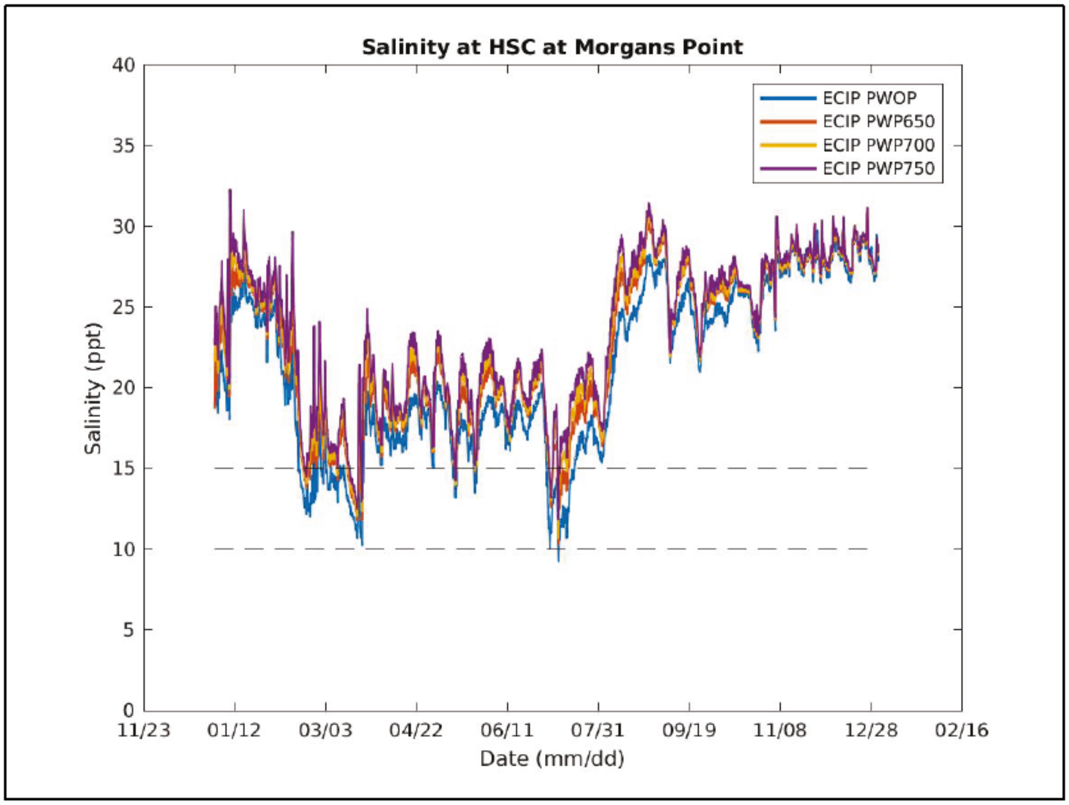
Tate, J. N., and R. C. Berger. 2006. *Houston-Galveston Navigation Channels, Texas Project: Navigation Channel Sedimentation Study, Phase 1*. ERDC/CHL TR-06-8. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

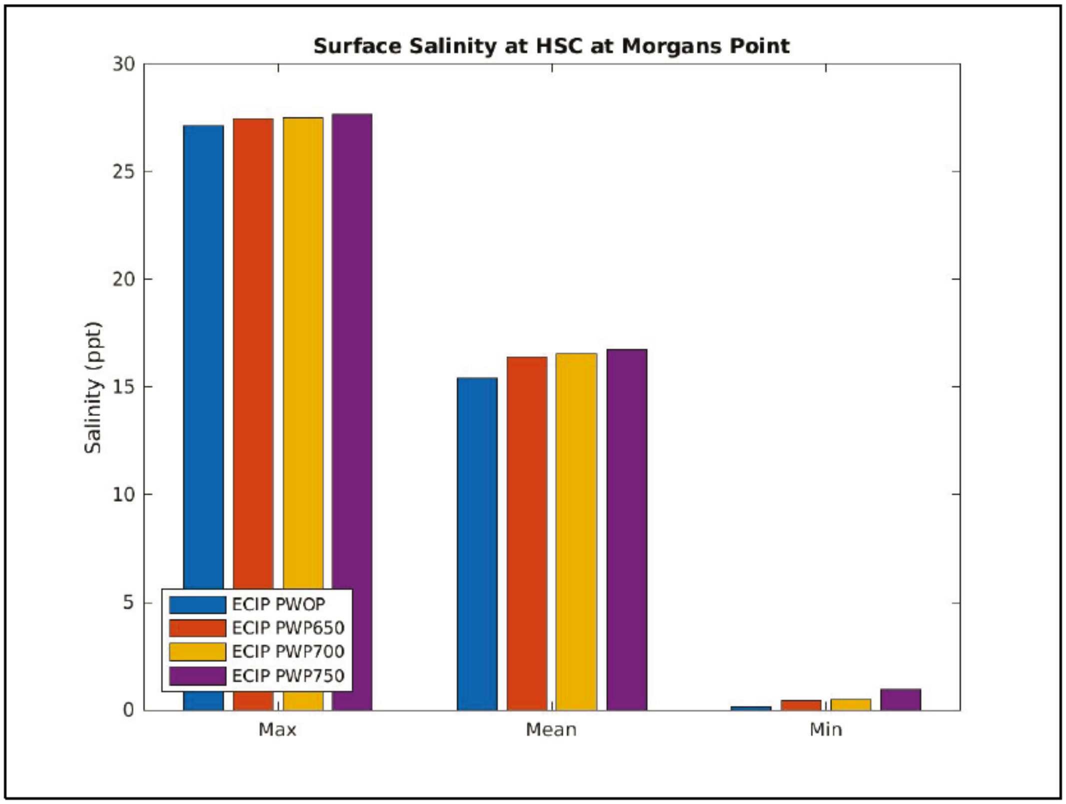
Tate, J. N., R. C. Berger, and C. G. Ross. 2008. *Houston-Galveston Navigation Channels, Texas Project, Navigation Channel Sedimentation Study, Phase 2*. ERDC/CHL TR-08-8. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

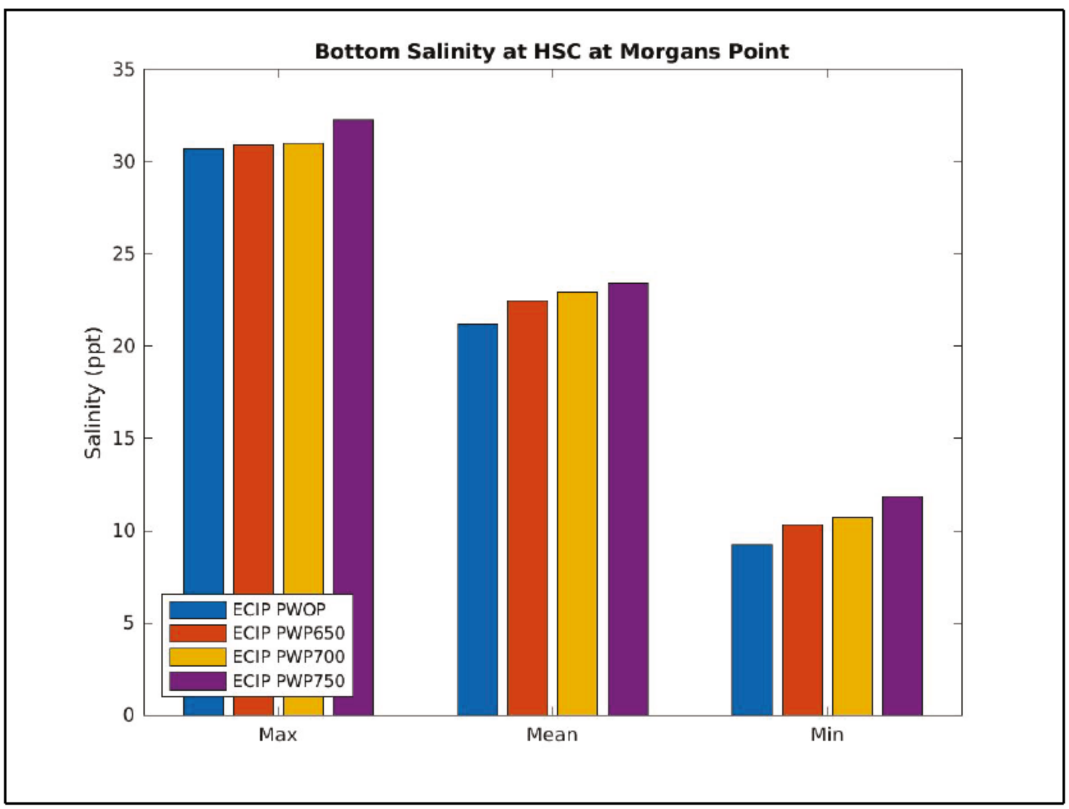
Tate. Jennifer N., and Cassandra G. Ross. 2012. *Bayport Flare Hydrodynamic Study for Ship Simulation*. ERDC/CHL TR-12-13. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

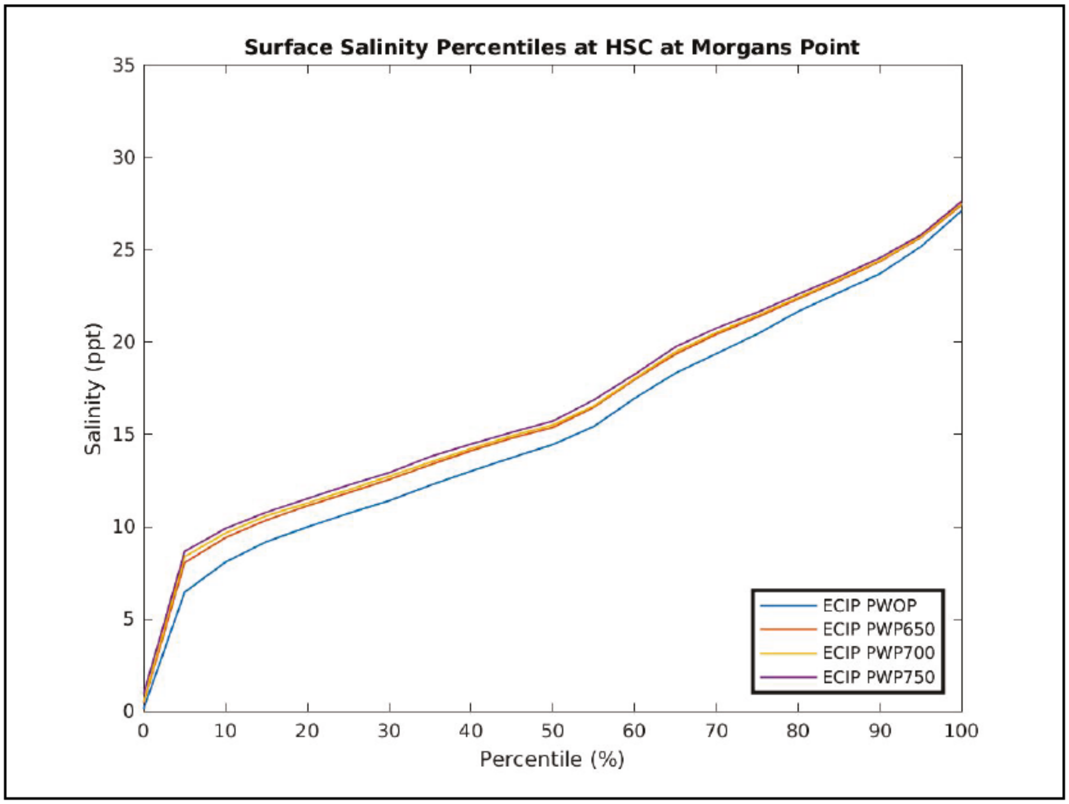
# Appendix

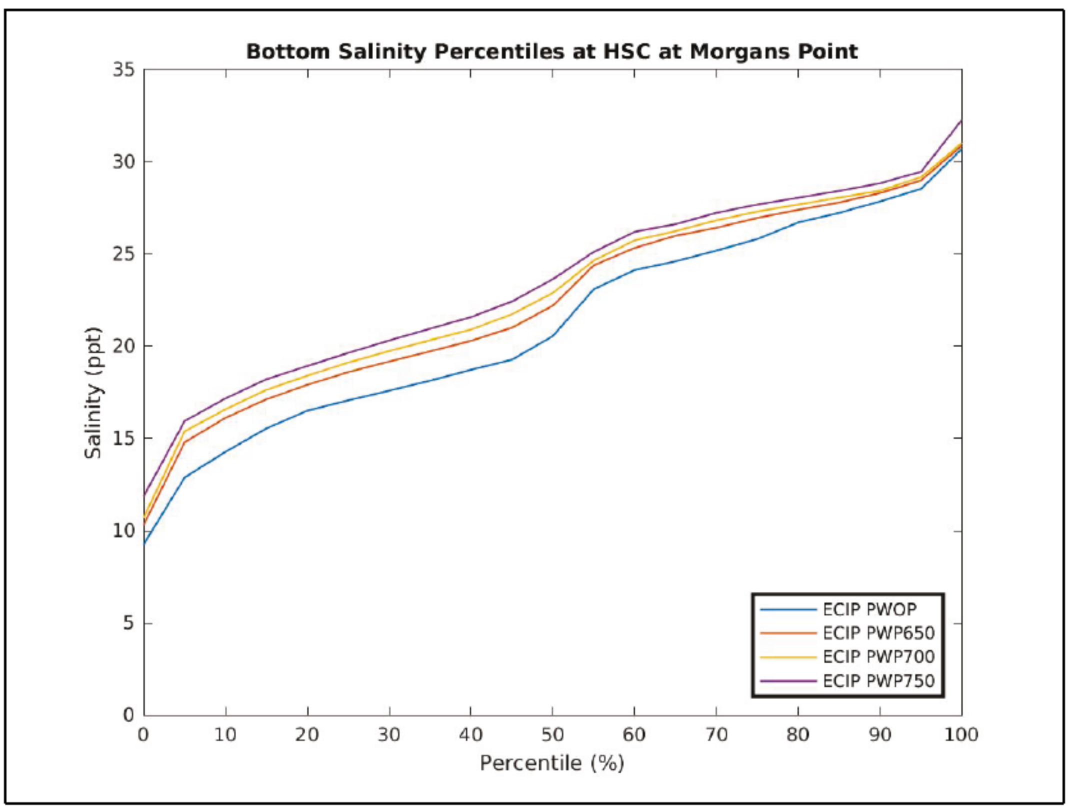
## Point Salinity Analysis

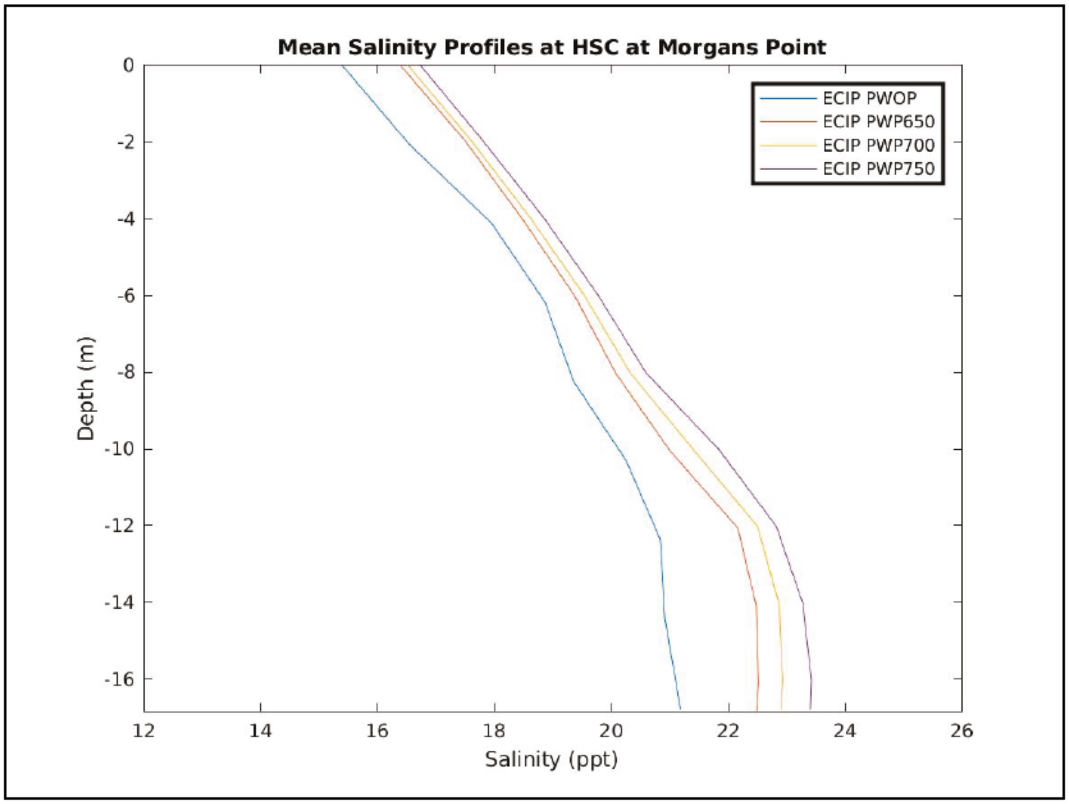


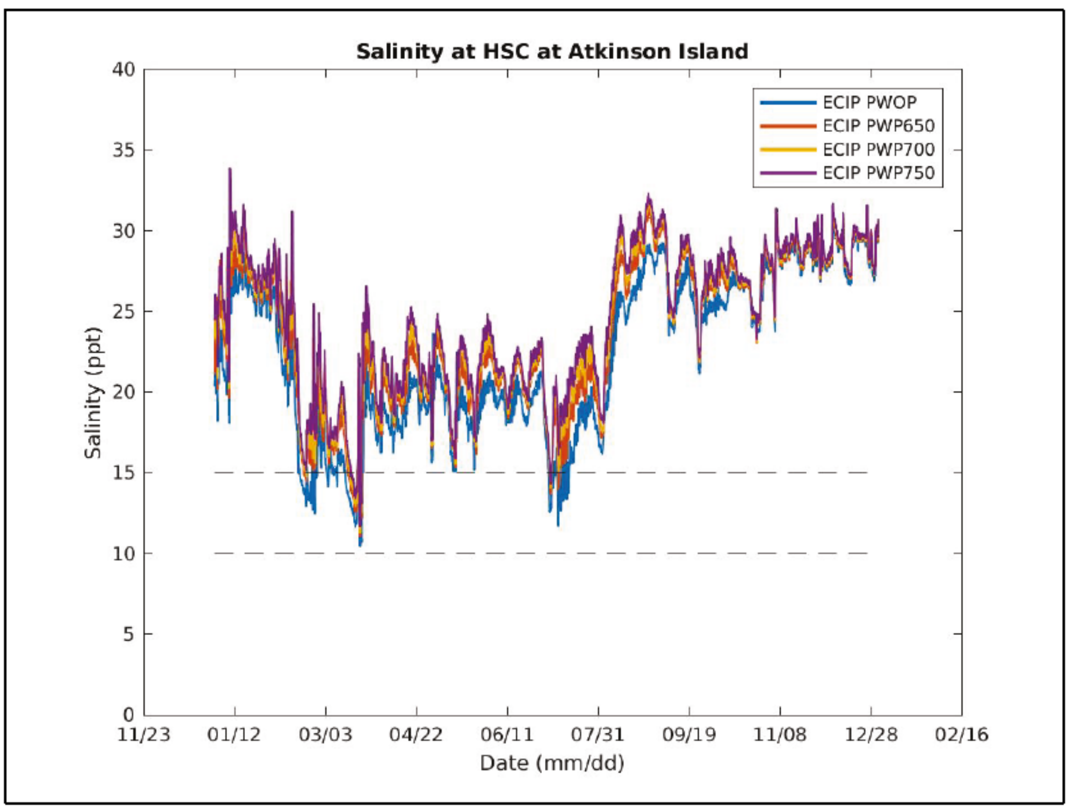

Surface Salinity at HSC at Morgans Point
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

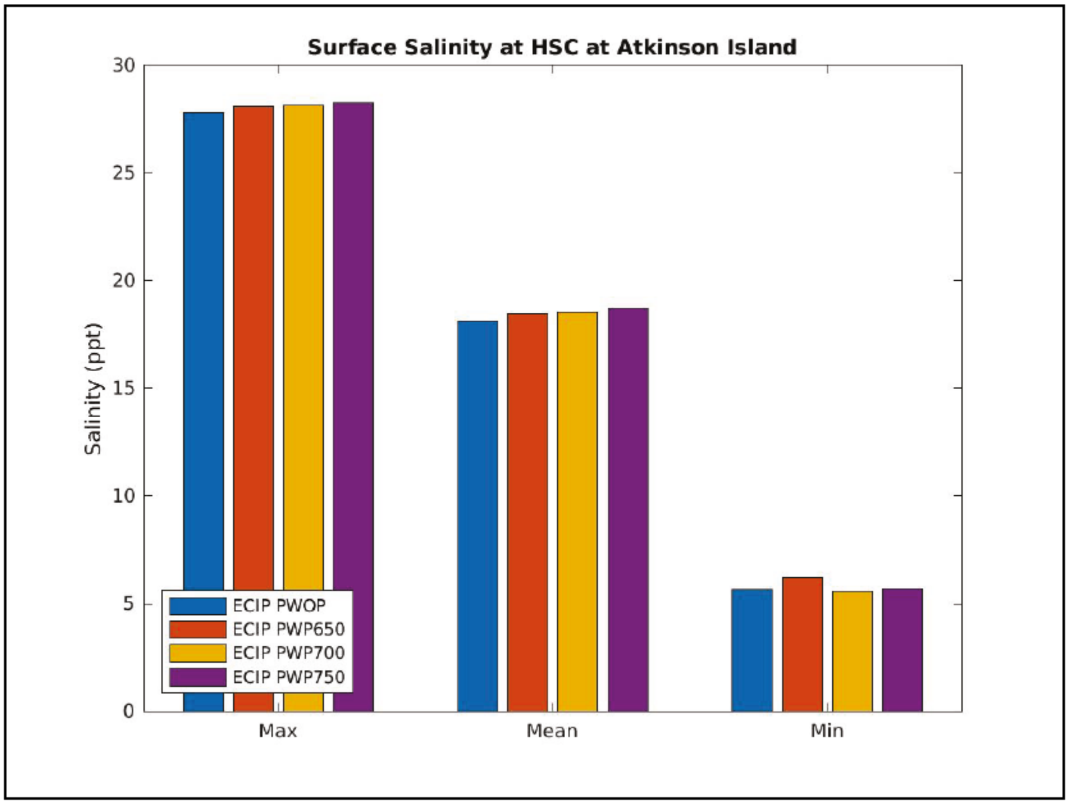

Bottom Salinity at HSC at Morgans Point
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

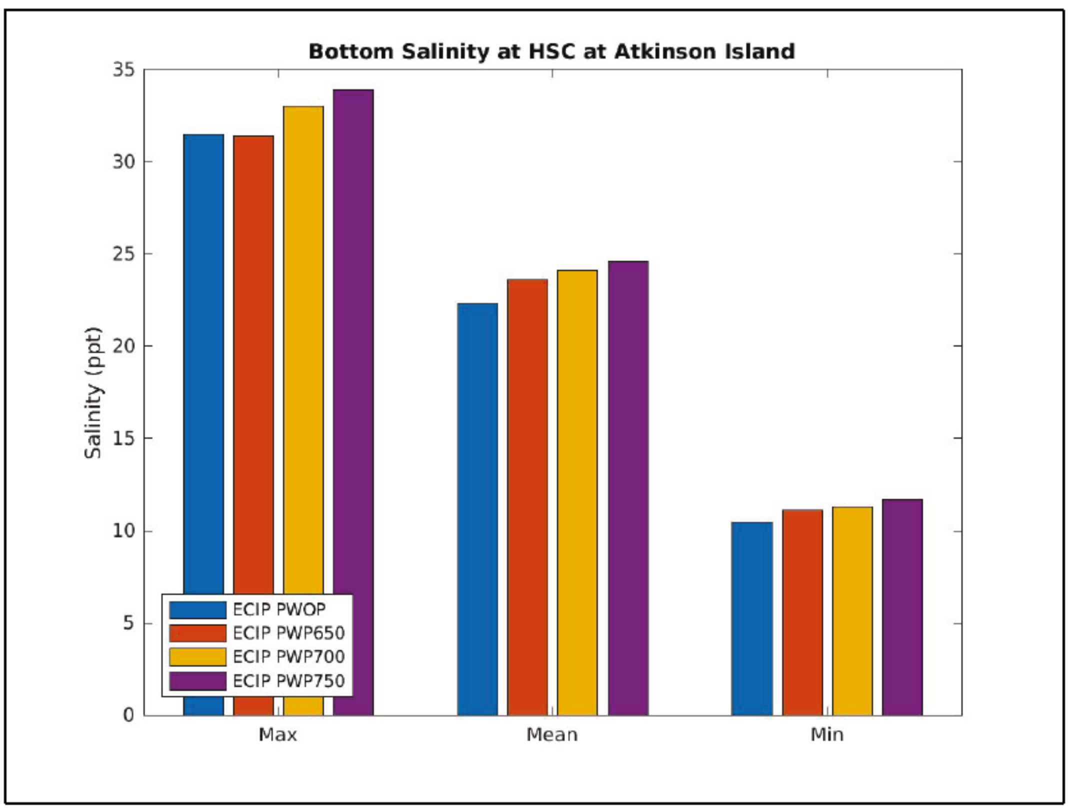

Surface Salinity Percentiles at HSC at Morgans Point
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

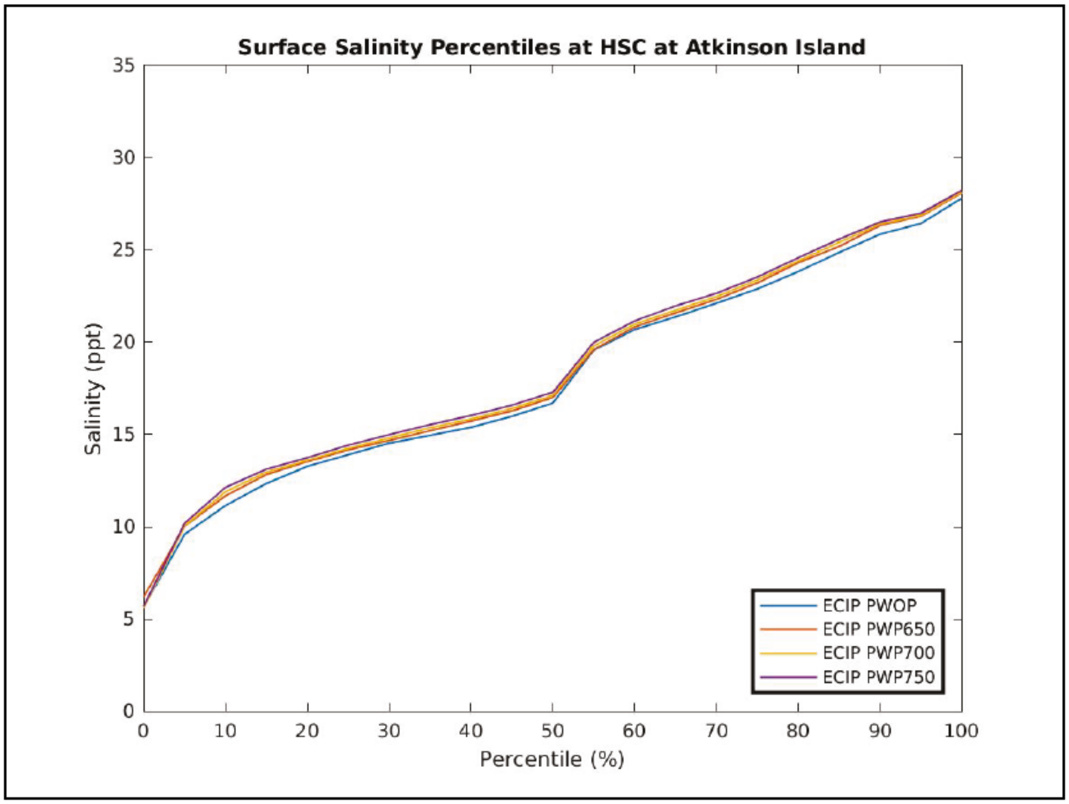

Bottom Salinity Percentiles at HSC at Morgans Point
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

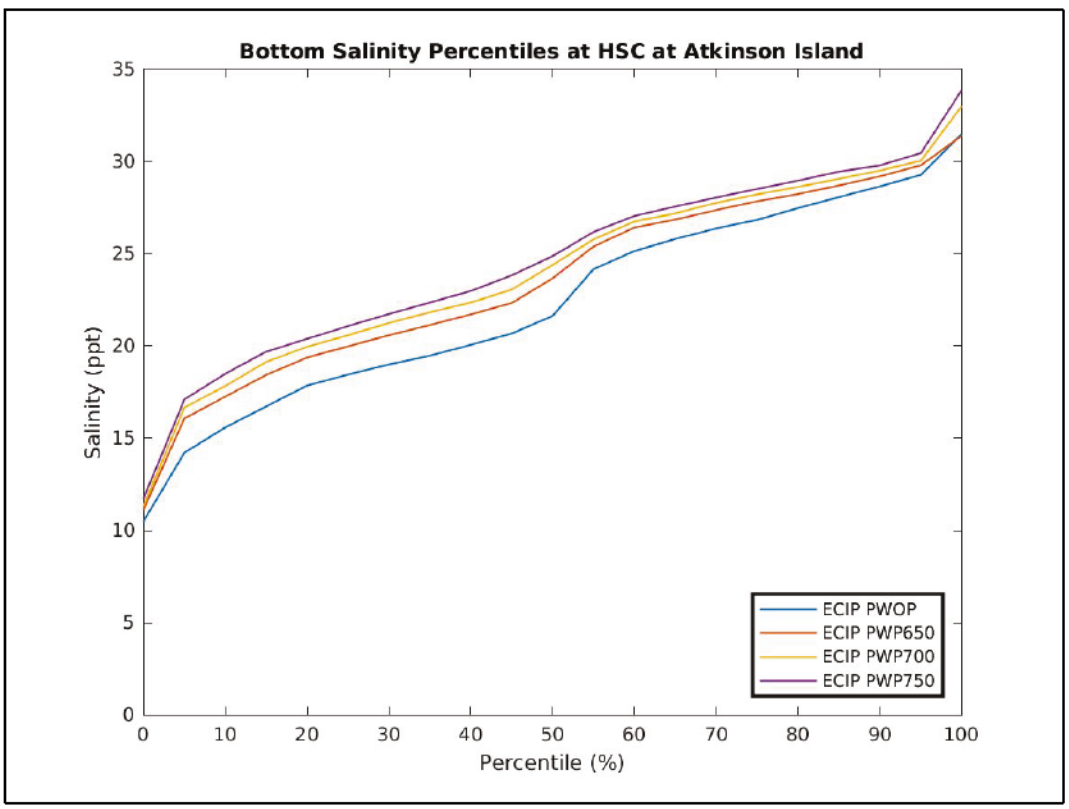

Mean Salinity Profiles at HSC at Morgans Point
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
12
14
16
18
20
22
24
26

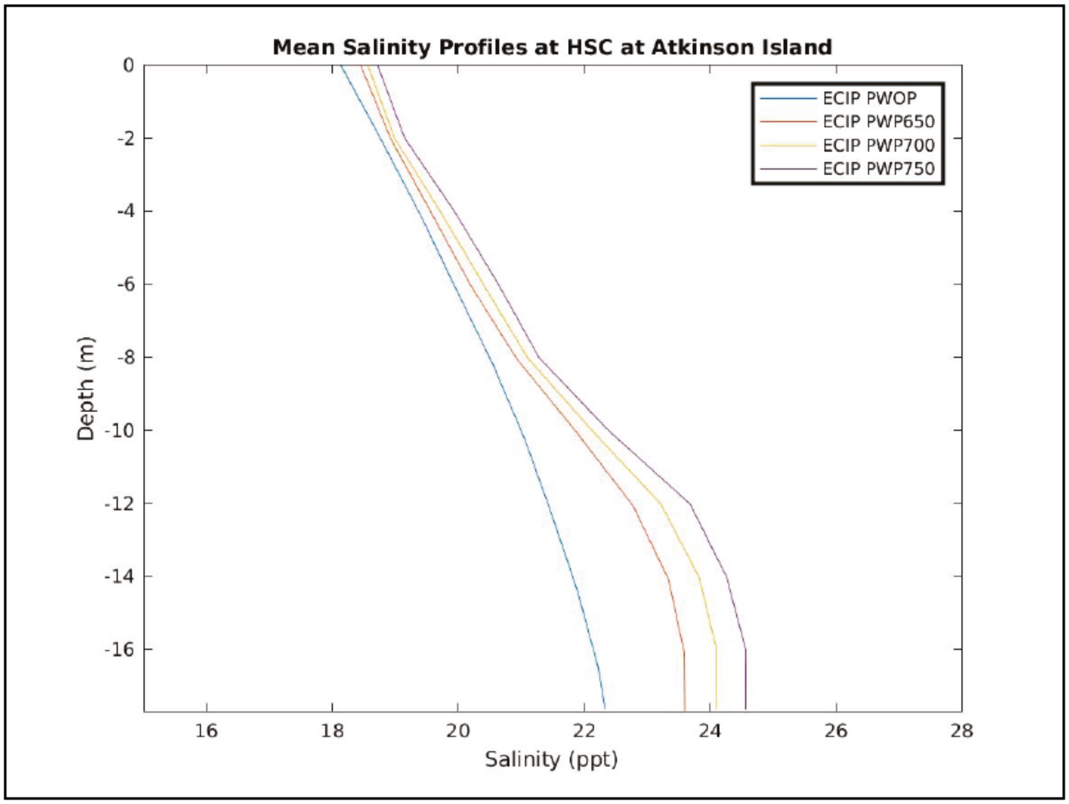

Salinity at HSC at Atkinson Island
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
Date (mm/dd)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

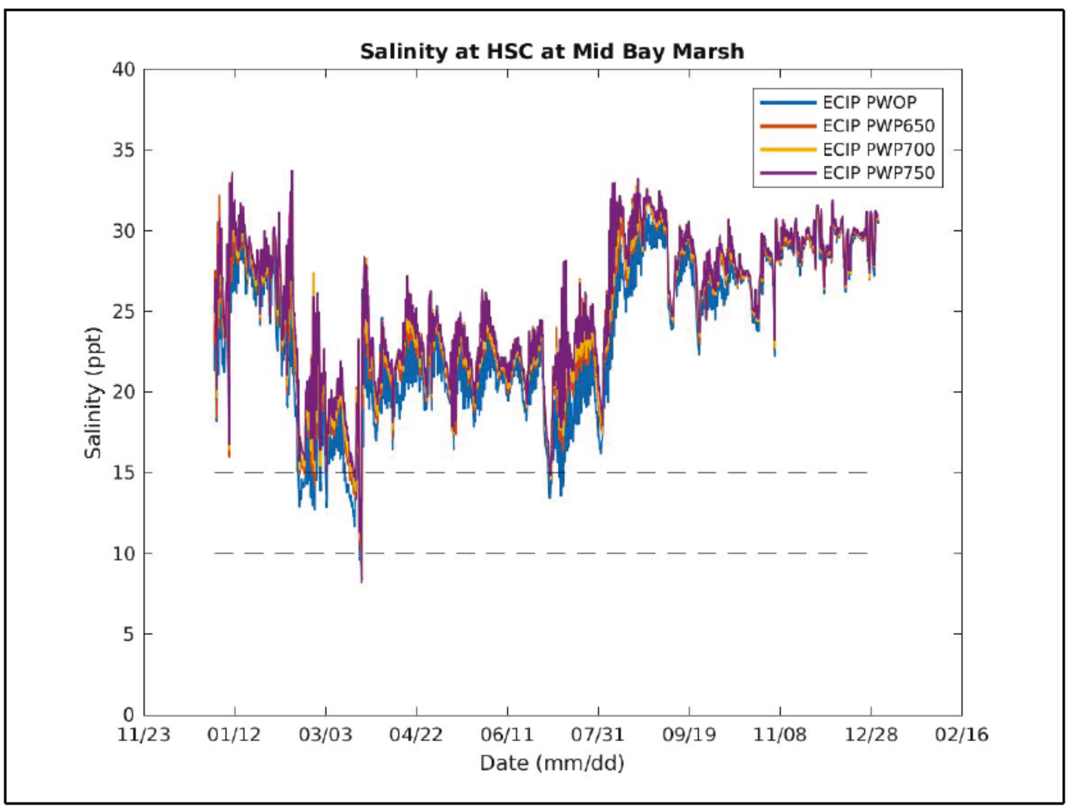

Surface Salinity at HSC at Atkinson Island
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

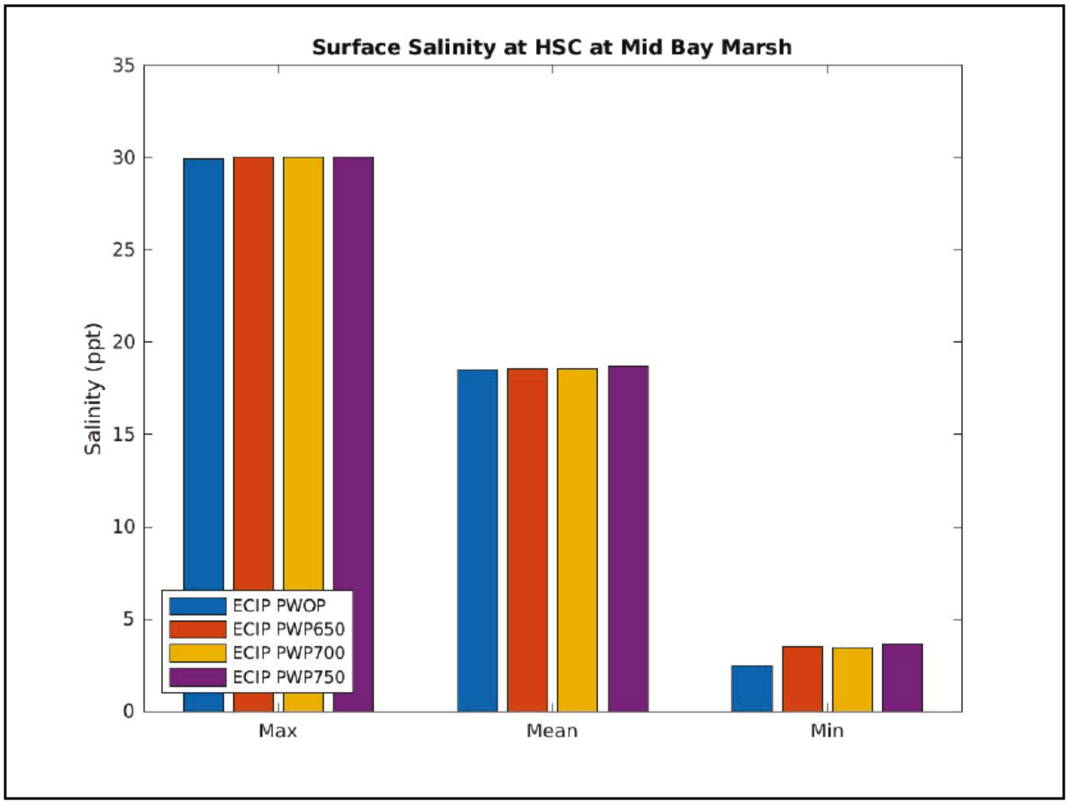

Bottom Salinity at HSC at Atkinson Island
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

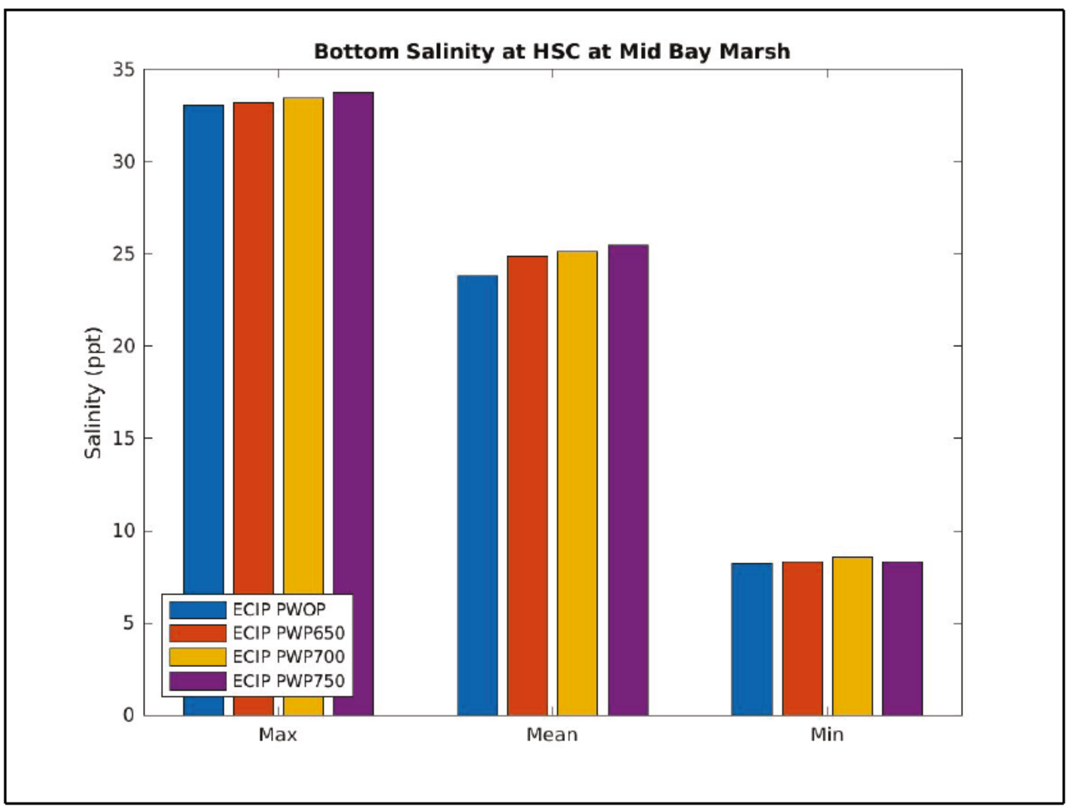

Surface Salinity Percentiles at HSC at Atkinson Island
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

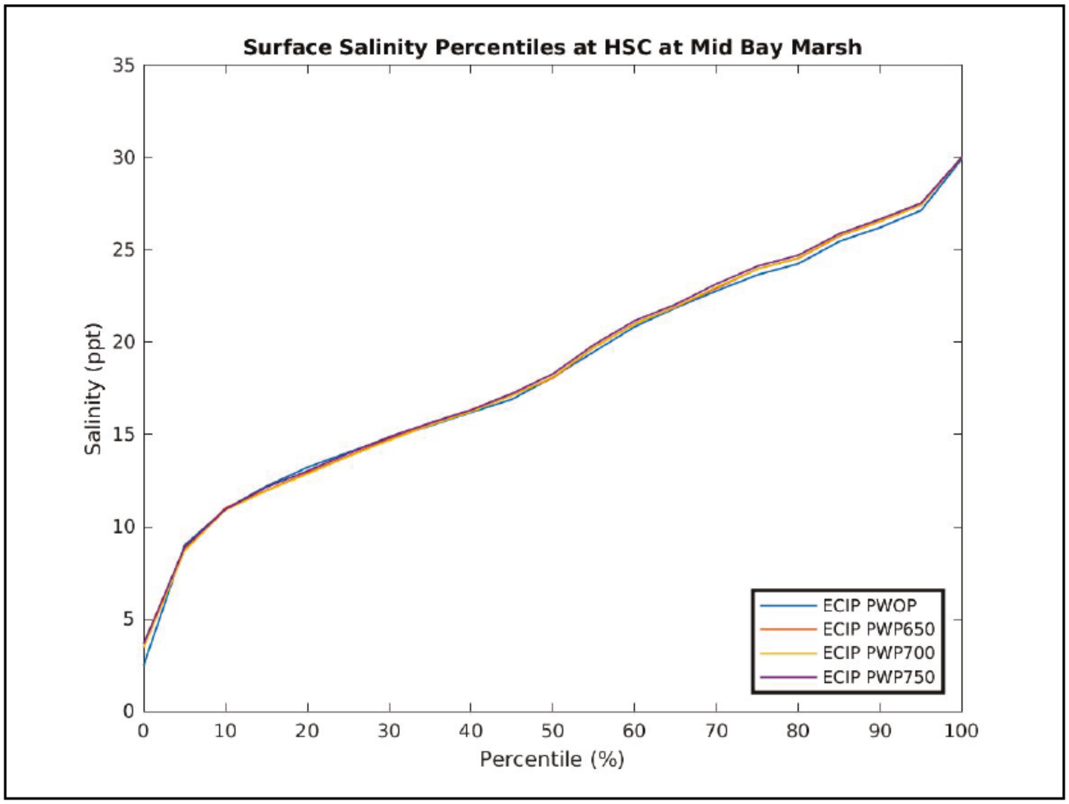

Bottom Salinity Percentiles at HSC at Atkinson Island
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

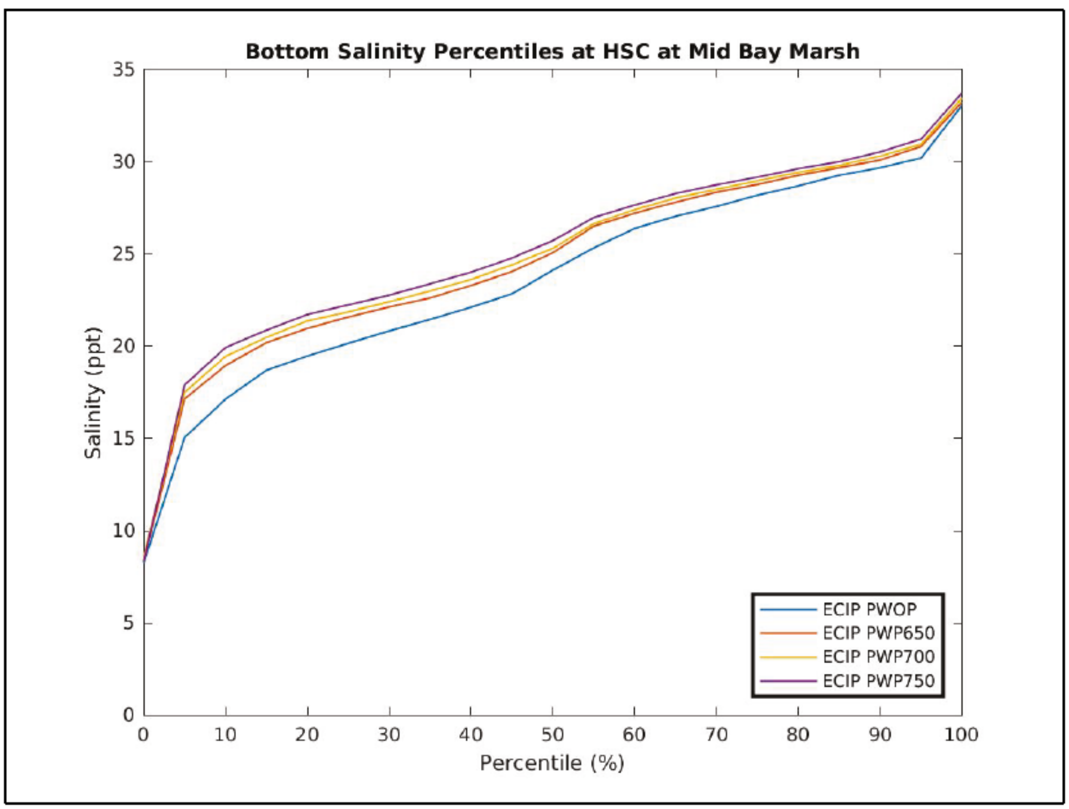

Mean Salinity Profiles at HSC at Atkinson Island
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
-16
16
18
20
22
24
26
28
Salinity (ppt)

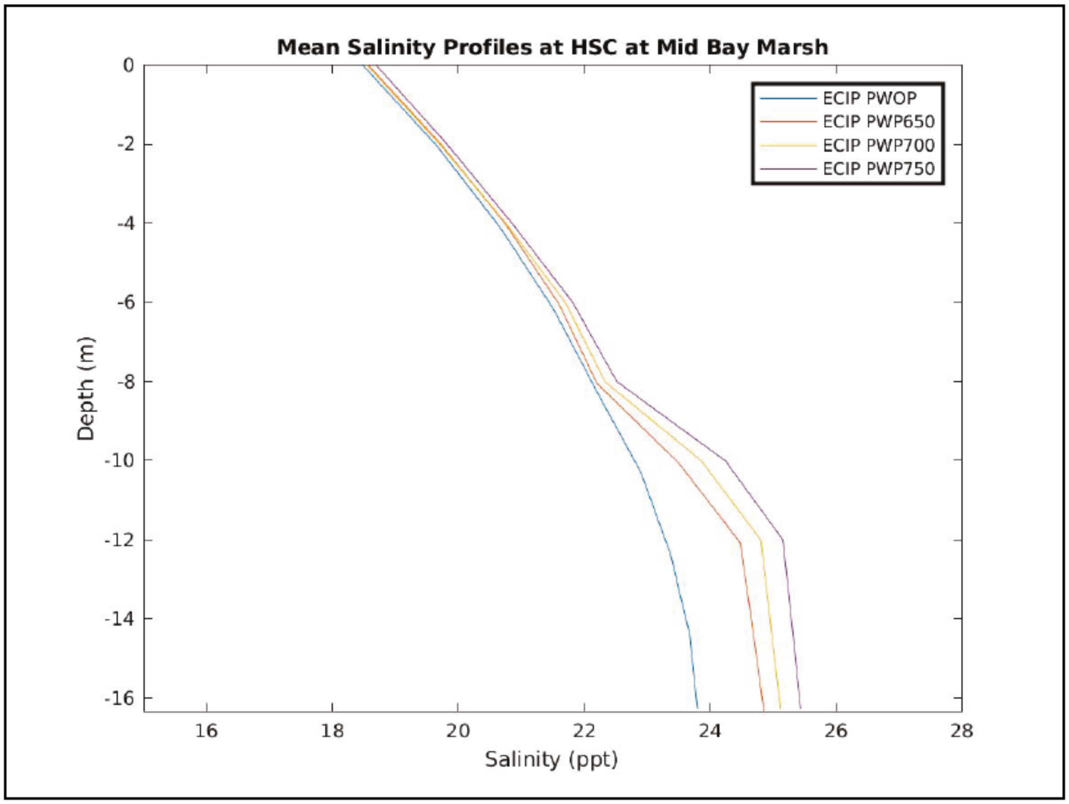

Salinity at HSC at Mid Bay Marsh
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

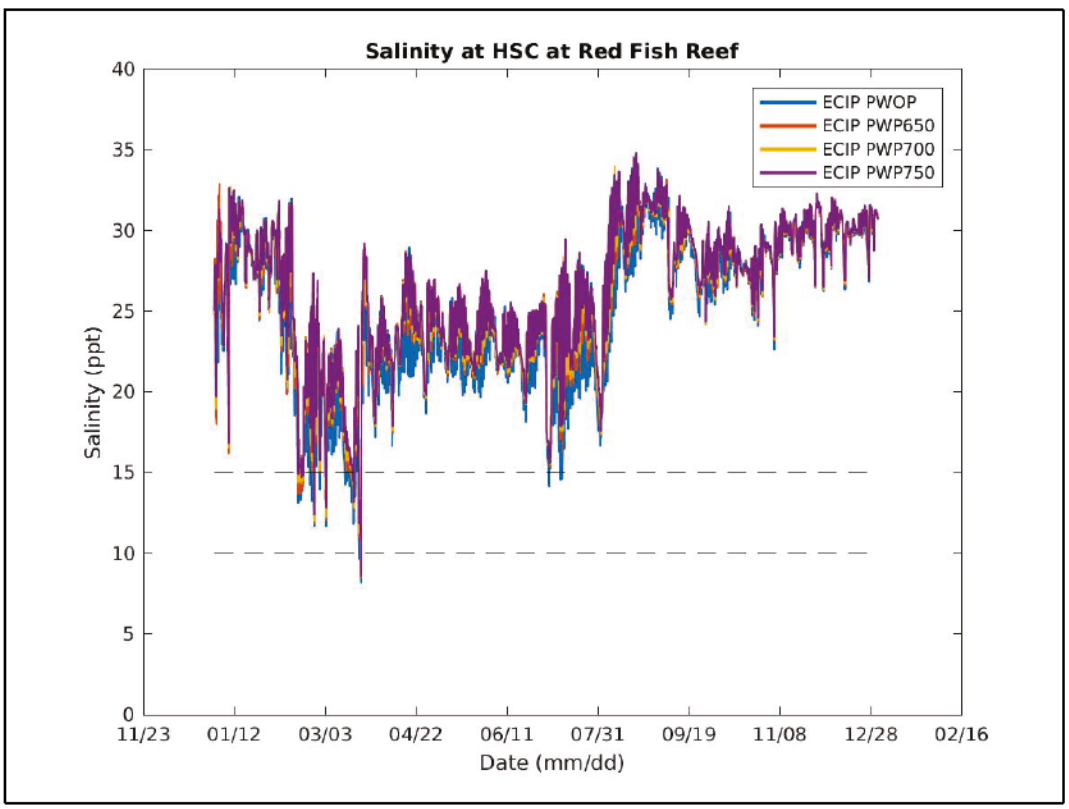

Surface Salinity at HSC at Mid Bay Marsh
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

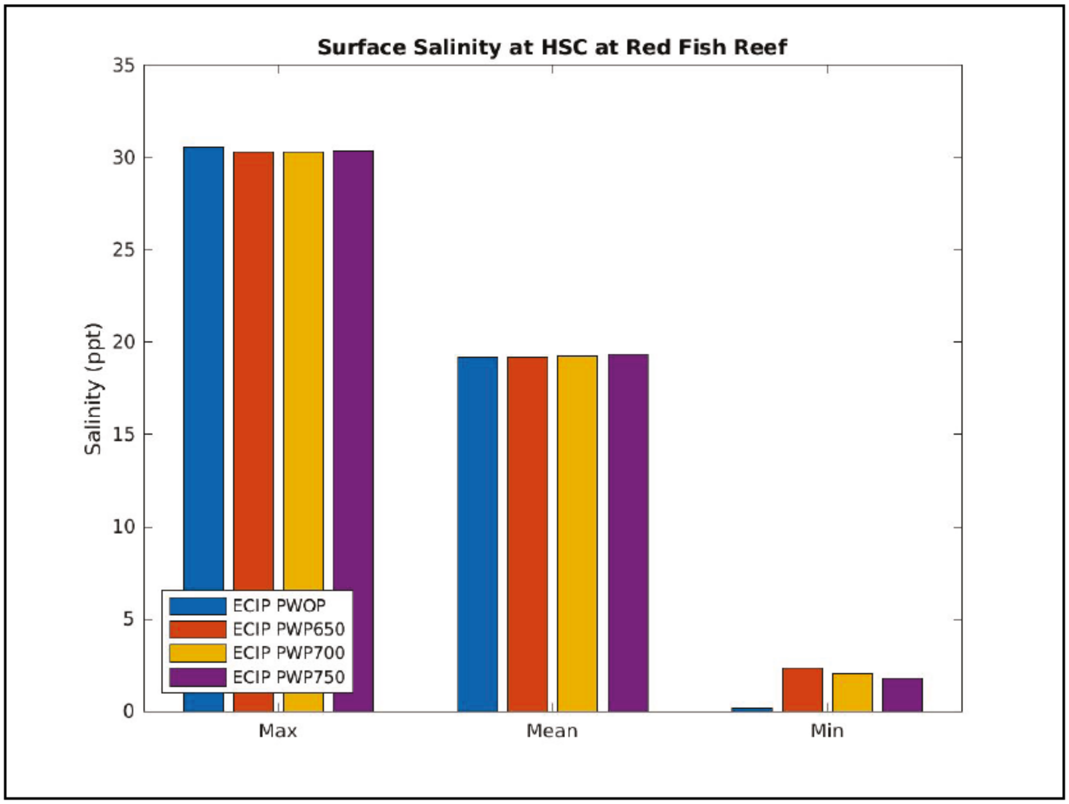

Bottom Salinity at HSC at Mid Bay Marsh
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

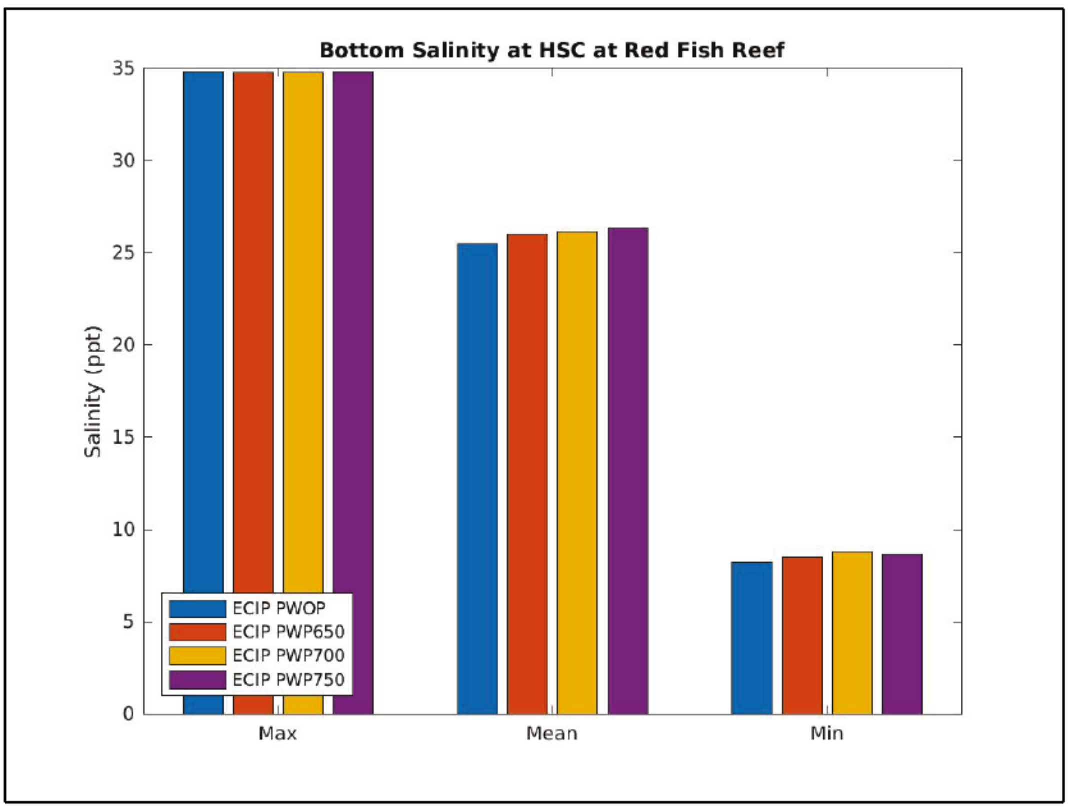

Surface Salinity Percentiles at HSC at Mid Bay Marsh
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

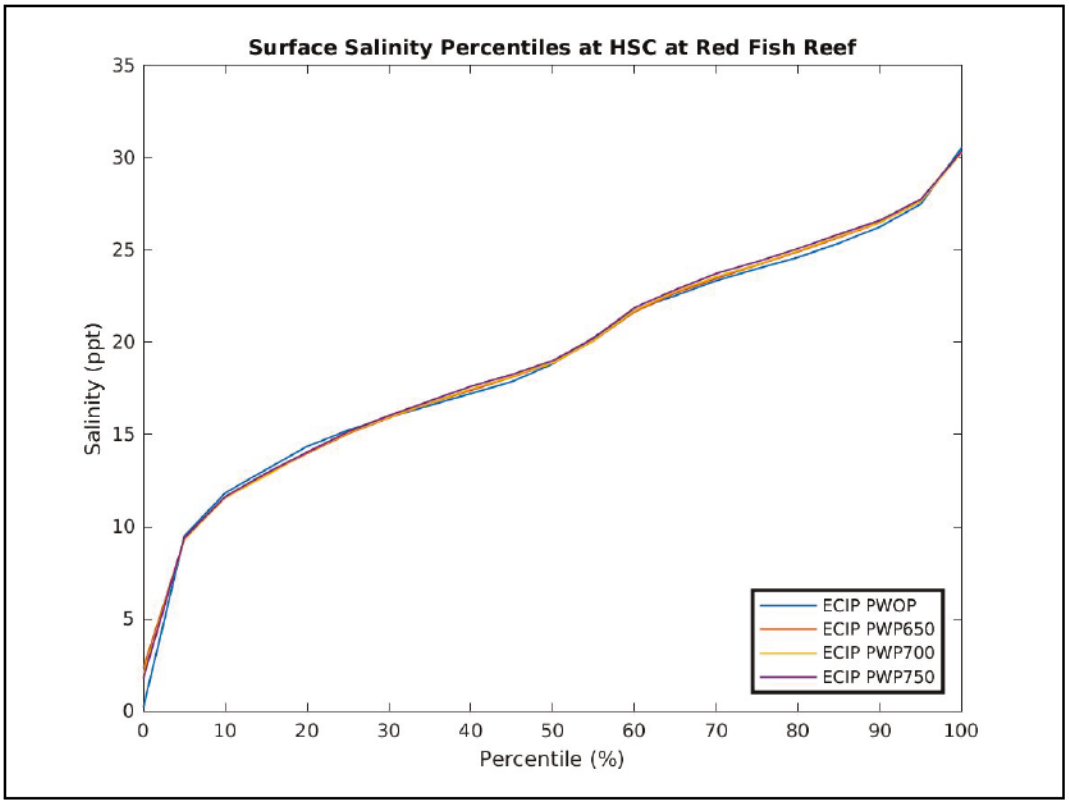

Bottom Salinity Percentiles at HSC at Mid Bay Marsh
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

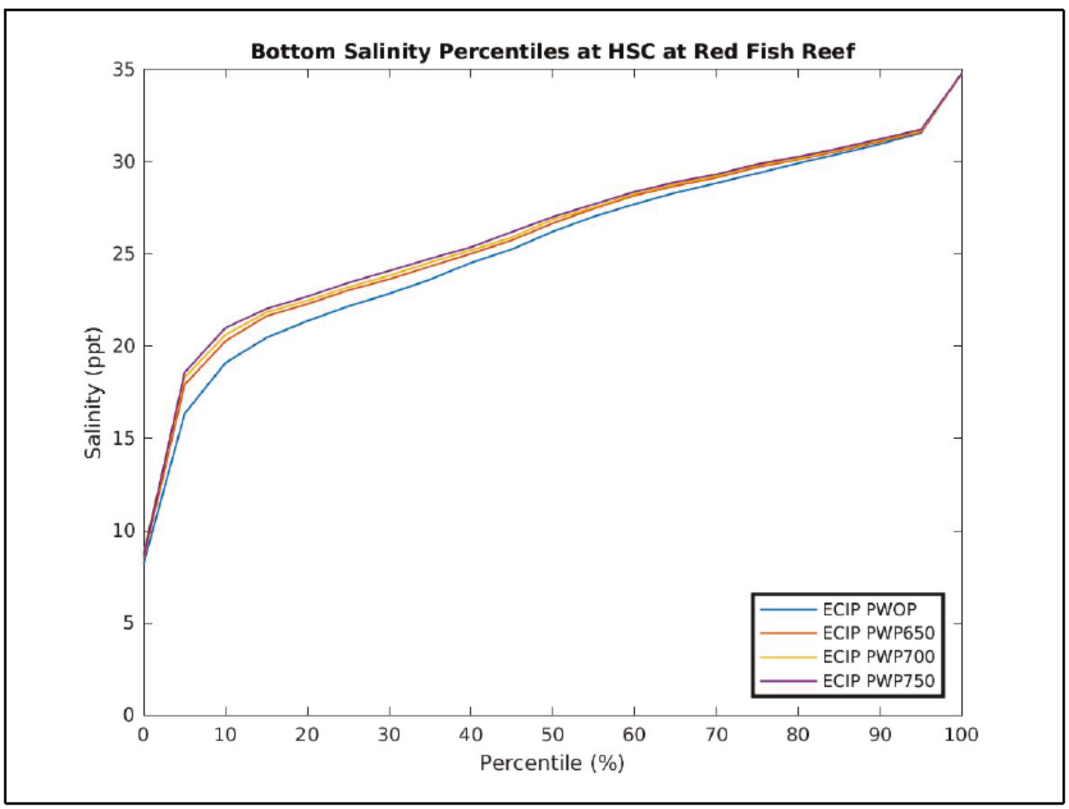

Mean Salinity Profiles at HSC at Mid Bay Marsh
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
-16
16
18
20
22
24
26
28
Salinity (ppt)

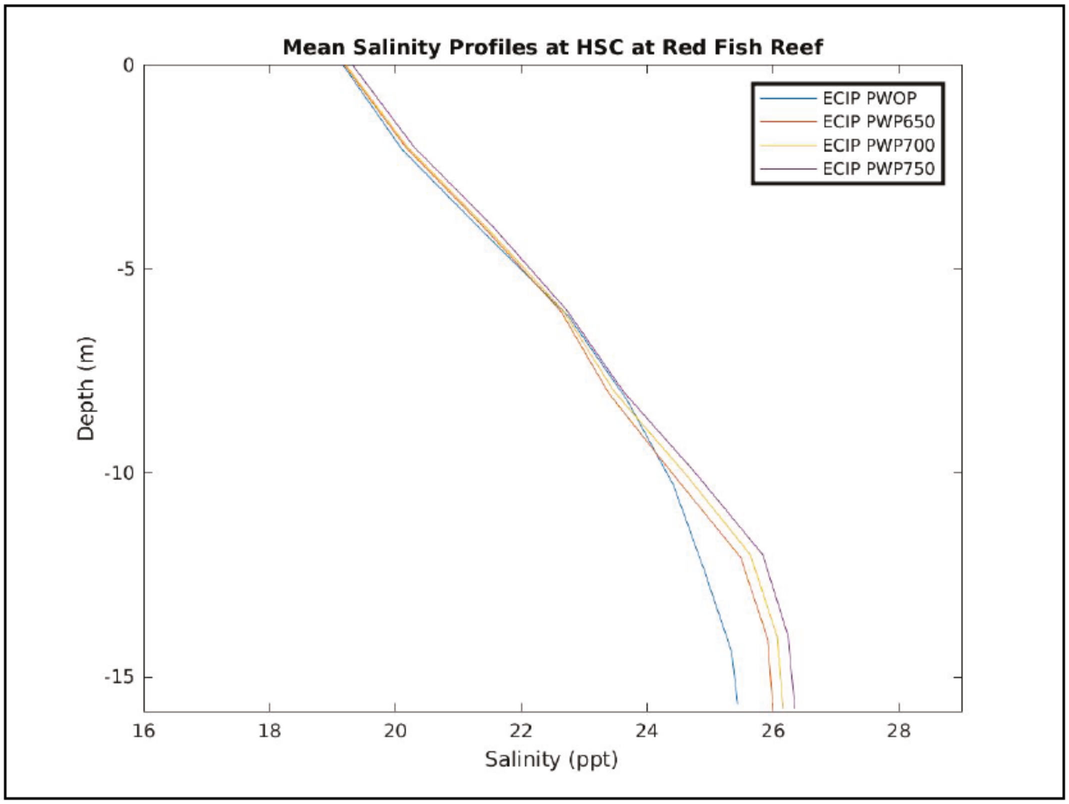

Salinity at HSC at Red Fish Reef
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

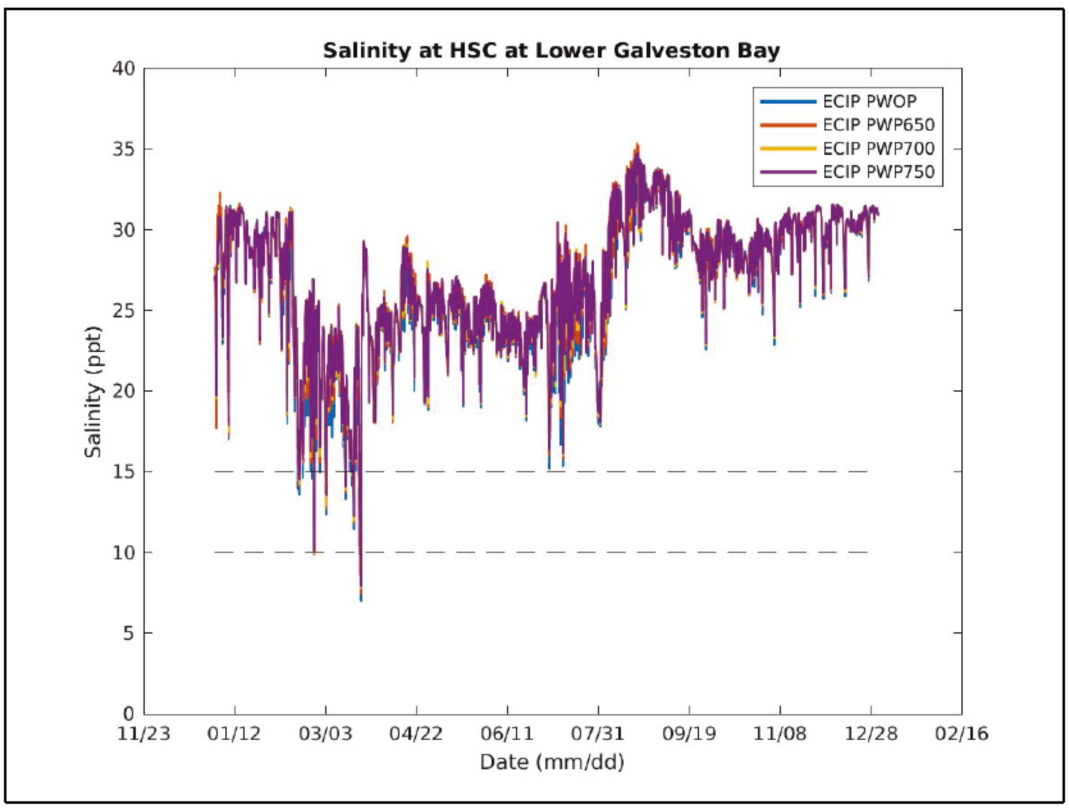

Surface Salinity at HSC at Red Fish Reef
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

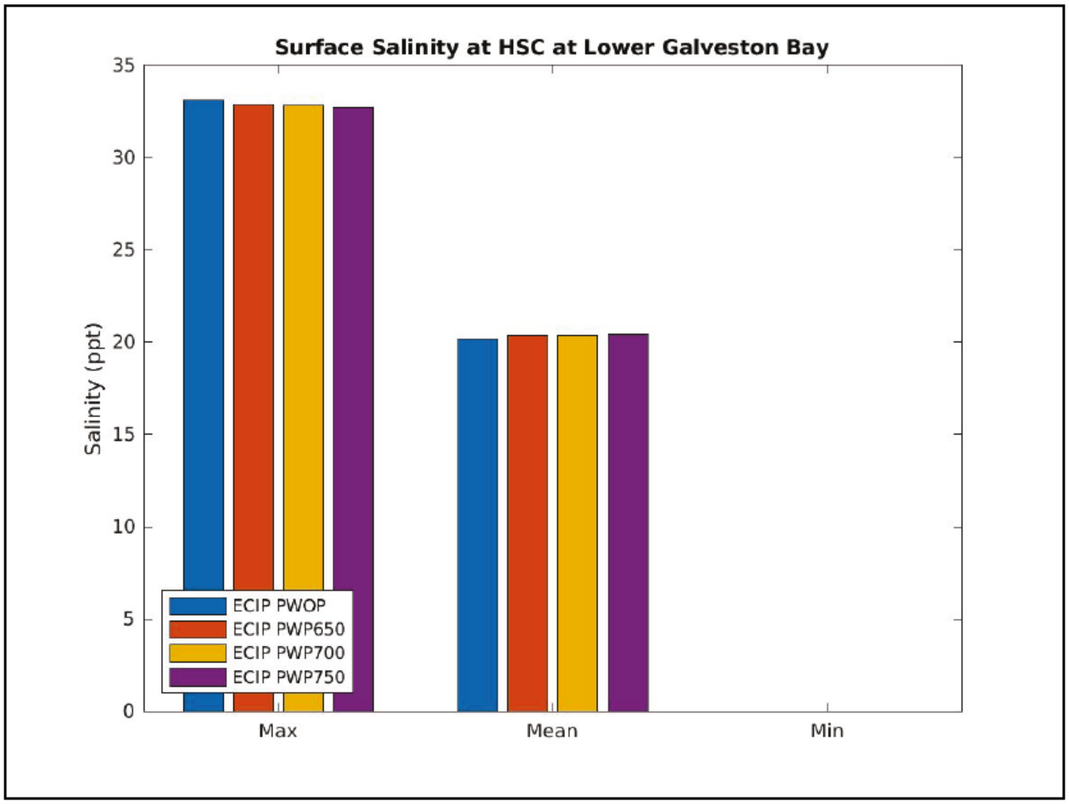

Bottom Salinity at HSC at Red Fish Reef
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

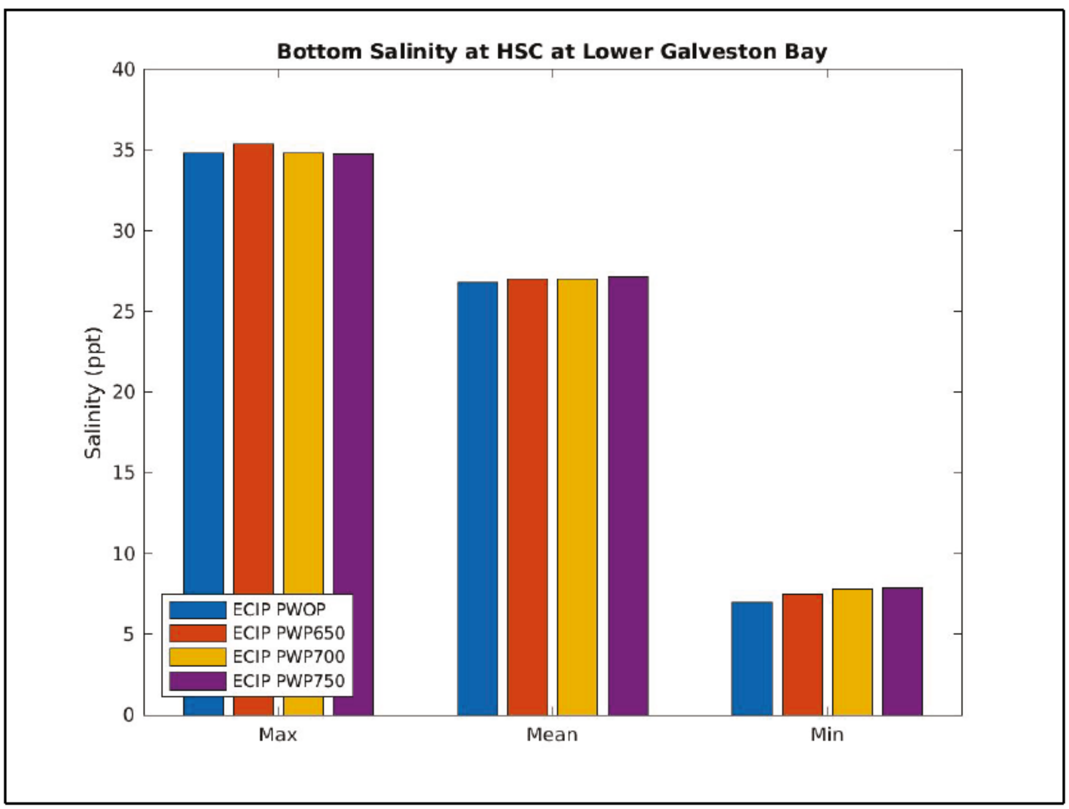

Surface Salinity Percentiles at HSC at Red Fish Reef
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

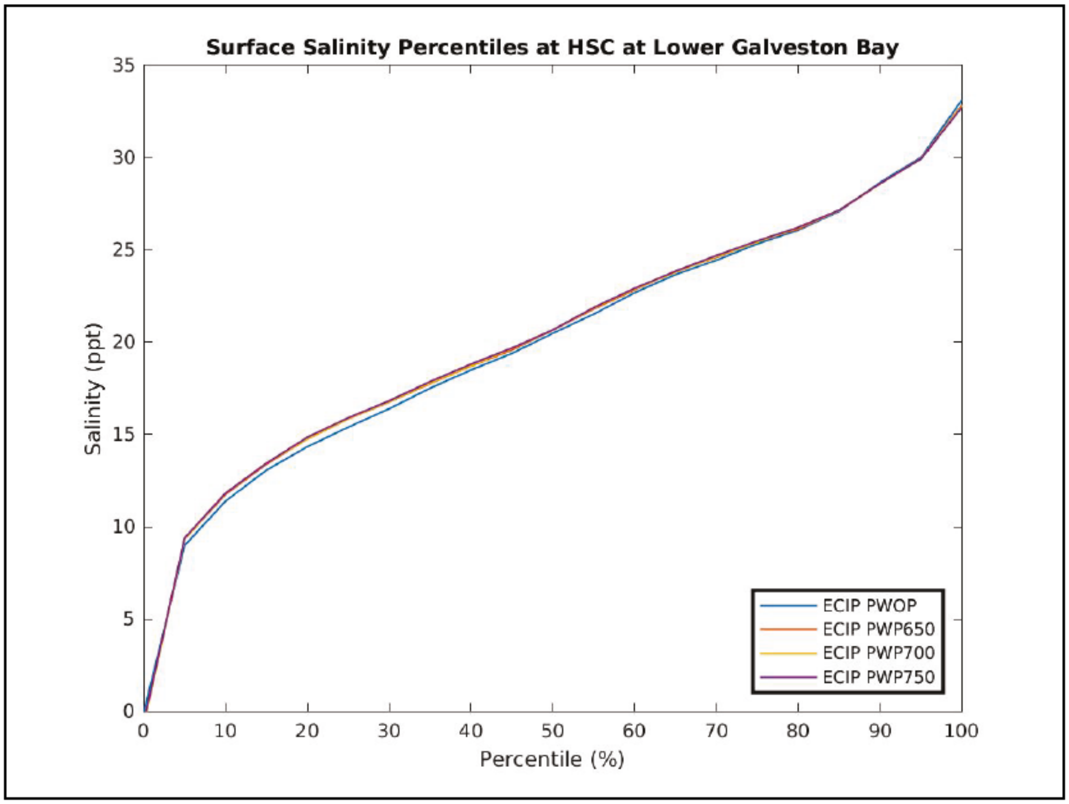

Bottom Salinity Percentiles at HSC at Red Fish Reef
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

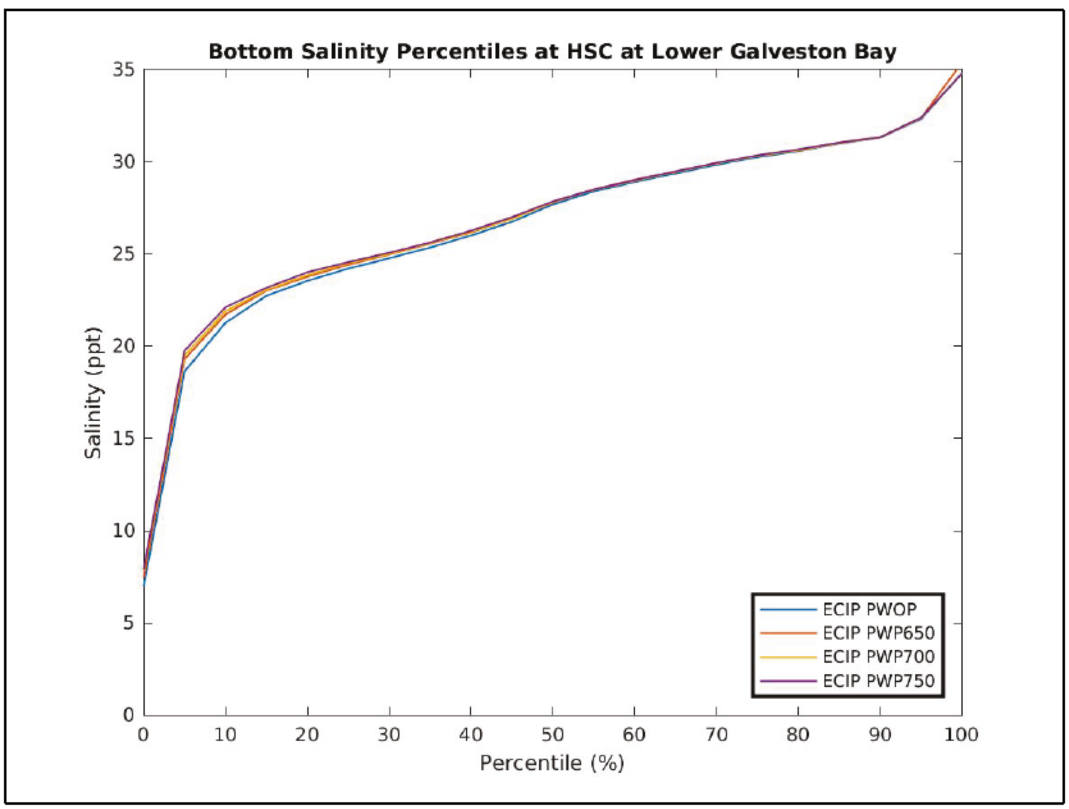

Mean Salinity Profiles at HSC at Red Fish Reef
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-5
-10
-15
16
18
20
22
24
26
28
Salinity (ppt)

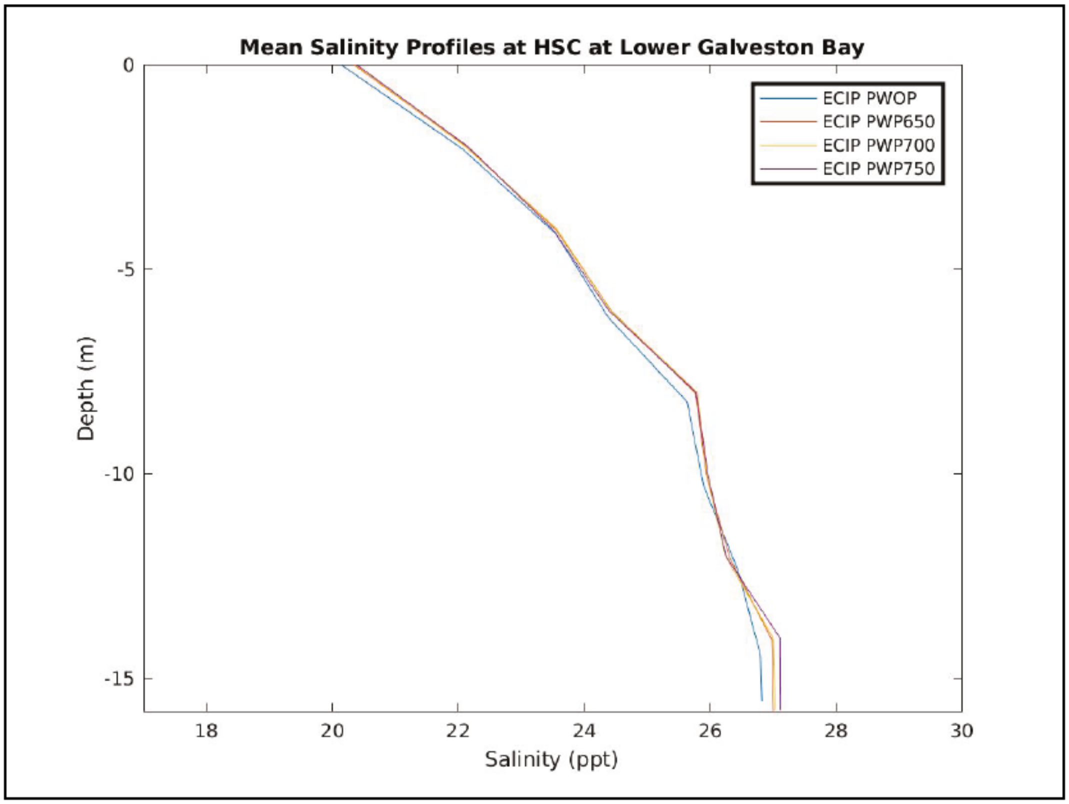

Salinity at HSC at Lower Galveston Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

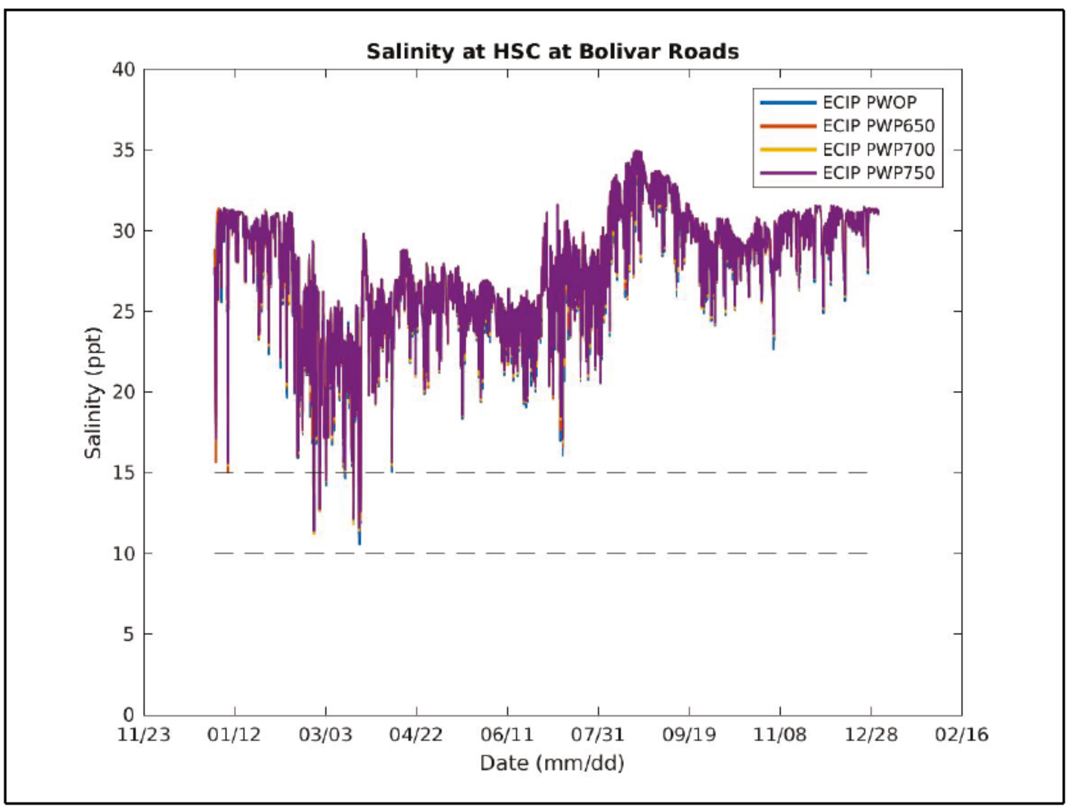

Surface Salinity at HSC at Lower Galveston Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

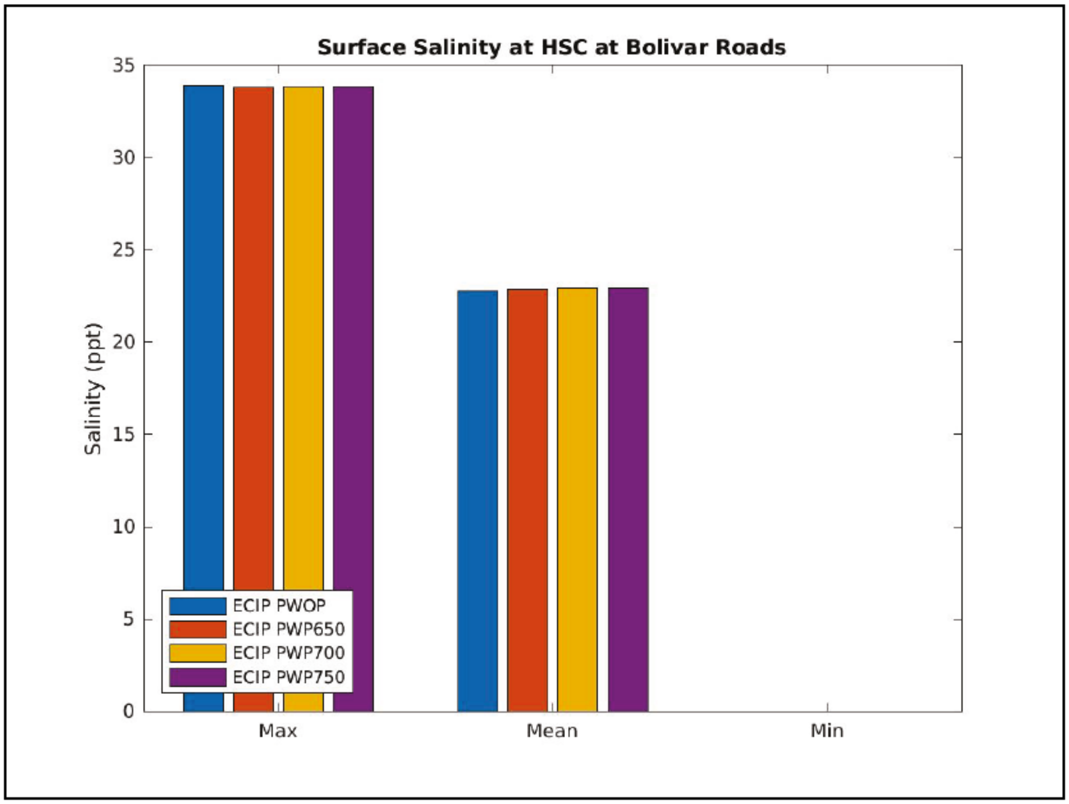

Bottom Salinity at HSC at Lower Galveston Bay
Salinity (ppt)
40
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

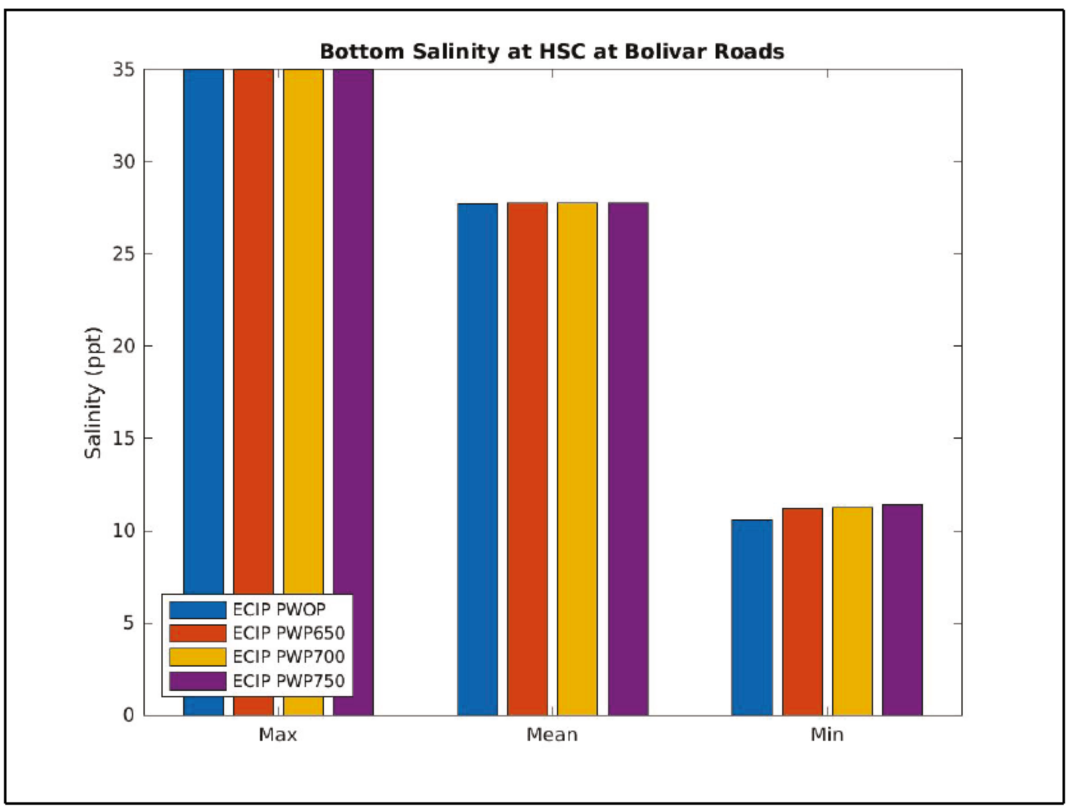

Surface Salinity Percentiles at HSC at Lower Galveston Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

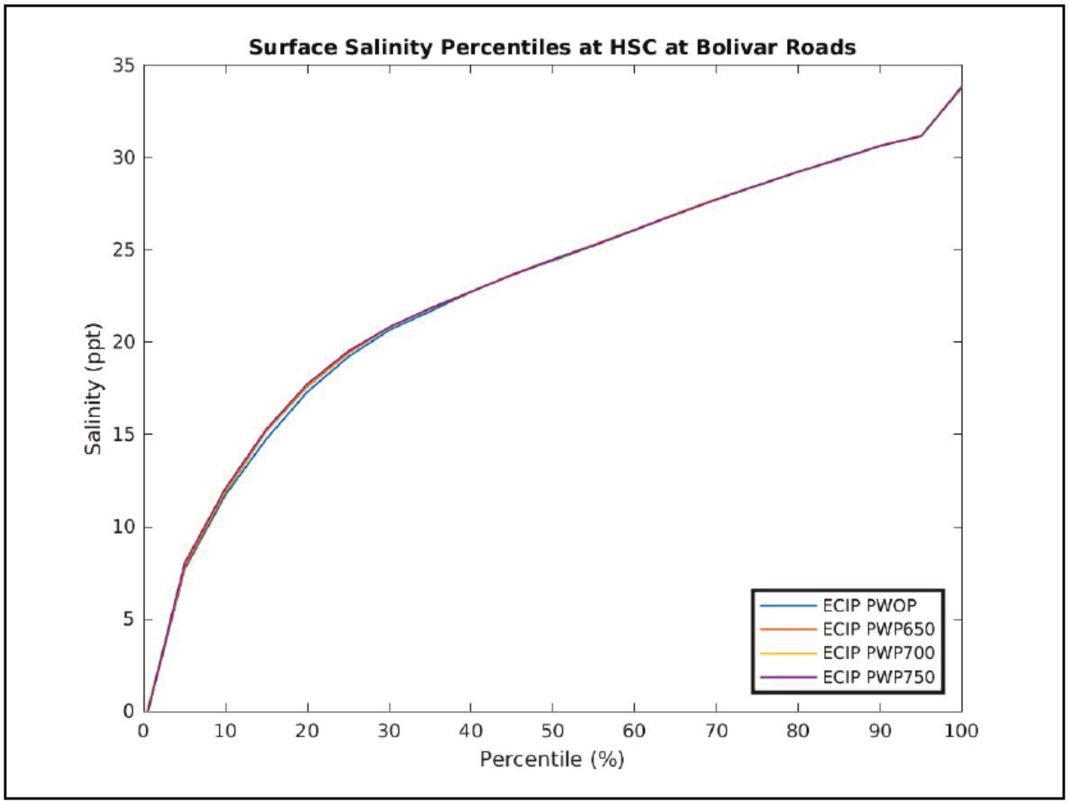

Bottom Salinity Percentiles at HSC at Lower Galveston Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

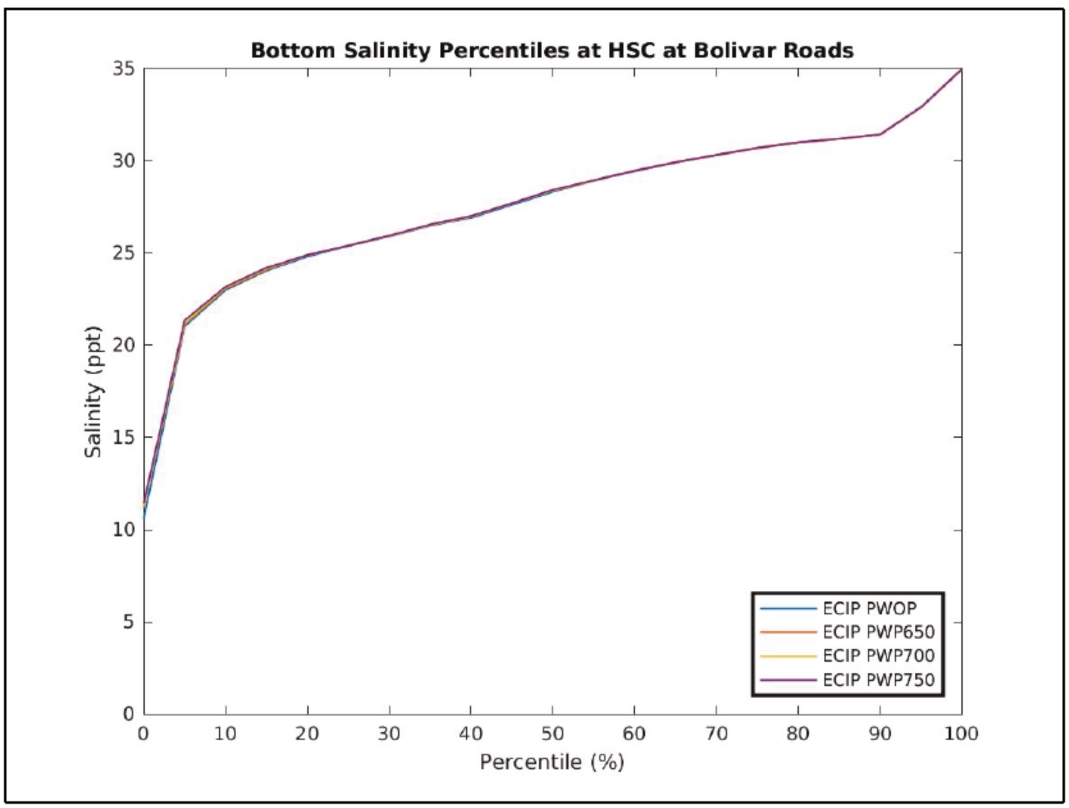

Mean Salinity Profiles at HSC at Lower Galveston Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
Salinity (ppt)
0
-5
-10
-15
18
20
22
24
26
28
30

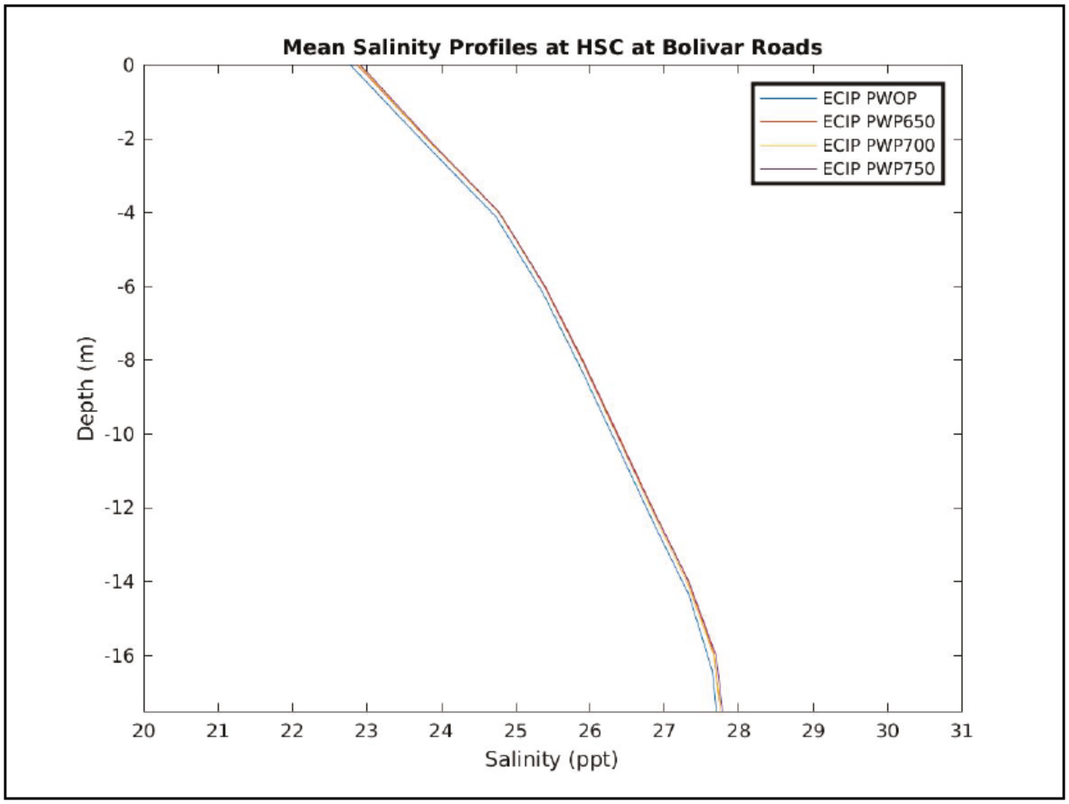

Salinity at HSC at Bolivar Roads
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
Date (mm/dd)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

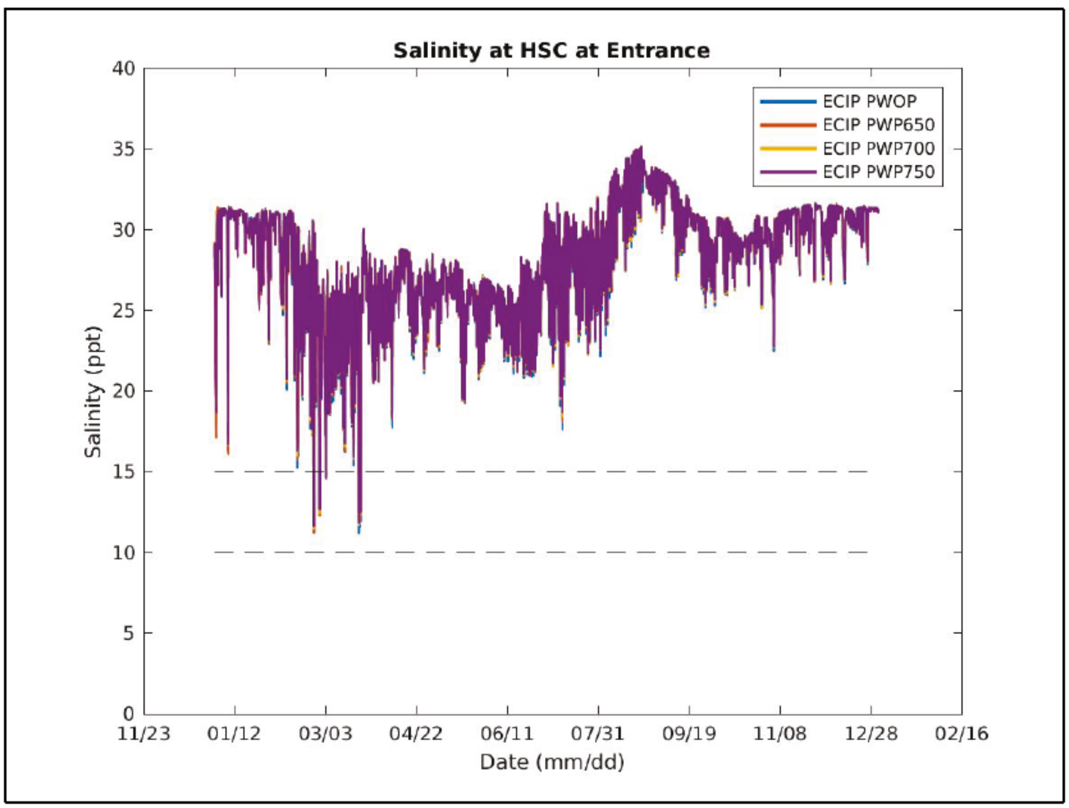

Surface Salinity at HSC at Bolivar Roads
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

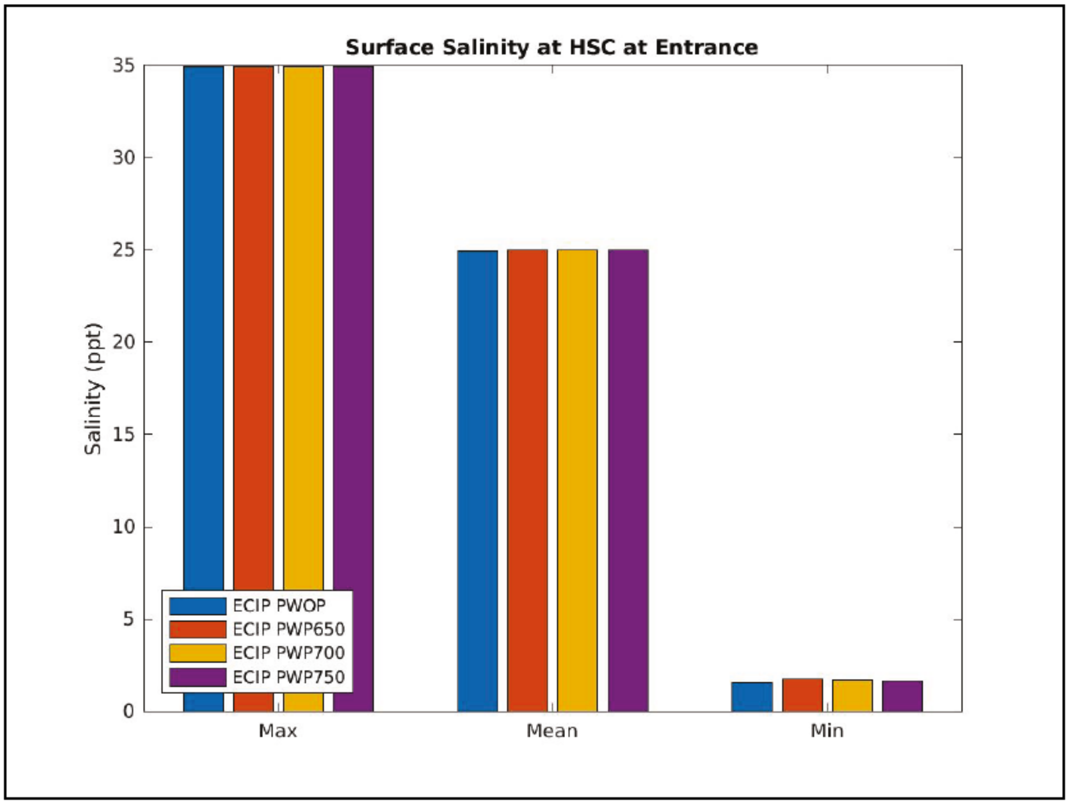

Bottom Salinity at HSC at Bolivar Roads
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

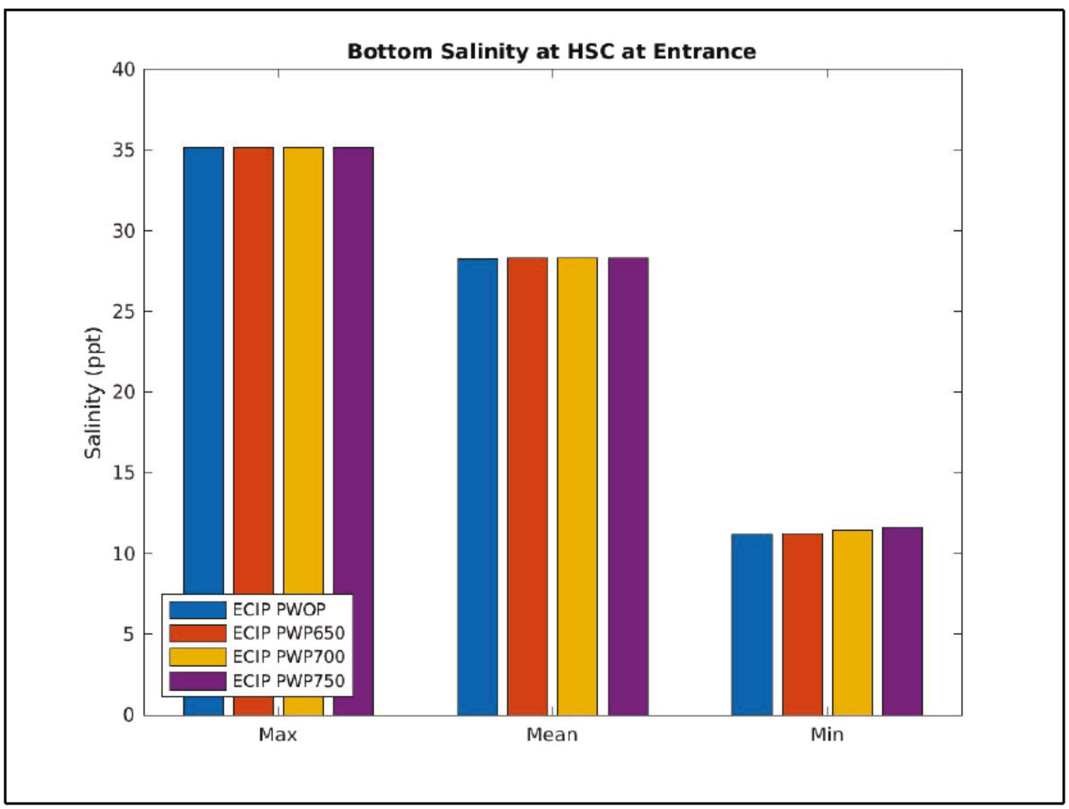

Surface Salinity Percentiles at HSC at Bolivar Roads
Salinity (ppt)
0
5
10
15
20
25
30
35
Percentile (%)
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

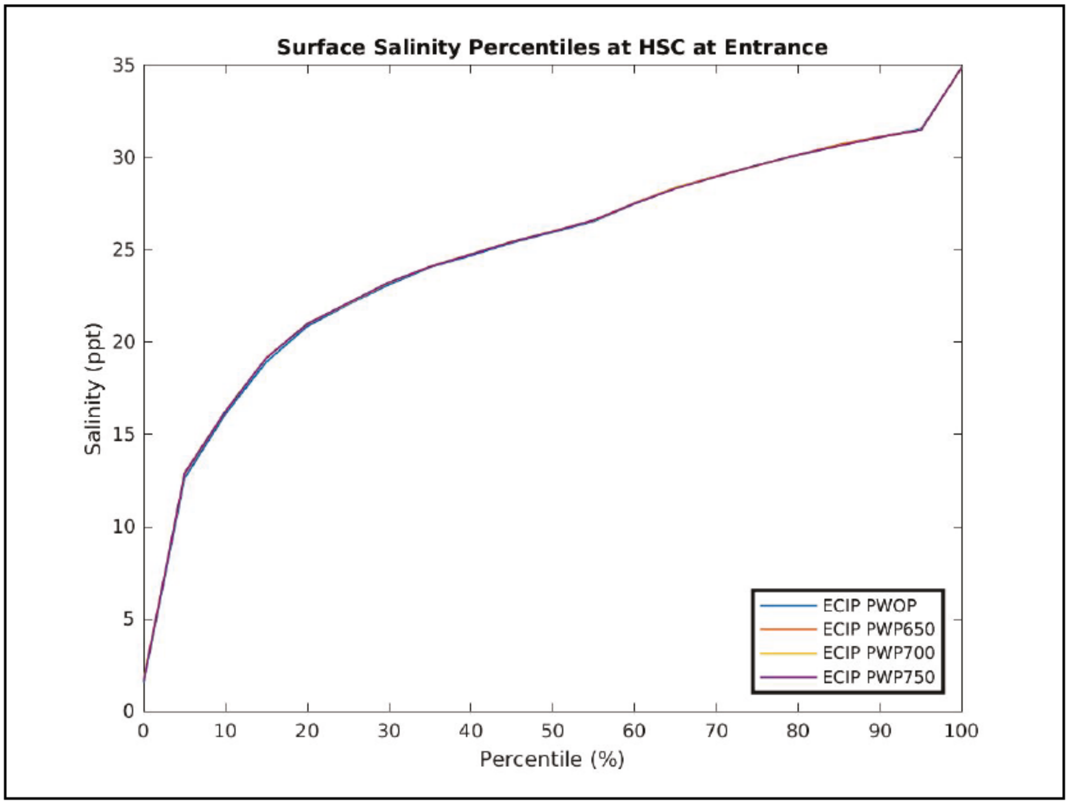

Bottom Salinity Percentiles at HSC at Bolivar Roads
Salinity (ppt)
0
5
10
15
20
25
30
35
Percentile (%)
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

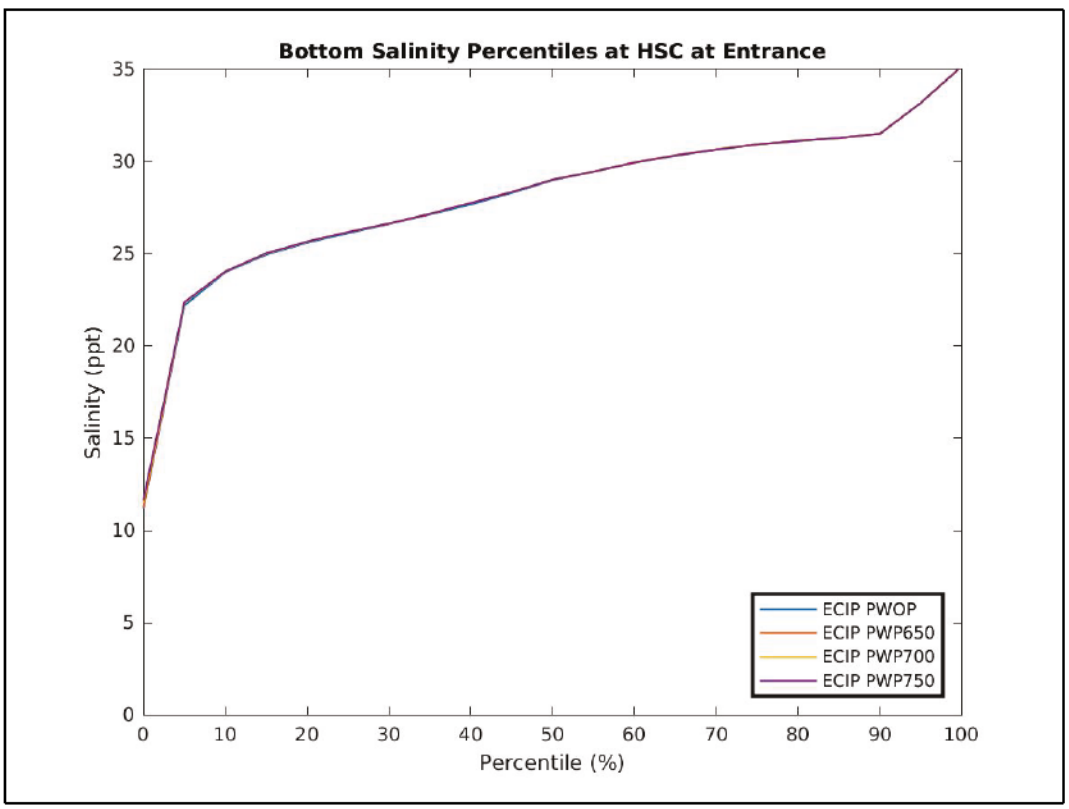

Mean Salinity Profiles at HSC at Bolivar Roads
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
-16
20
21
22
23
24
25
26
27
28
29
30
31
Salinity (ppt)

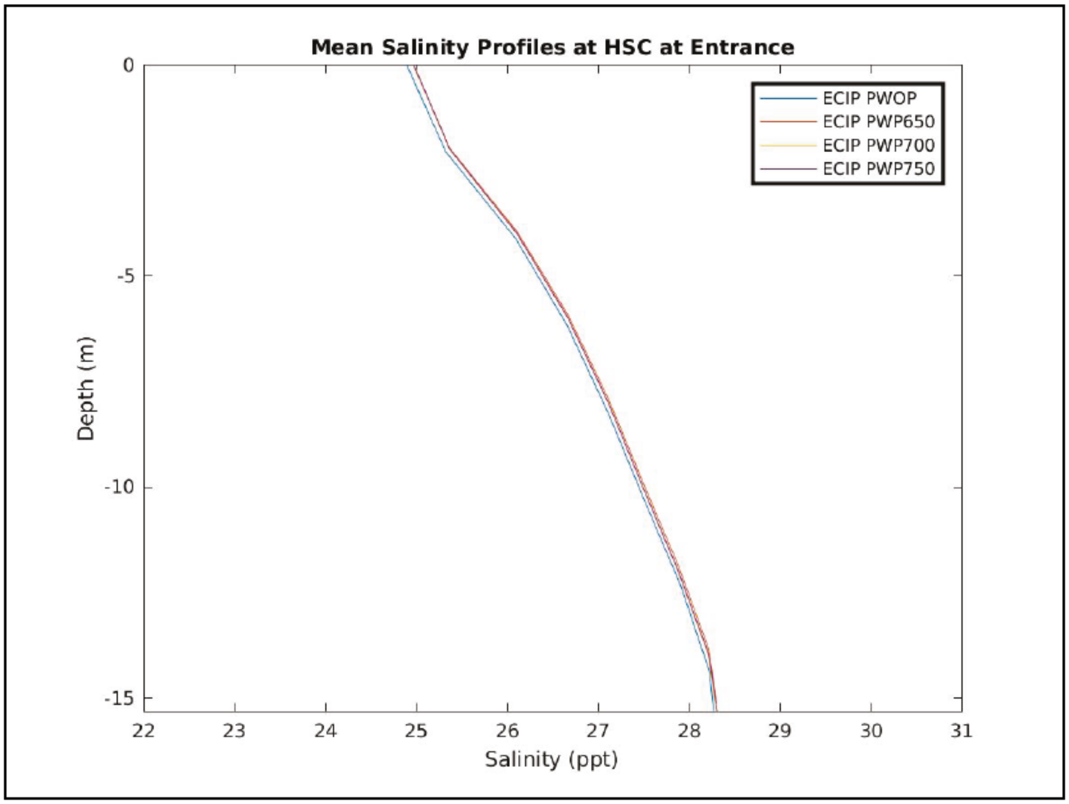

Salinity at HSC at Entrance
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

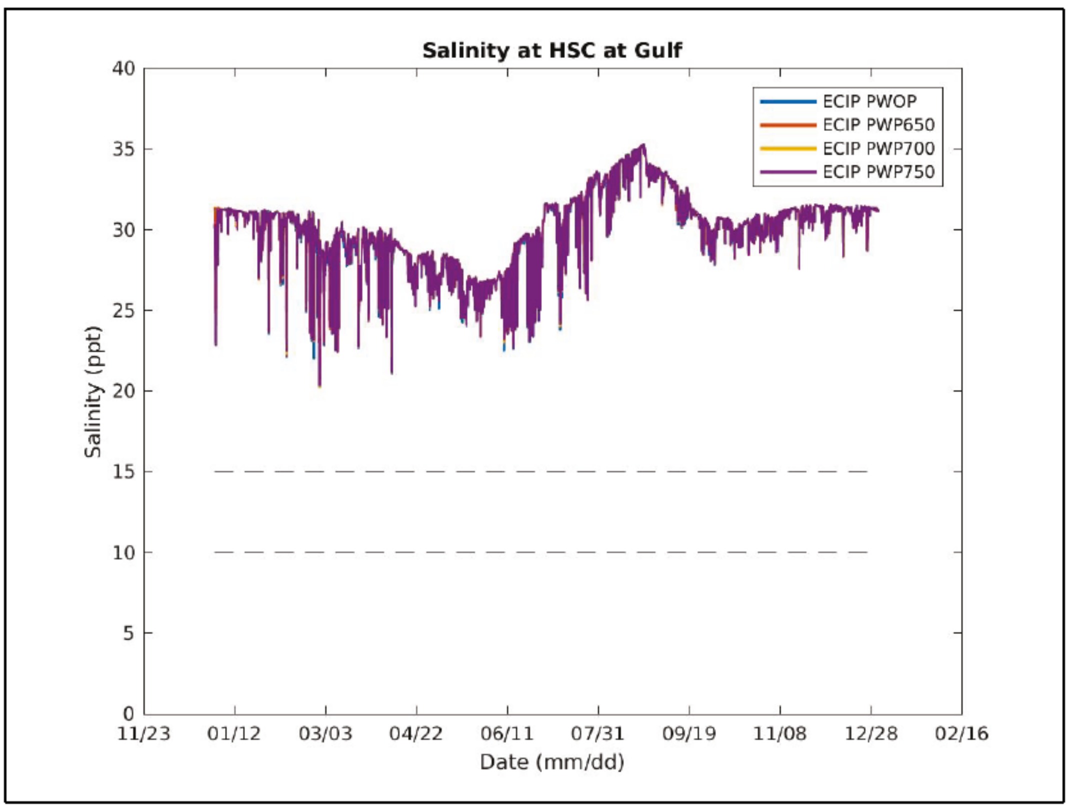

Surface Salinity at HSC at Entrance
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

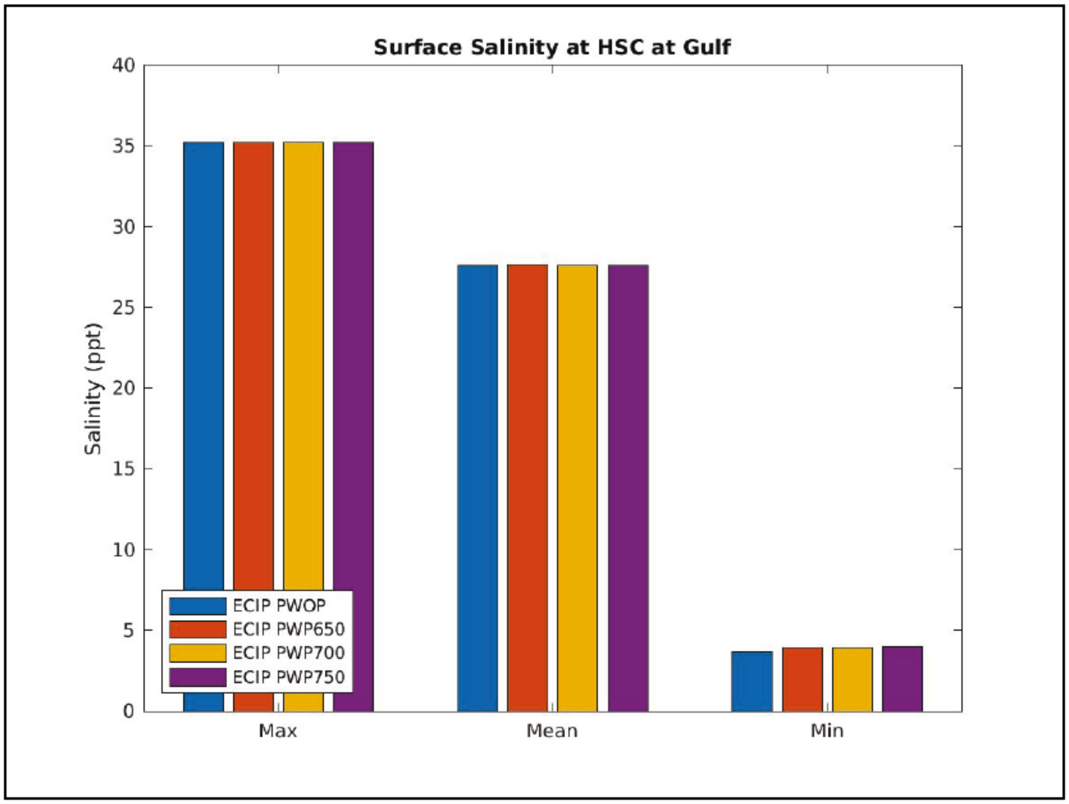

Bottom Salinity at HSC at Entrance
Salinity (ppt)
40
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

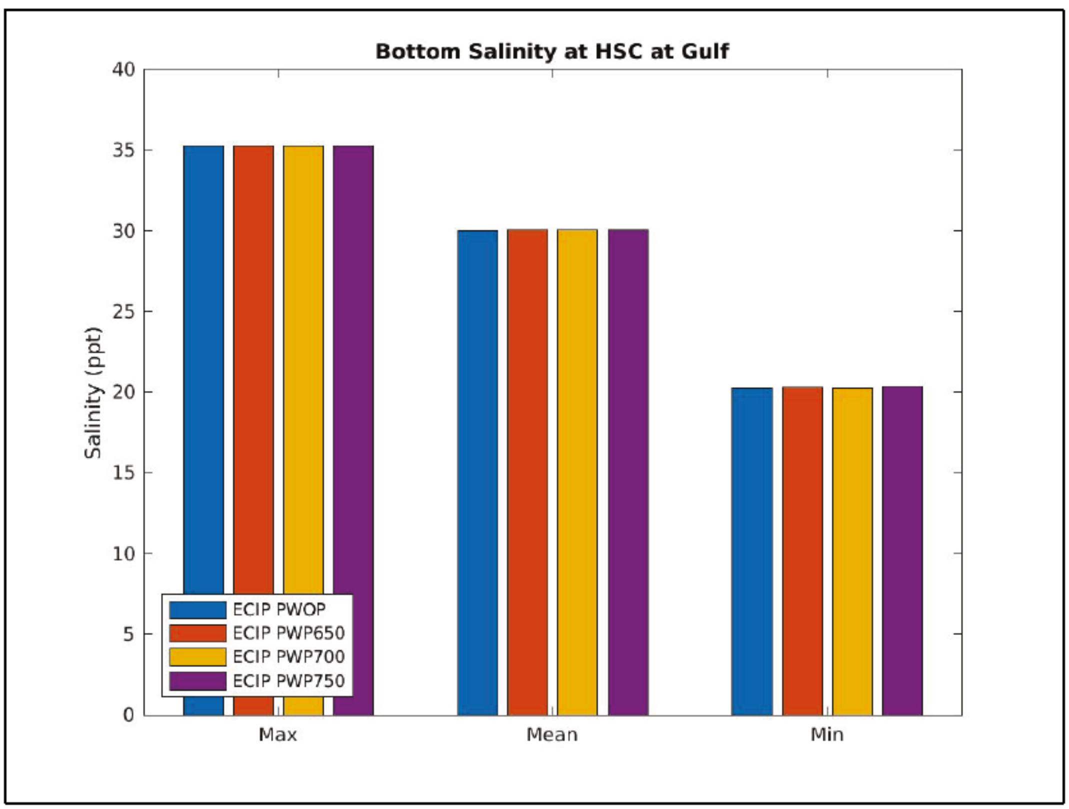

Surface Salinity Percentiles at HSC at Entrance
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

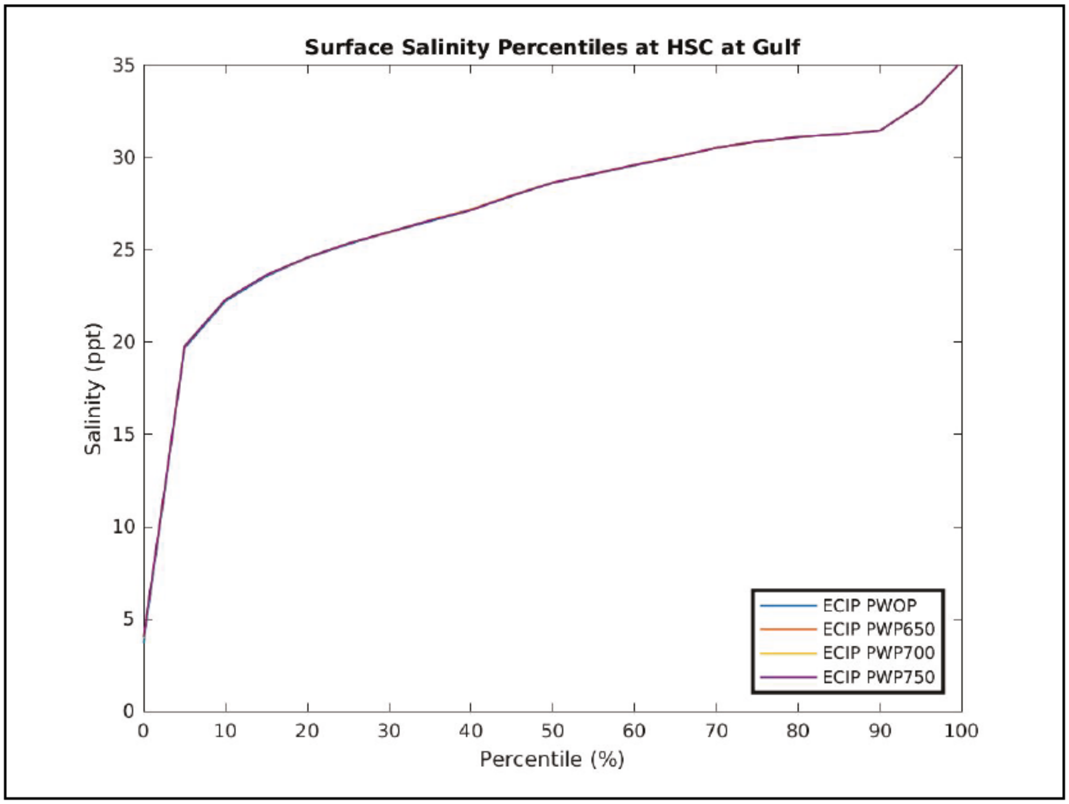

Bottom Salinity Percentiles at HSC at Entrance
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

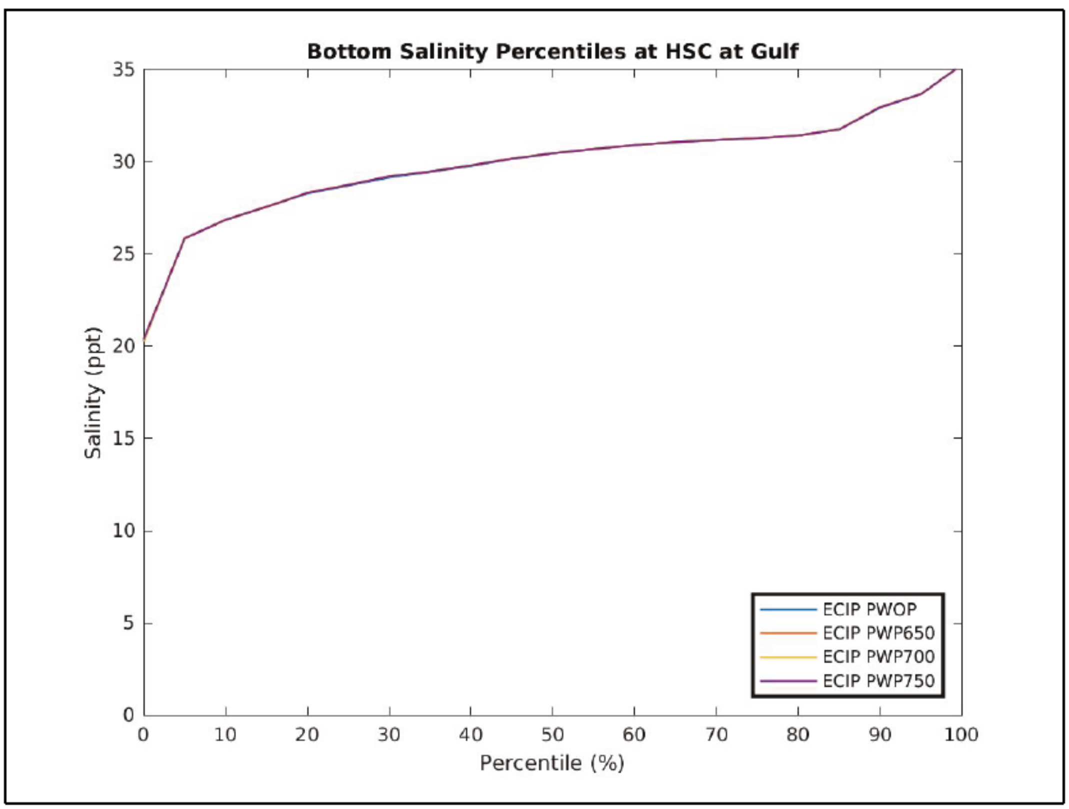

Mean Salinity Profiles at HSC at Entrance
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
Salinity (ppt)
0
-5
-10
-15
22
23
24
25
26
27
28
29
30
31

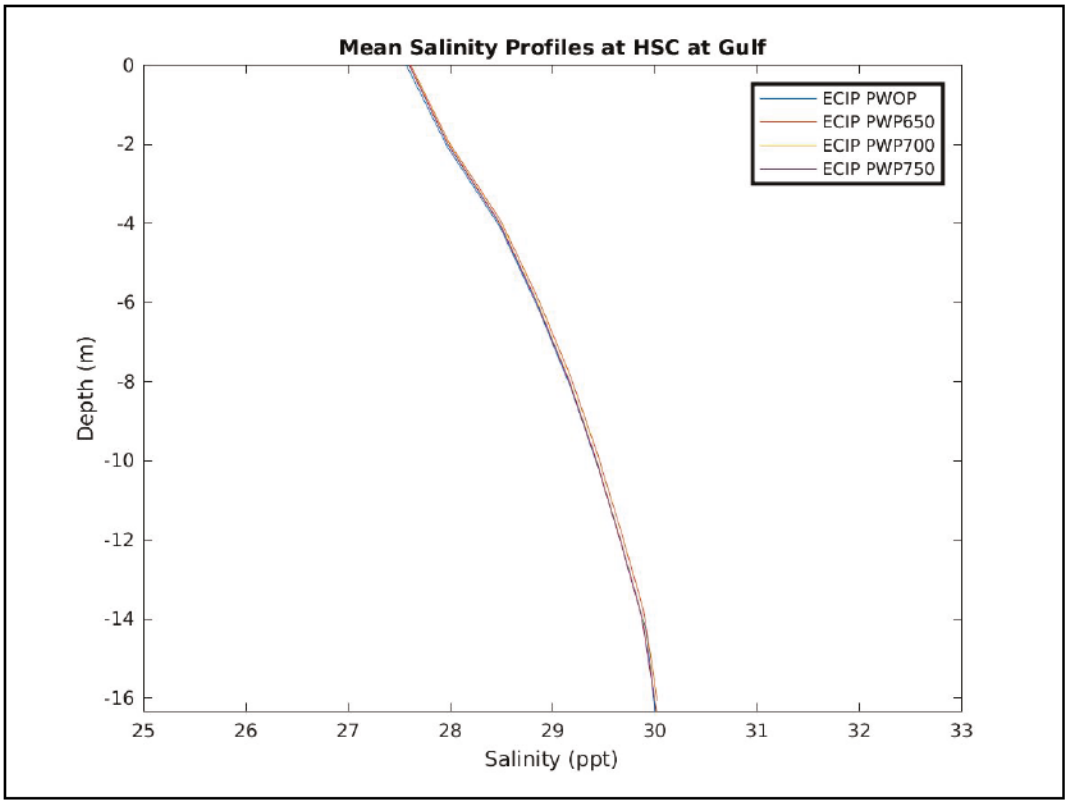

Salinity at HSC at Gulf
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
Date (mm/dd)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

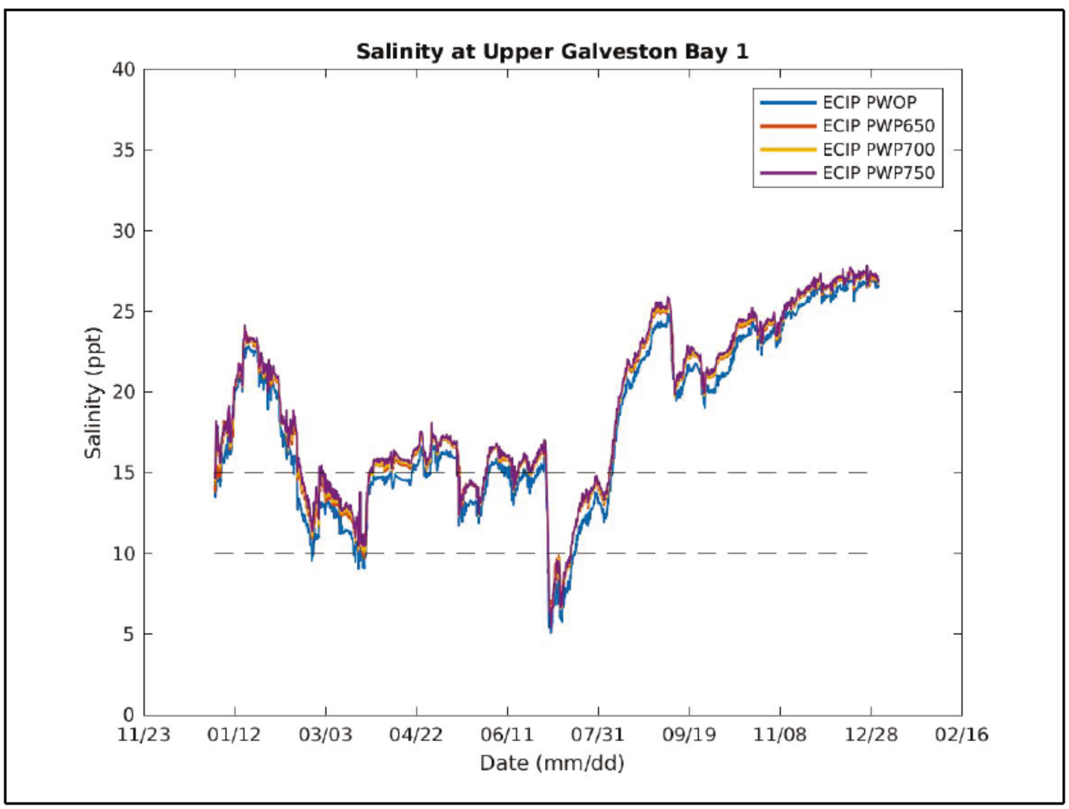

Surface Salinity at HSC at Gulf
Salinity (ppt)
0
5
10
15
20
25
30
35
40
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

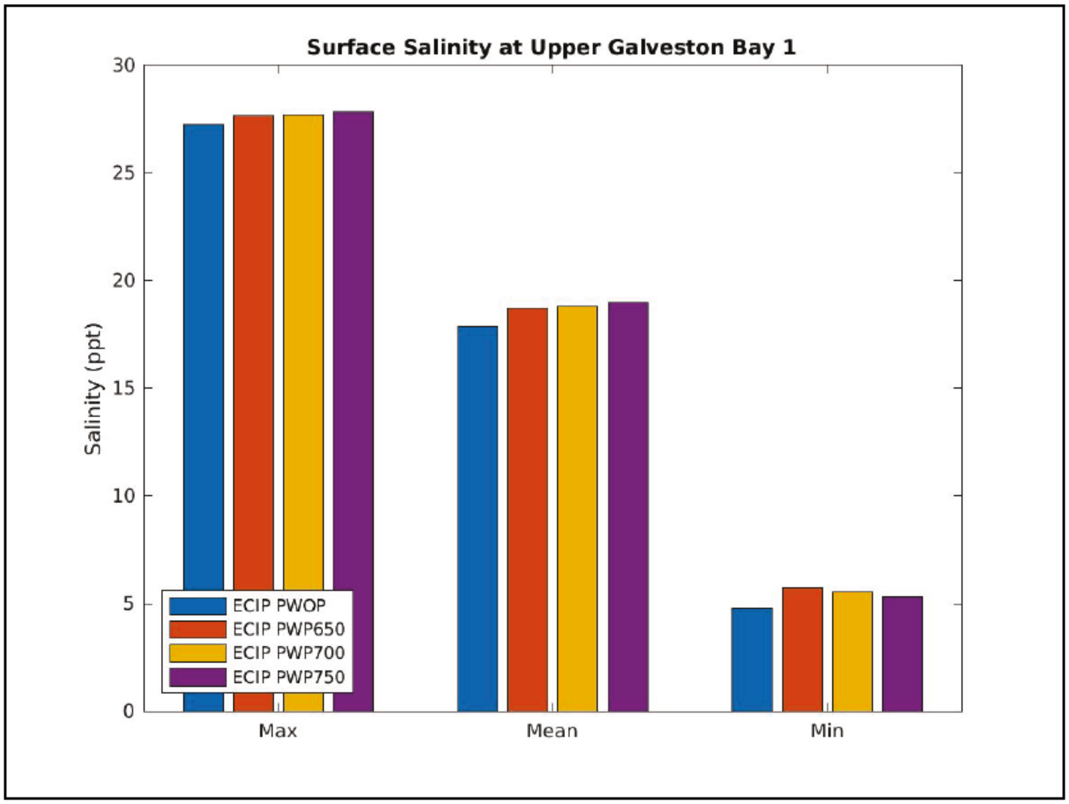

Bottom Salinity at HSC at Gulf
Salinity (ppt)
0
5
10
15
20
25
30
35
40
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

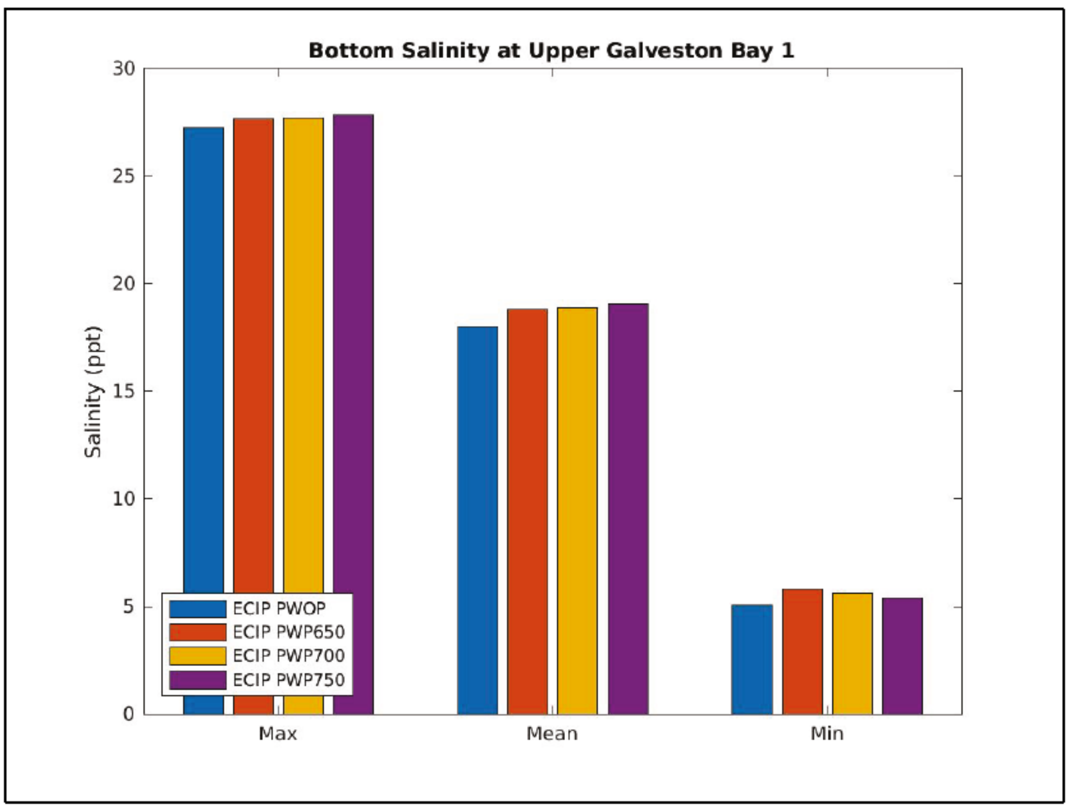

Surface Salinity Percentiles at HSC at Gulf
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

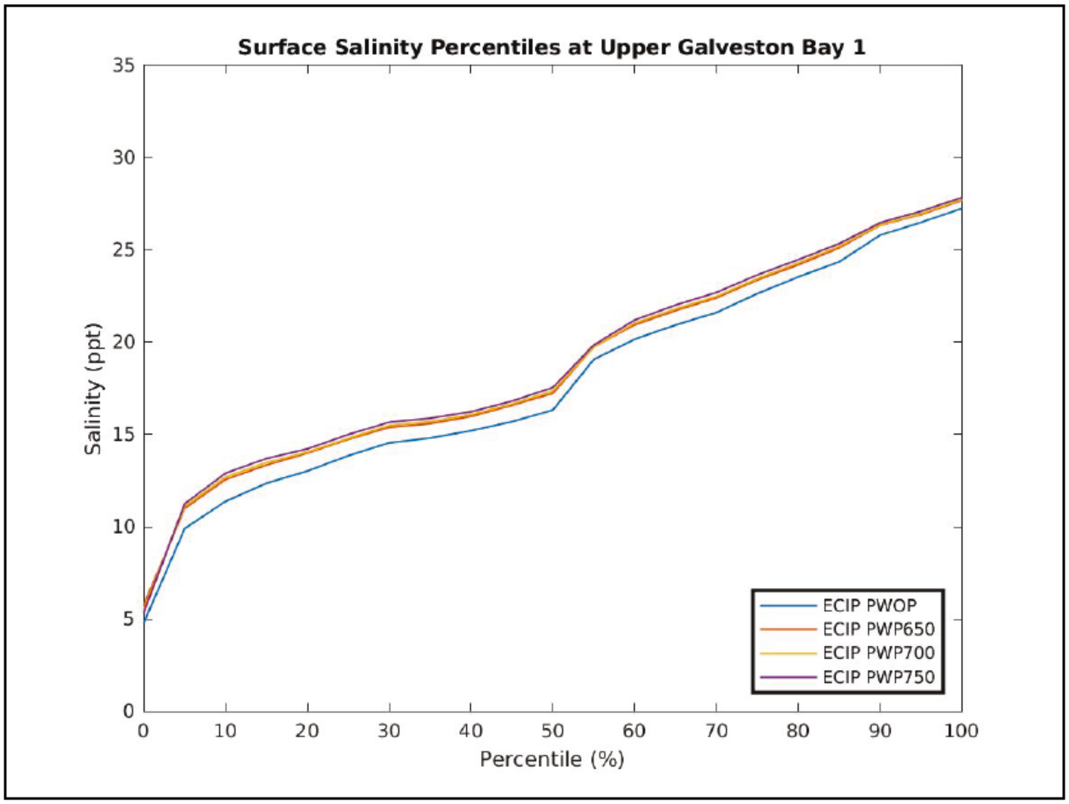

Bottom Salinity Percentiles at HSC at Gulf
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

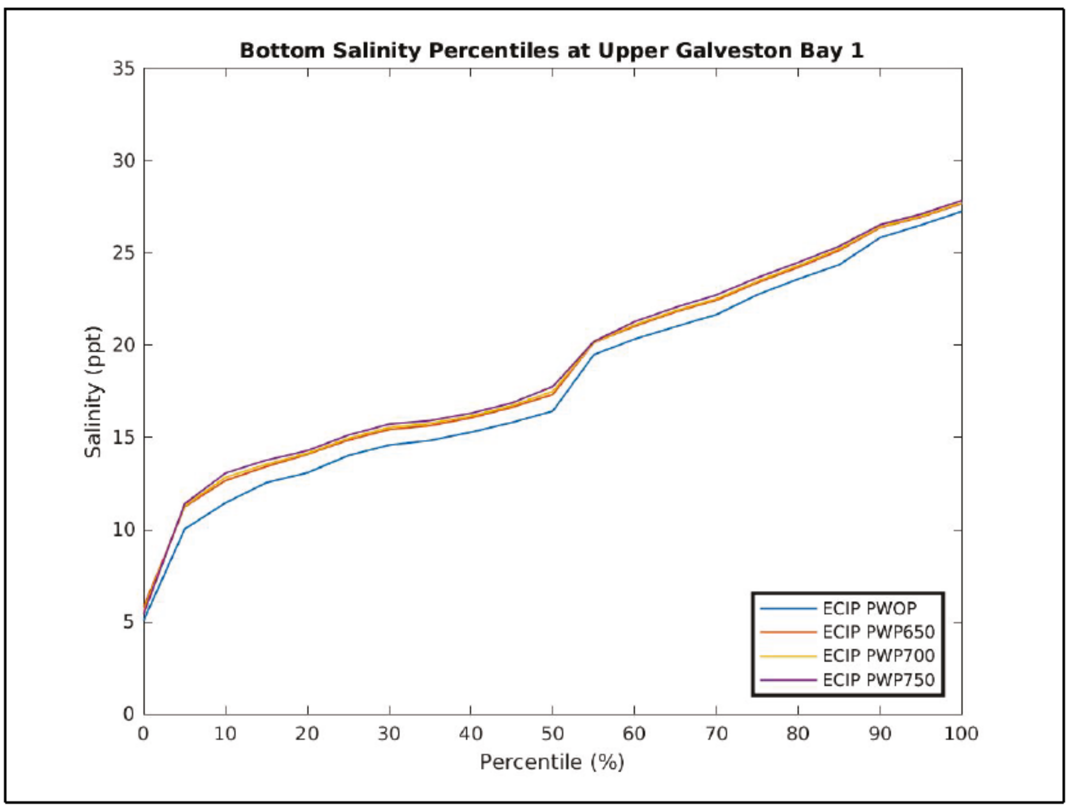

Mean Salinity Profiles at HSC at Gulf
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
-16
25
26
27
28
29
30
31
32
33
Salinity (ppt)

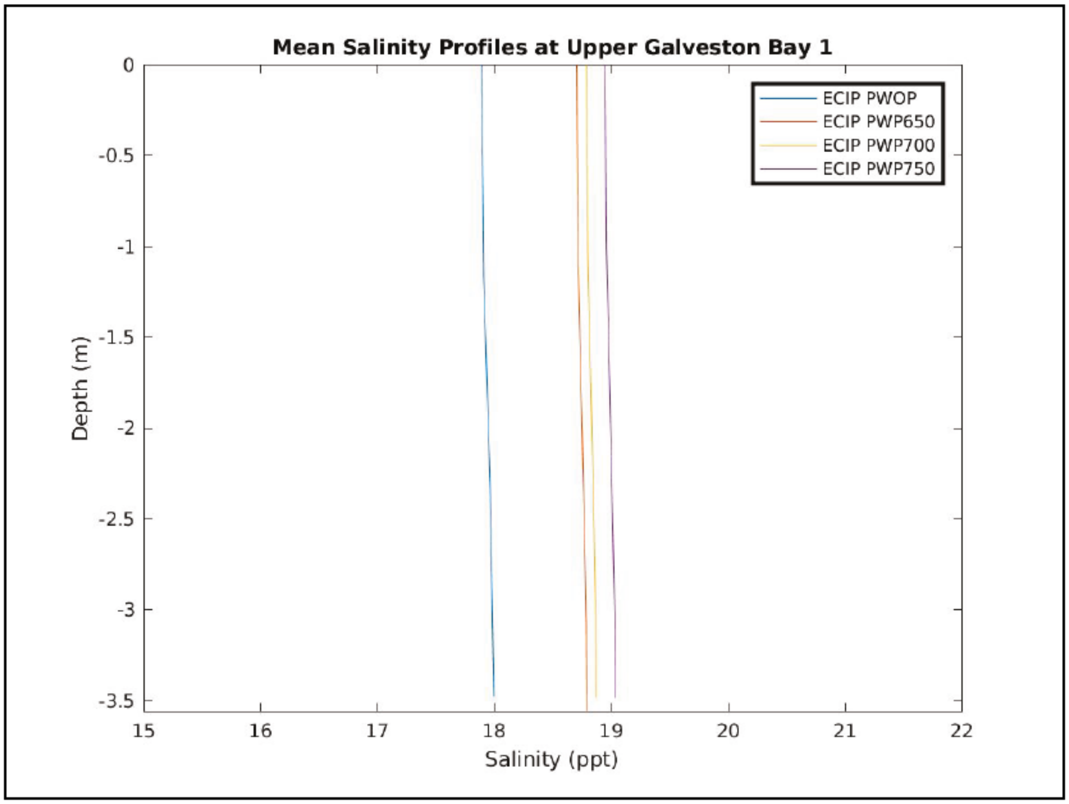

Salinity at Upper Galveston Bay 1
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

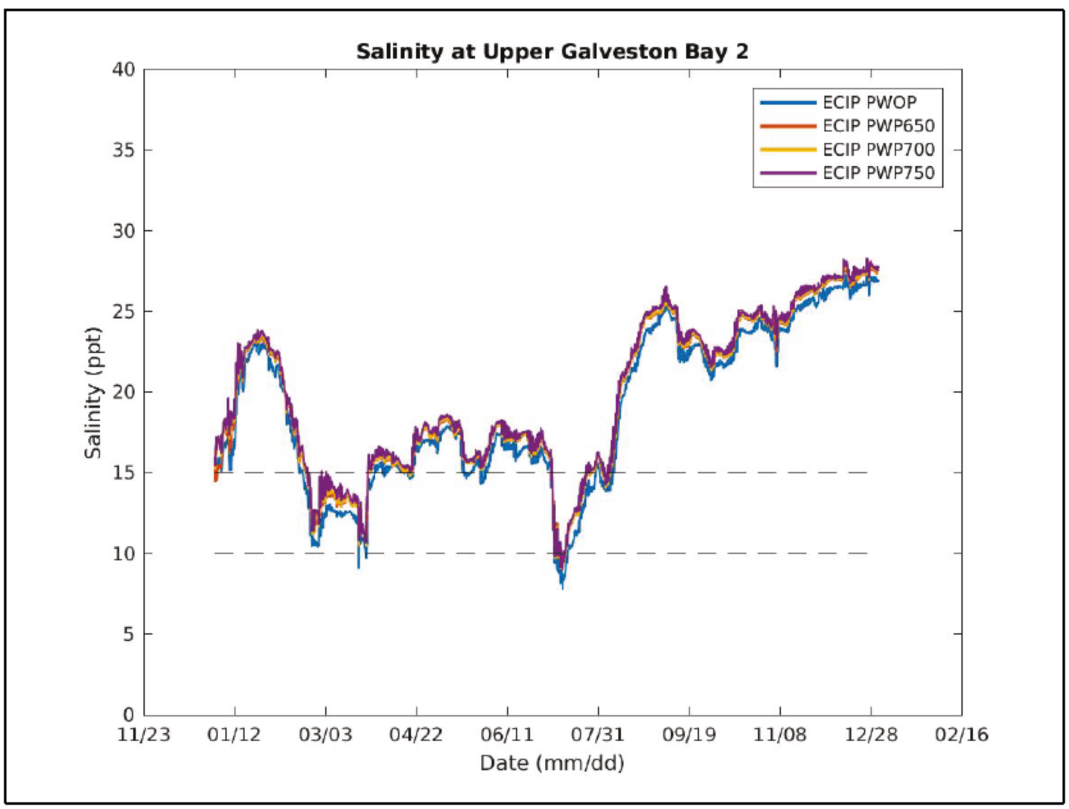

Surface Salinity at Upper Galveston Bay 1
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

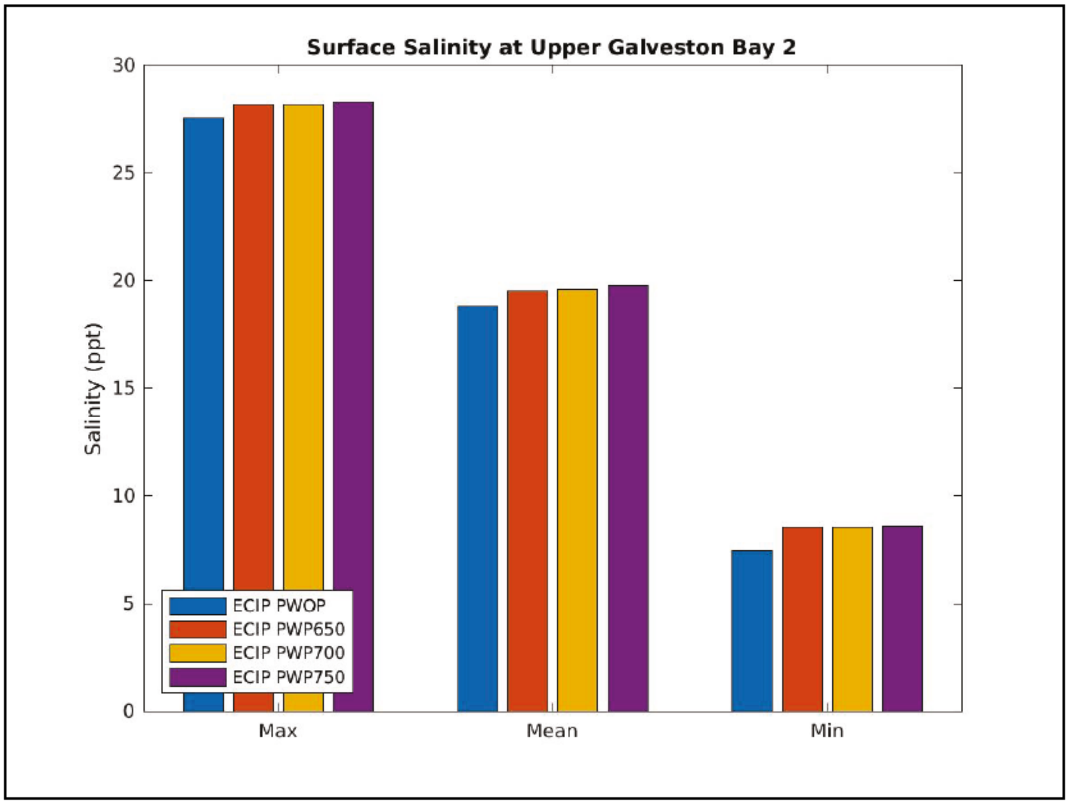

Bottom Salinity at Upper Galveston Bay 1
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

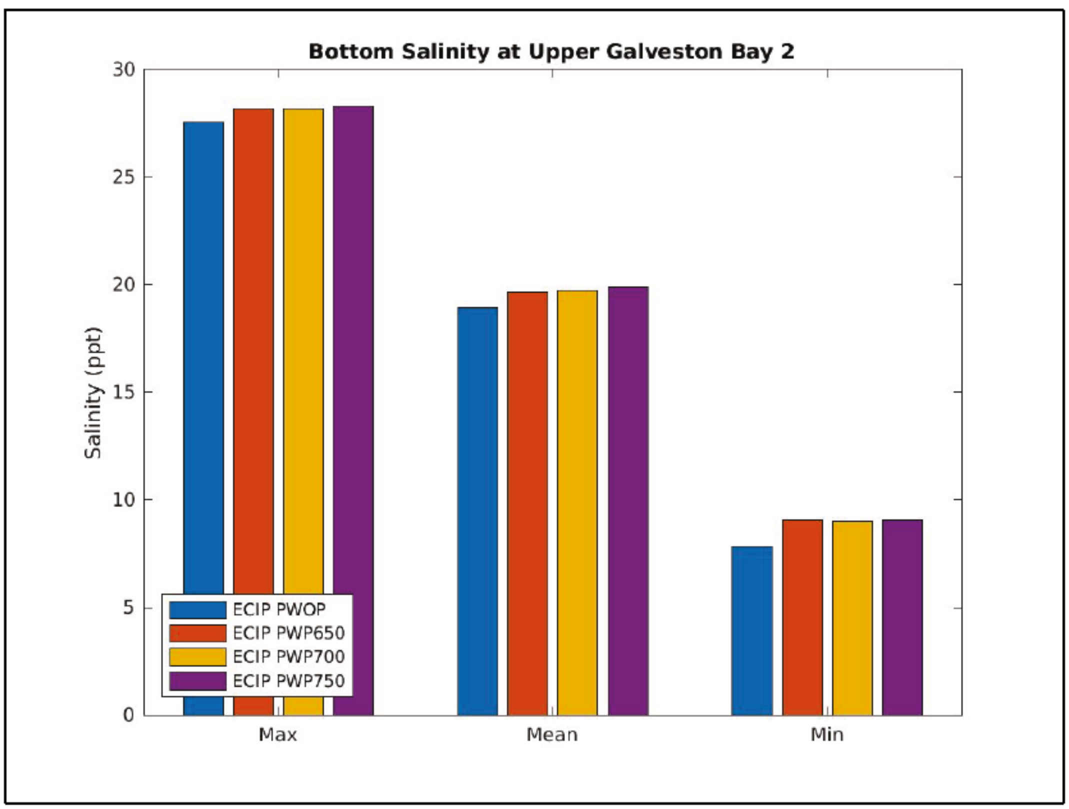

Surface Salinity Percentiles at Upper Galveston Bay 1
Salinity (ppt)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

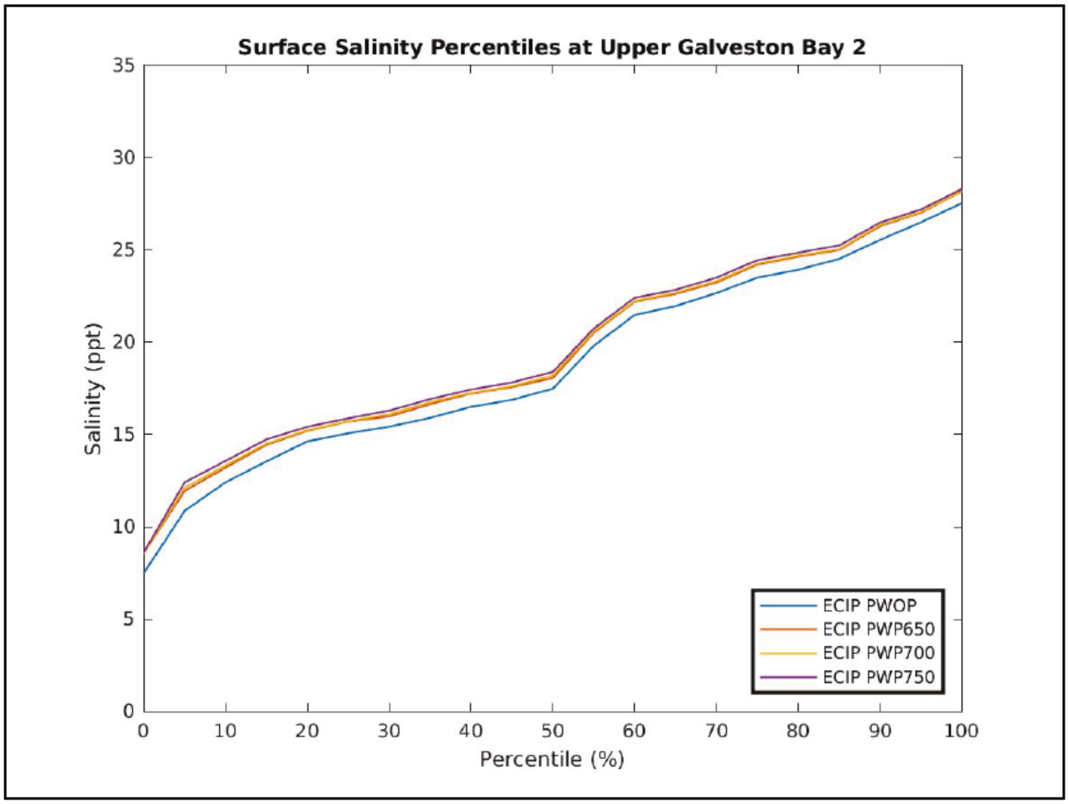

Bottom Salinity Percentiles at Upper Galveston Bay 1
Salinity (ppt)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

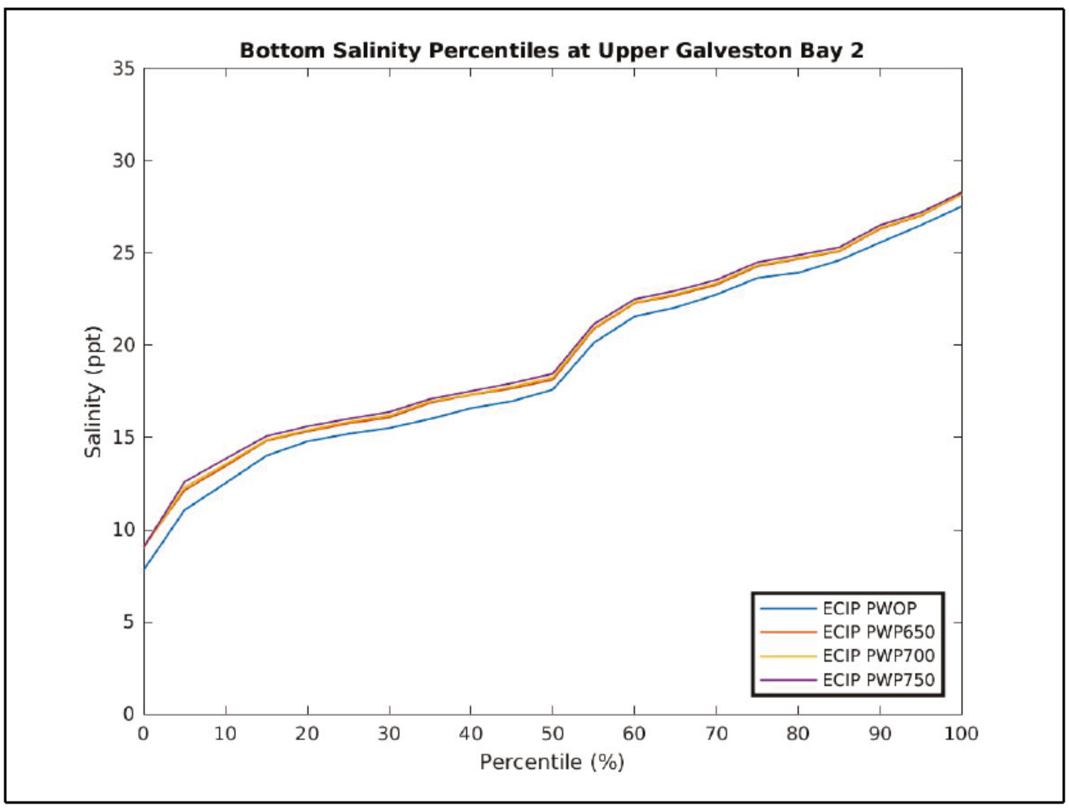

Mean Salinity Profiles at Upper Galveston Bay 1
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
15
16
17
18
19
20
21
22
Salinity (ppt)

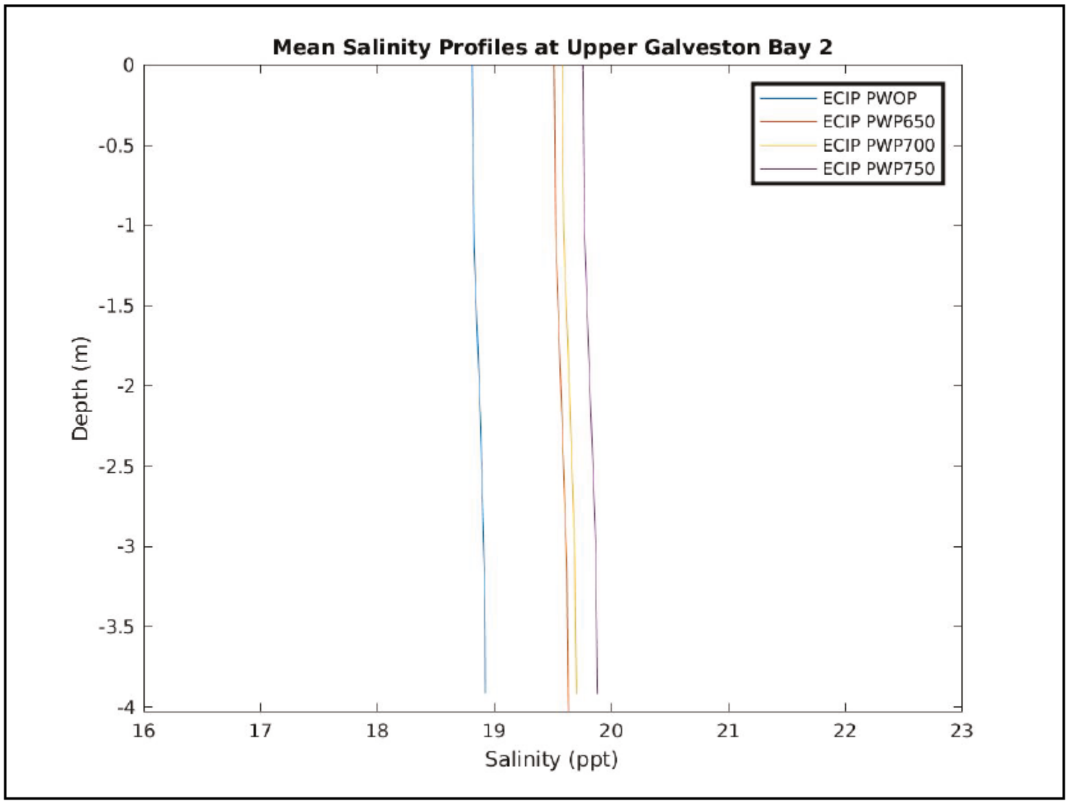

Salinity at Upper Galveston Bay 2
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

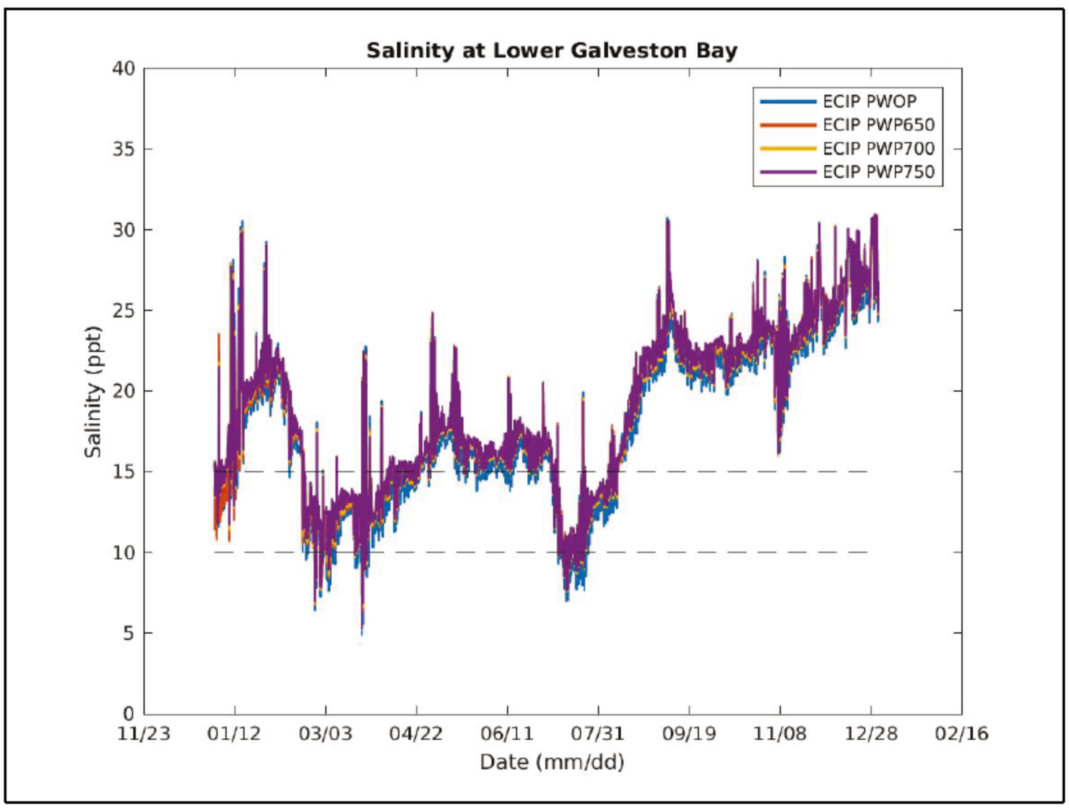

Surface Salinity at Upper Galveston Bay 2
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

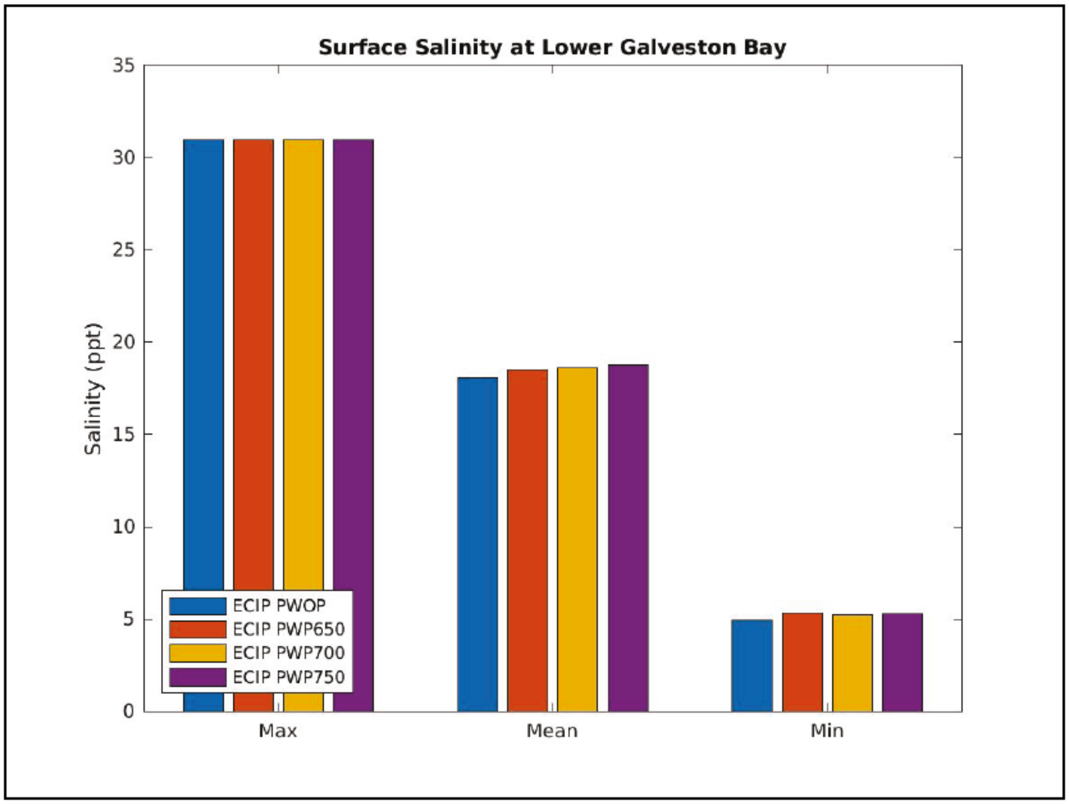

Bottom Salinity at Upper Galveston Bay 2
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

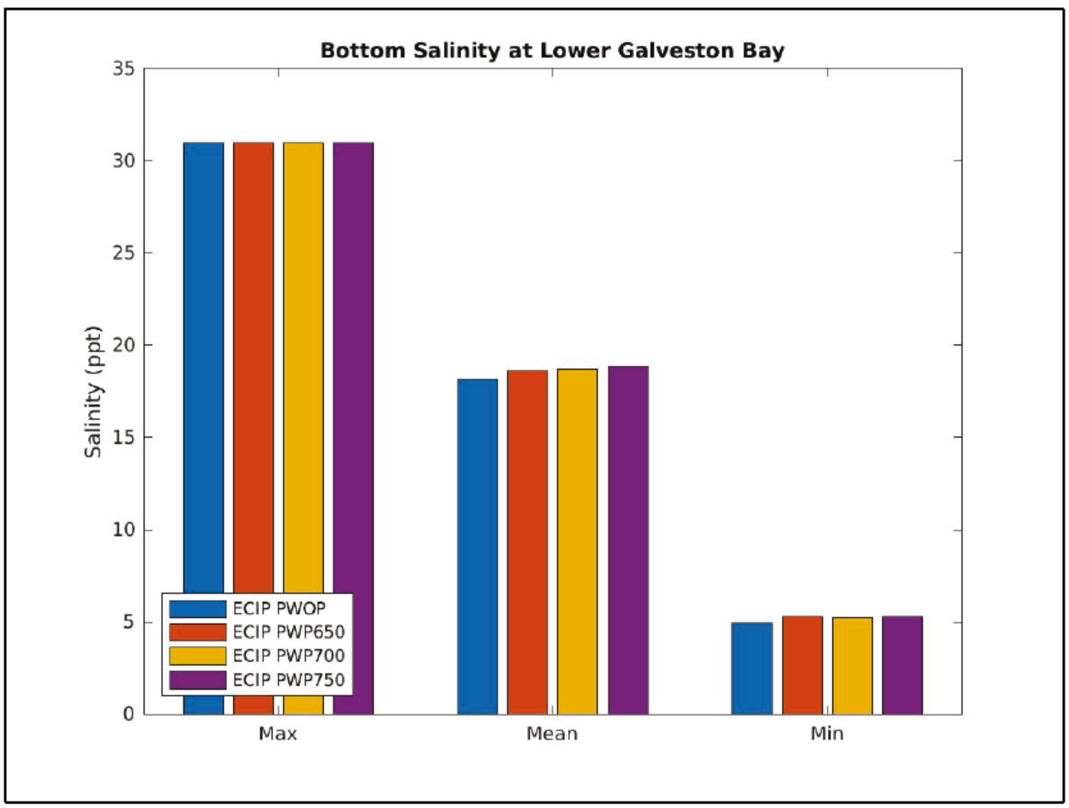

Surface Salinity Percentiles at Upper Galveston Bay 2
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

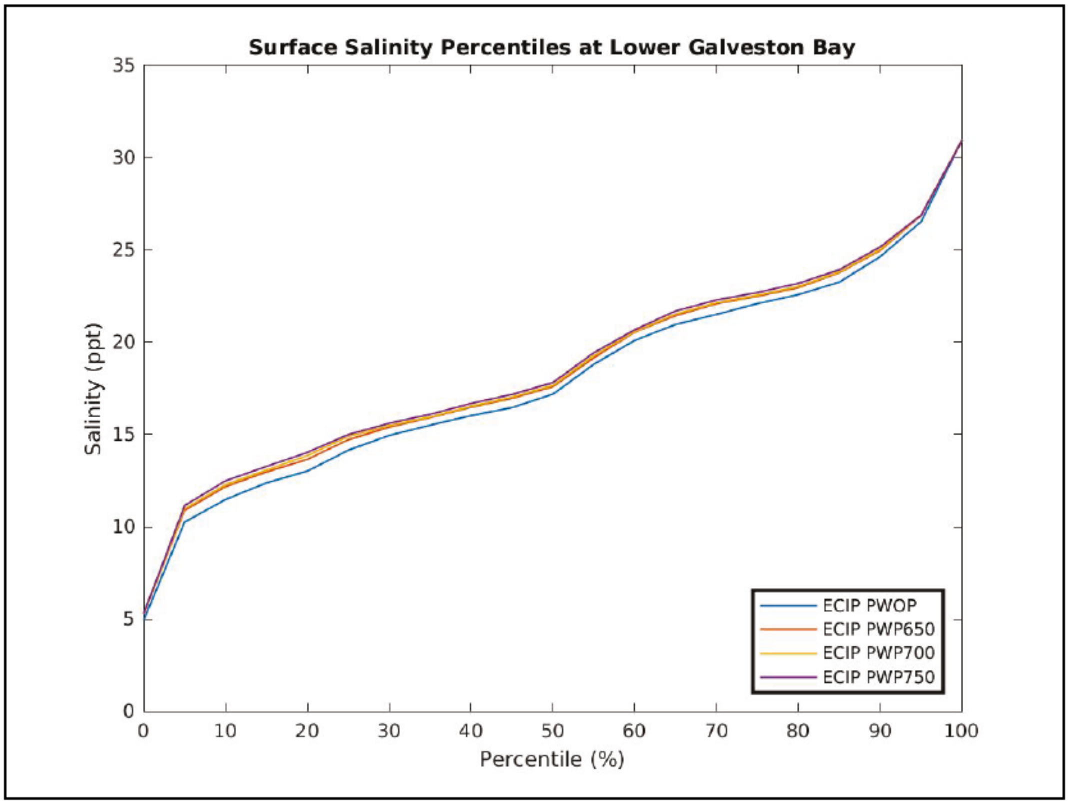

Bottom Salinity Percentiles at Upper Galveston Bay 2
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

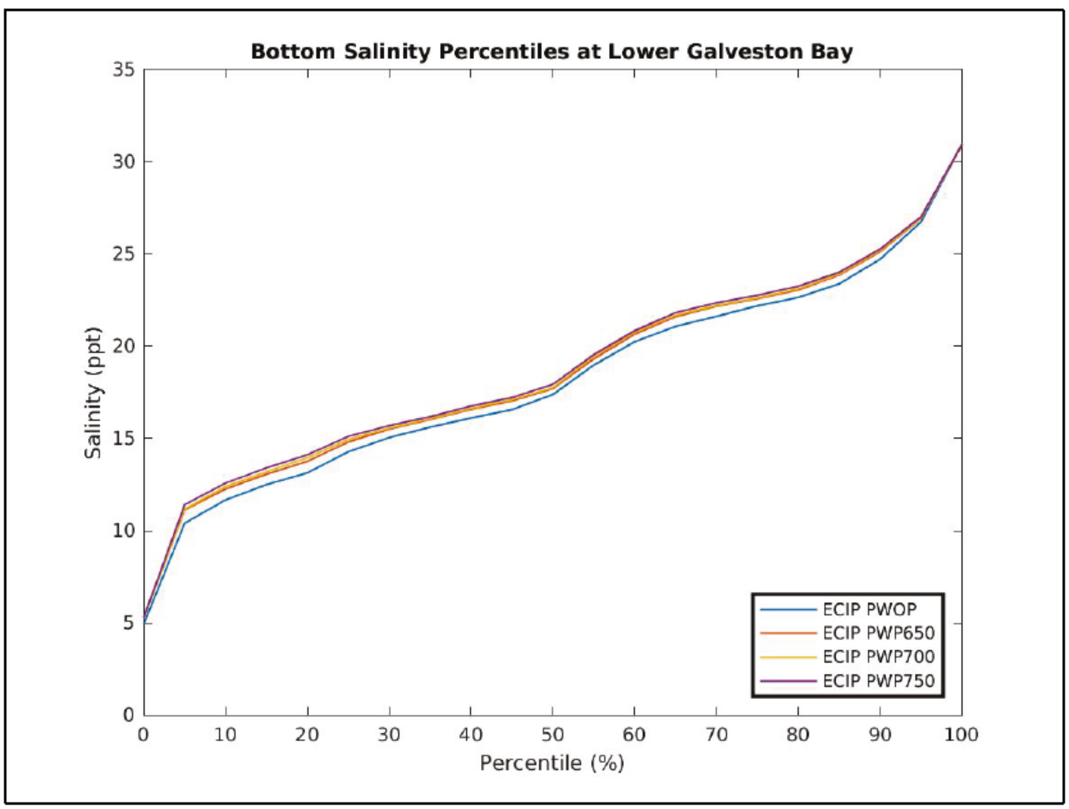

Mean Salinity Profiles at Upper Galveston Bay 2
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
16
17
18
19
20
21
22
23
Salinity (ppt)

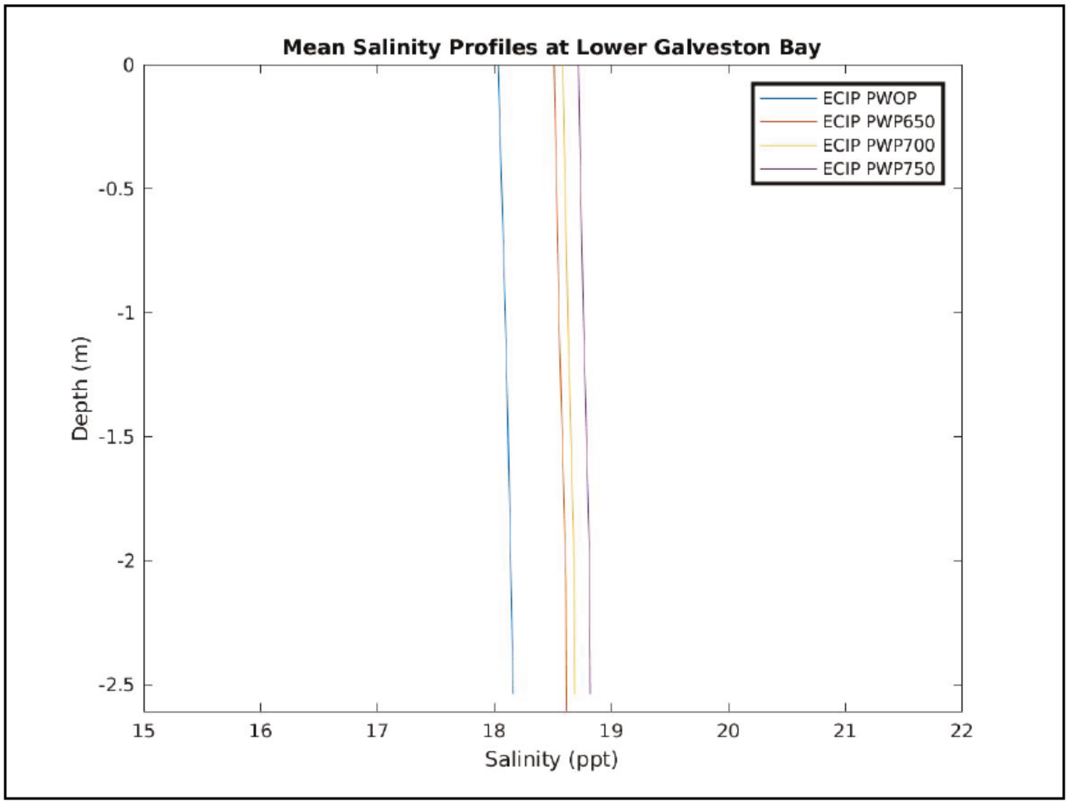

Salinity at Lower Galveston Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

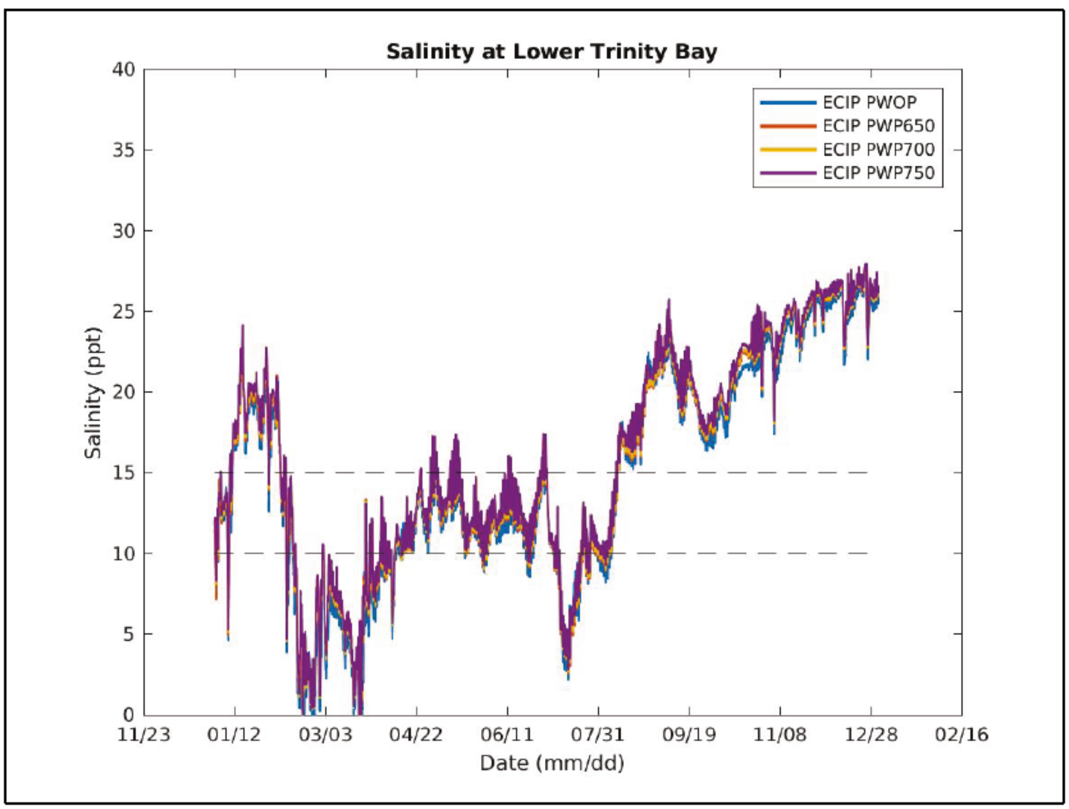

Surface Salinity at Lower Galveston Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

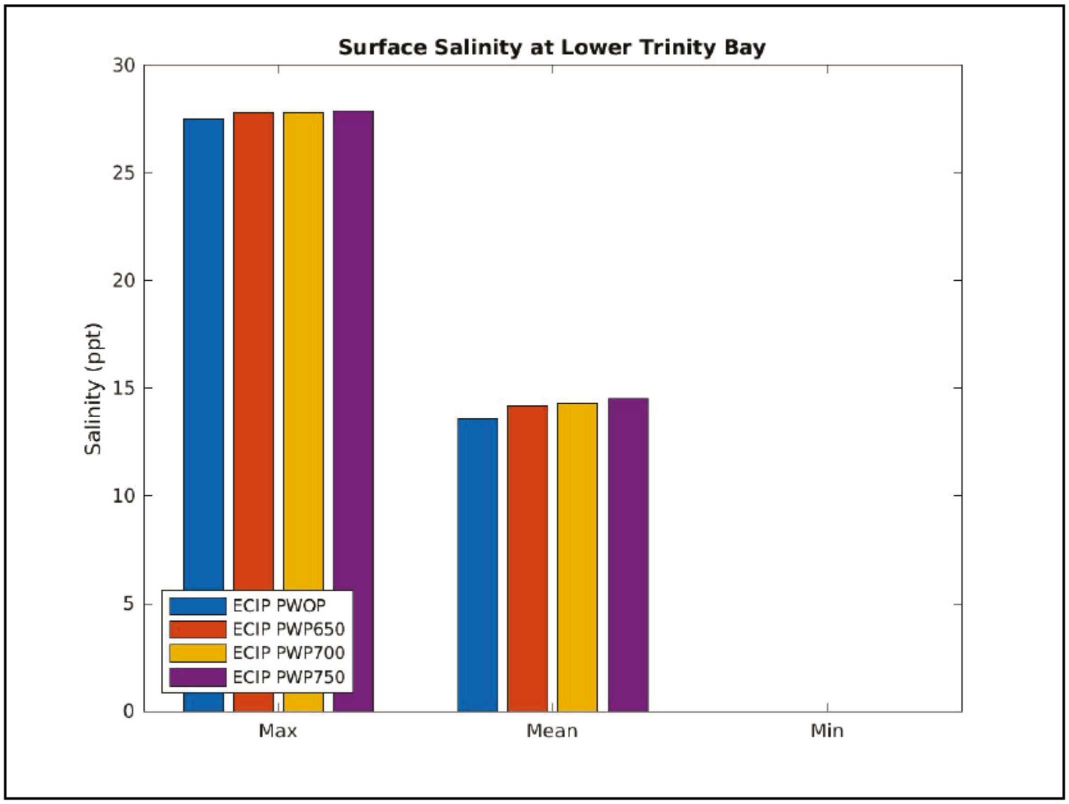

Bottom Salinity at Lower Galveston Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

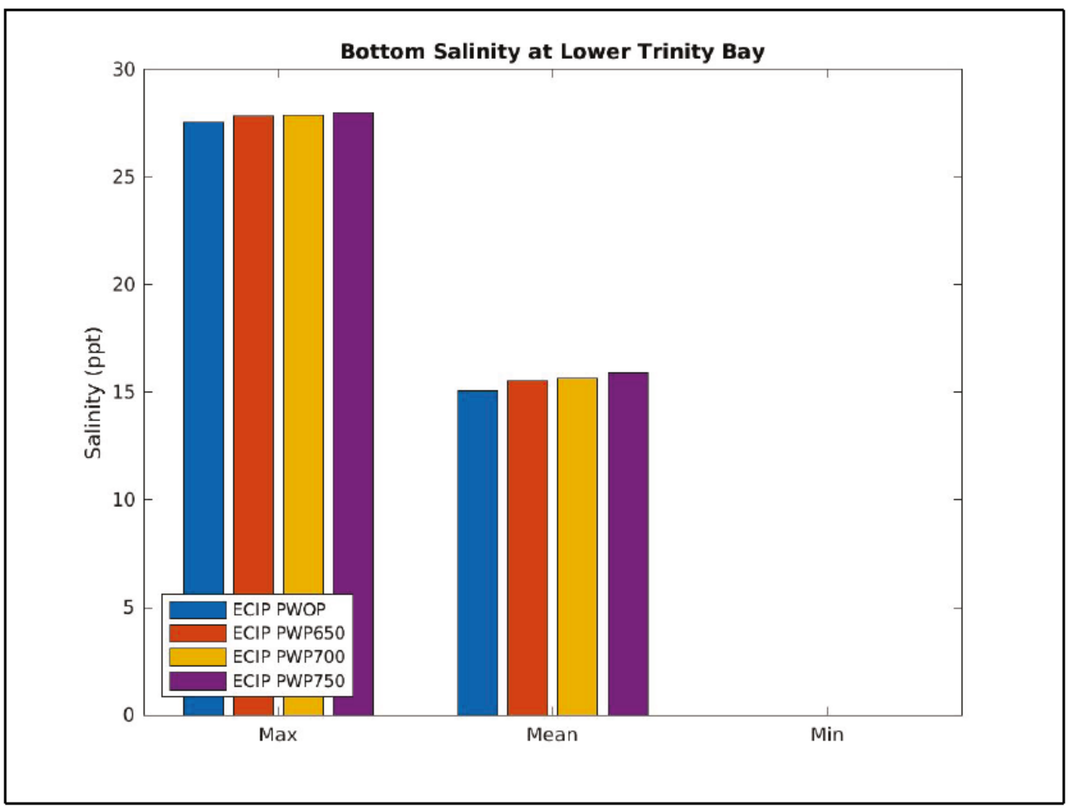

Surface Salinity Percentiles at Lower Galveston Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

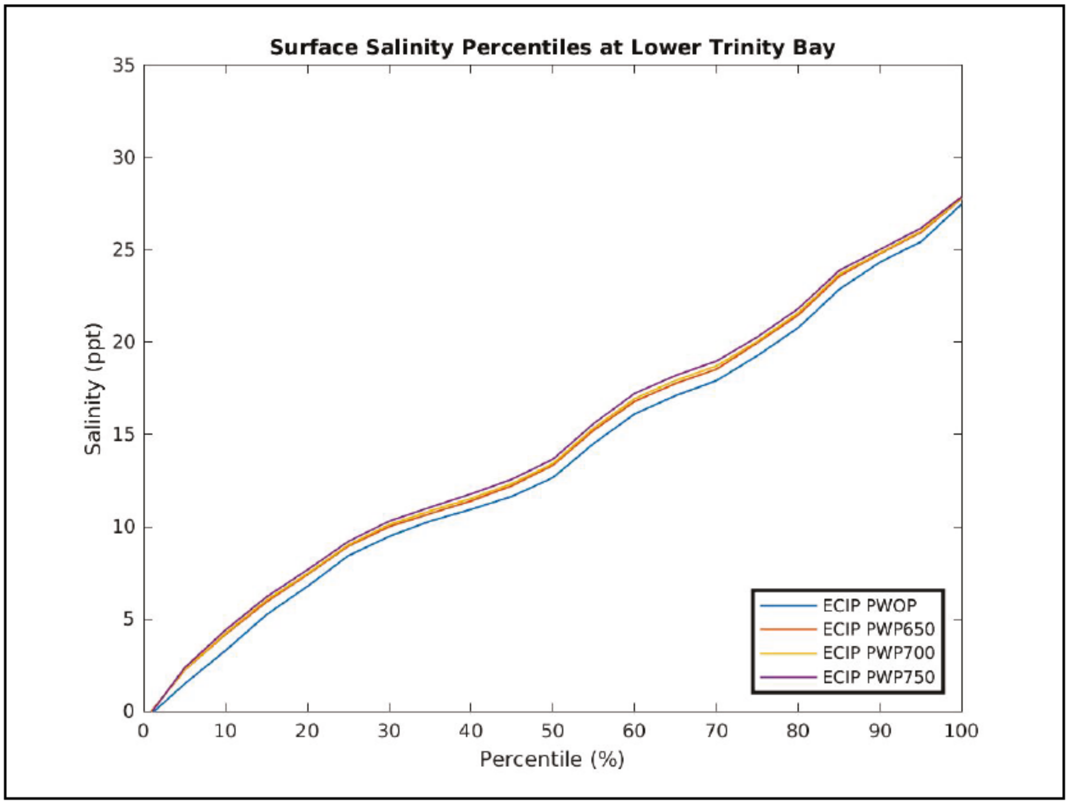

Bottom Salinity Percentiles at Lower Galveston Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

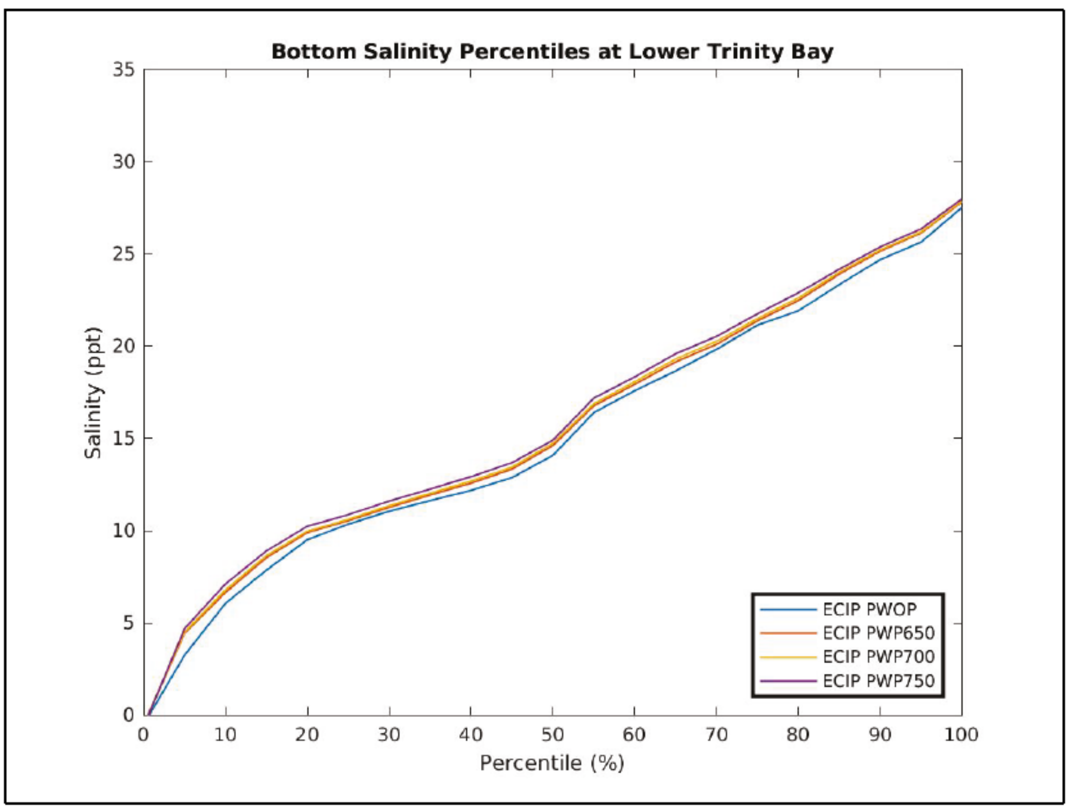

Mean Salinity Profiles at Lower Galveston Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
15
16
17
18
19
20
21
22
Salinity (ppt)

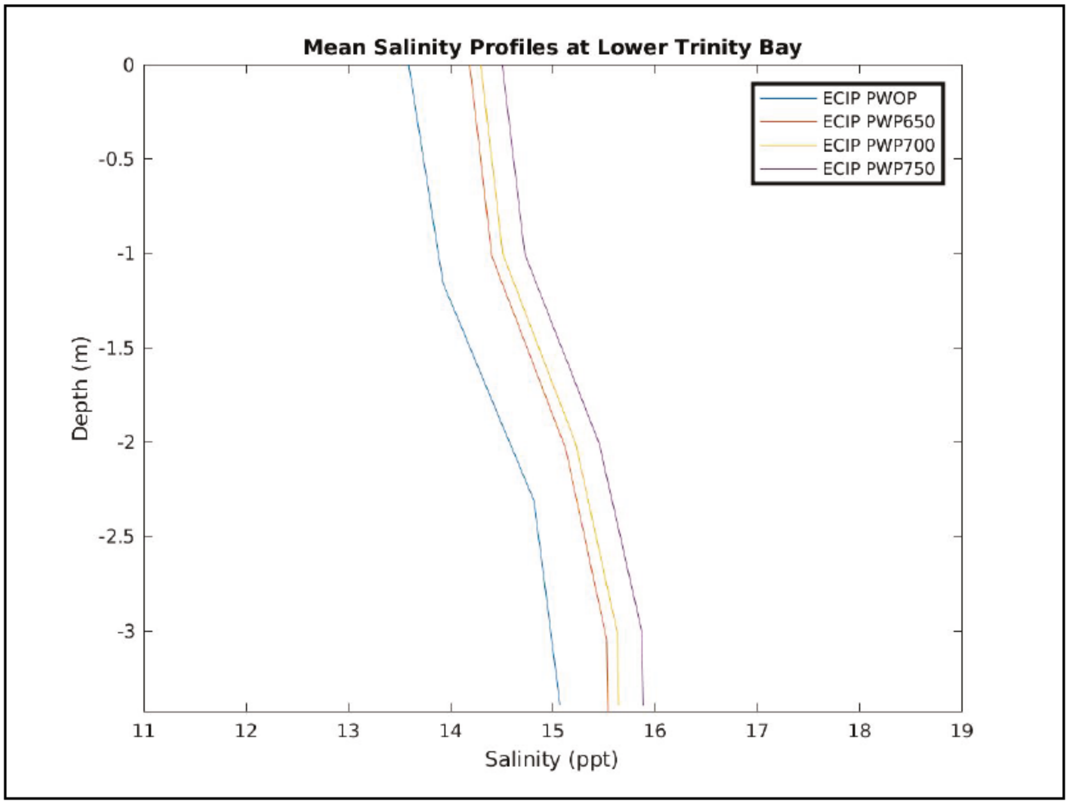

Salinity at Lower Trinity Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

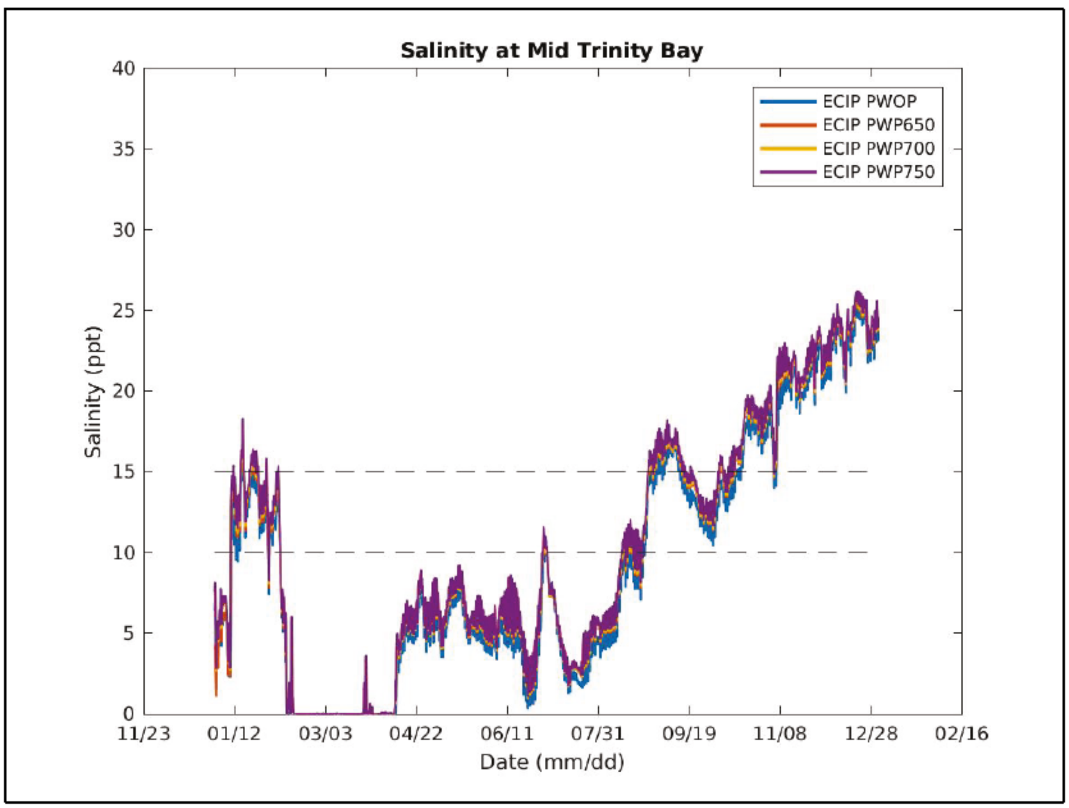

Surface Salinity at Lower Trinity Bay
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

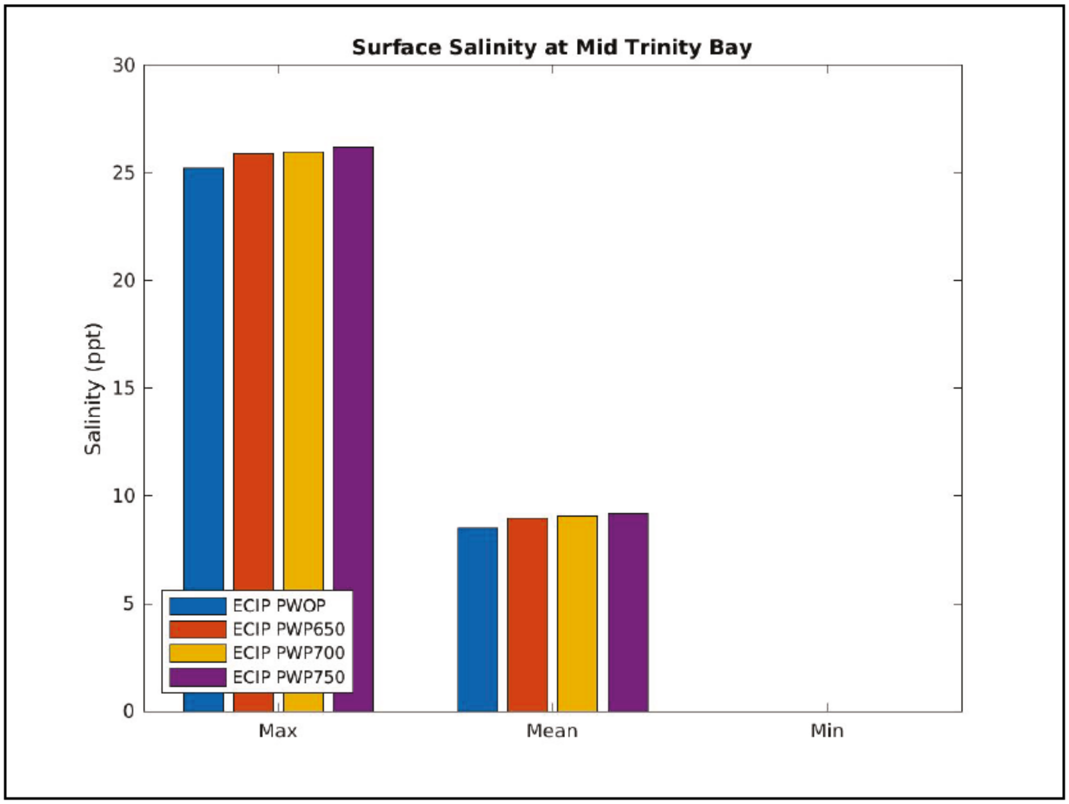

Bottom Salinity at Lower Trinity Bay
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

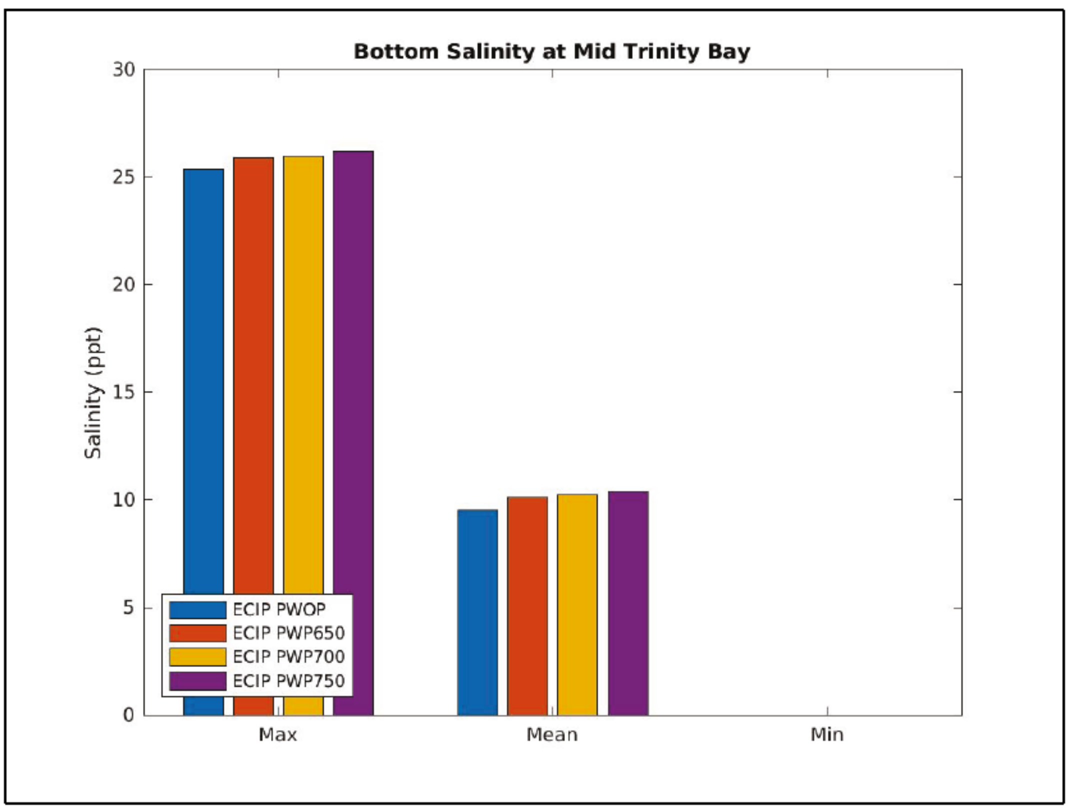

Surface Salinity Percentiles at Lower Trinity Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

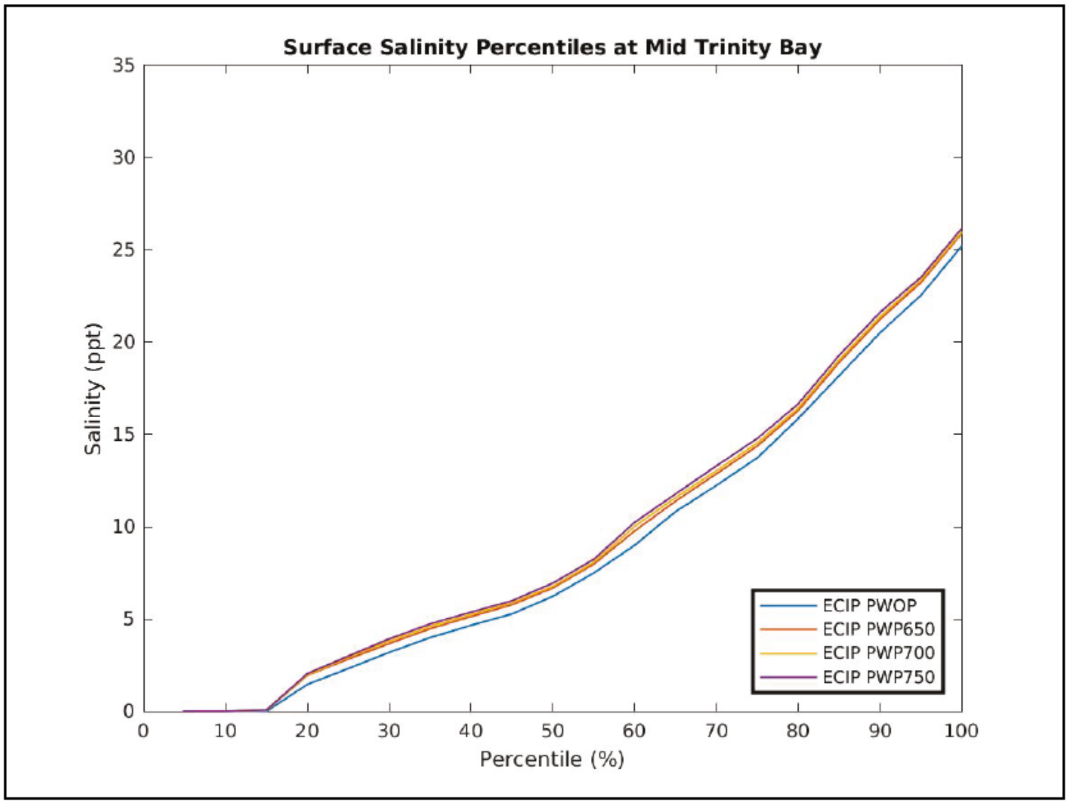

Bottom Salinity Percentiles at Lower Trinity Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

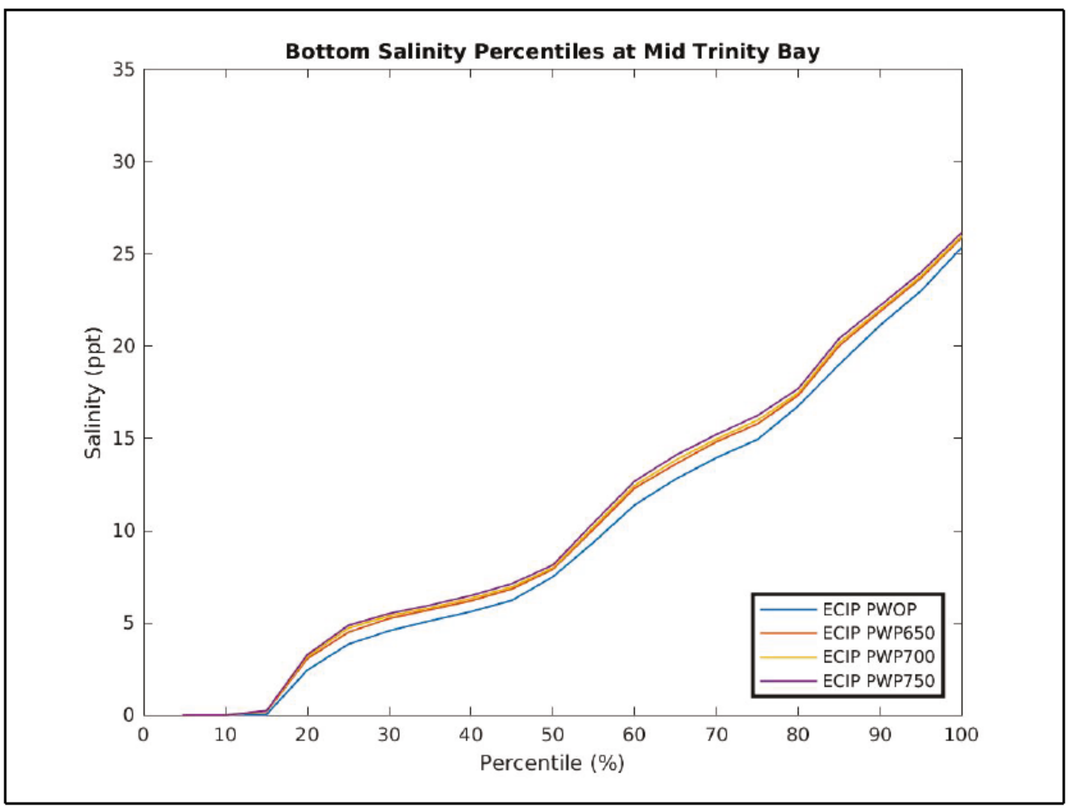

Mean Salinity Profiles at Lower Trinity Bay
Depth (m)
Salinity (ppt)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
-0.5
-1
-1.5
-2
-2.5
-3
11
12
13
14
15
16
17
18
19

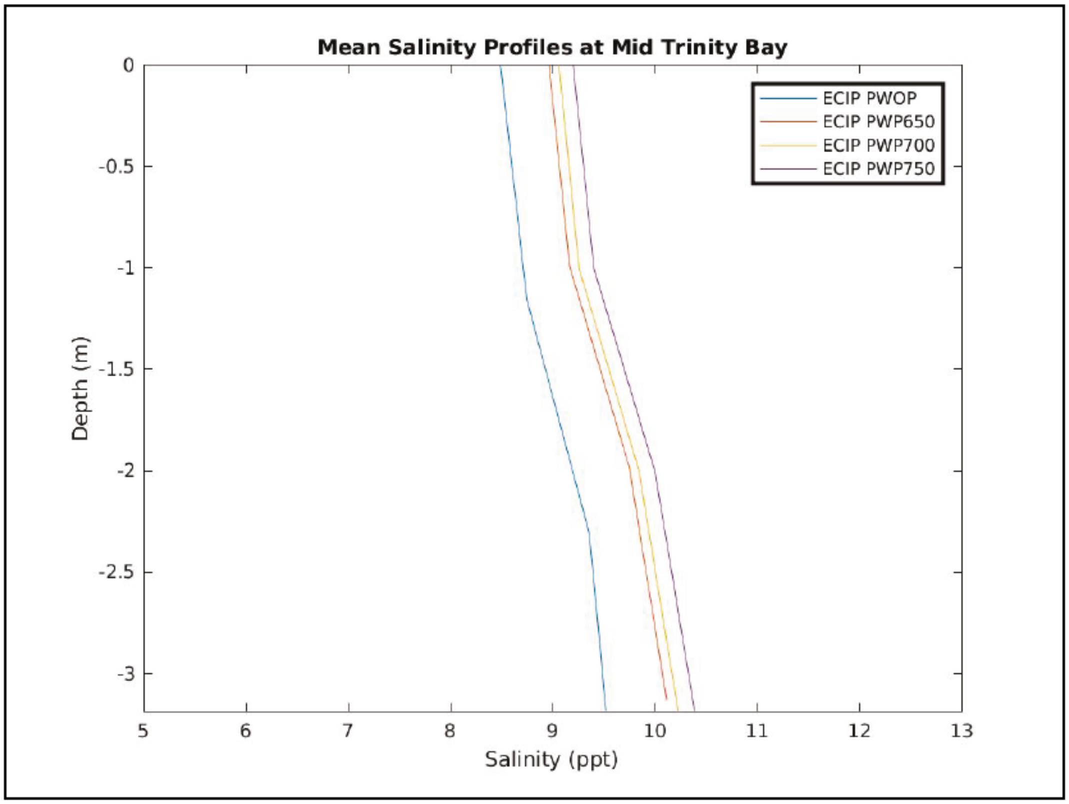

Salinity at Mid Trinity Bay
Salinity (ppt)
Date (mm/dd)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

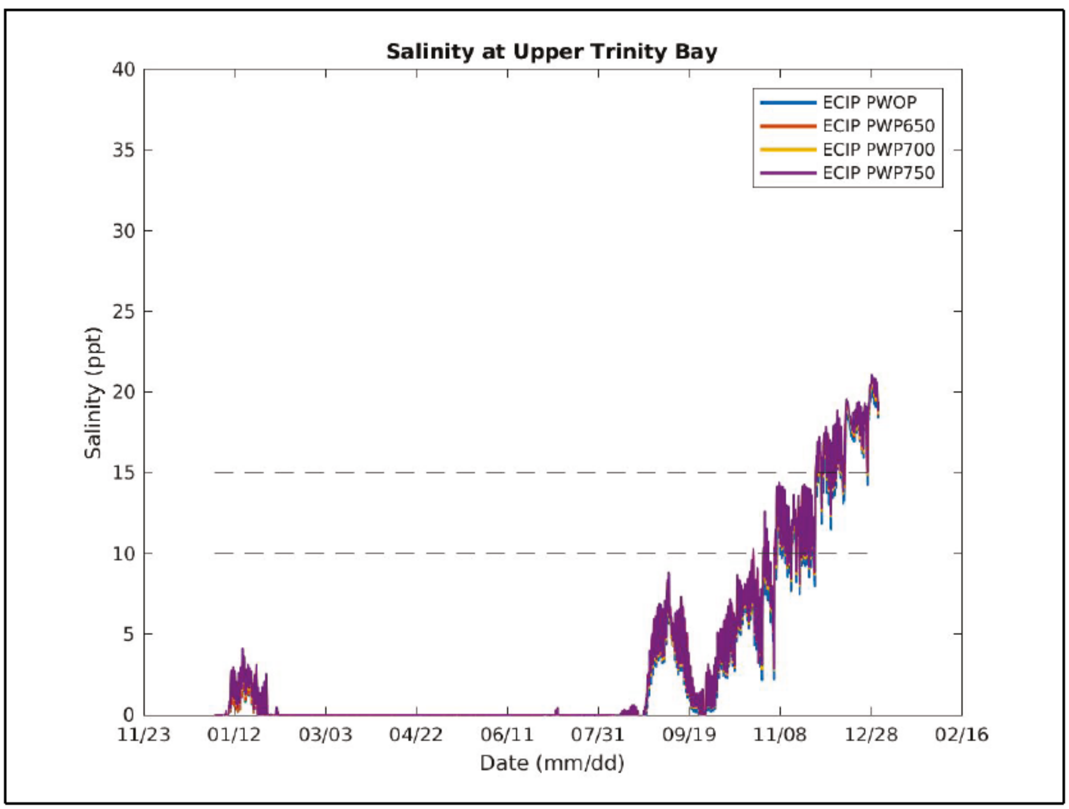

Surface Salinity at Mid Trinity Bay
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

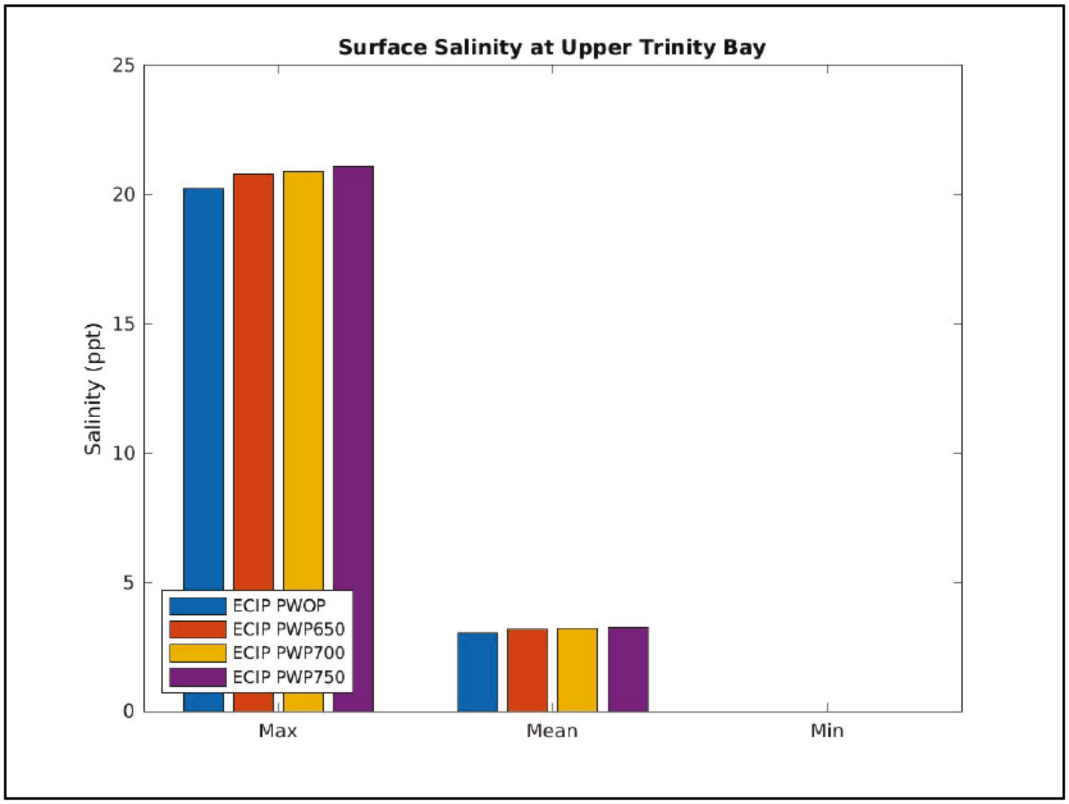

Bottom Salinity at Mid Trinity Bay
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

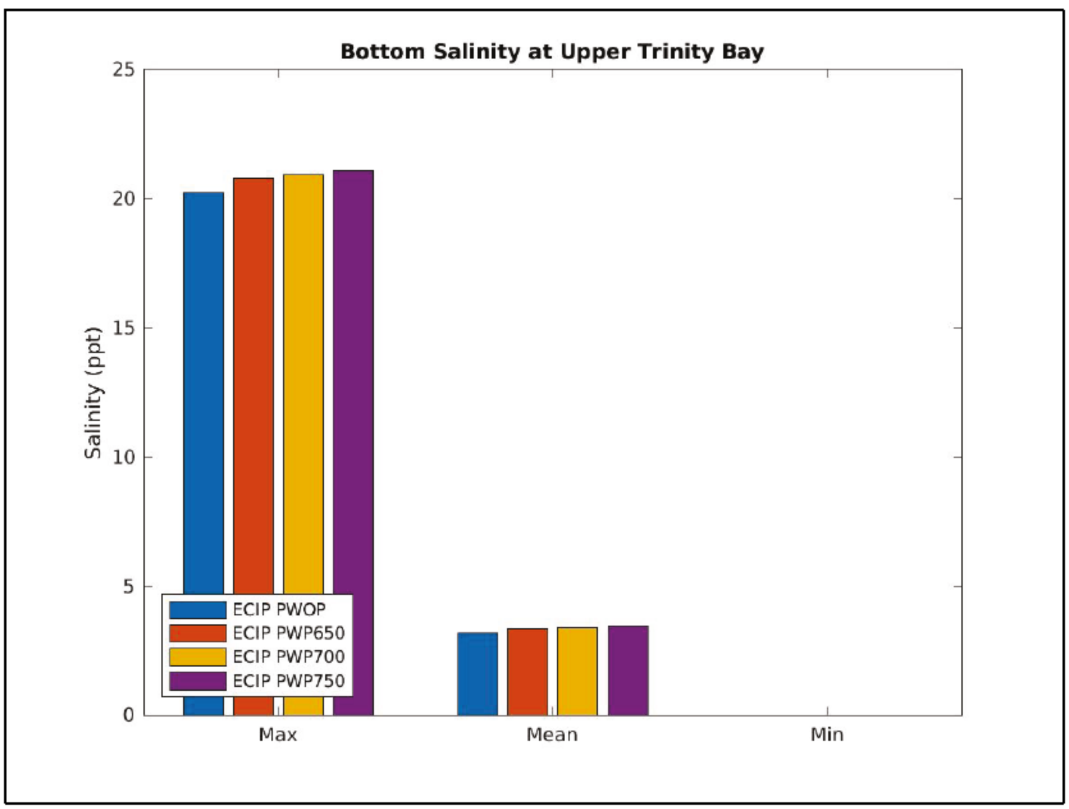

Surface Salinity Percentiles at Mid Trinity Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

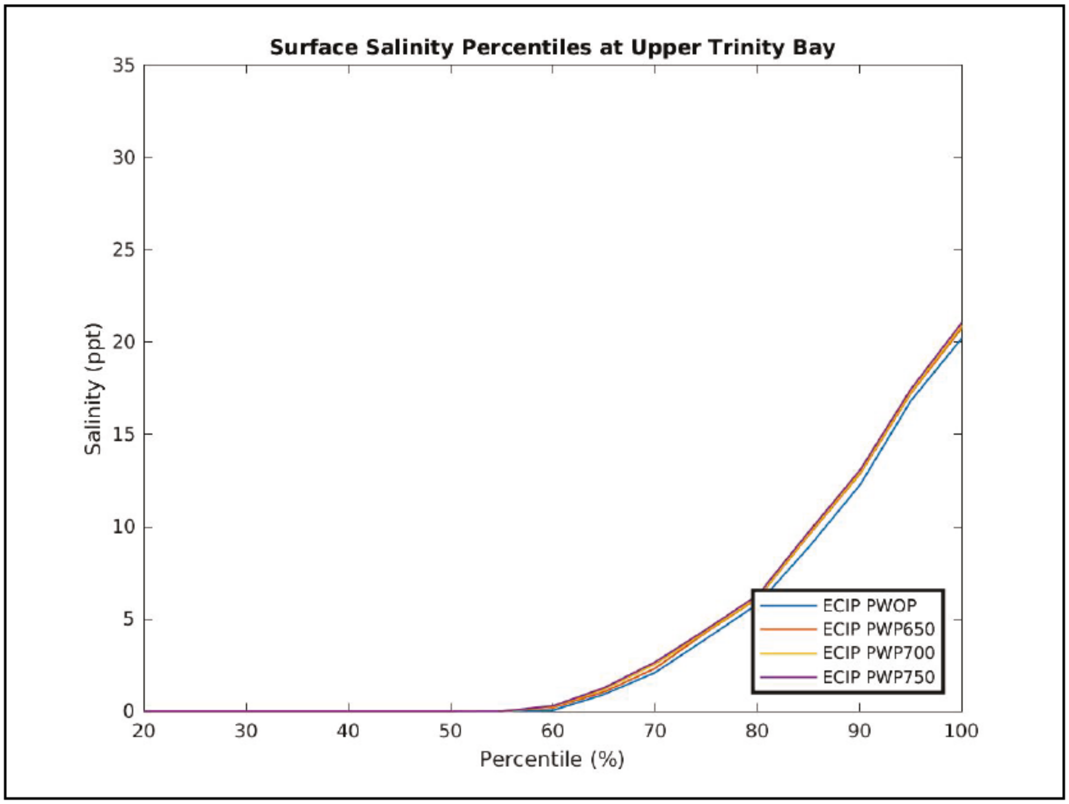

Bottom Salinity Percentiles at Mid Trinity Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750


Mean Salinity Profiles at Mid Trinity Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
5
6
7
8
9
10
11
12
13
Salinity (ppt)

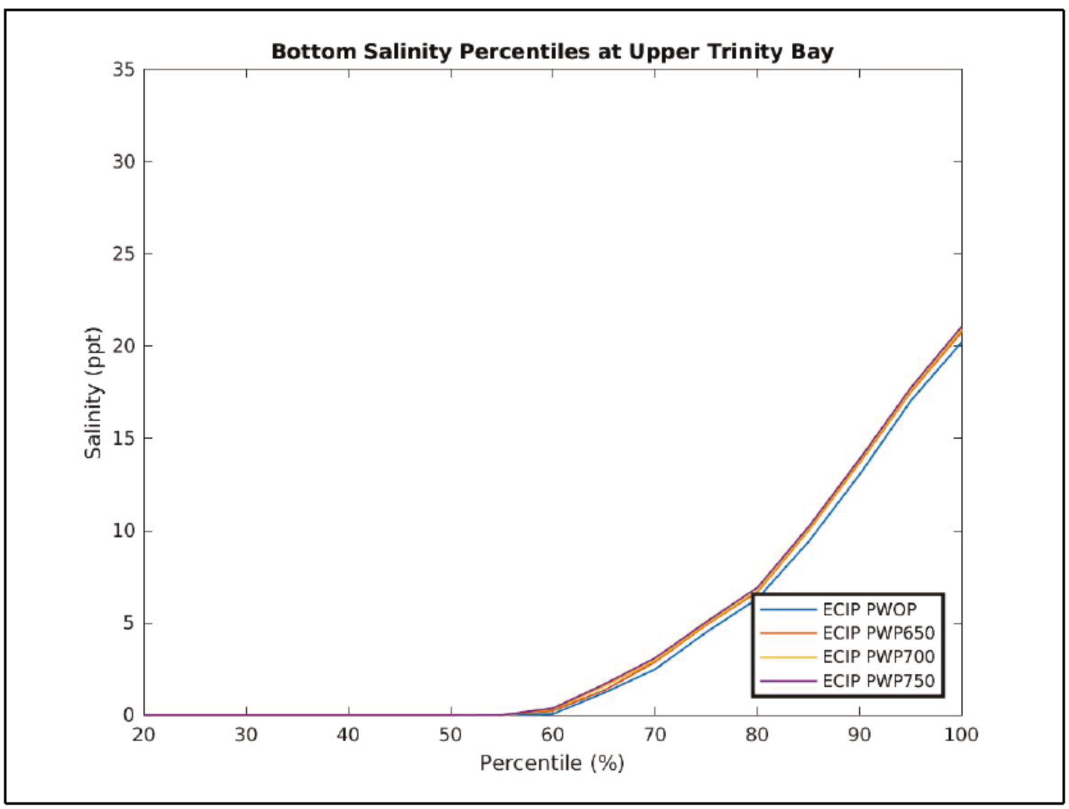

Salinity at Upper Trinity Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)


Surface Salinity at Upper Trinity Bay
Salinity (ppt)
25
20
15
10
5
0
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Max
Mean
Min

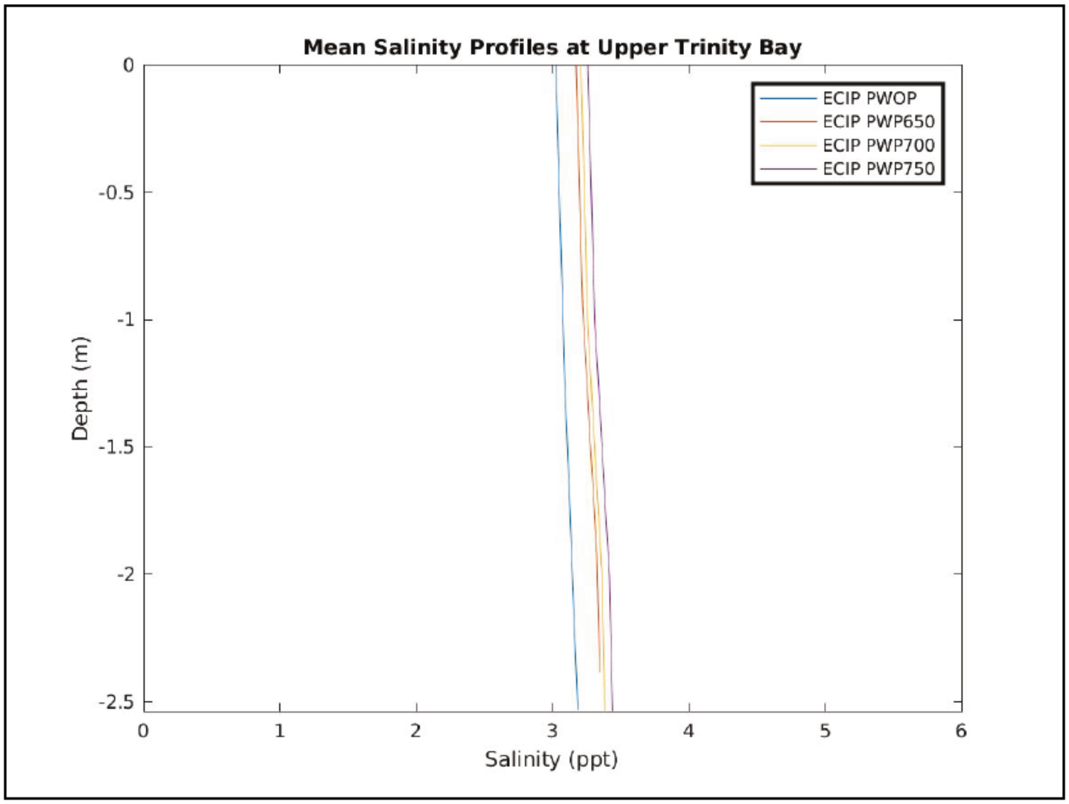

Bottom Salinity at Upper Trinity Bay
Salinity (ppt)
25
20
15
10
5
0
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Max
Mean
Min

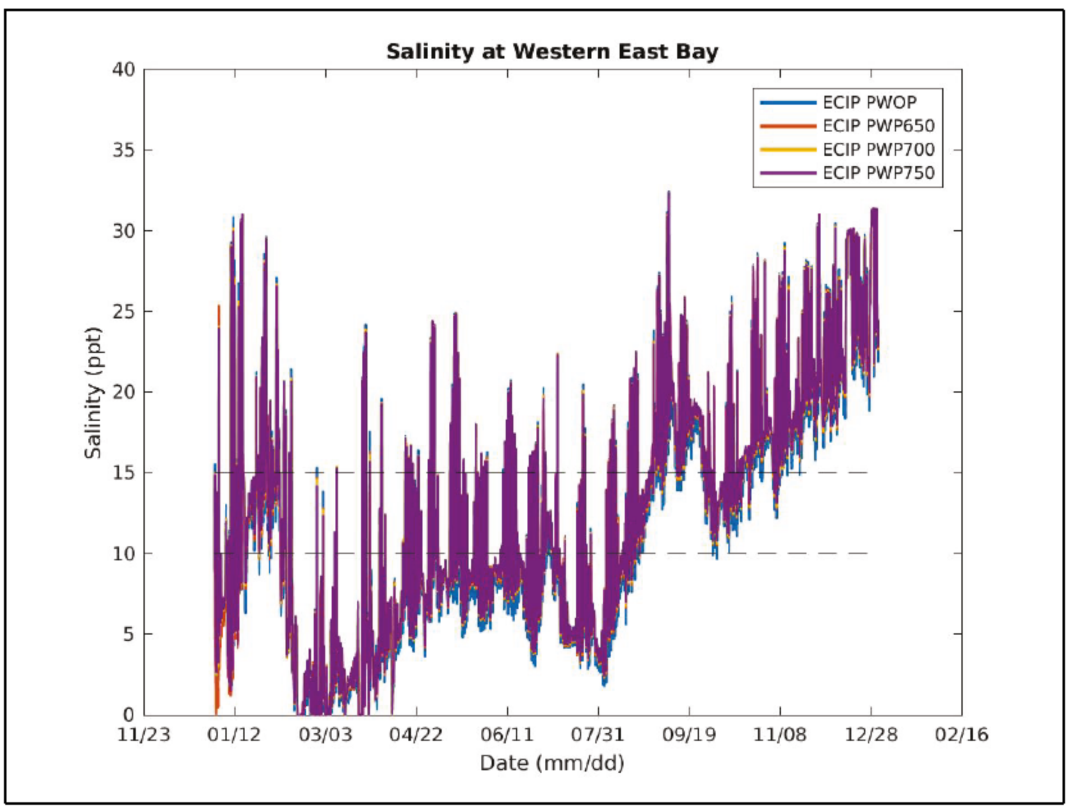


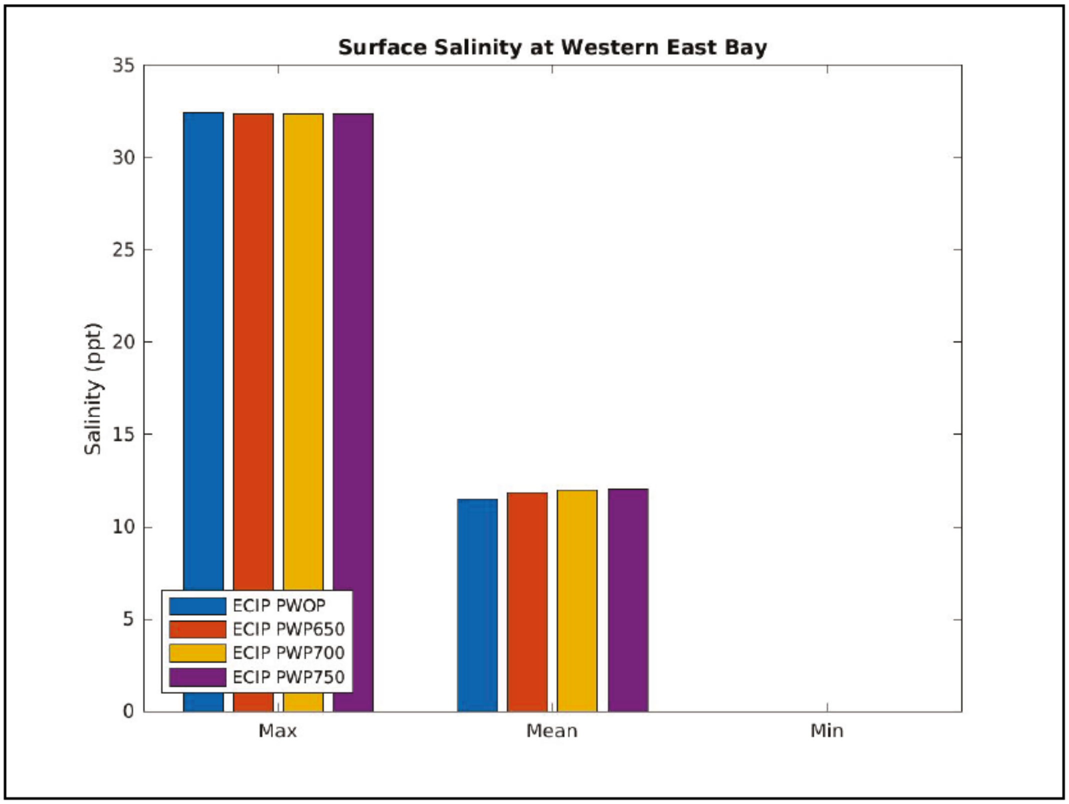
Surface Salinity Percentiles at Upper Trinity Bay
Salinity (ppt)
Percentile (%)
35
30
25
20
15
10
5
0
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

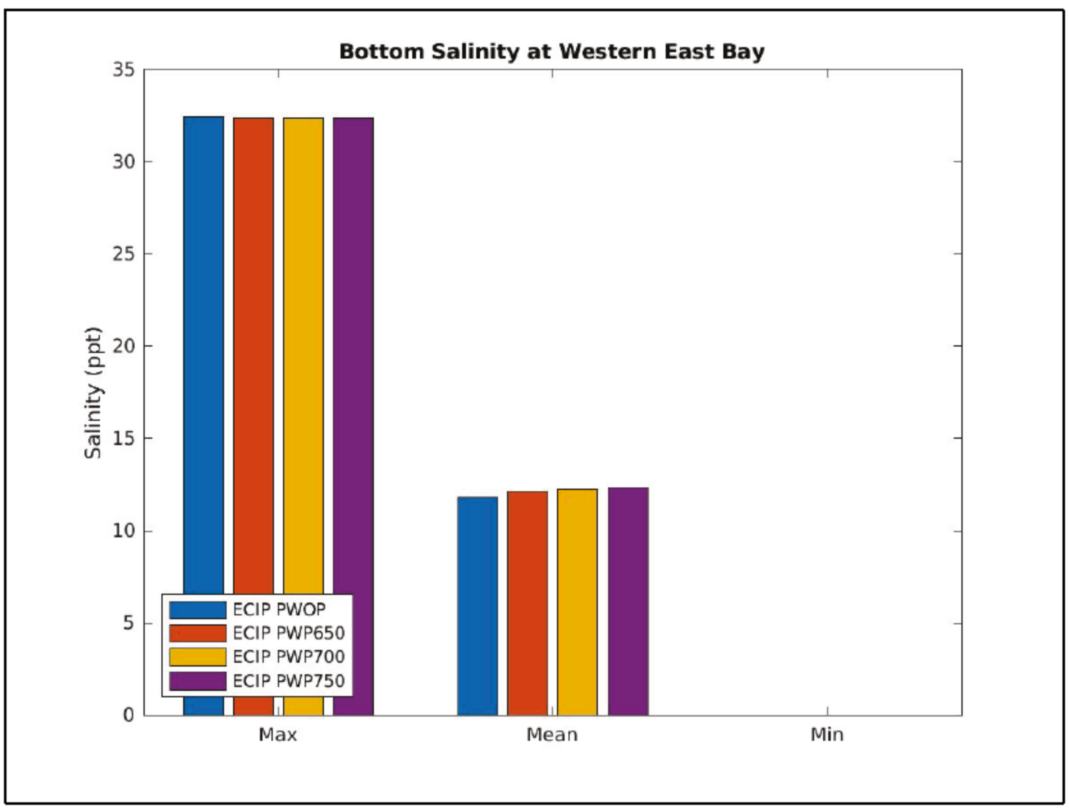



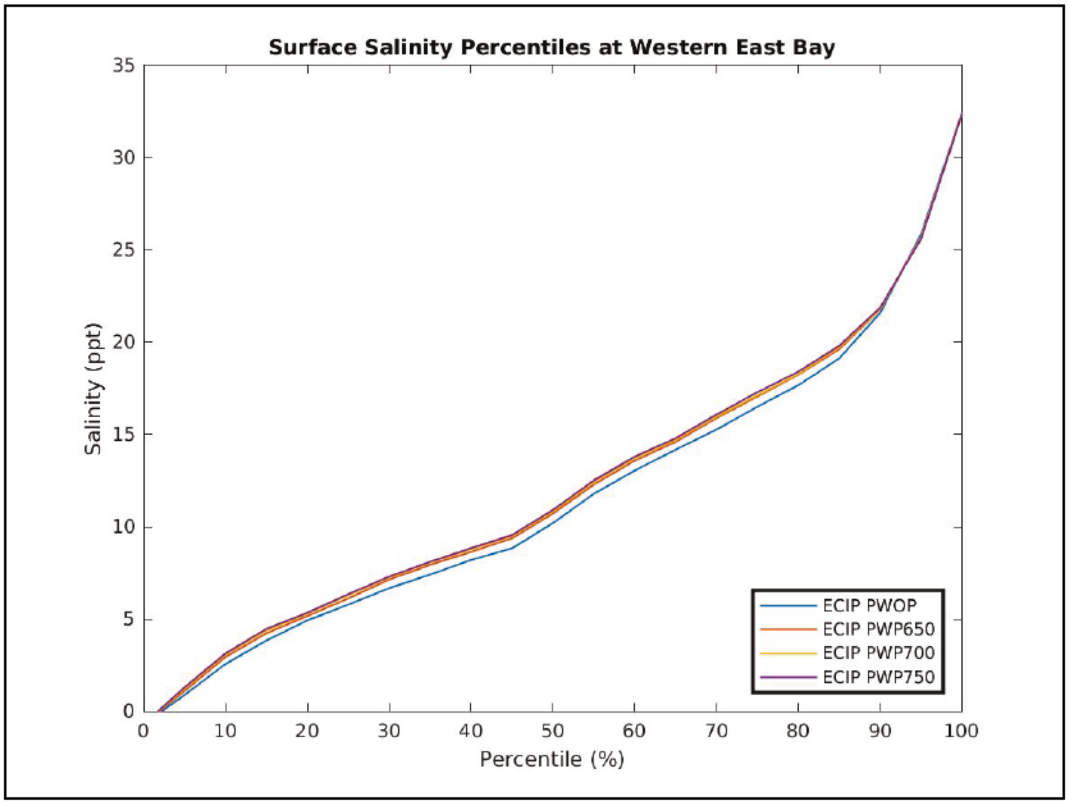
Bottom Salinity Percentiles at Upper Trinity Bay
Salinity (ppt)
Percentile (%)
35
30
25
20
15
10
5
0
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

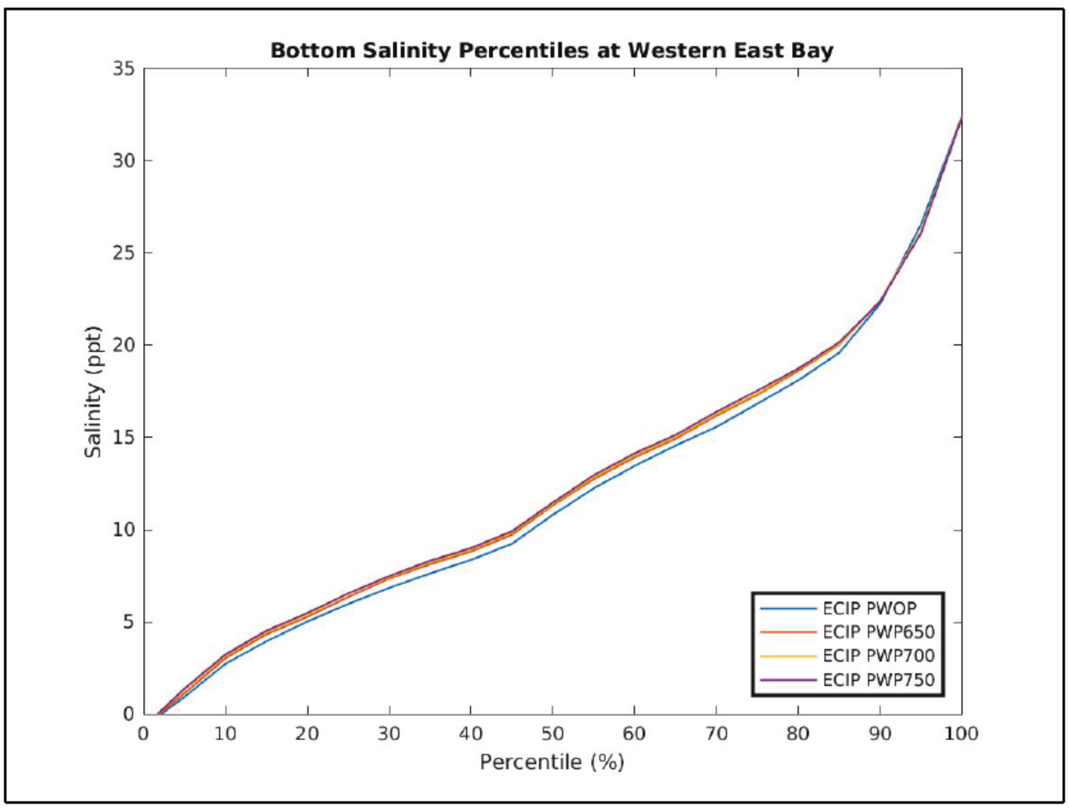

Mean Salinity Profiles at Upper Trinity Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
Salinity (ppt)
0
1
2
3
4
5
6

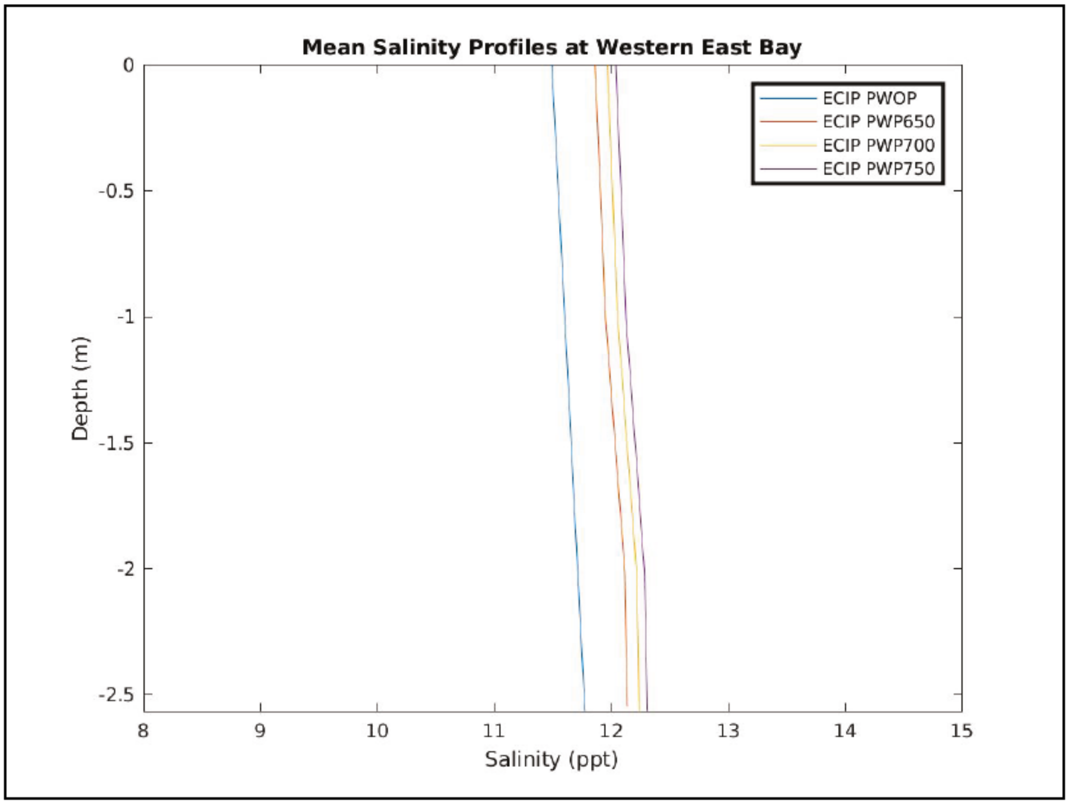

Salinity at Western East Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
Date (mm/dd)
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

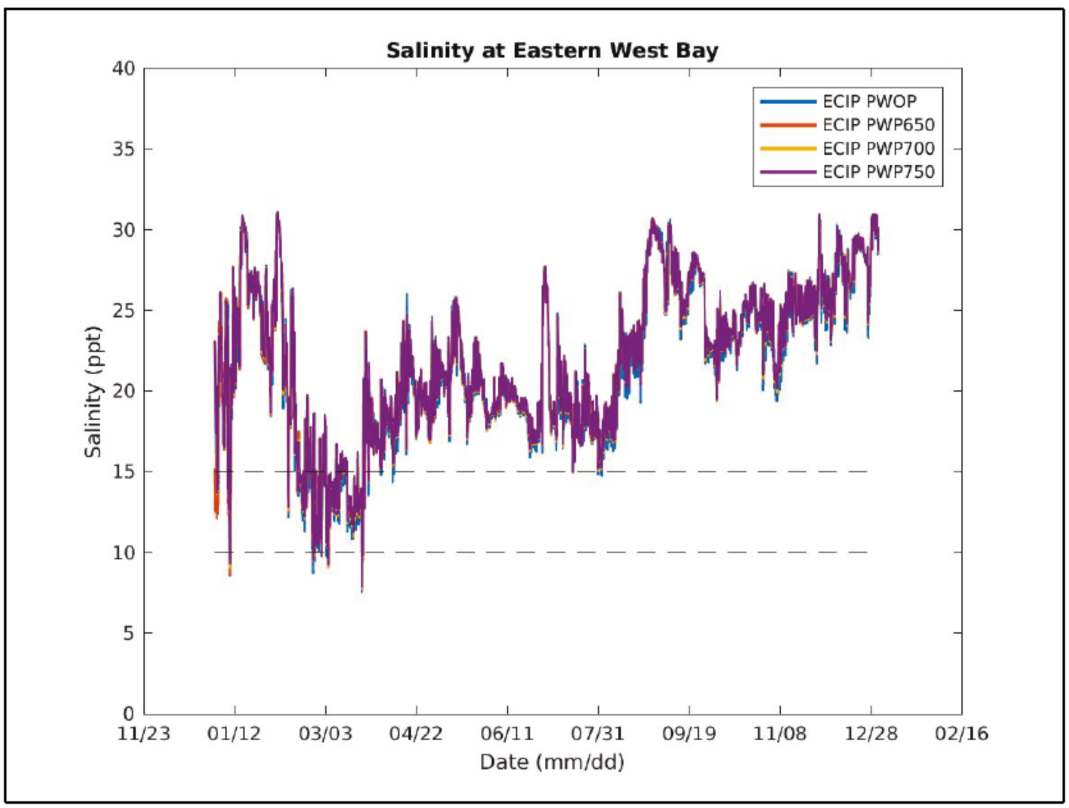

Surface Salinity at Western East Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

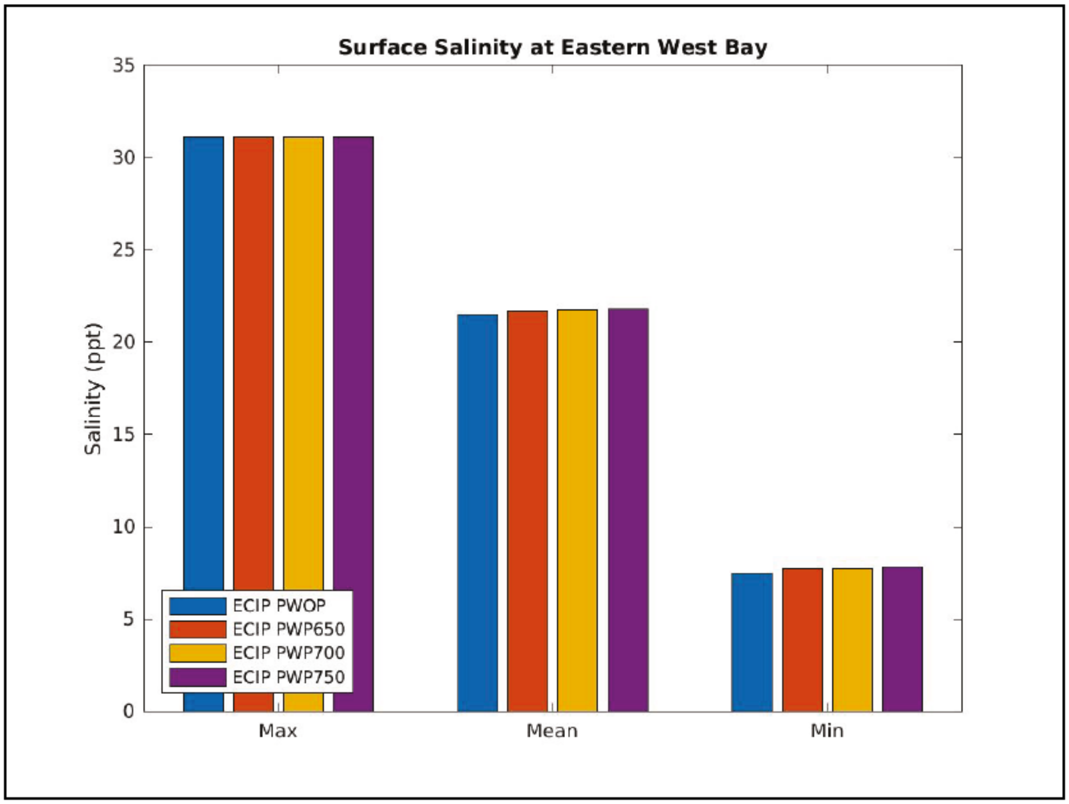

Bottom Salinity at Western East Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

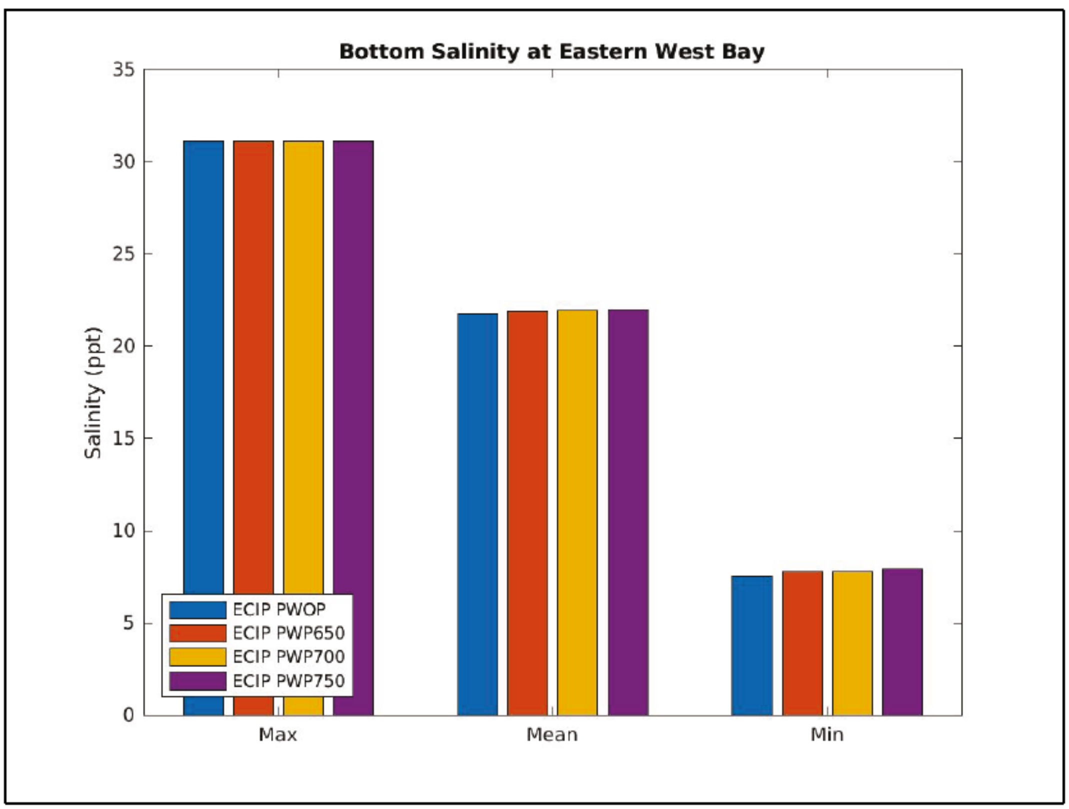

Surface Salinity Percentiles at Western East Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100

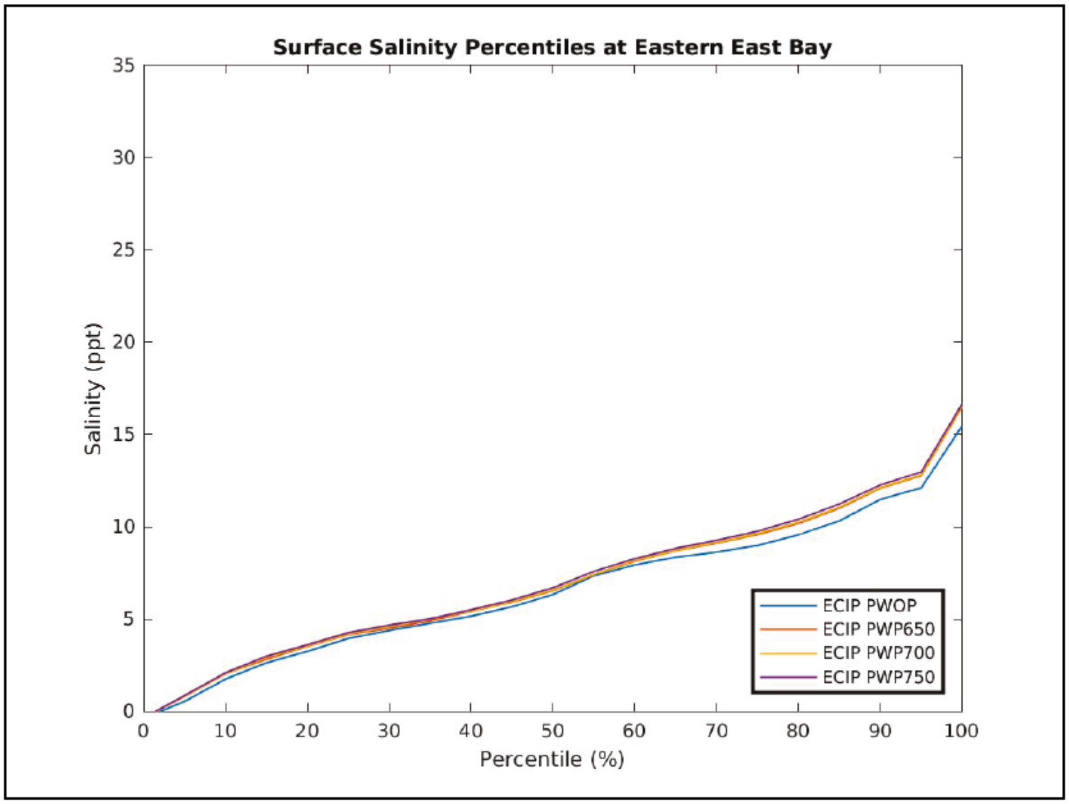

Bottom Salinity Percentiles at Western East Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100

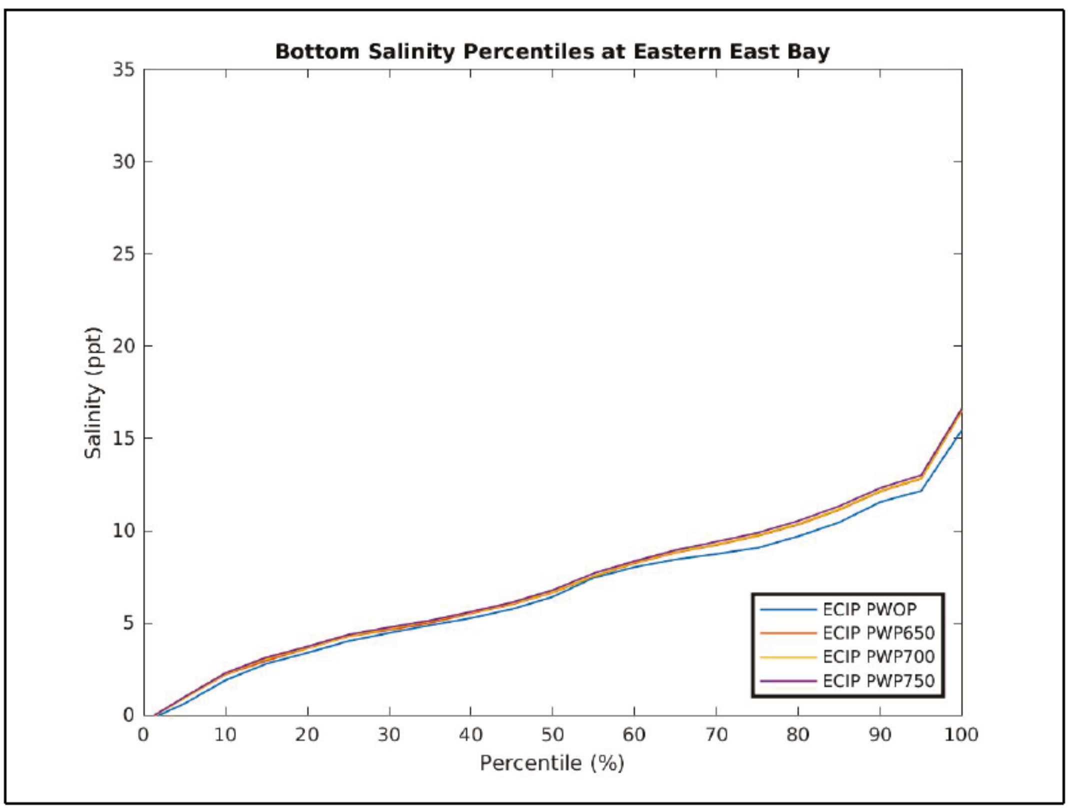

Mean Salinity Profiles at Western East Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
8
9
10
11
12
13
14
15
Salinity (ppt)

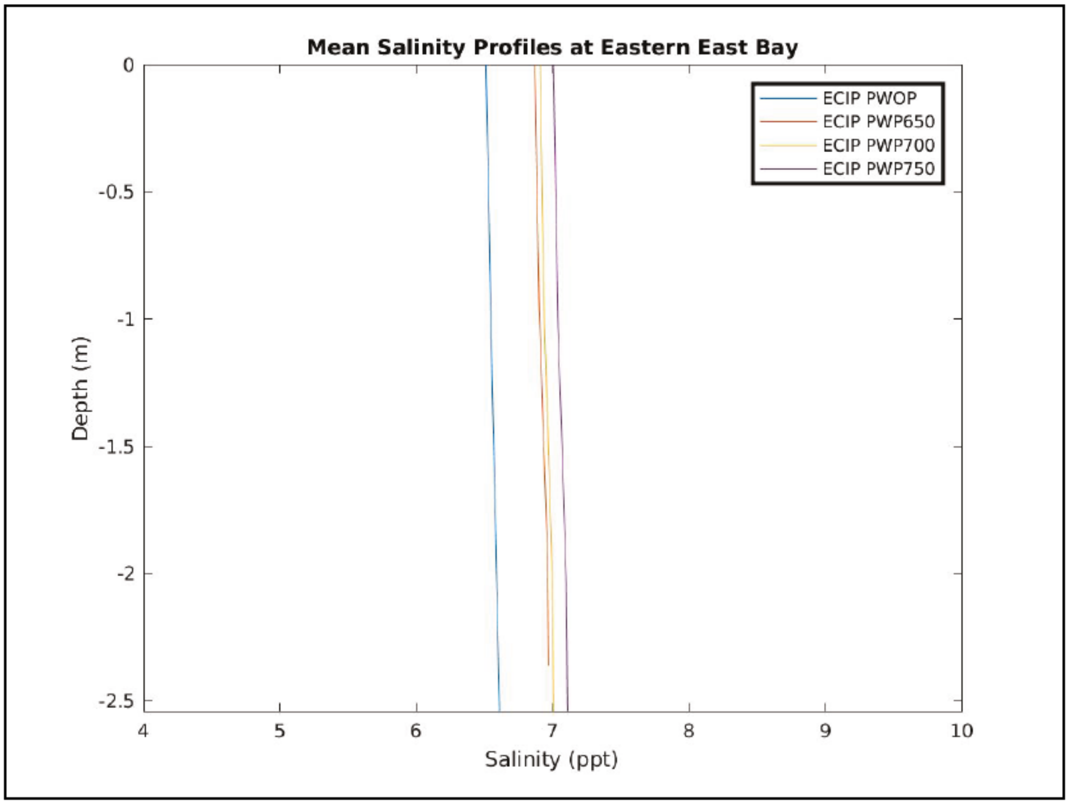

Salinity at Eastern West Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

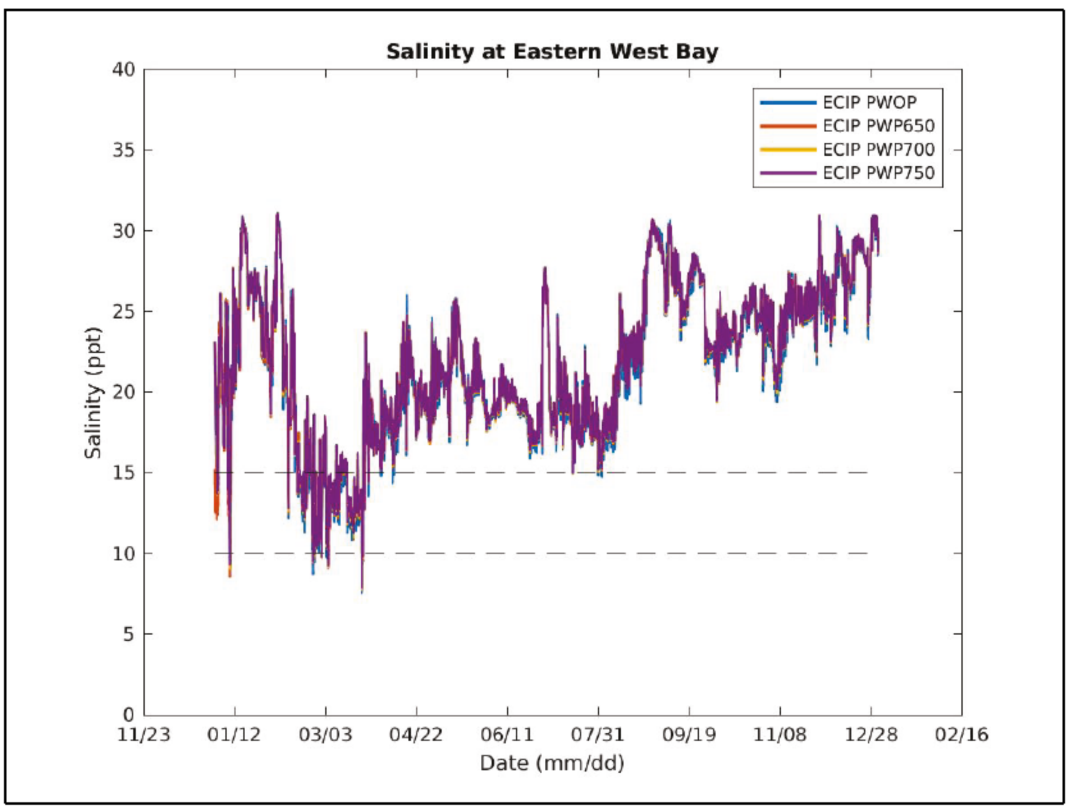

Surface Salinity at Eastern West Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

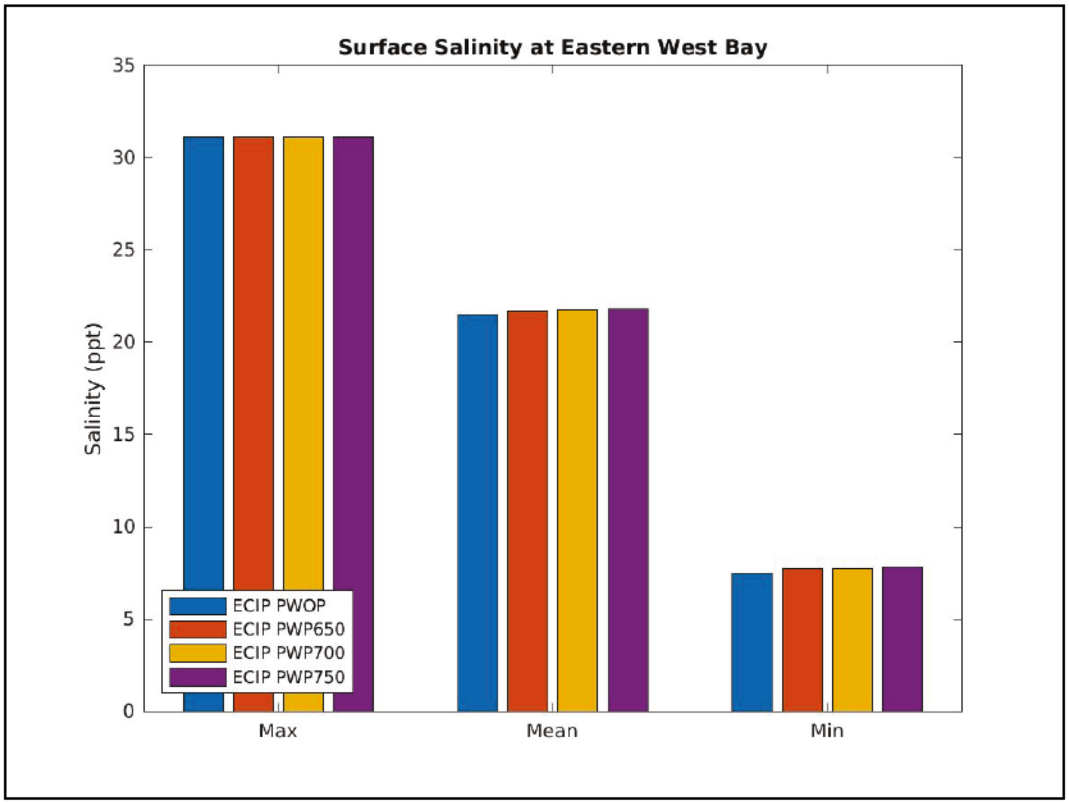

Bottom Salinity at Eastern West Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

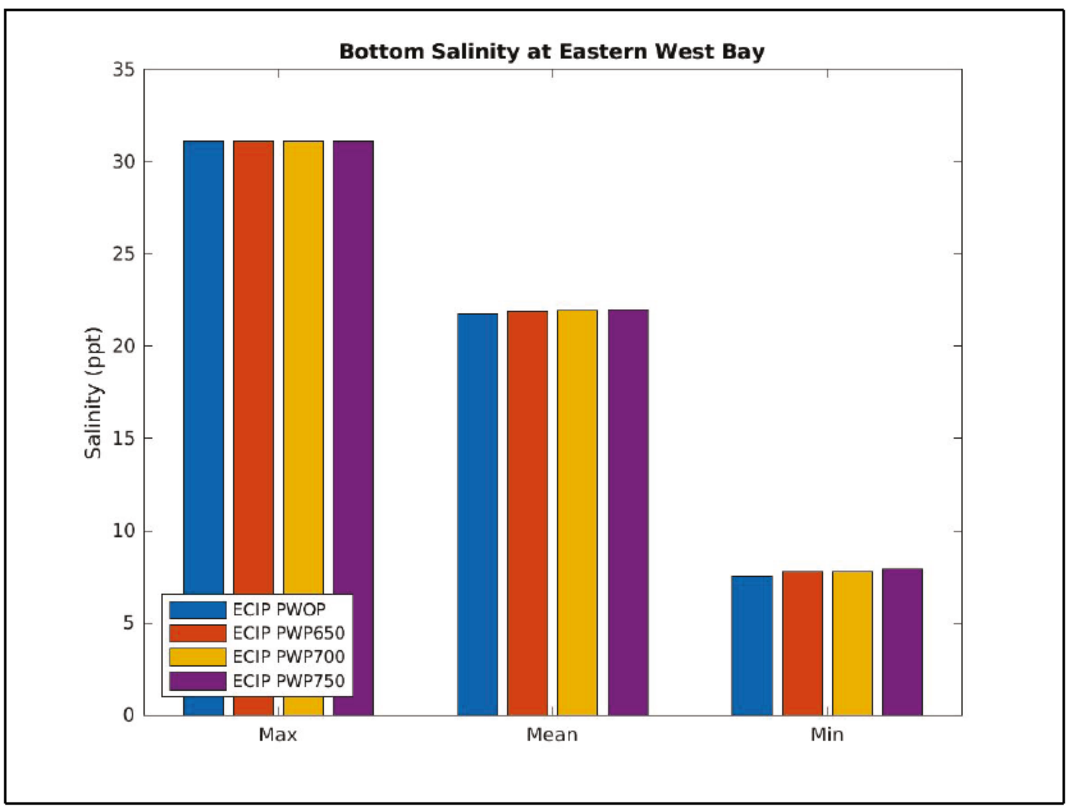

Surface Salinity Percentiles at Eastern East Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

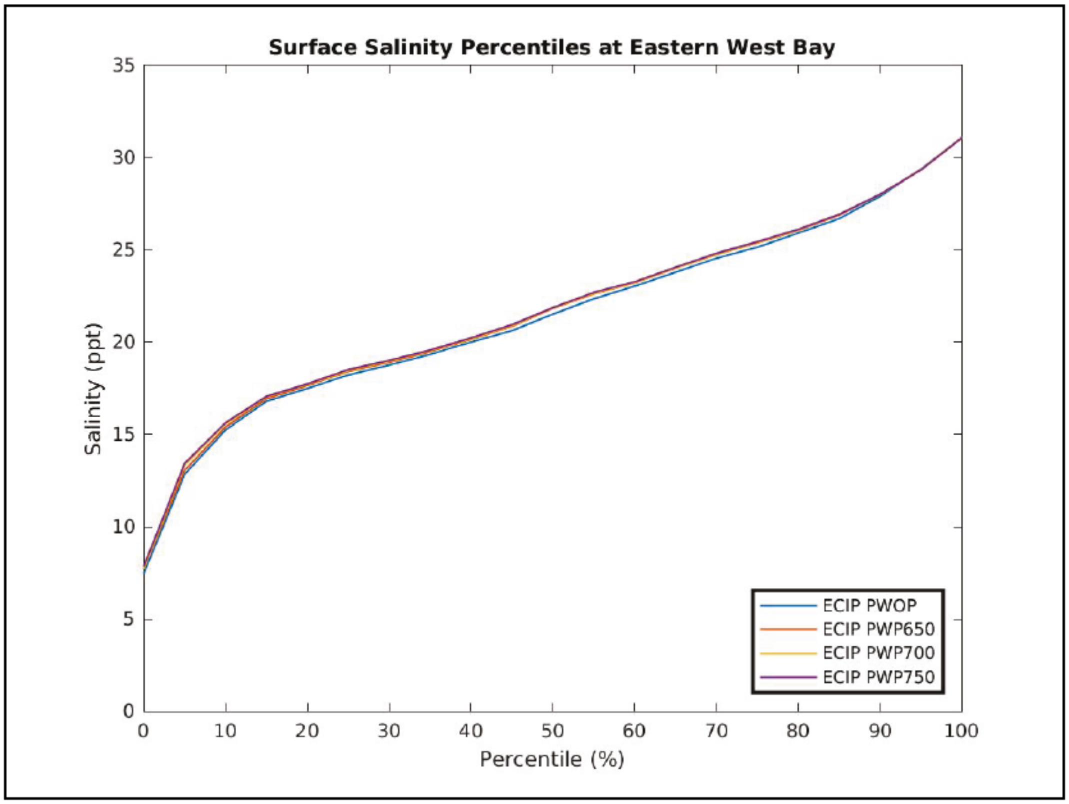

Bottom Salinity Percentiles at Eastern East Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

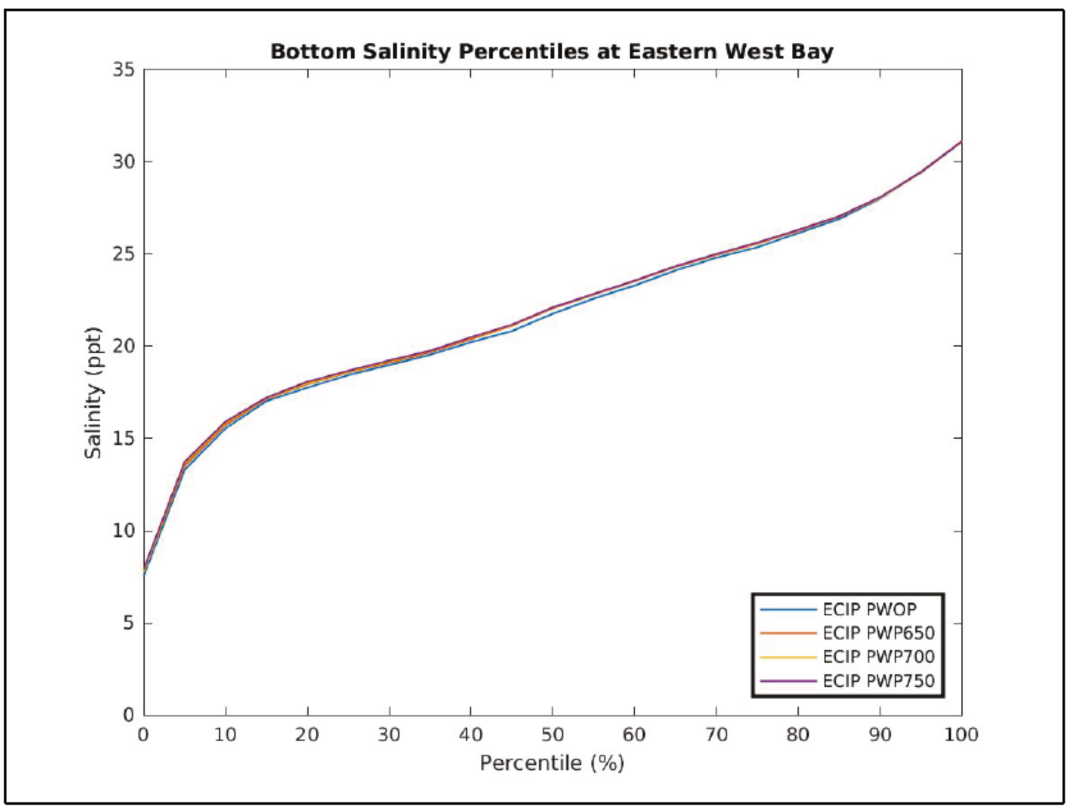

Mean Salinity Profiles at Eastern East Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
4
5
6
7
8
9
10
Salinity (ppt)

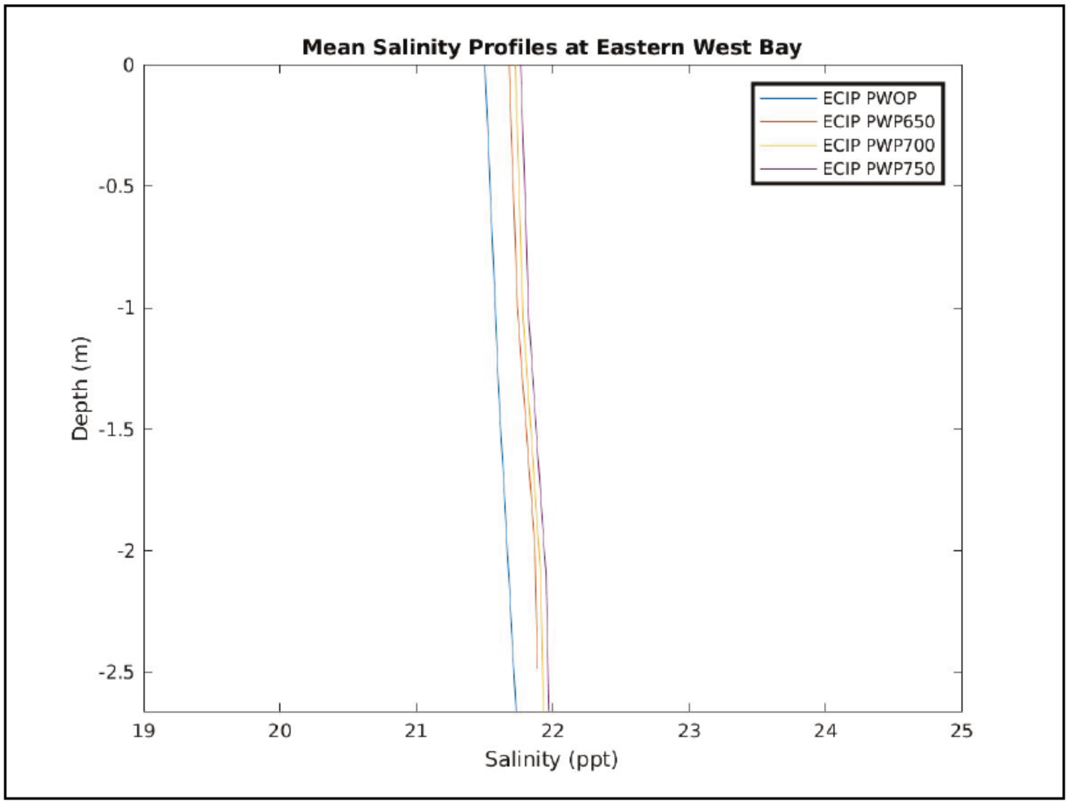

Salinity at Eastern West Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

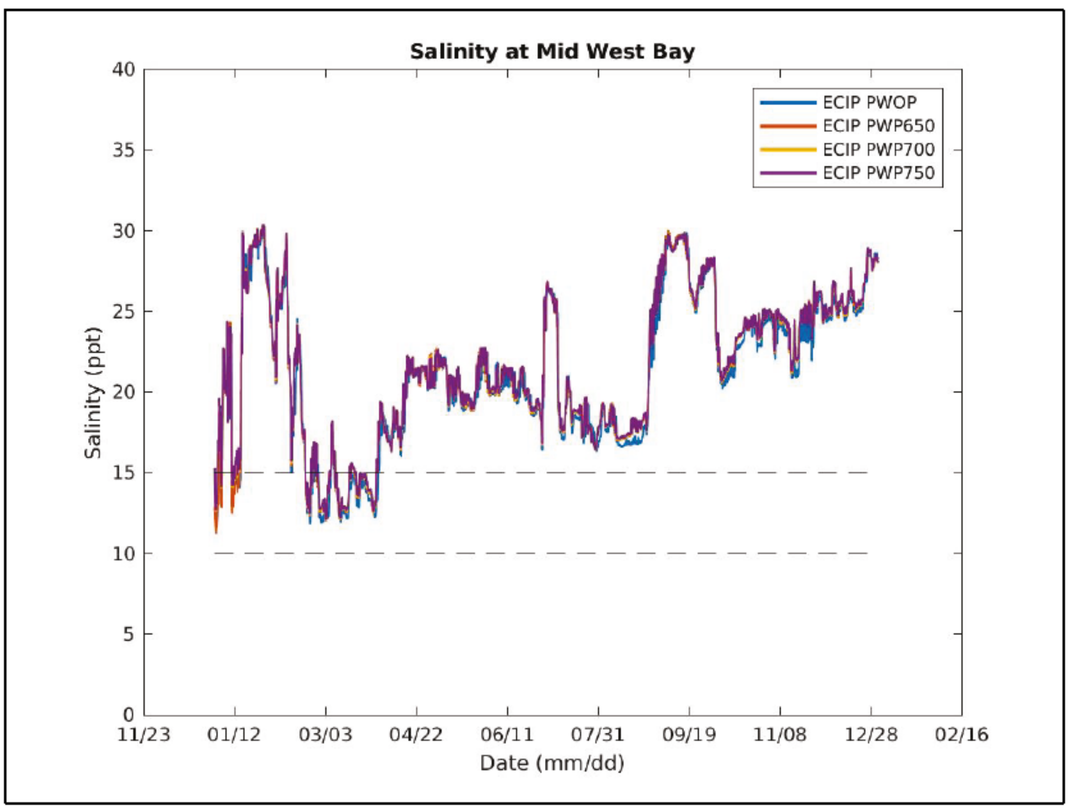

Surface Salinity at Eastern West Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

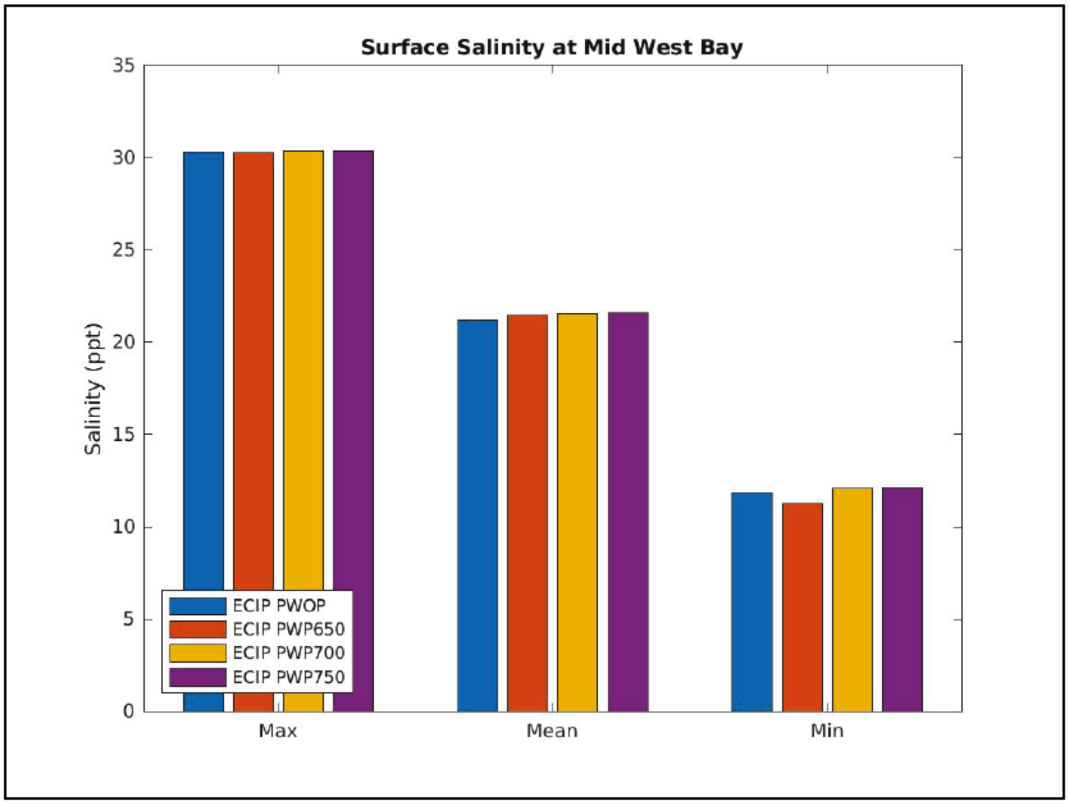

Bottom Salinity at Eastern West Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

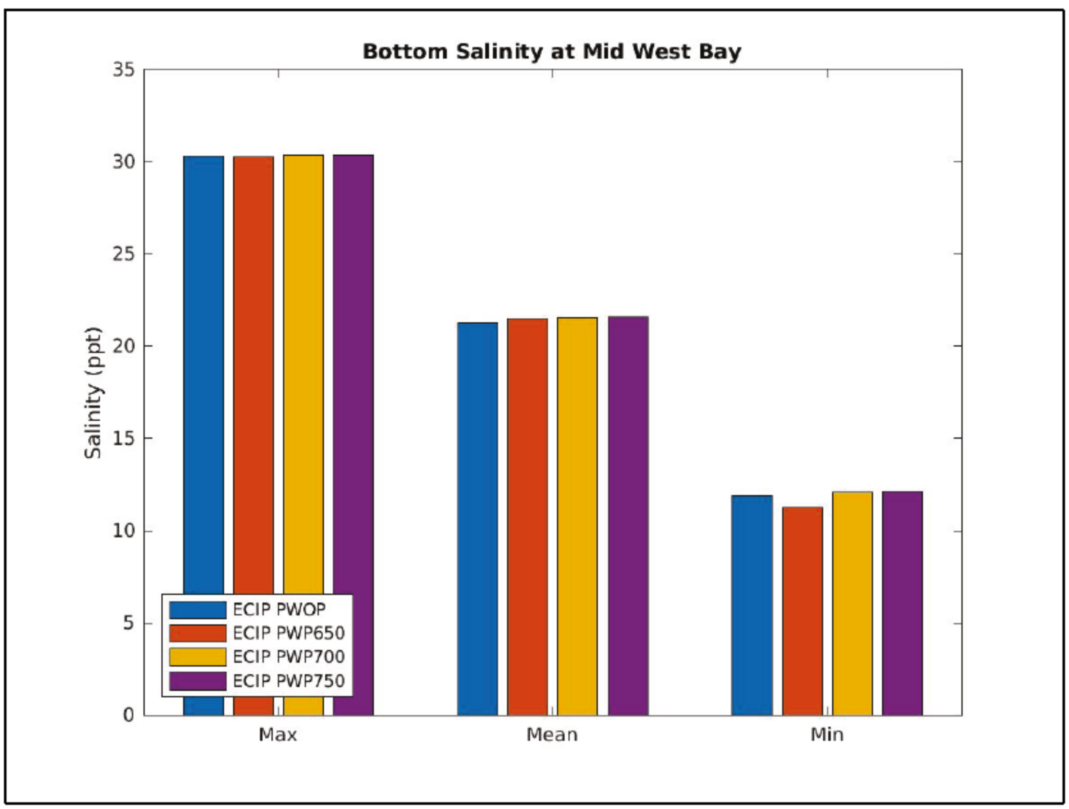

Surface Salinity Percentiles at Eastern West Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

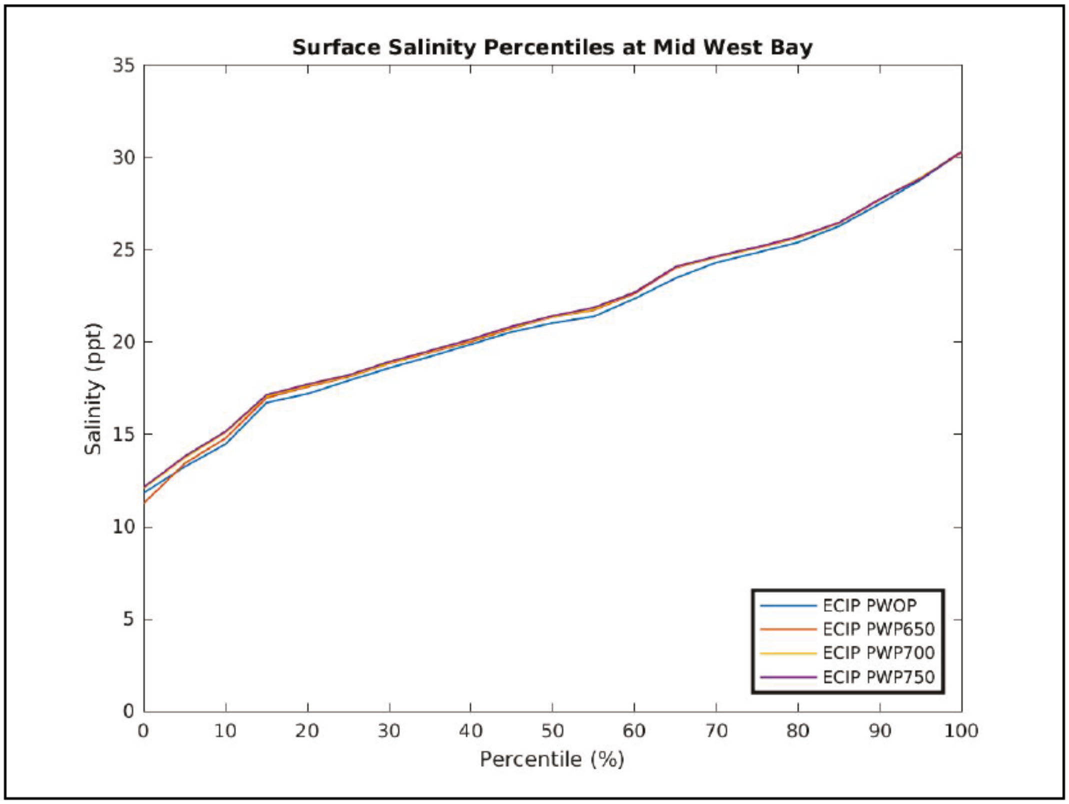

Bottom Salinity Percentiles at Eastern West Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

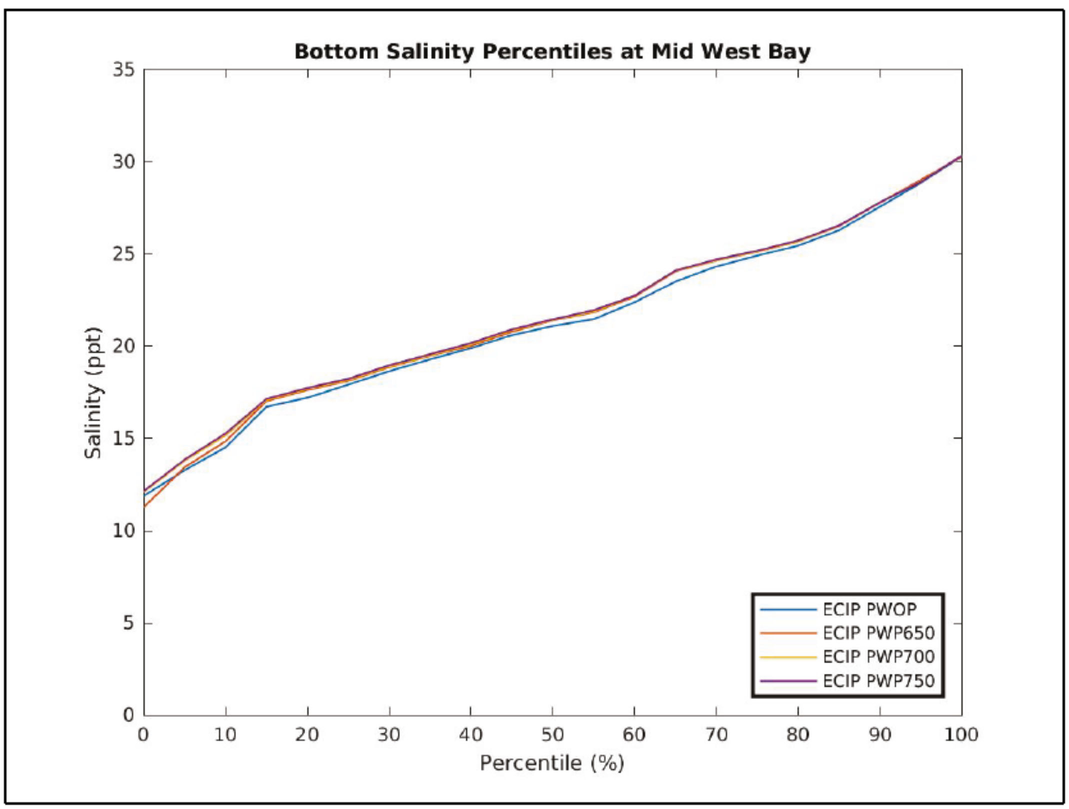

Mean Salinity Profiles at Eastern West Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
19
20
21
22
23
24
25
Salinity (ppt)

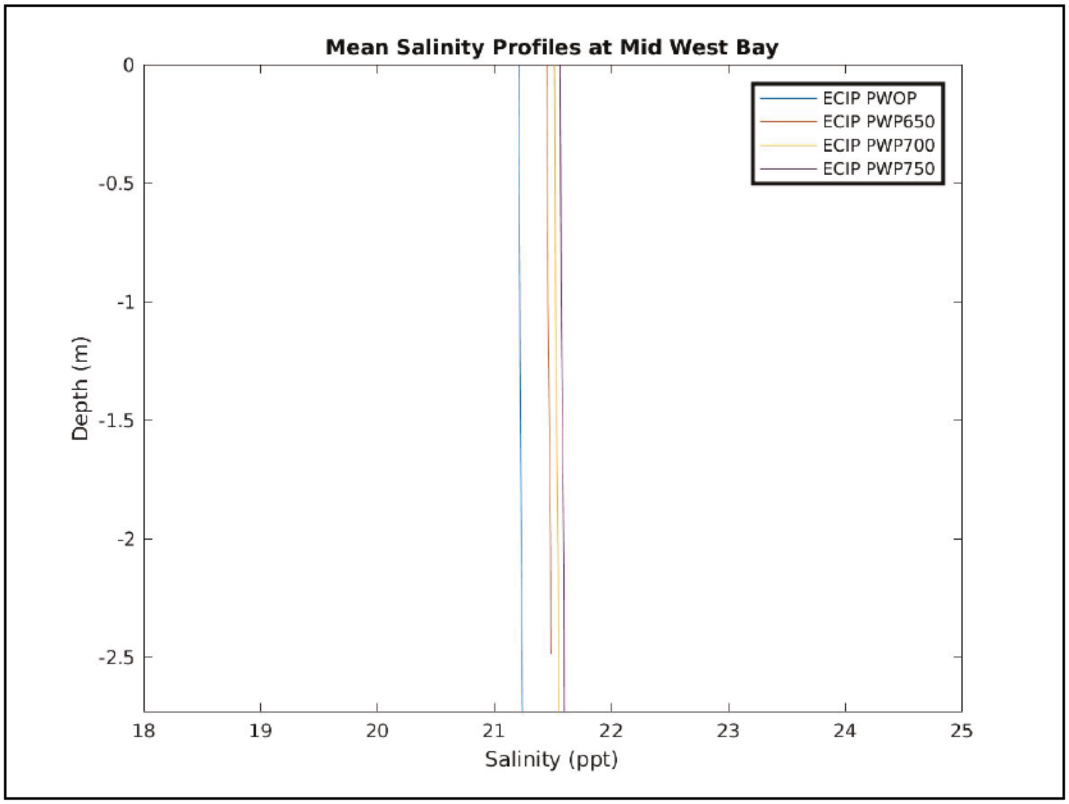

Salinity at Mid West Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)


Surface Salinity at Mid West Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

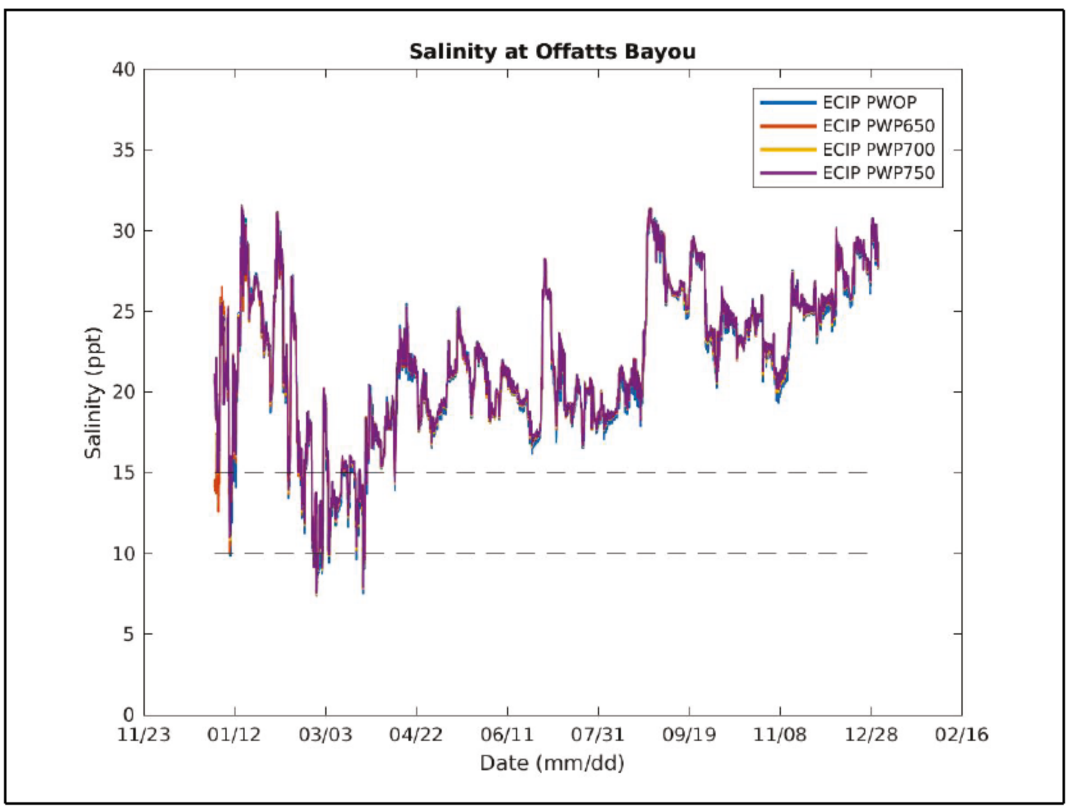

Bottom Salinity at Mid West Bay
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750


Surface Salinity Percentiles at Mid West Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

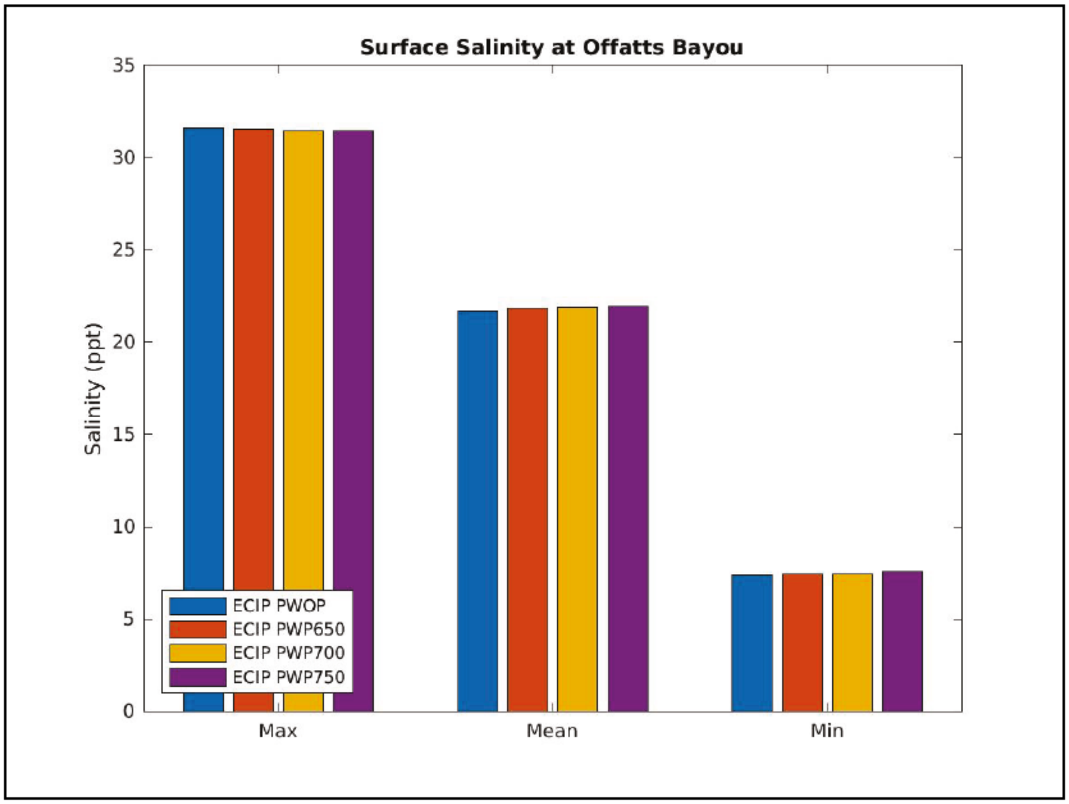

Bottom Salinity Percentiles at Mid West Bay
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

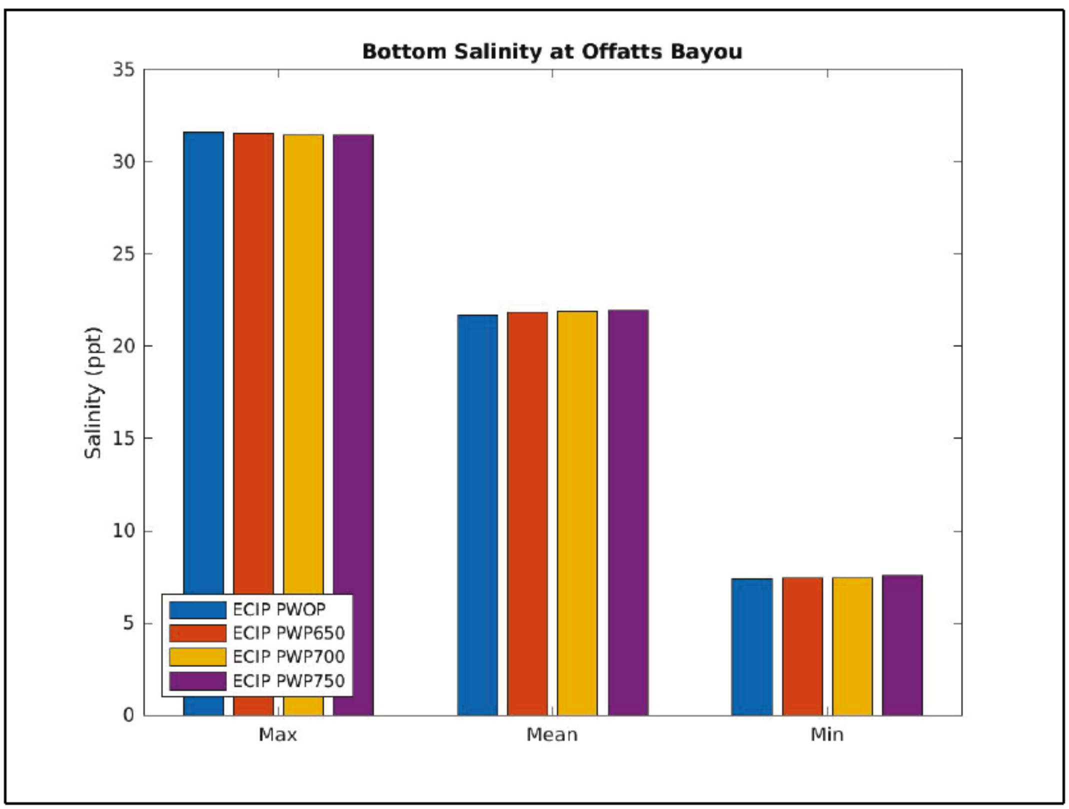


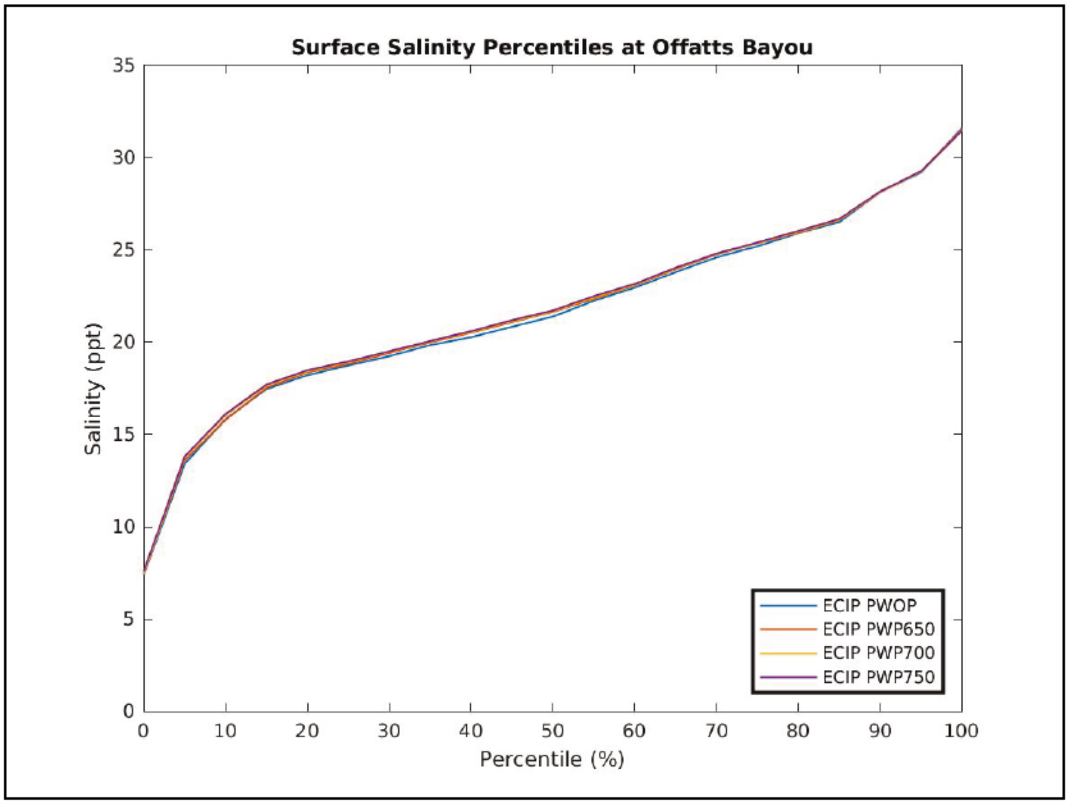
Mean Salinity Profiles at Mid West Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
18
19
20
21
22
23
24
25
Salinity (ppt)

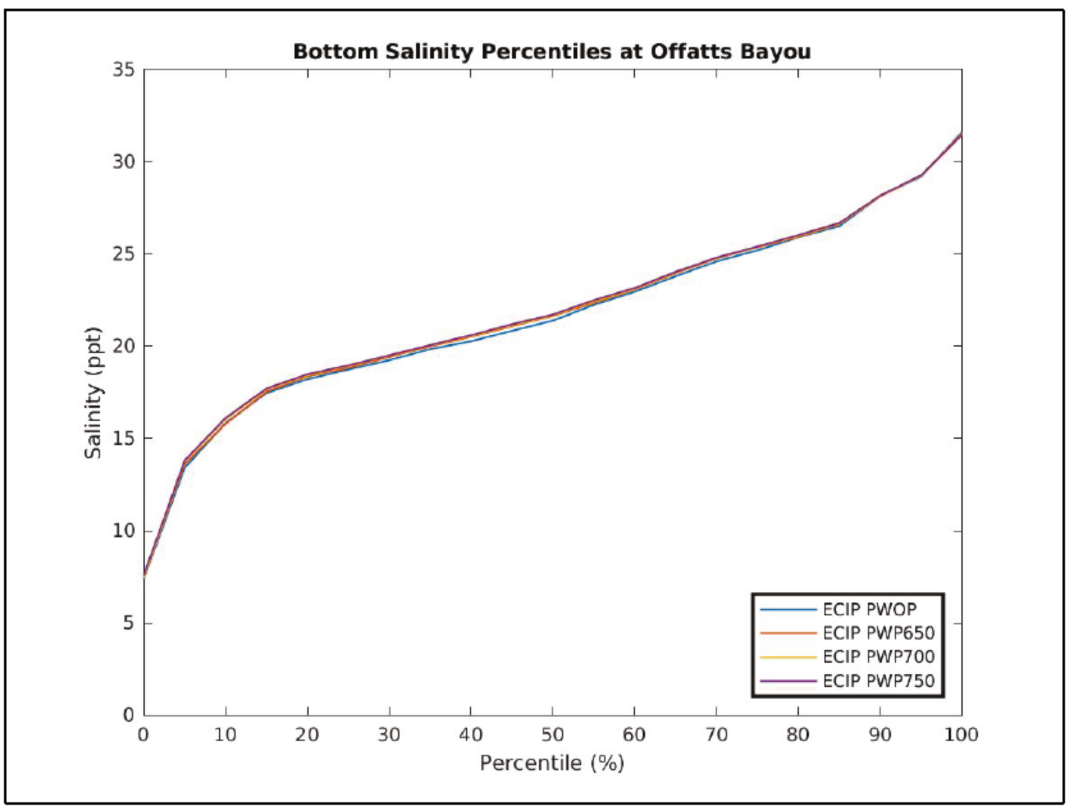



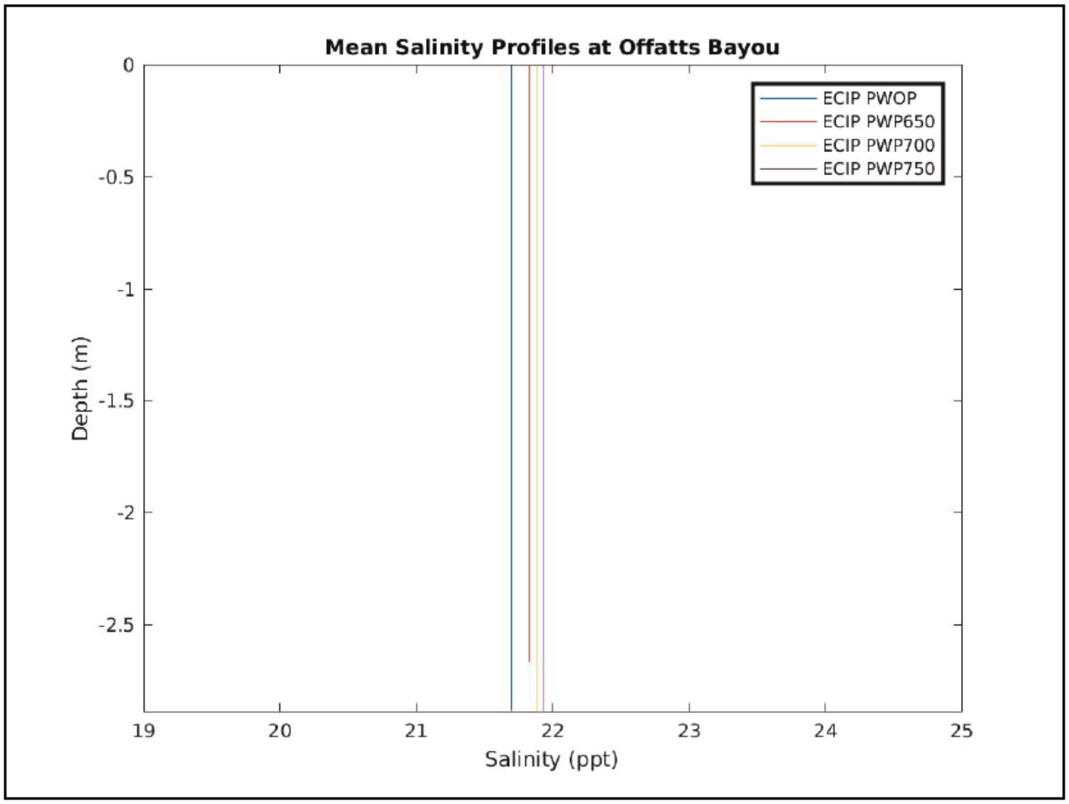
Salinity at Offatts Bayou
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

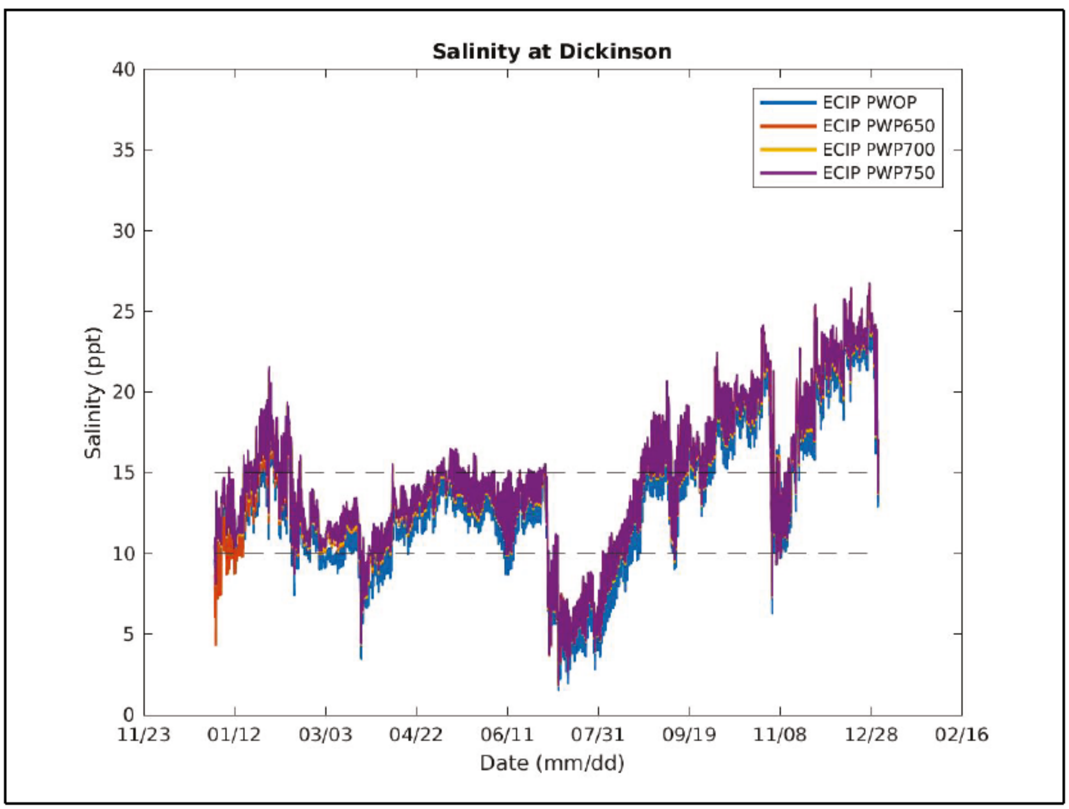

Surface Salinity at Offatts Bayou
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

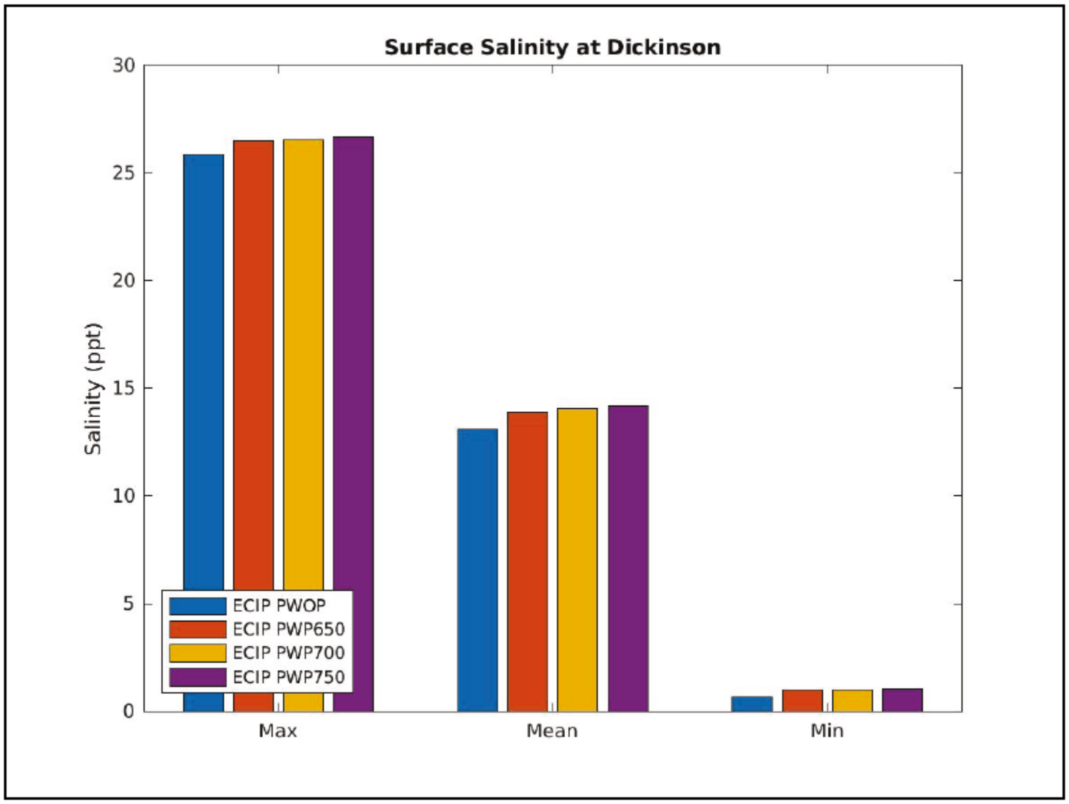

Bottom Salinity at Offatts Bayou
Salinity (ppt)
0
5
10
15
20
25
30
35
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

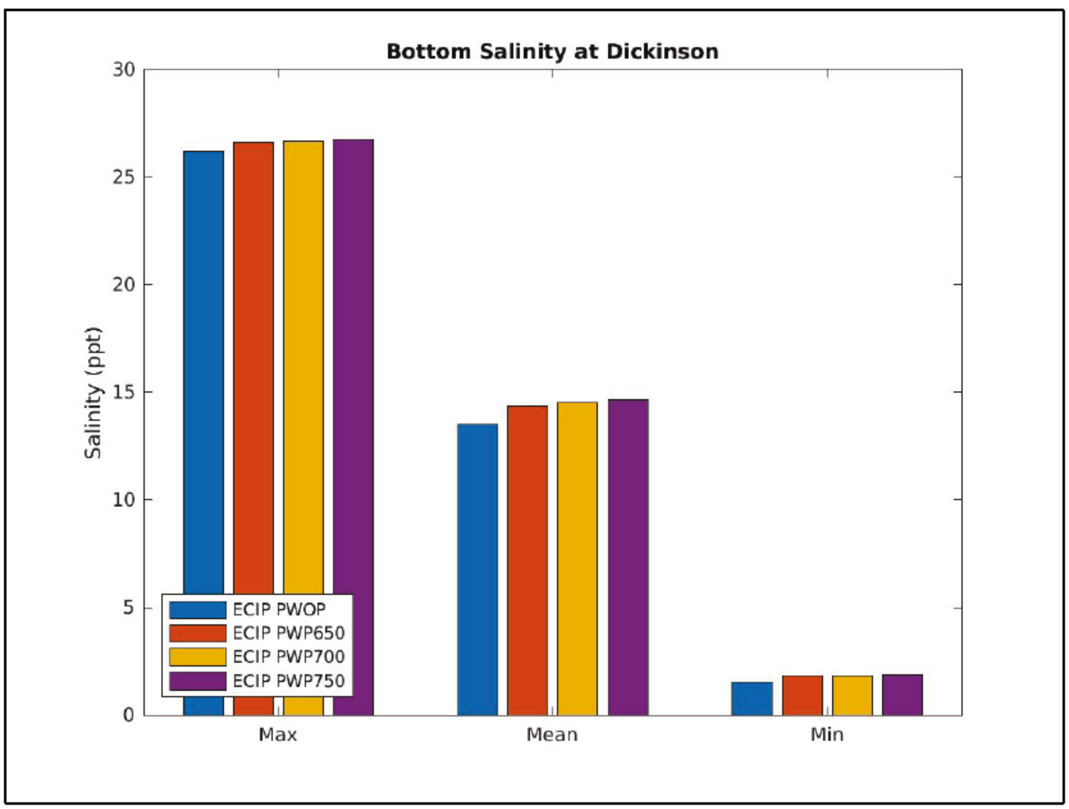

Surface Salinity Percentiles at Offatts Bayou
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

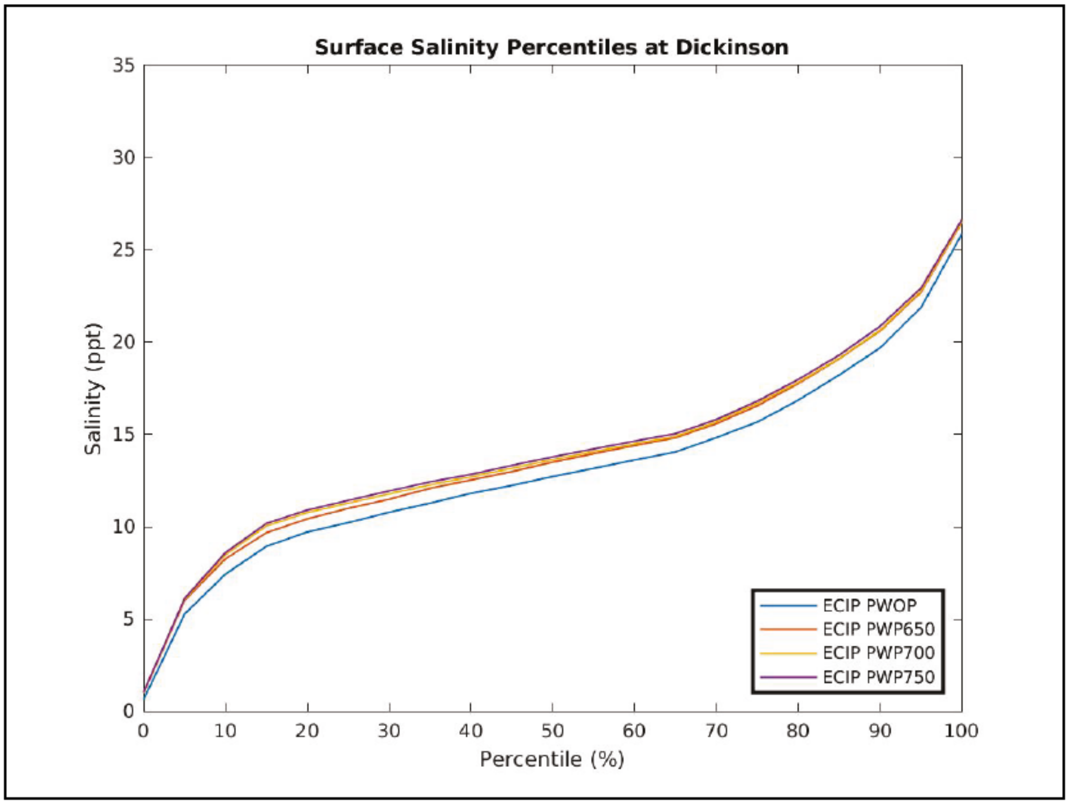

Bottom Salinity Percentiles at Offatts Bayou
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

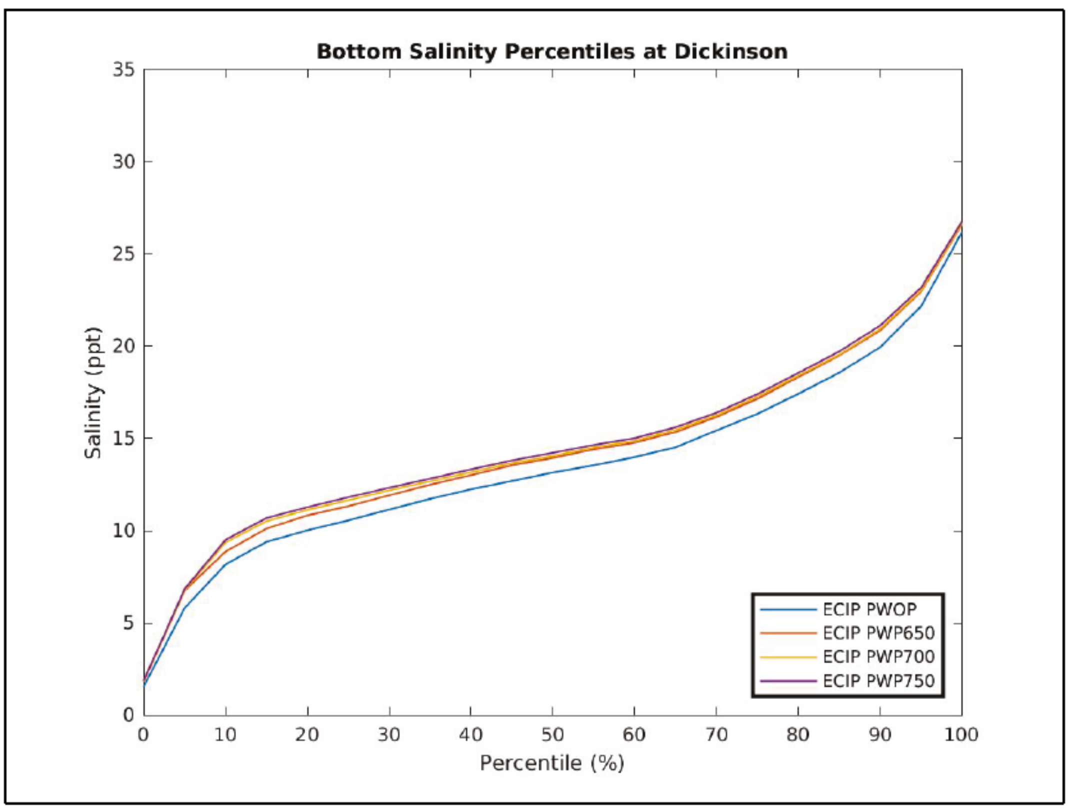

Mean Salinity Profiles at Offatts Bayou
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
19
20
21
22
23
24
25
Salinity (ppt)

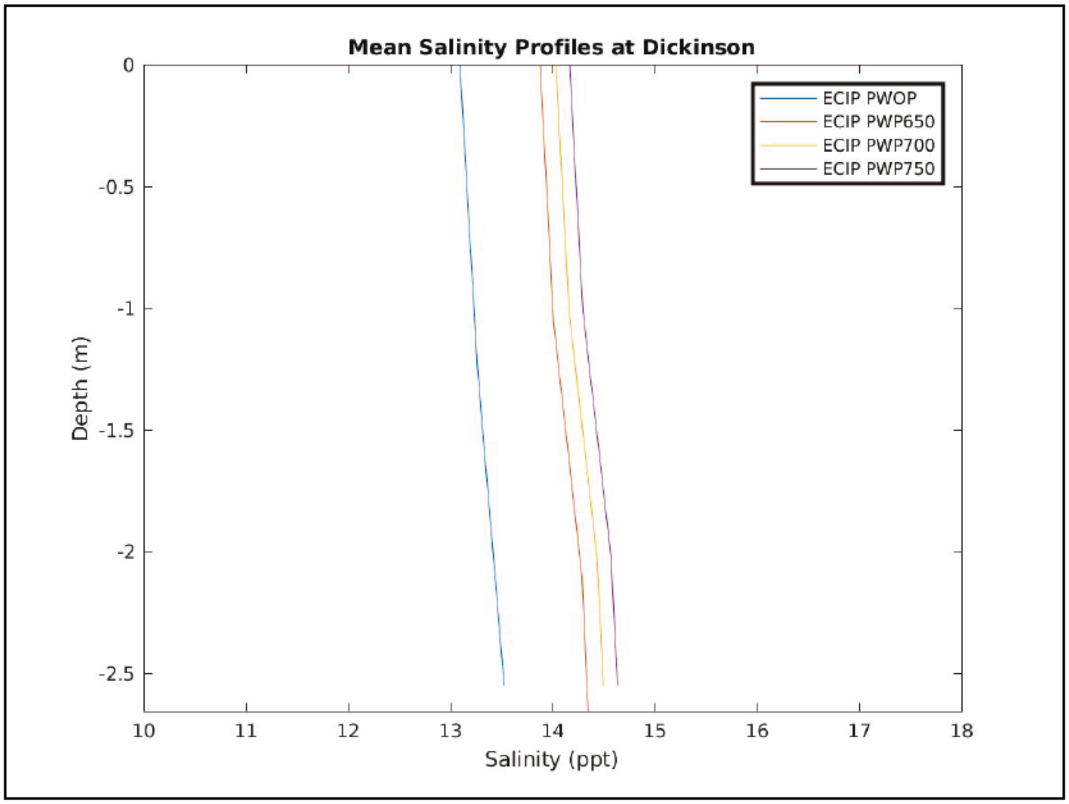

Salinity at Dickinson
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

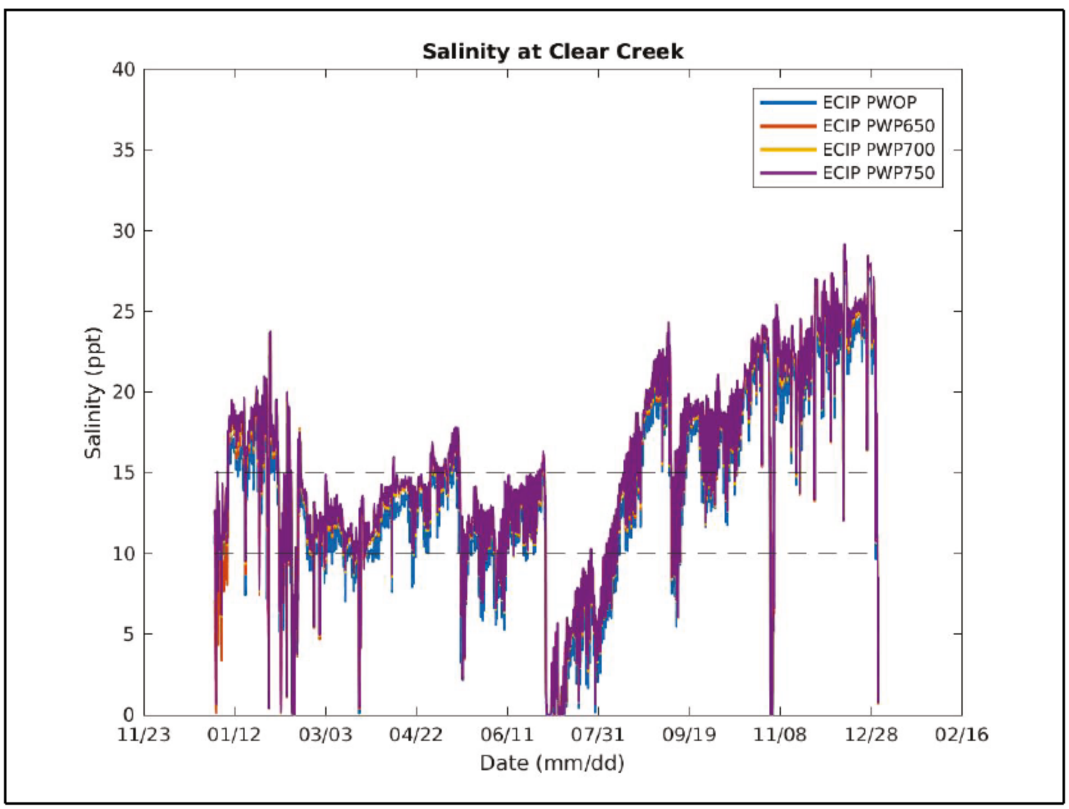

Surface Salinity at Dickinson
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

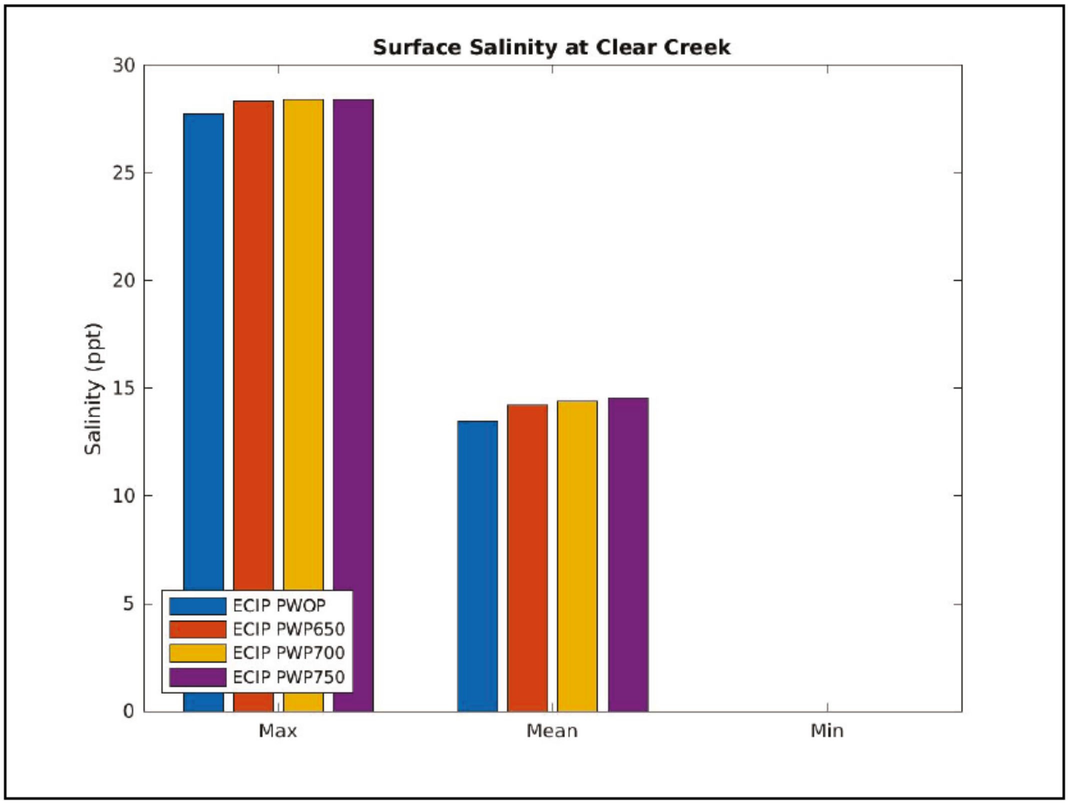

Bottom Salinity at Dickinson
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

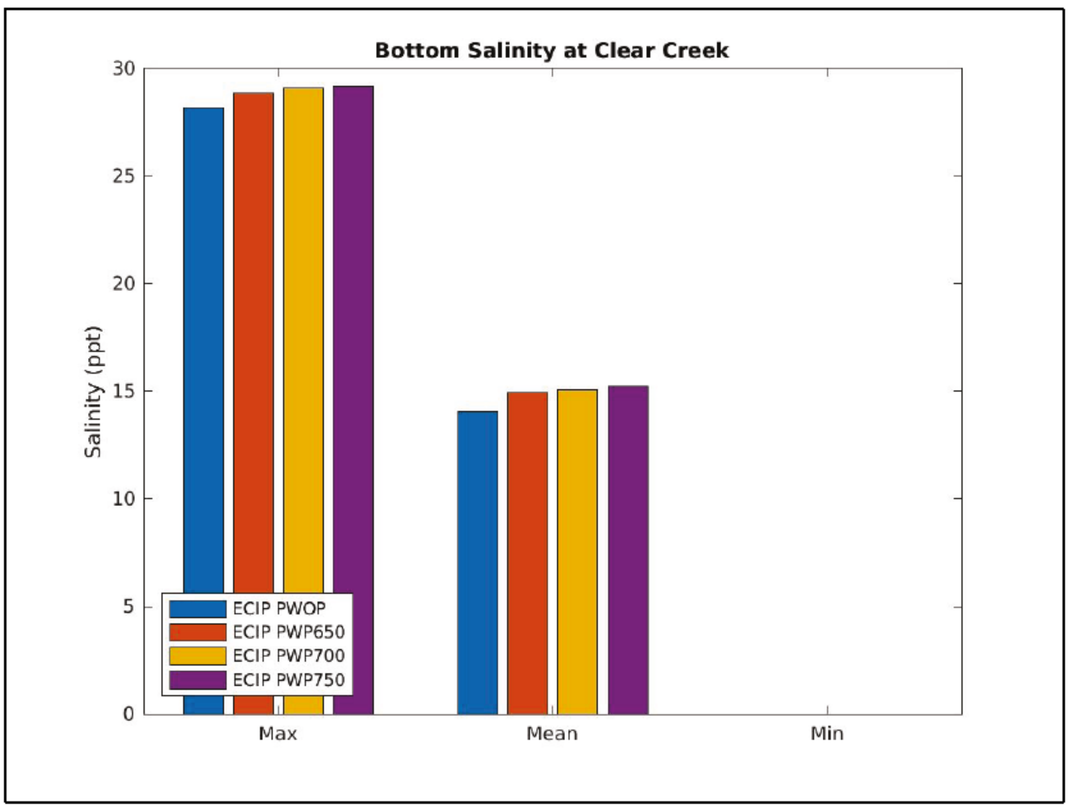

Surface Salinity Percentiles at Dickinson
Salinity (ppt)
Percentile (%)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

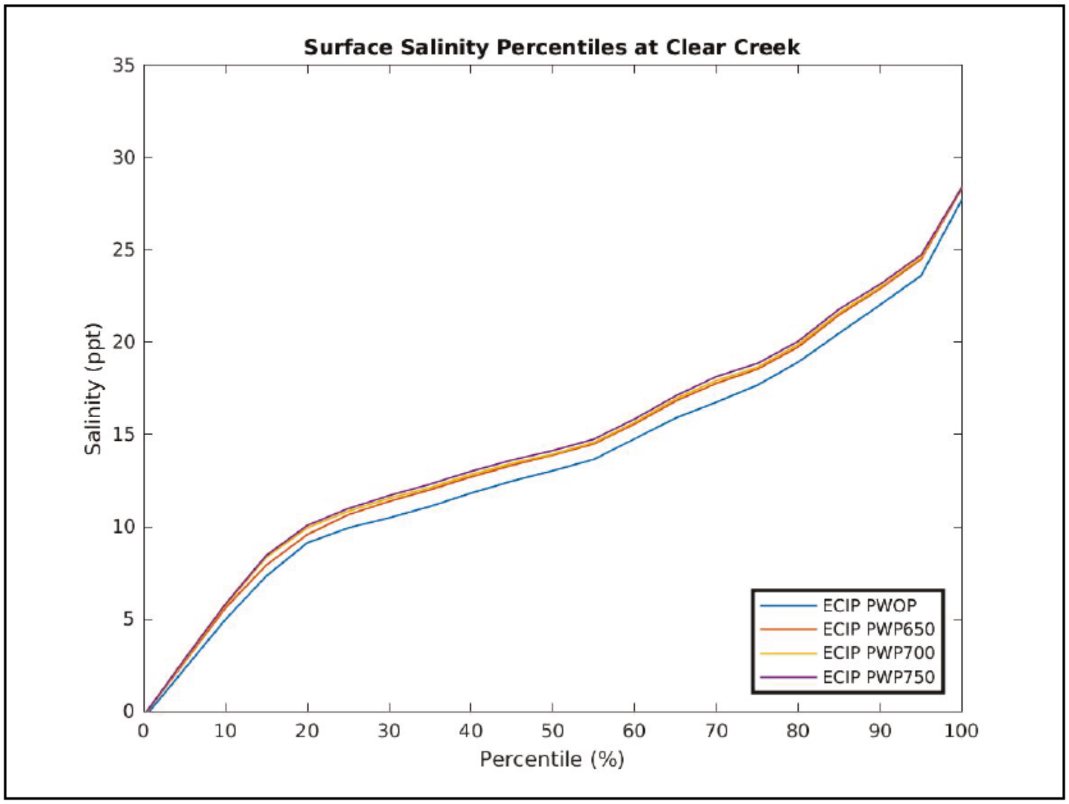

Bottom Salinity Percentiles at Dickinson
Salinity (ppt)
Percentile (%)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

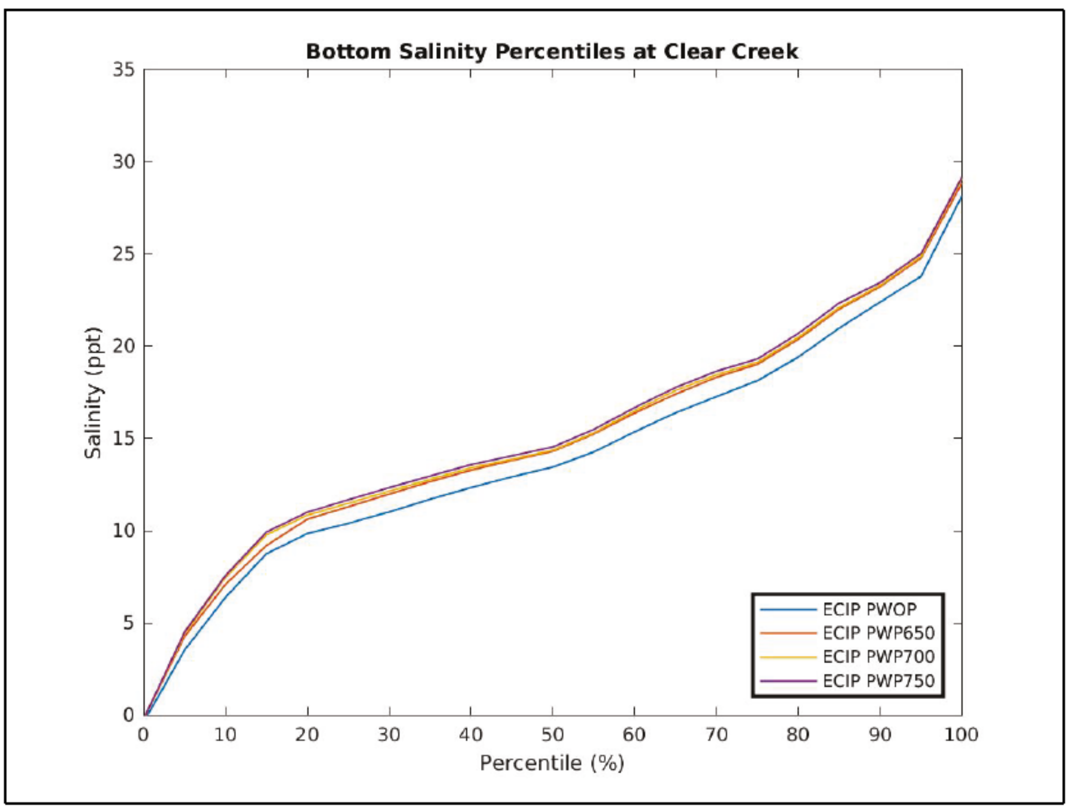

Mean Salinity Profiles at Dickinson
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
10
11
12
13
14
15
16
17
18
Salinity (ppt)

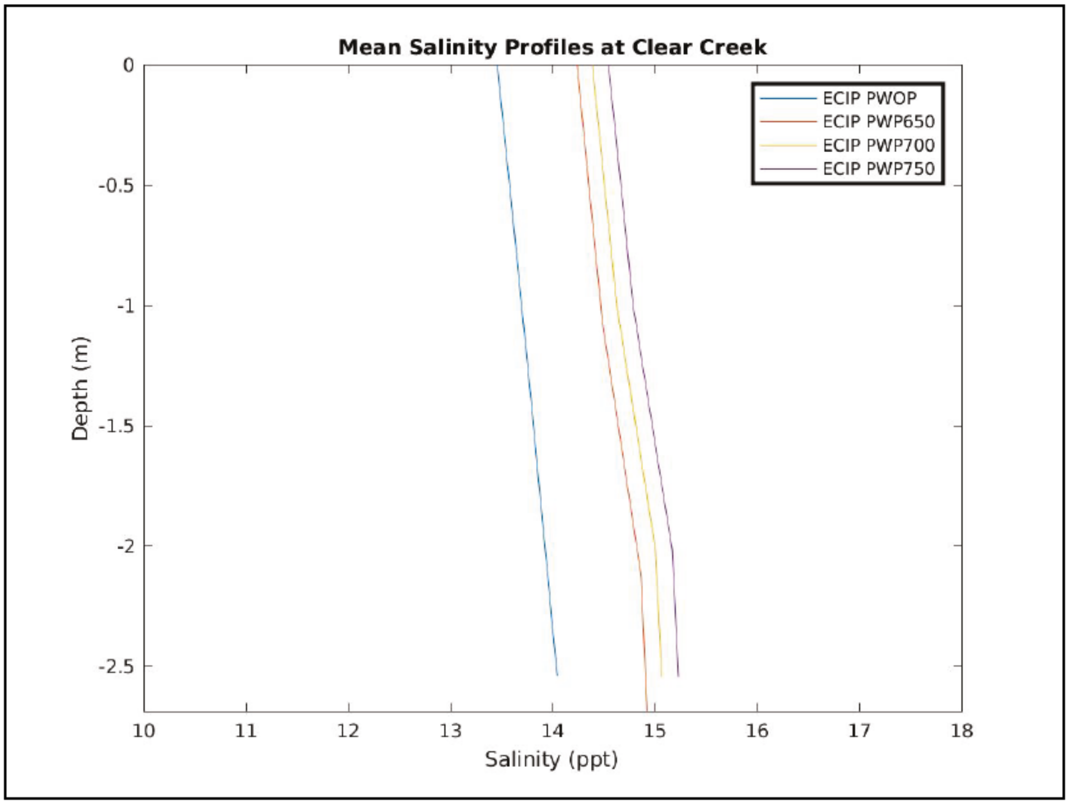

Salinity at Clear Creek
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

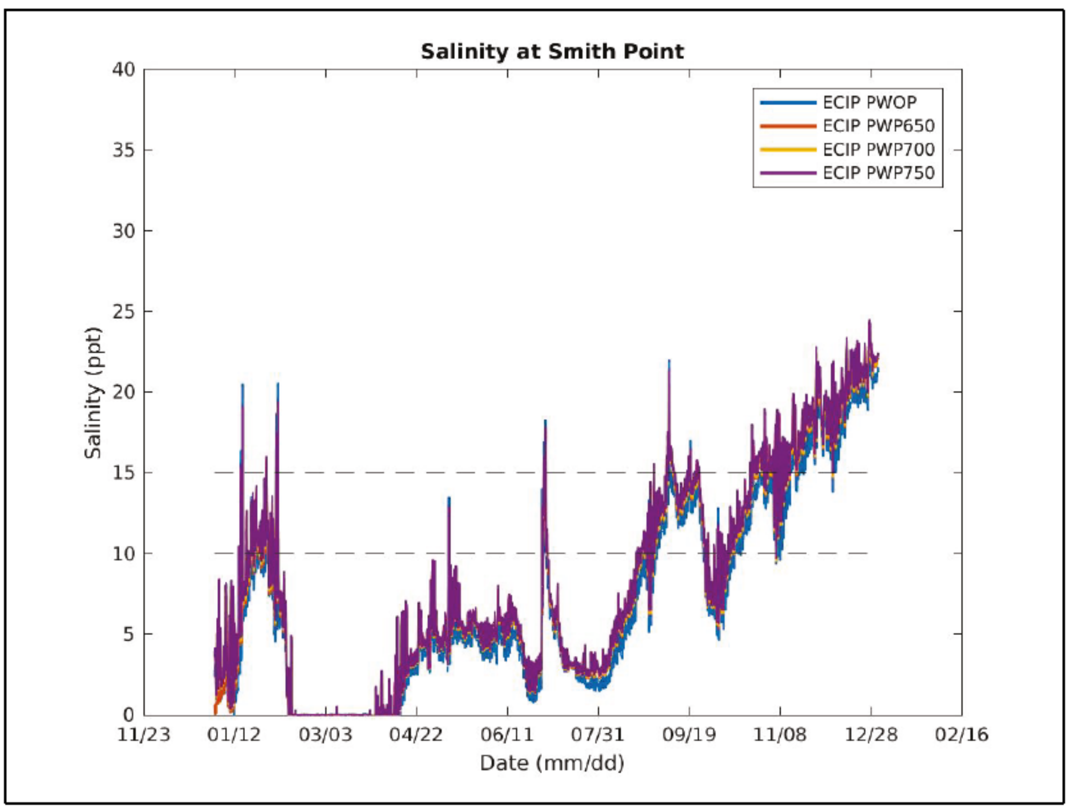

Surface Salinity at Clear Creek
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

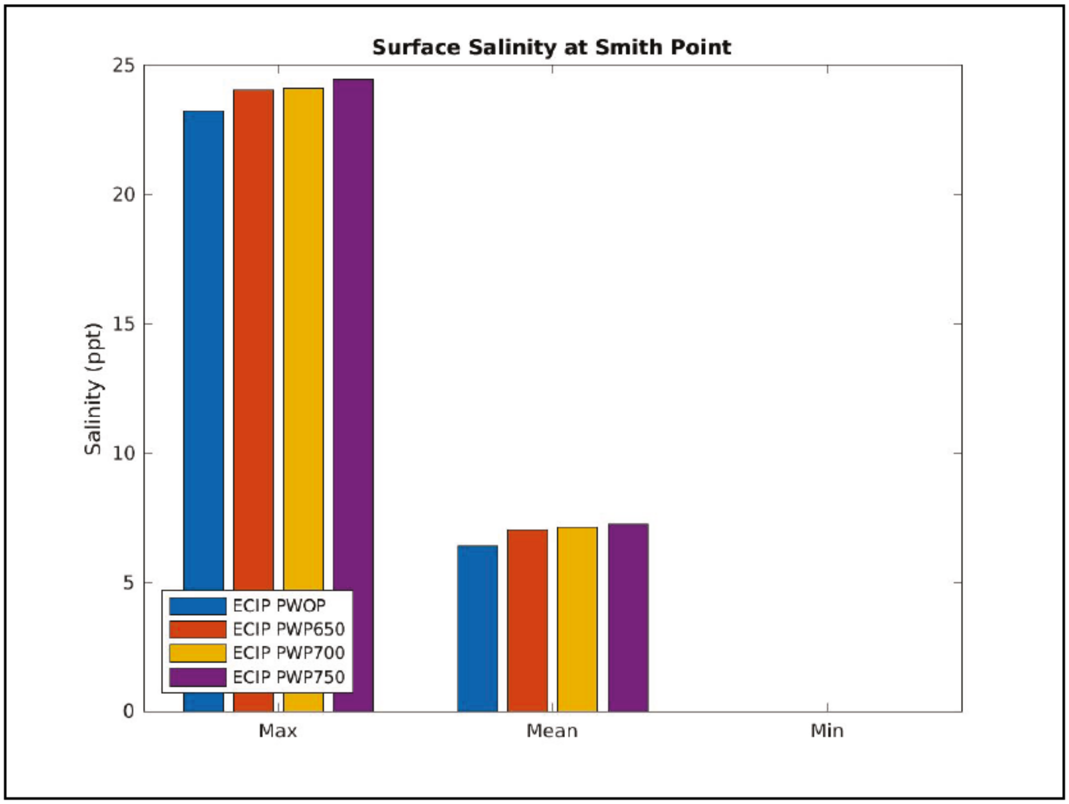

Bottom Salinity at Clear Creek
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

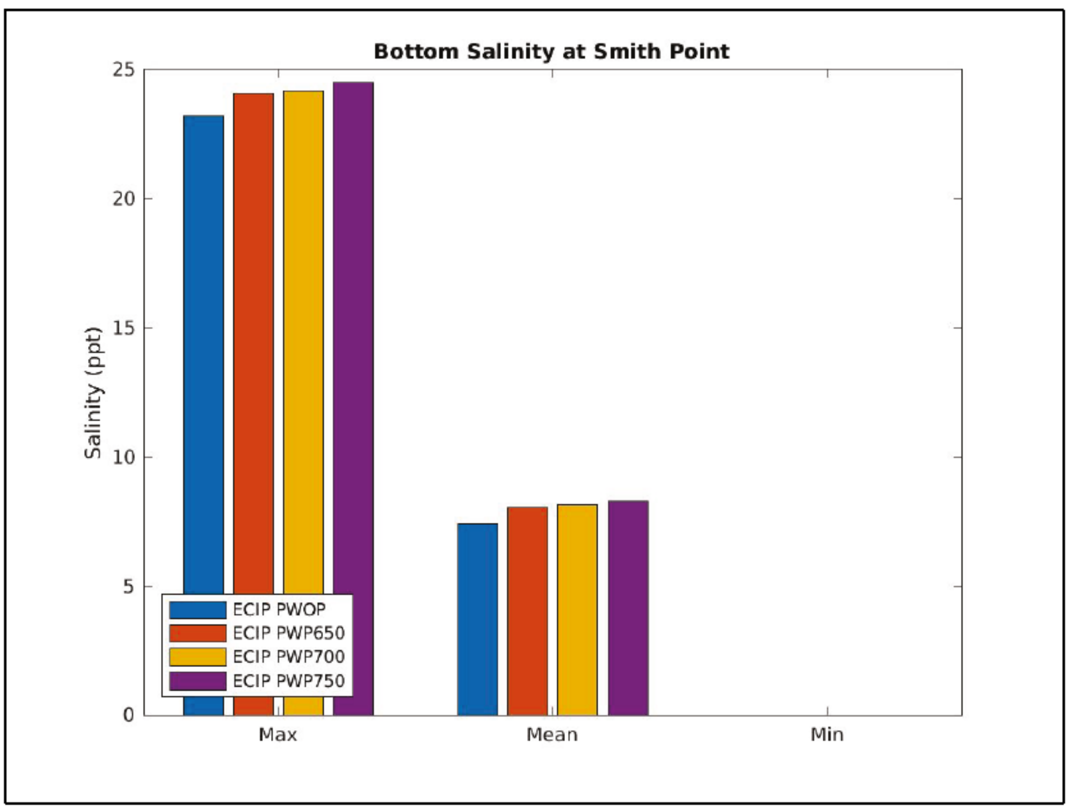

Surface Salinity Percentiles at Clear Creek
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

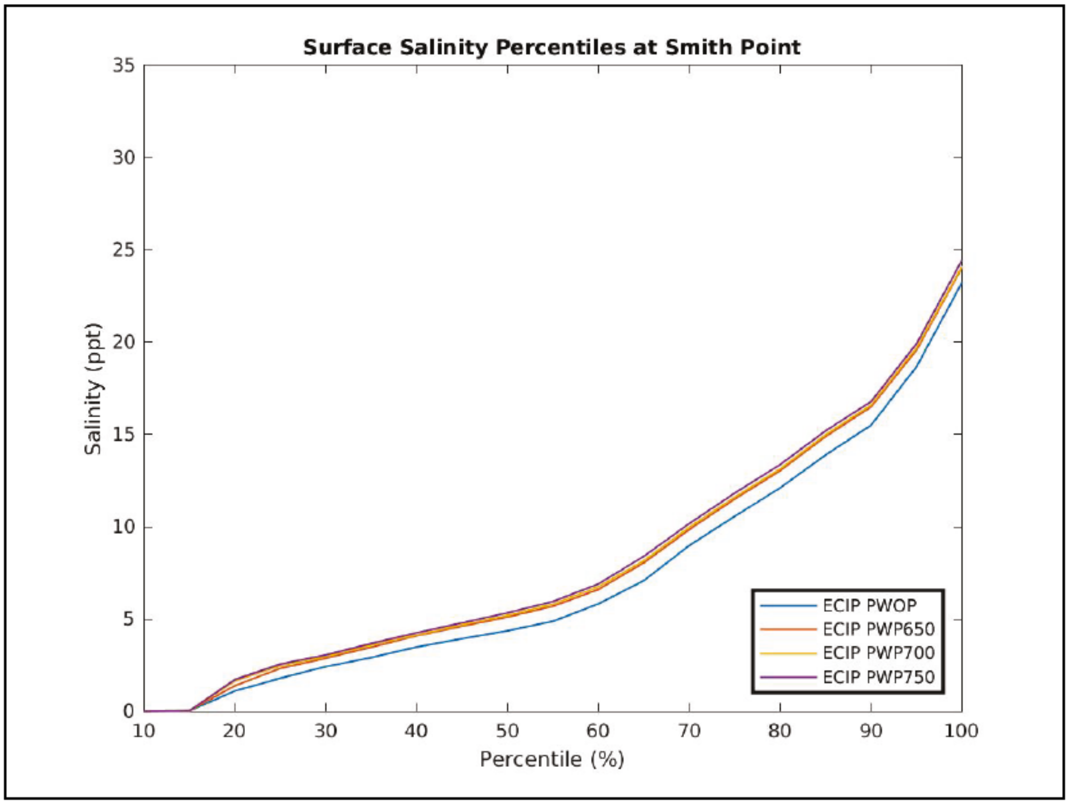

Bottom Salinity Percentiles at Clear Creek
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

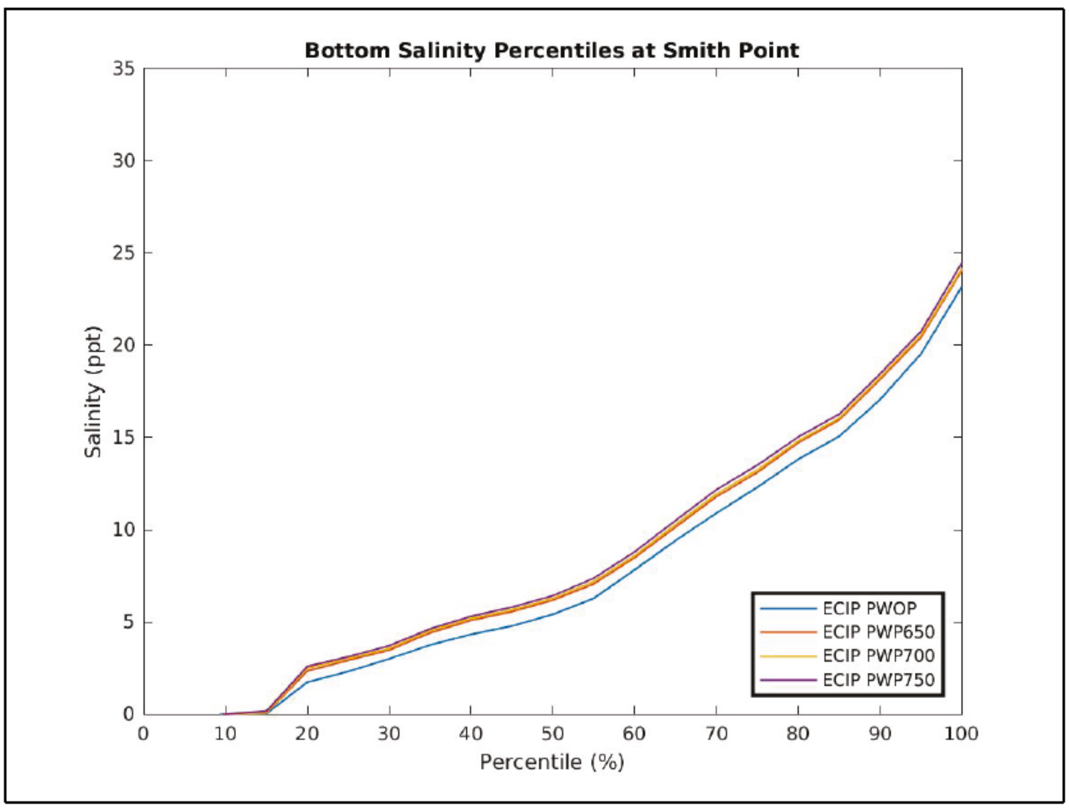

Mean Salinity Profiles at Clear Creek
Depth (m)
Salinity (ppt)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
-0.5
-1
-1.5
-2
-2.5
10
11
12
13
14
15
16
17
18

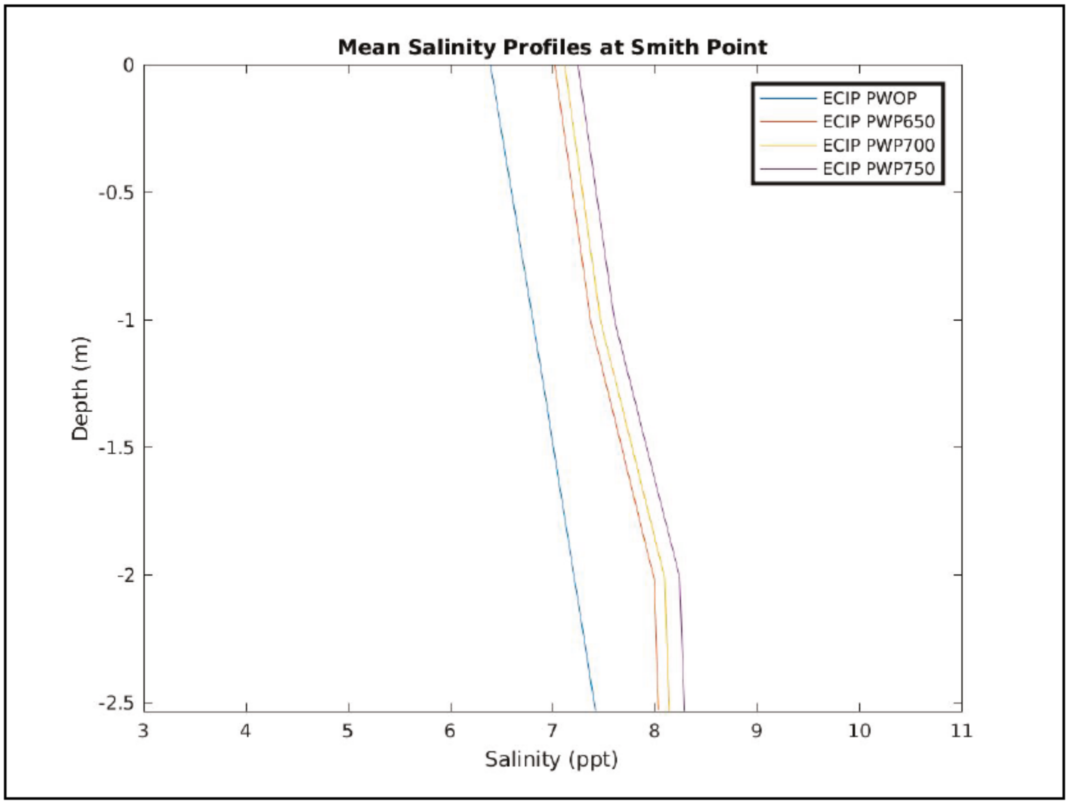

Salinity at Smith Point
Salinity (ppt)
Date (mm/dd)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

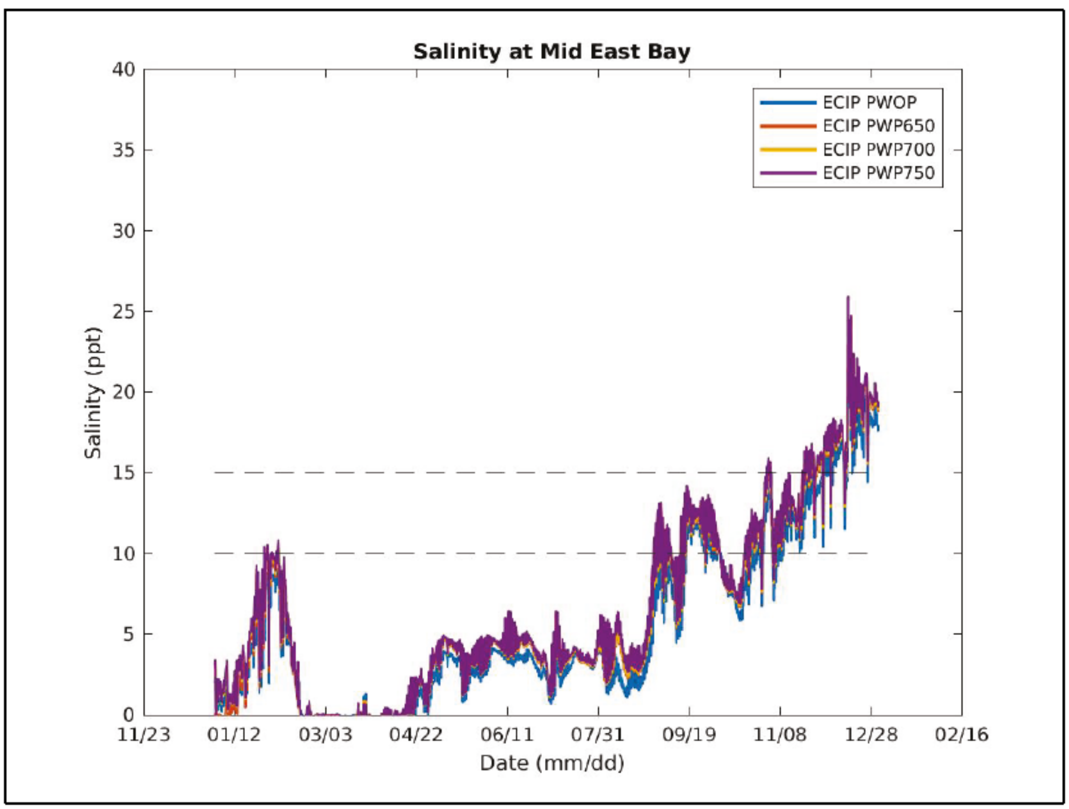

Surface Salinity at Smith Point
Salinity (ppt)
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

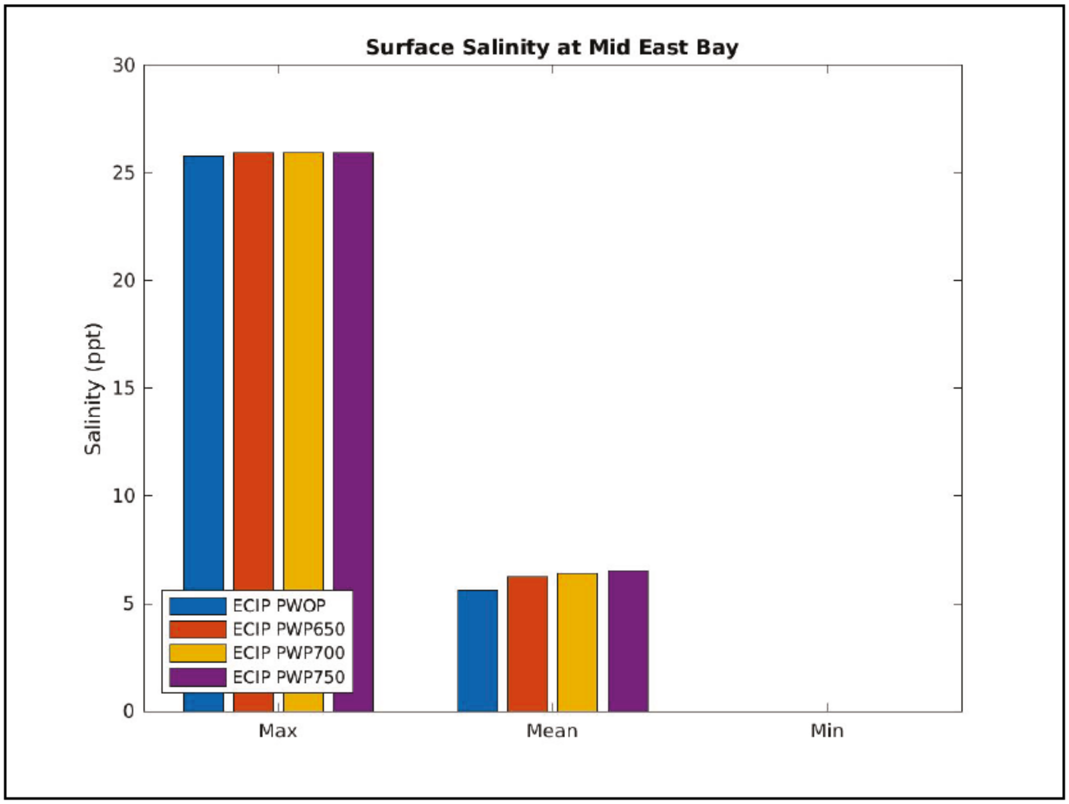

Bottom Salinity at Smith Point
Salinity (ppt)
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

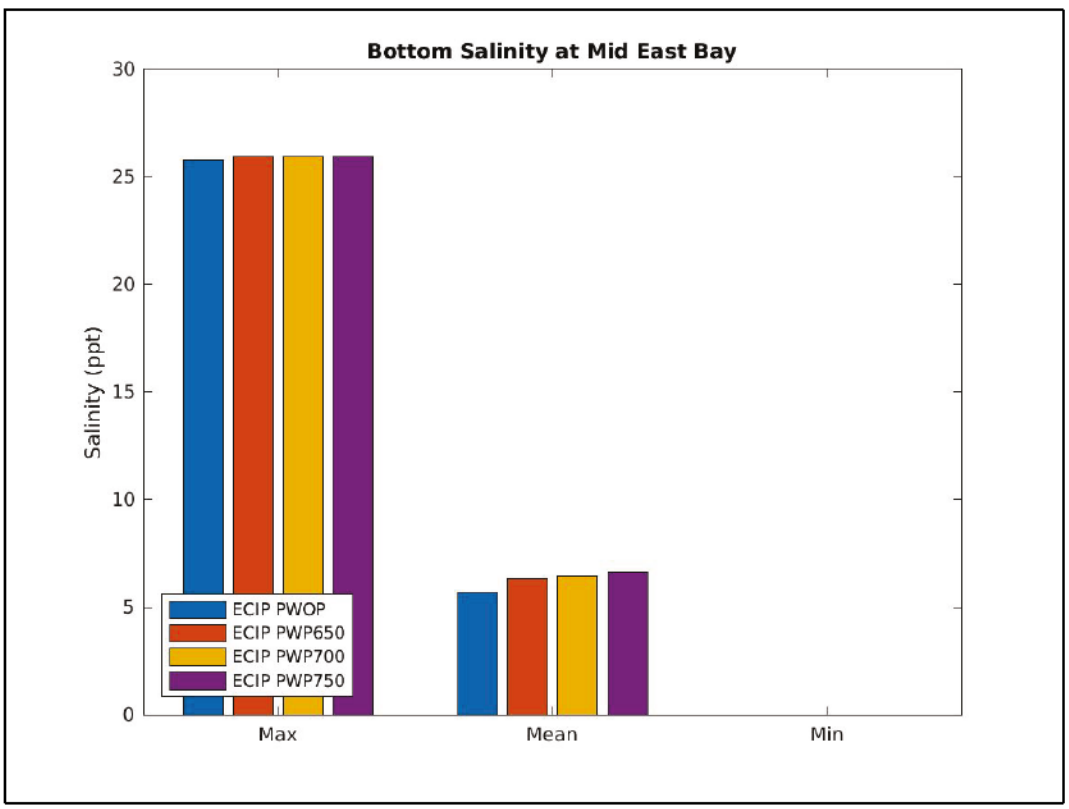

Surface Salinity Percentiles at Smith Point
Salinity (ppt)
Percentile (%)
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

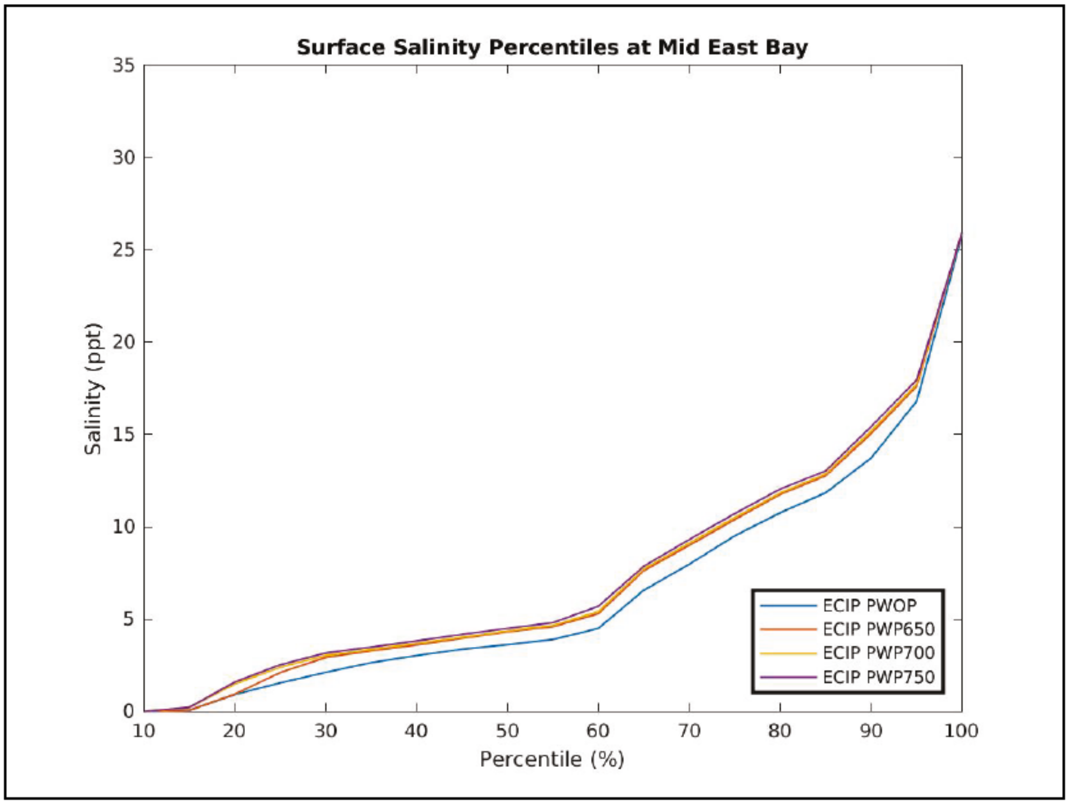

Bottom Salinity Percentiles at Smith Point
Salinity (ppt)
Percentile (%)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

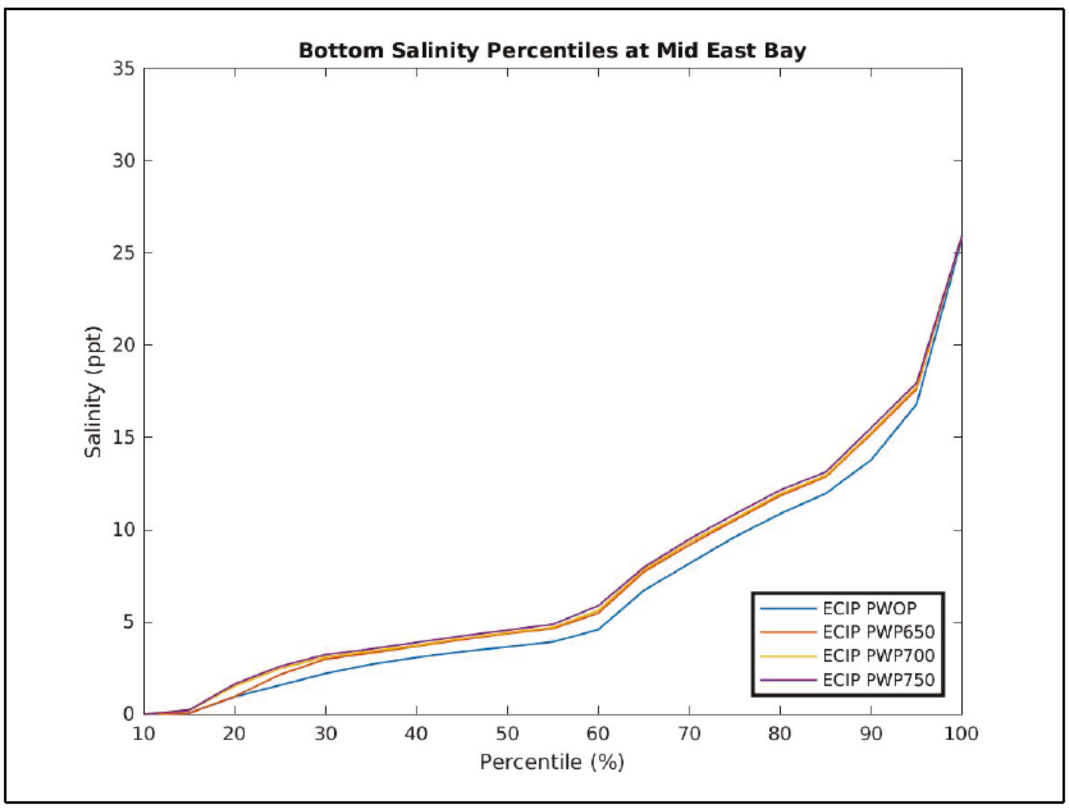

Mean Salinity Profiles at Smith Point
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
Salinity (ppt)
0
-0.5
-1
-1.5
-2
-2.5
3
4
5
6
7
8
9
10
11

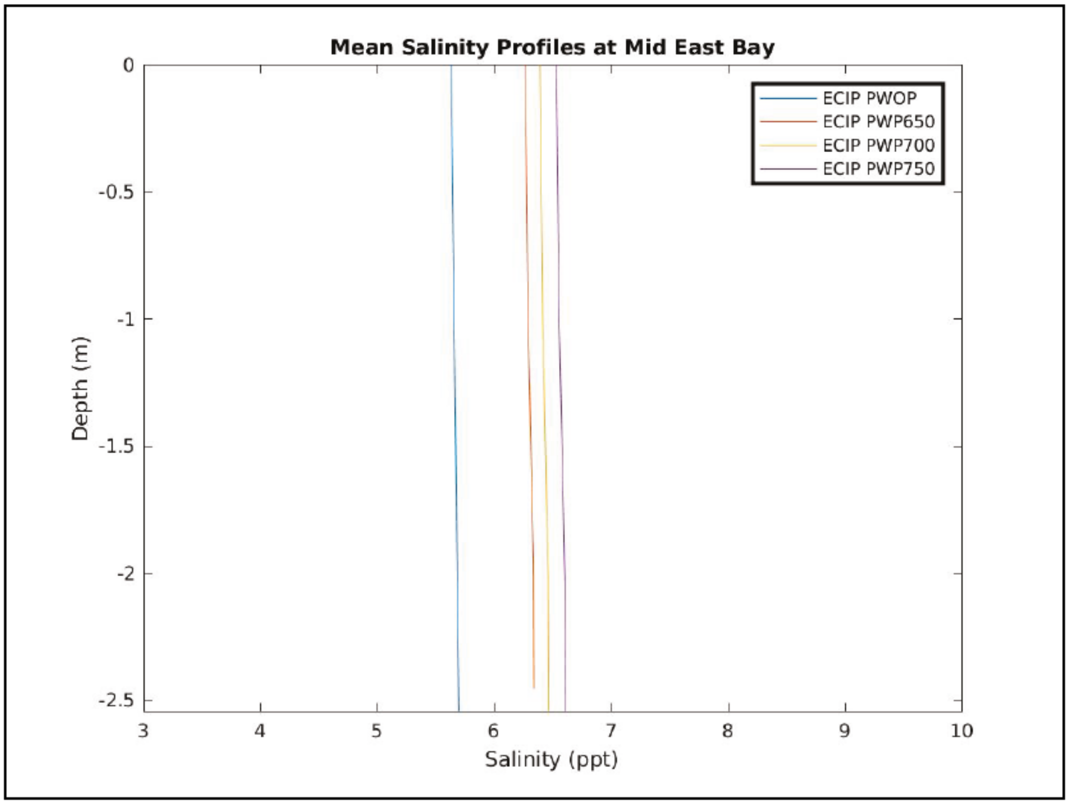

Salinity at Mid East Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
Date (mm/dd)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16


Surface Salinity at Mid East Bay
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

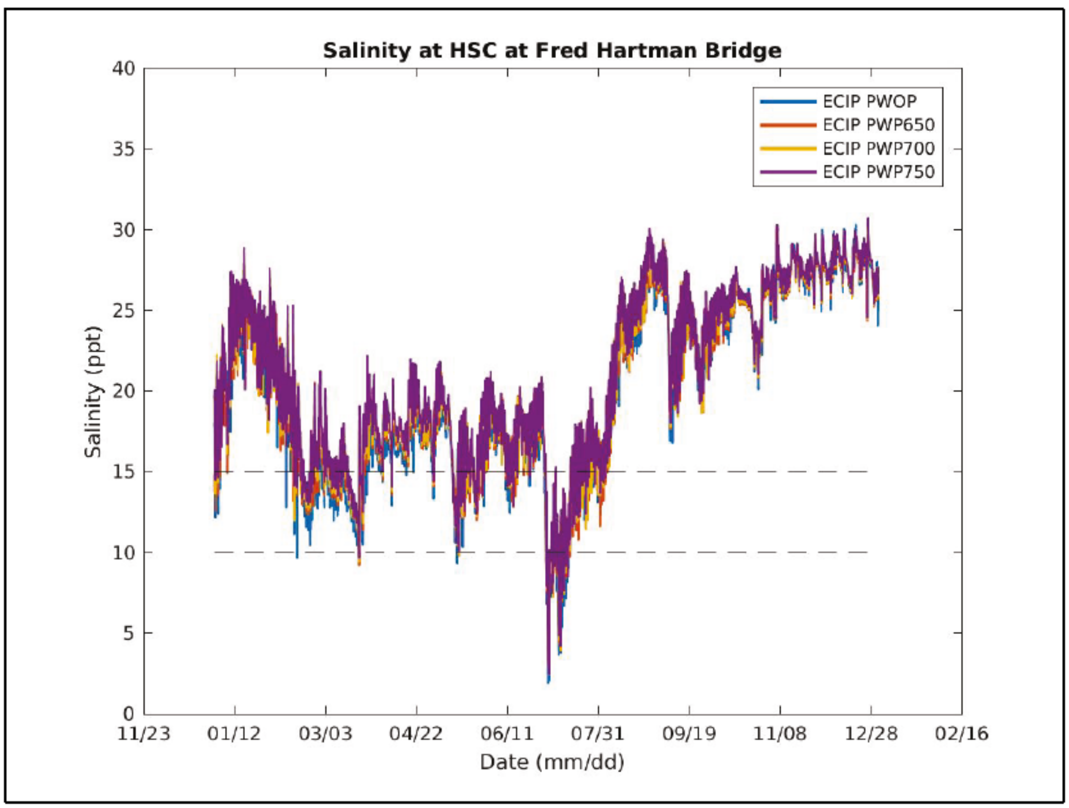

Bottom Salinity at Mid East Bay
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750


Surface Salinity Percentiles at Mid East Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

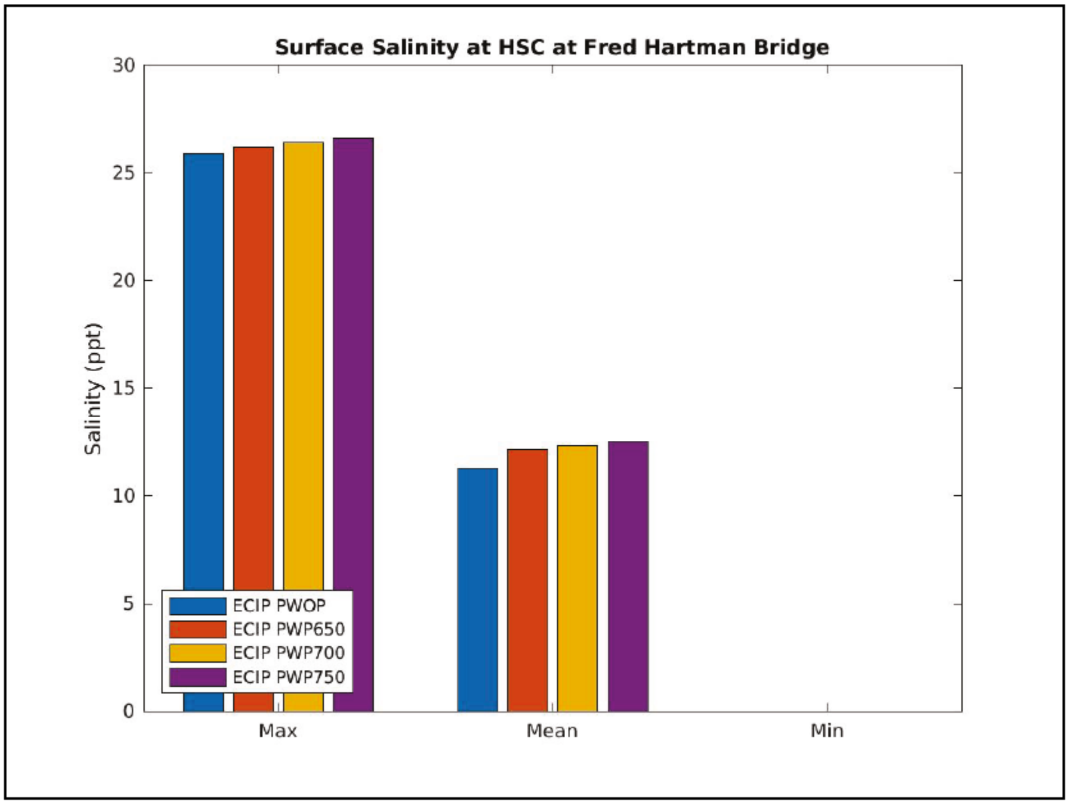

Bottom Salinity Percentiles at Mid East Bay
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

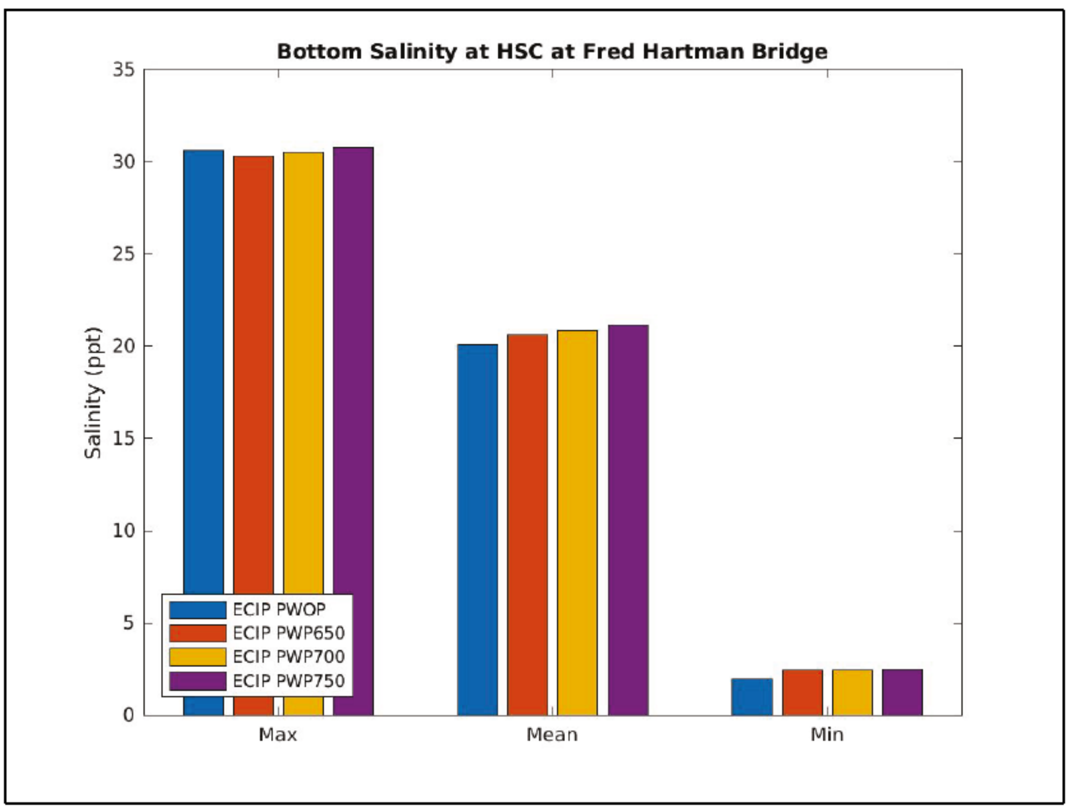


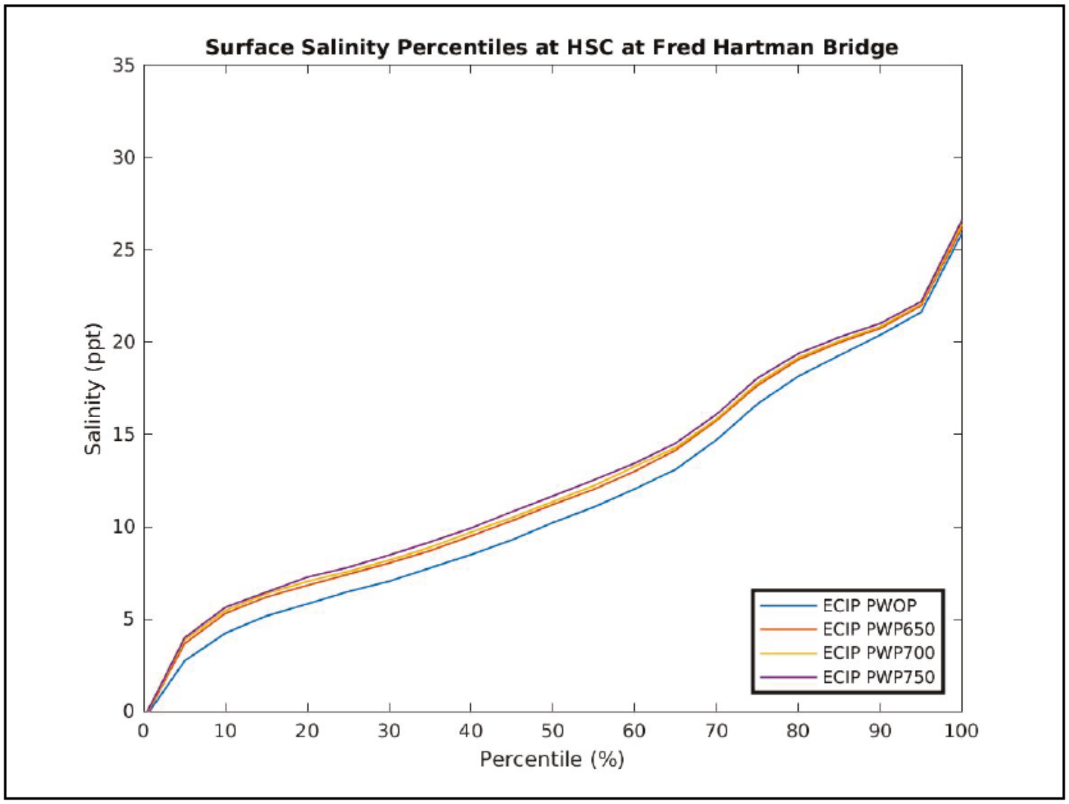
Mean Salinity Profiles at Mid East Bay
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-0.5
-1
-1.5
-2
-2.5
3
4
5
6
7
8
9
10
Salinity (ppt)

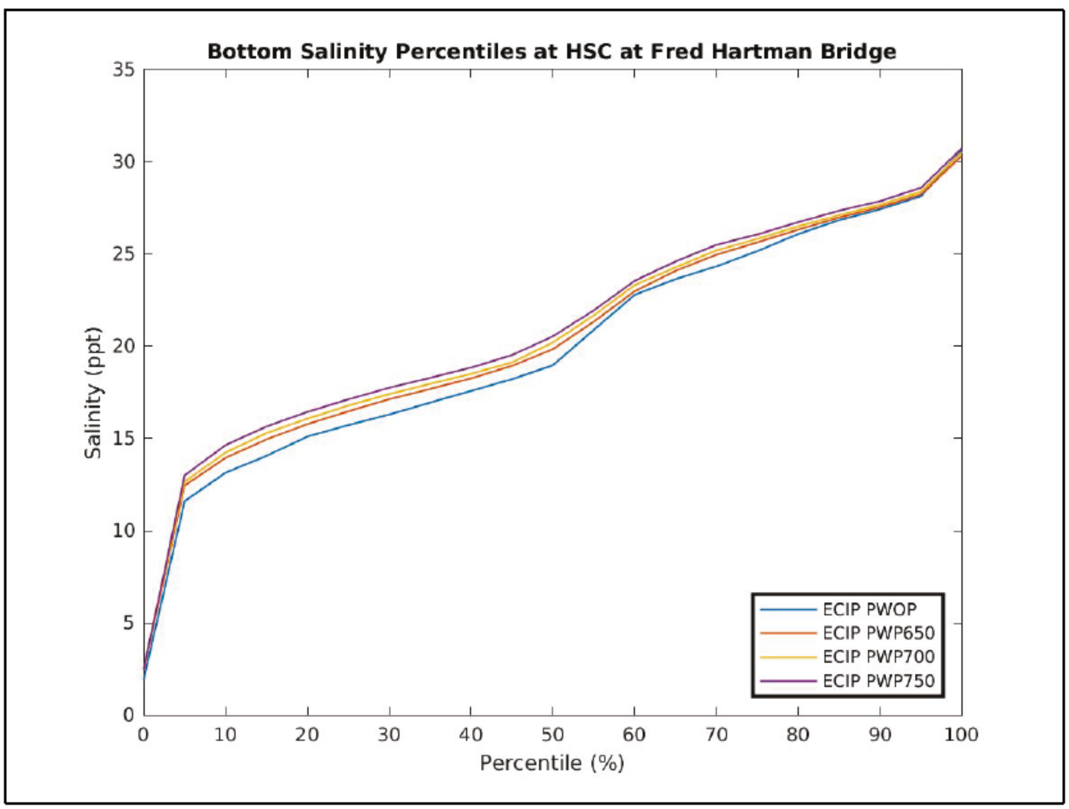



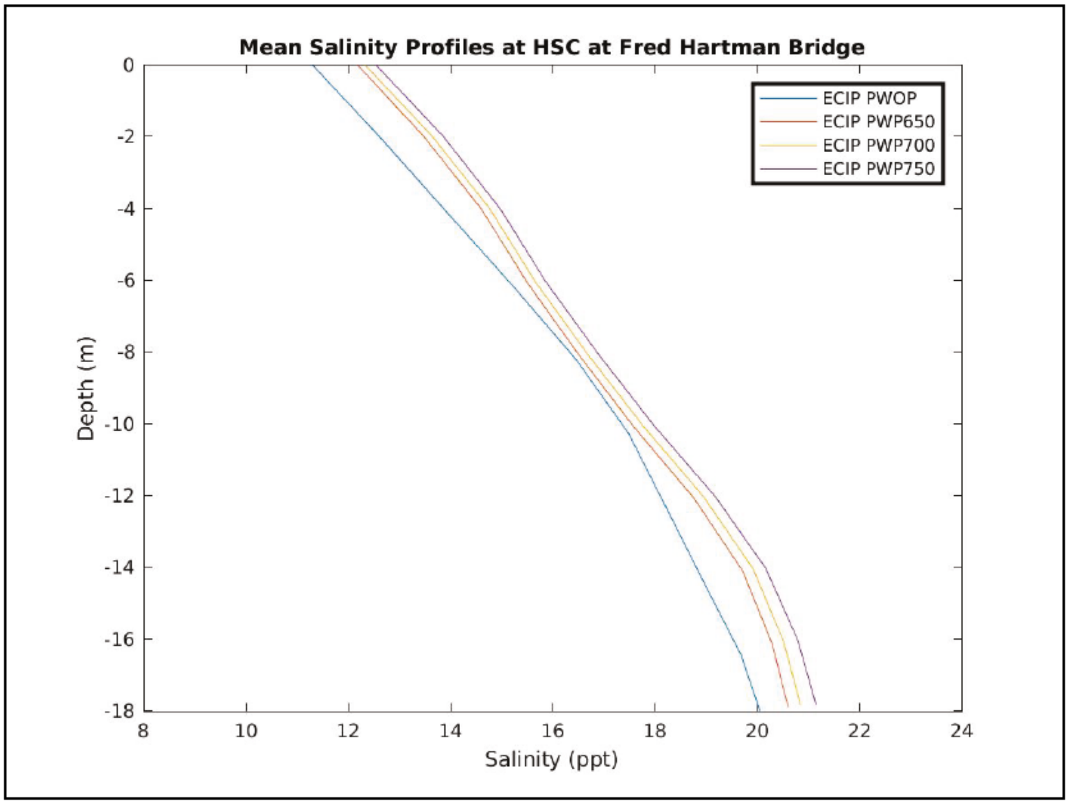
Salinity at HSC at Fred Hartman Bridge
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

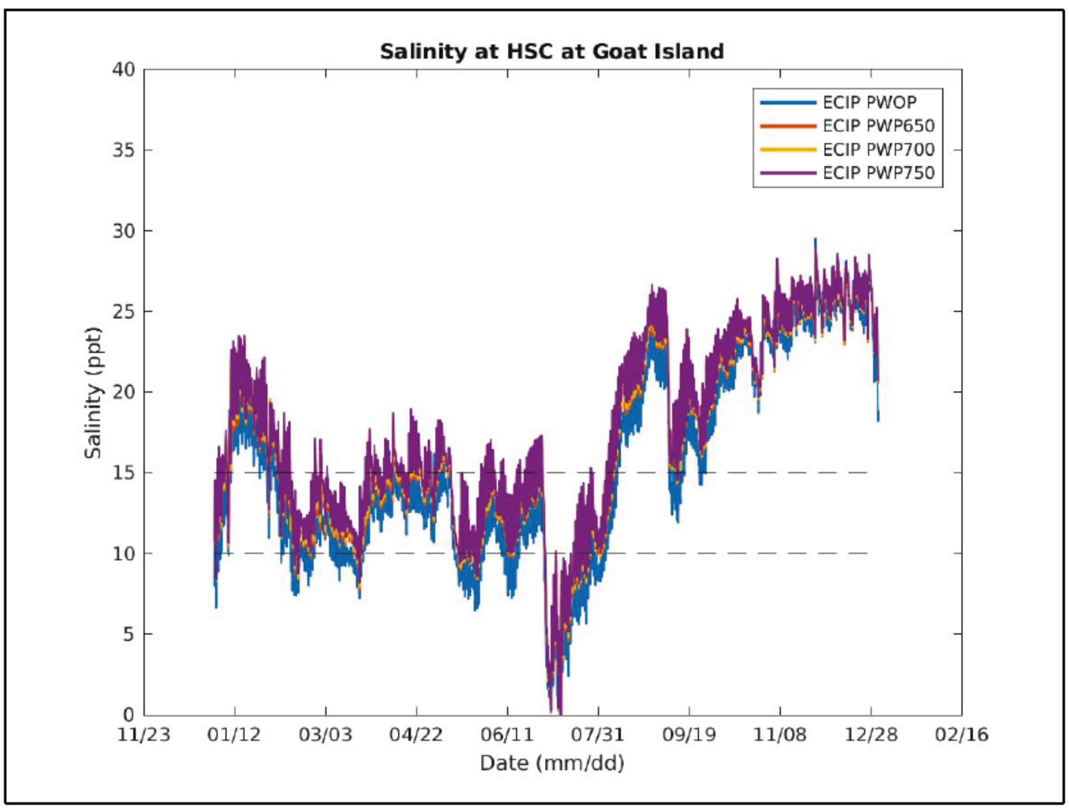

Surface Salinity at HSC at Fred Hartman Bridge
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

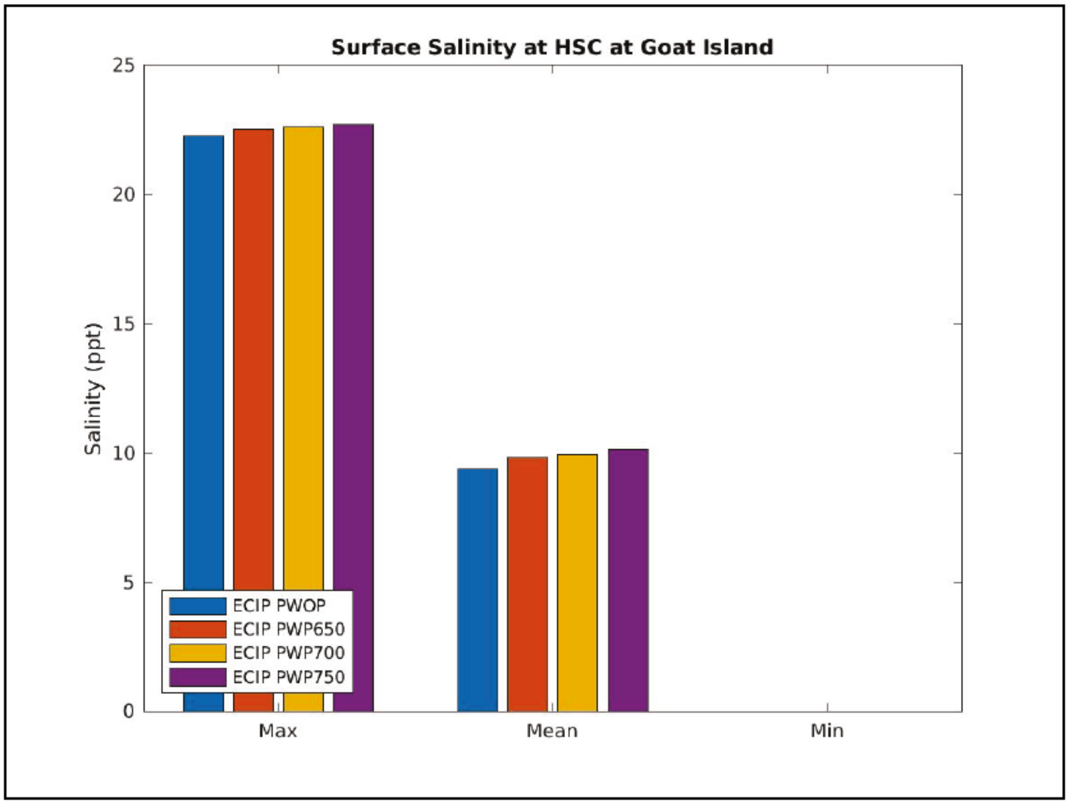

Bottom Salinity at HSC at Fred Hartman Bridge
Salinity (ppt)
35
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

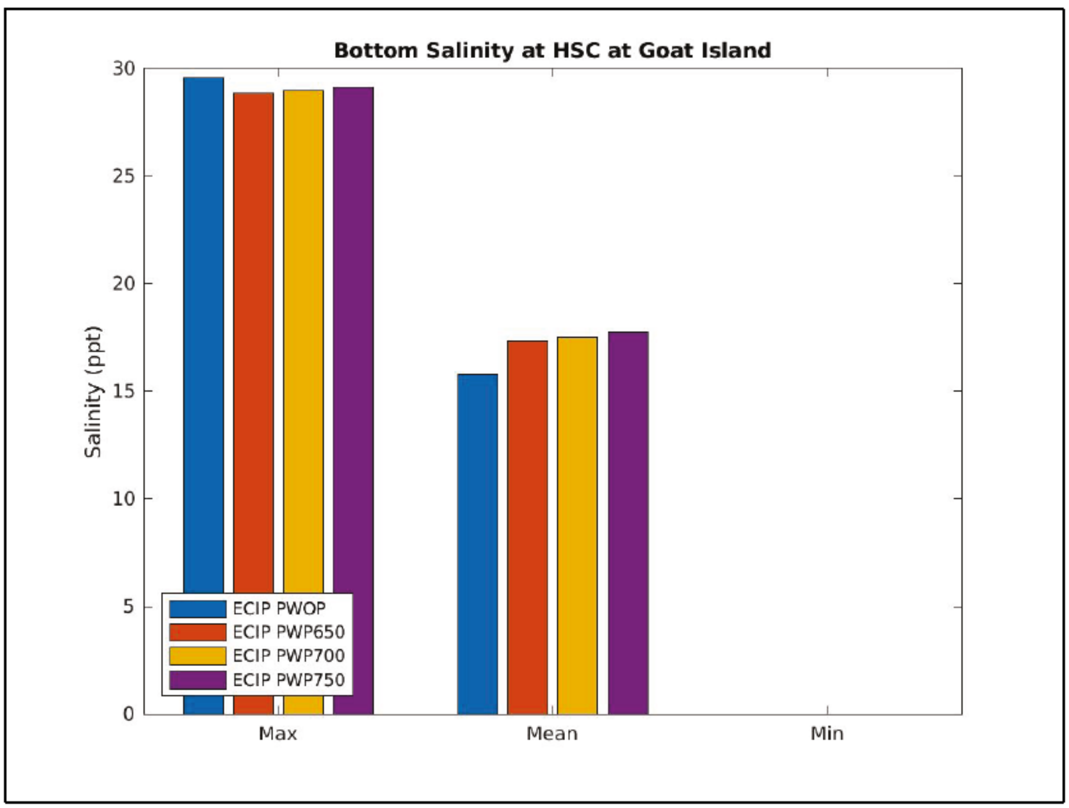

Surface Salinity Percentiles at HSC at Fred Hartman Bridge
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

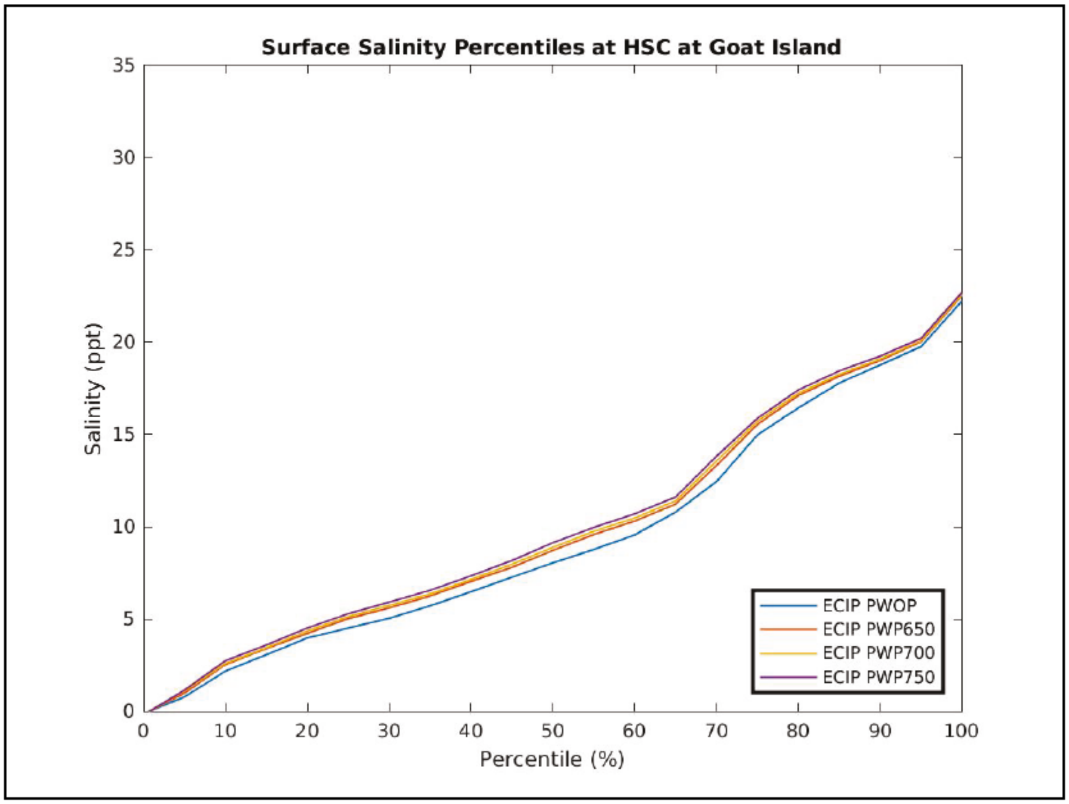

Bottom Salinity Percentiles at HSC at Fred Hartman Bridge
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

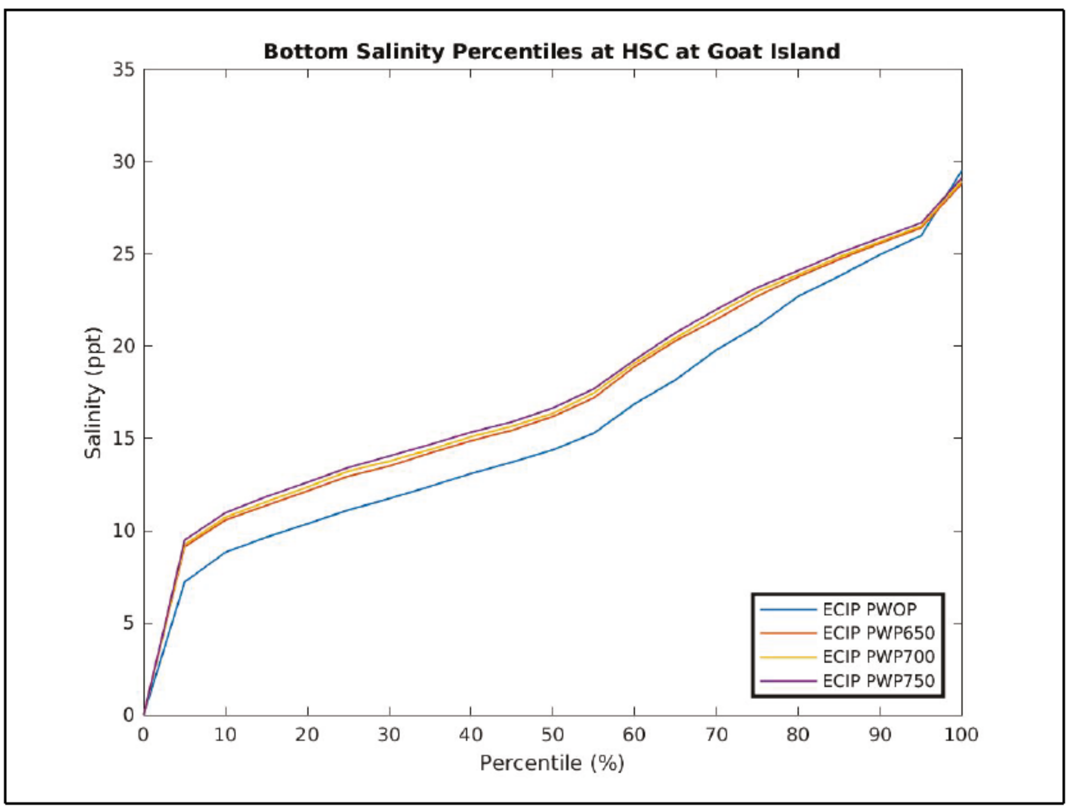

Mean Salinity Profiles at HSC at Fred Hartman Bridge
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
8
10
12
14
16
18
20
22
24

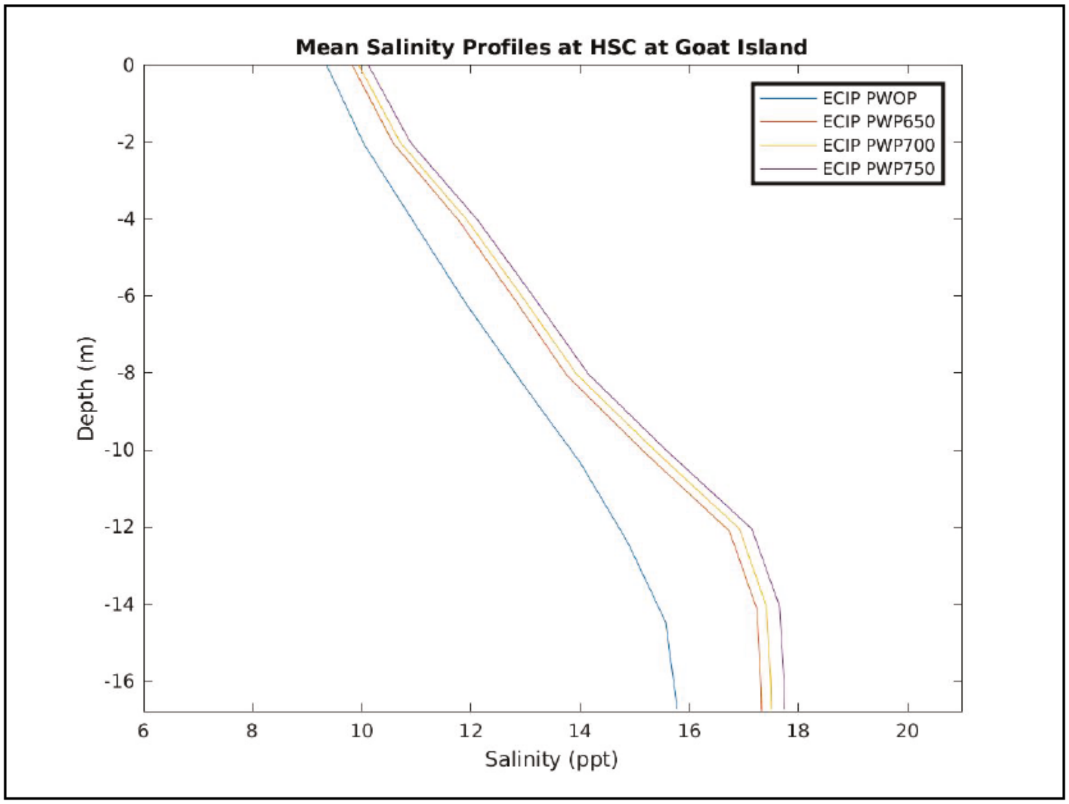

Salinity at HSC at Goat Island
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
Date (mm/dd)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

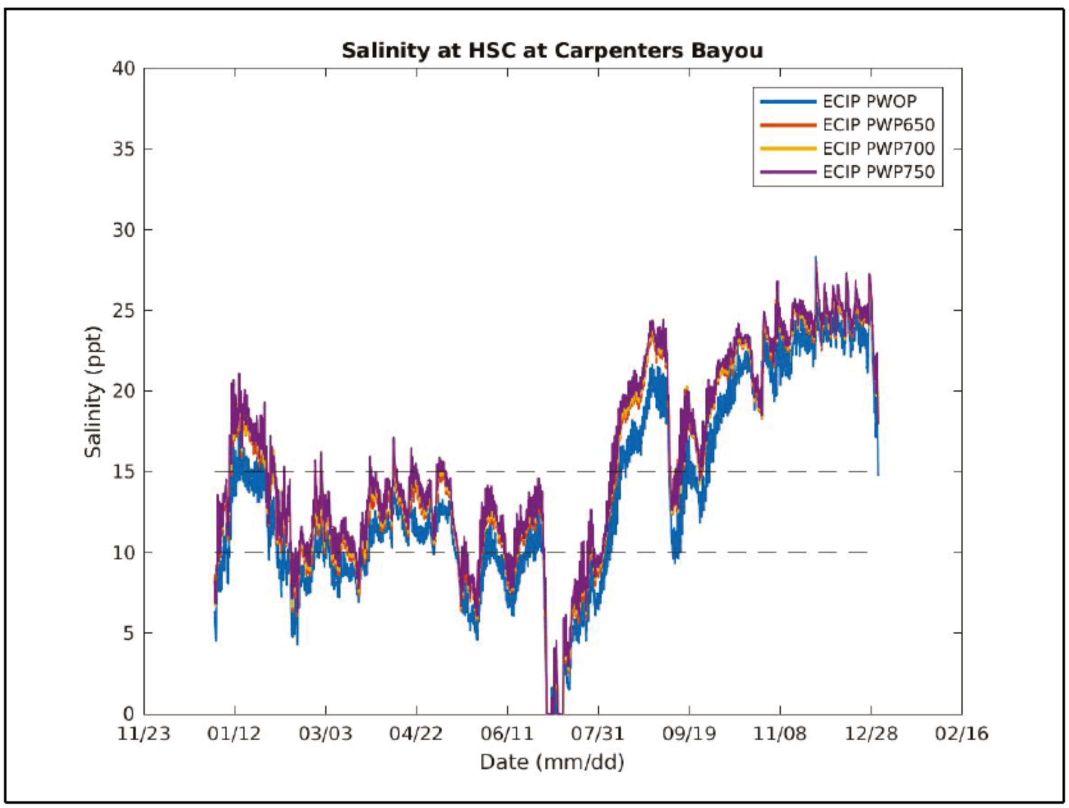

Surface Salinity at HSC at Goat Island
Salinity (ppt)
0
5
10
15
20
25
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

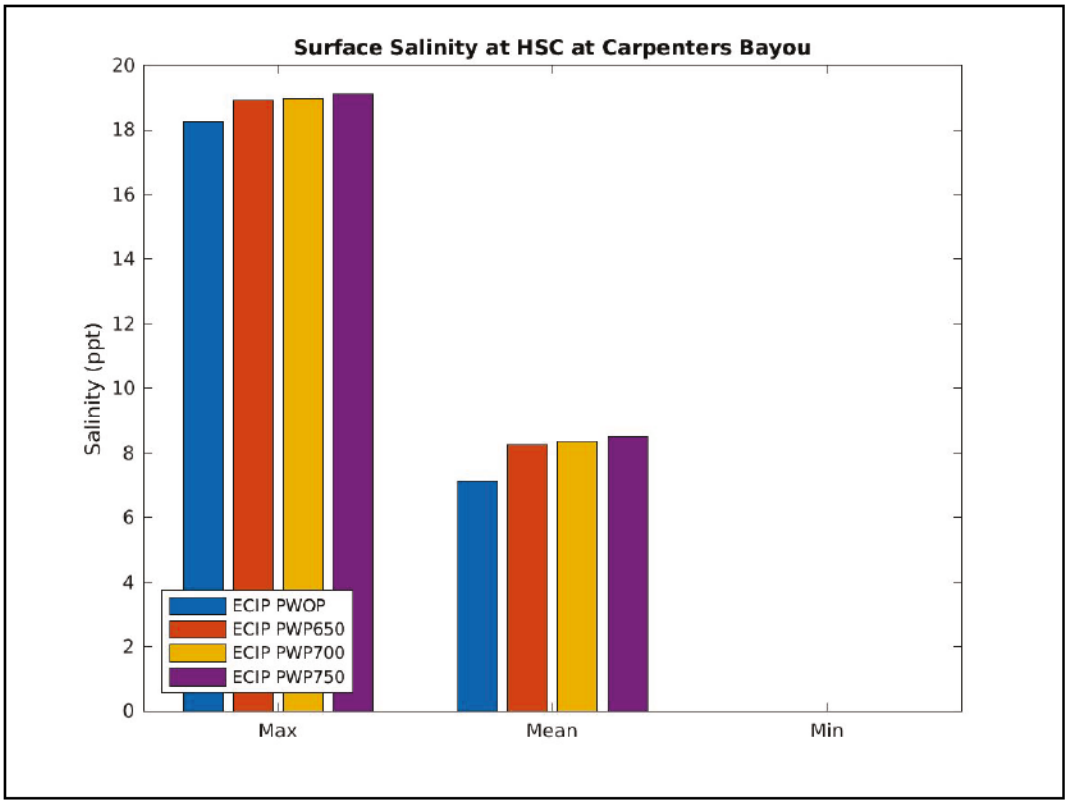

Bottom Salinity at HSC at Goat Island
Salinity (ppt)
0
5
10
15
20
25
30
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

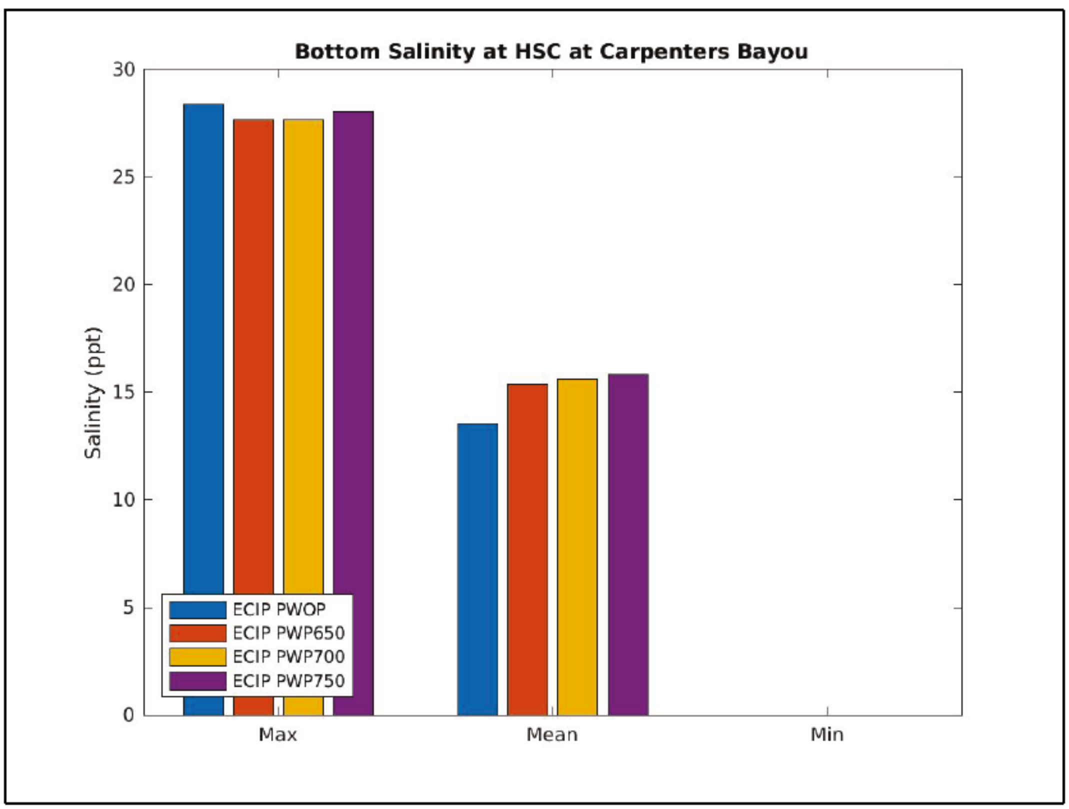

Surface Salinity Percentiles at HSC at Goat Island
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

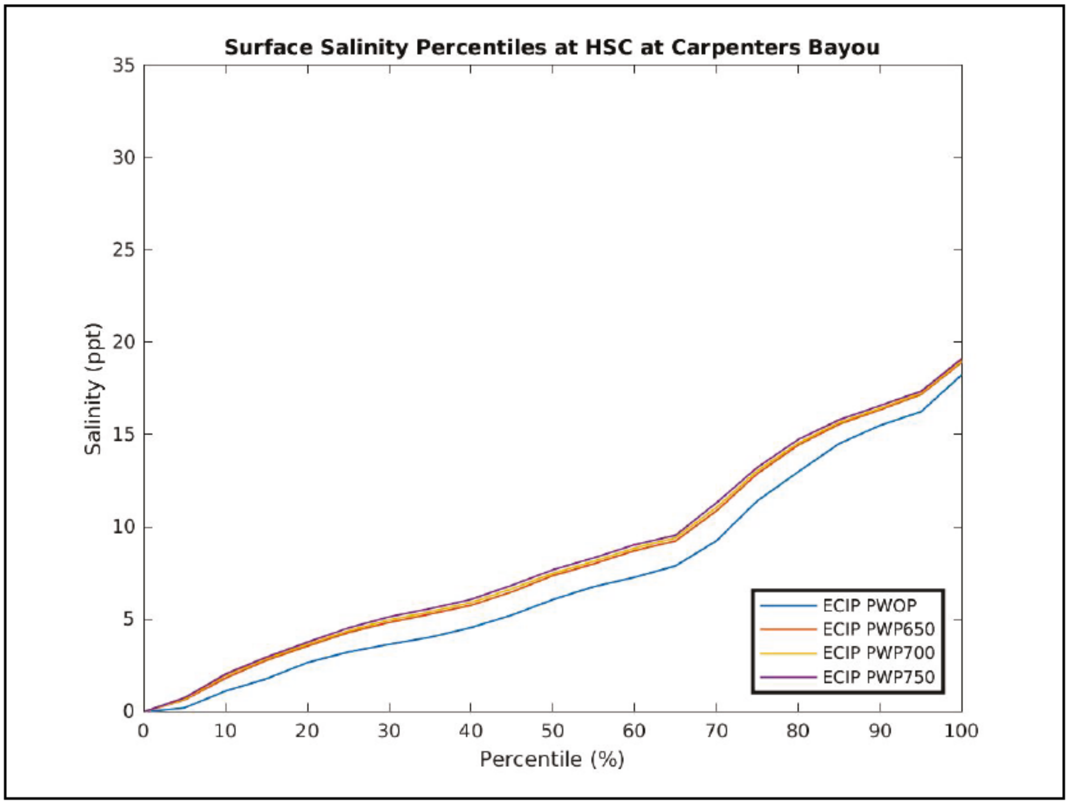

Bottom Salinity Percentiles at HSC at Goat Island
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

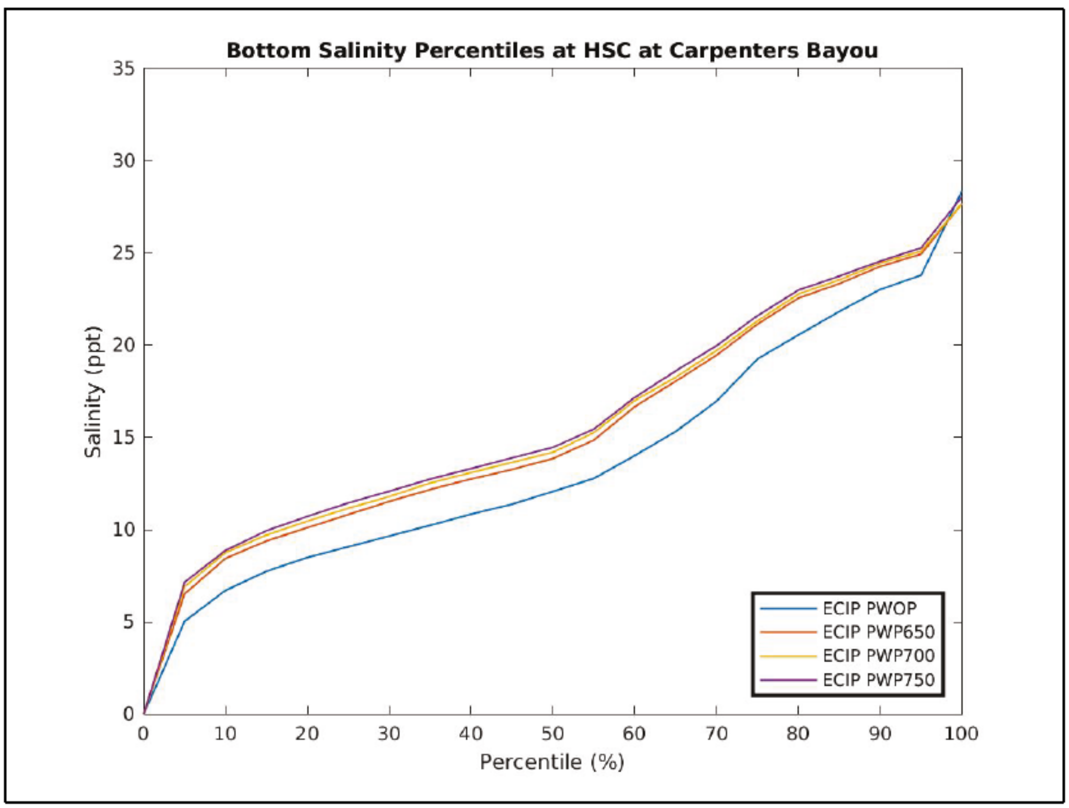

Mean Salinity Profiles at HSC at Goat Island
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
-16
6
8
10
12
14
16
18
20
Salinity (ppt)

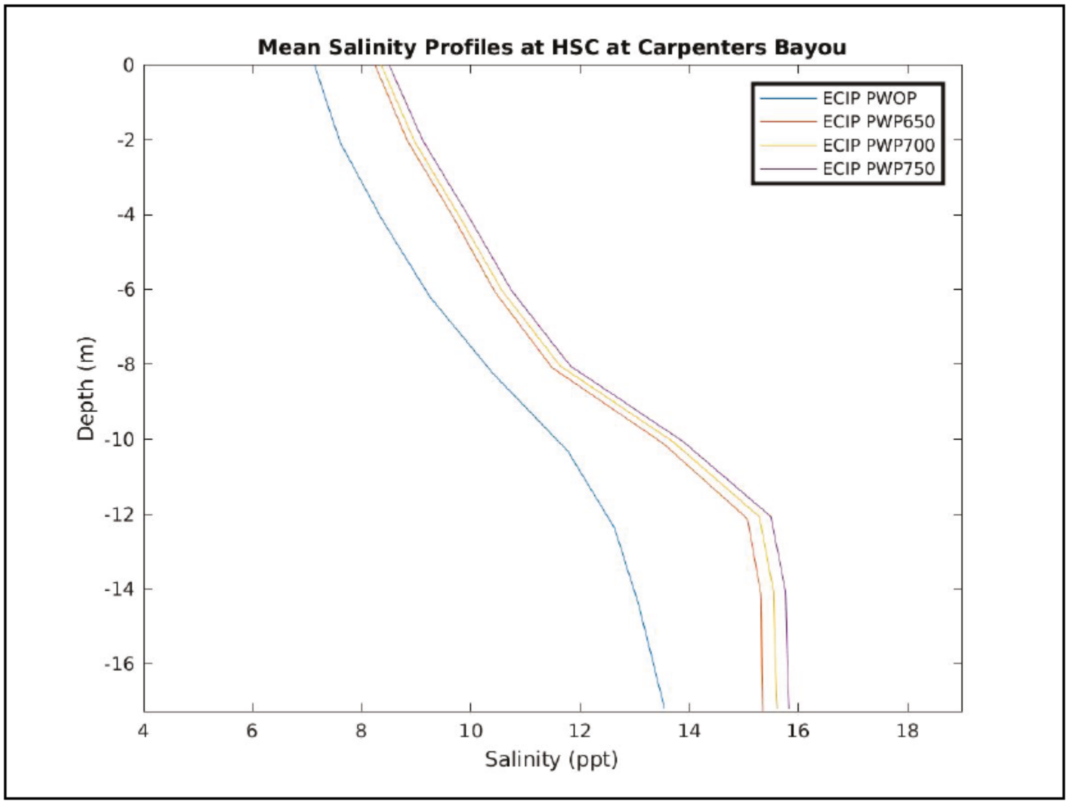

Salinity at HSC at Carpenters Bayou
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16
Date (mm/dd)

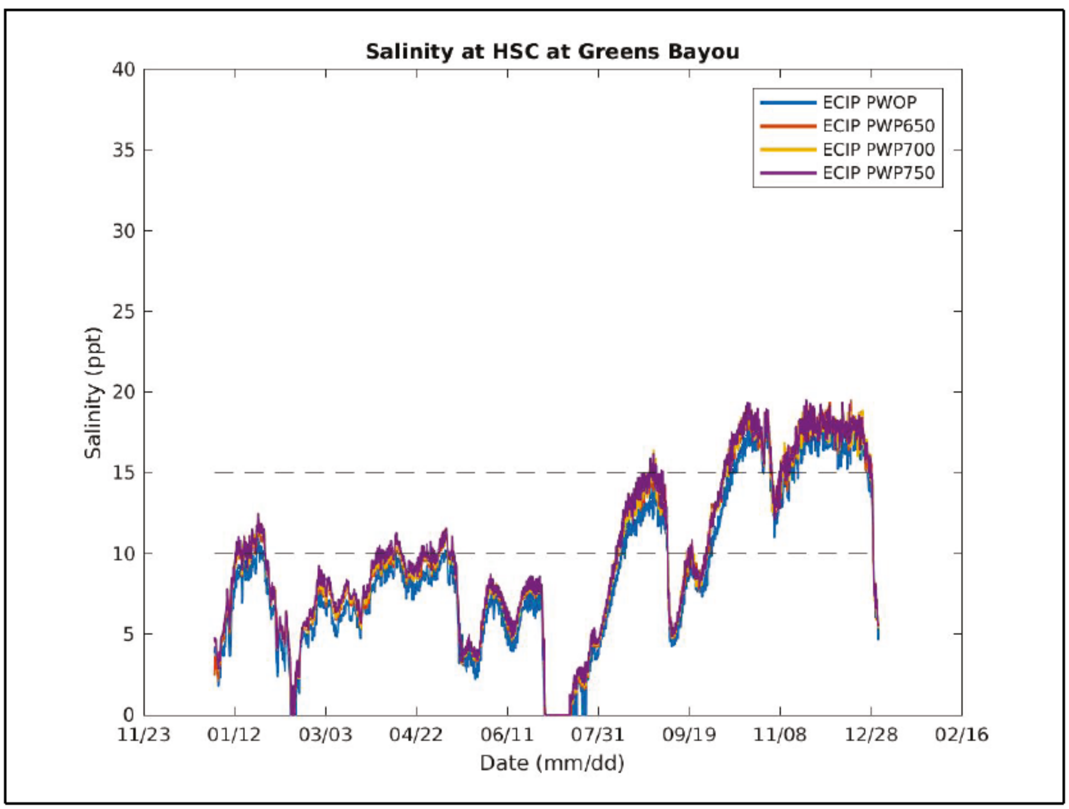

Surface Salinity at HSC at Carpenters Bayou
Salinity (ppt)
20
18
16
14
12
10
8
6
4
2
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

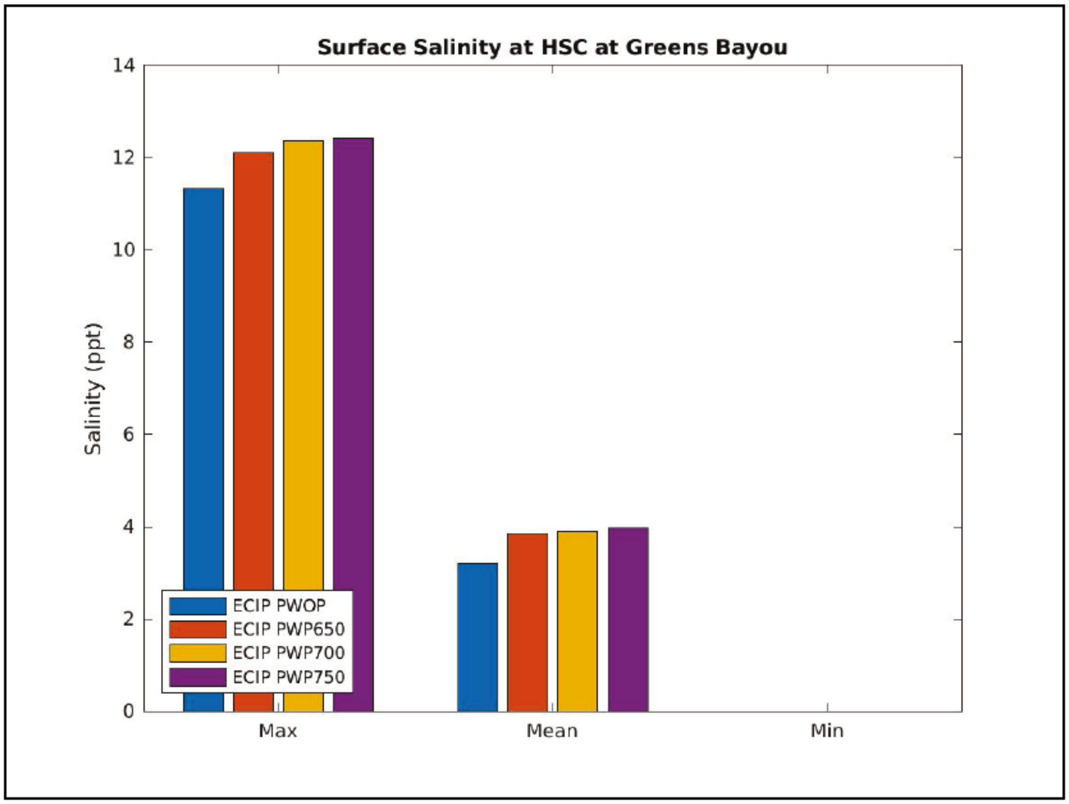

Bottom Salinity at HSC at Carpenters Bayou
Salinity (ppt)
30
25
20
15
10
5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

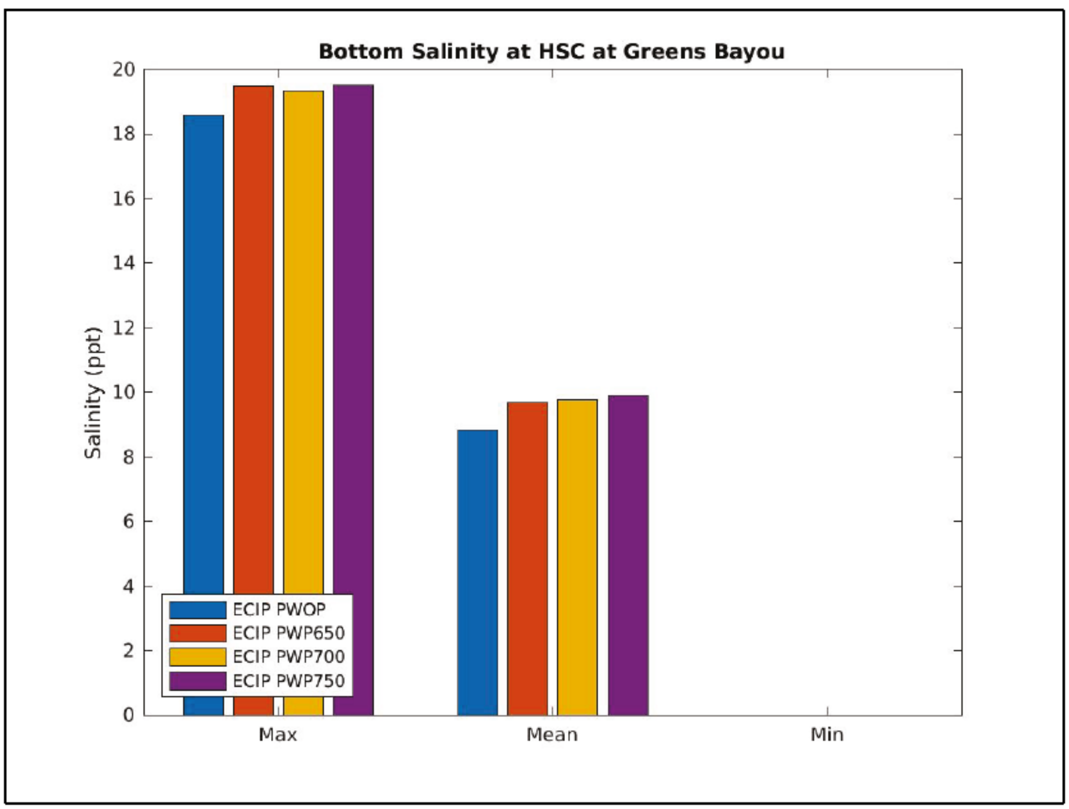

Surface Salinity Percentiles at HSC at Carpenters Bayou
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

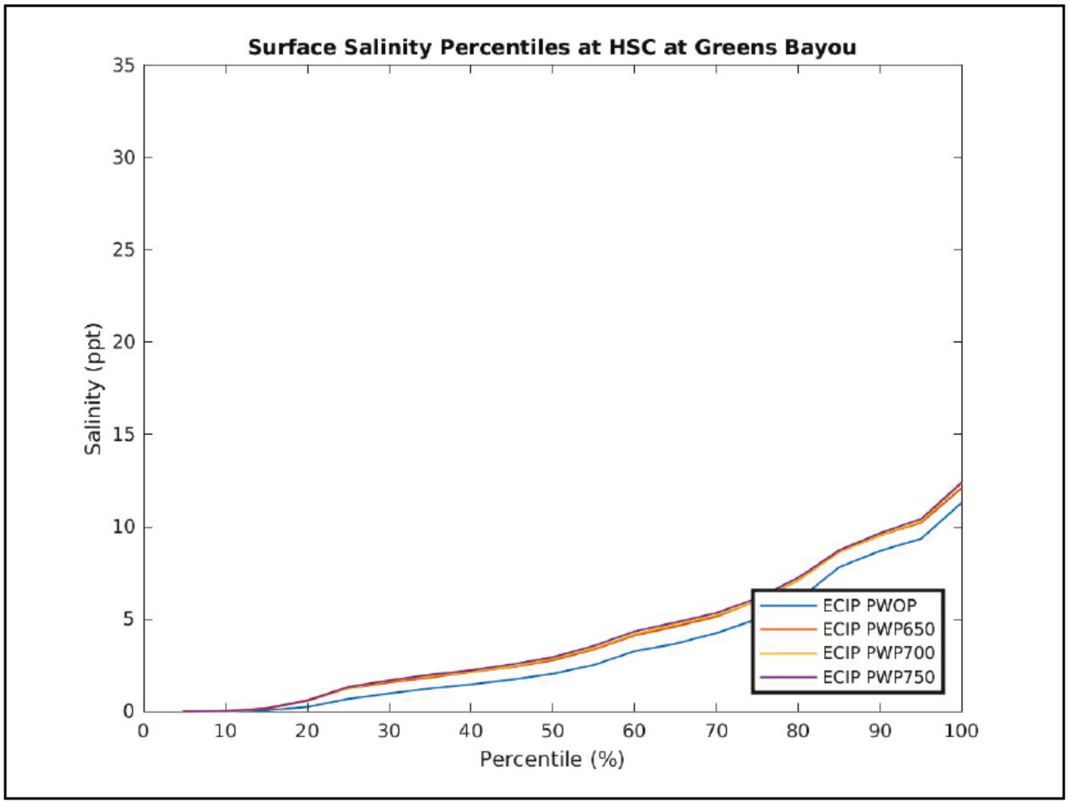

Bottom Salinity Percentiles at HSC at Carpenters Bayou
Salinity (ppt)
Percentile (%)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

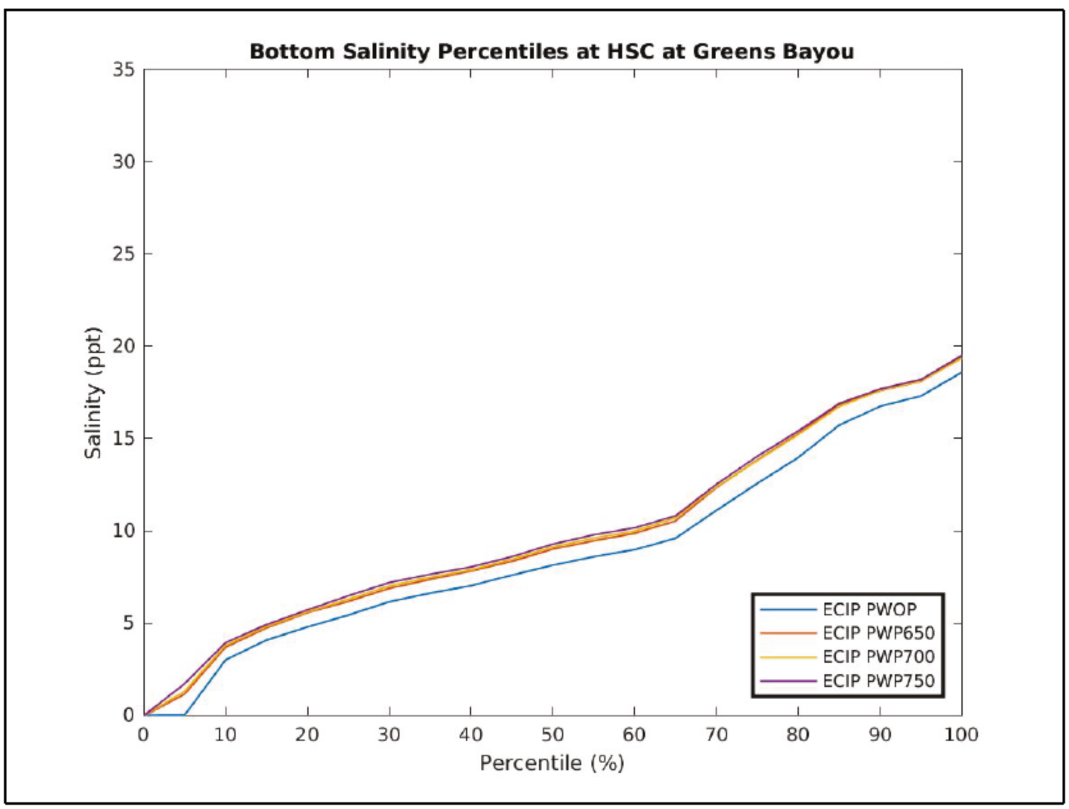

Mean Salinity Profiles at HSC at Carpenters Bayou
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
Salinity (ppt)
0
-2
-4
-6
-8
-10
-12
-14
-16
4
6
8
10
12
14
16
18

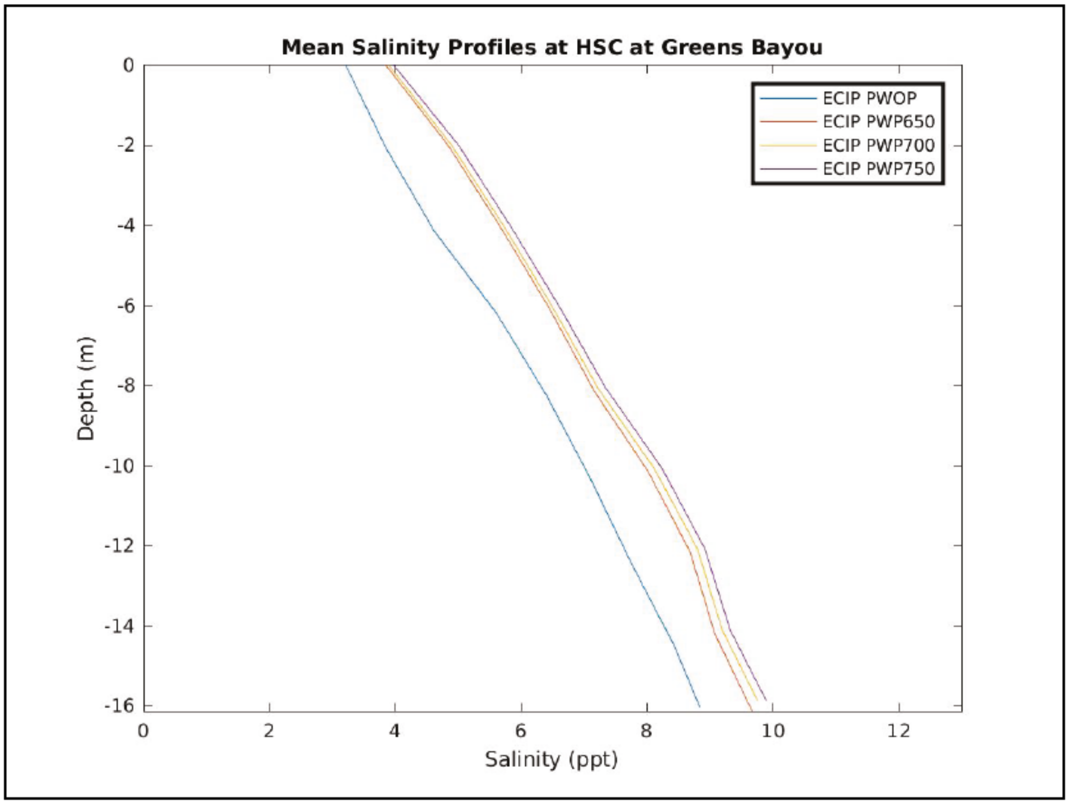

Salinity at HSC at Greens Bayou
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
Date (mm/dd)
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

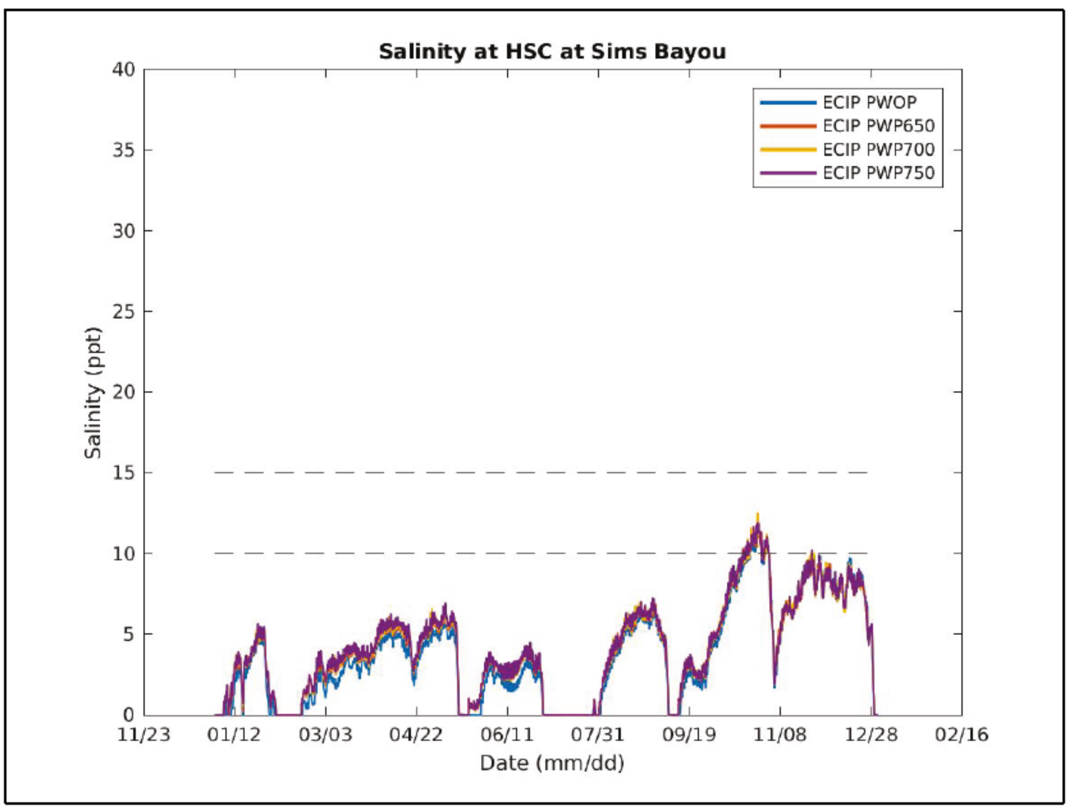

Surface Salinity at HSC at Greens Bayou
Salinity (ppt)
0
2
4
6
8
10
12
14
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

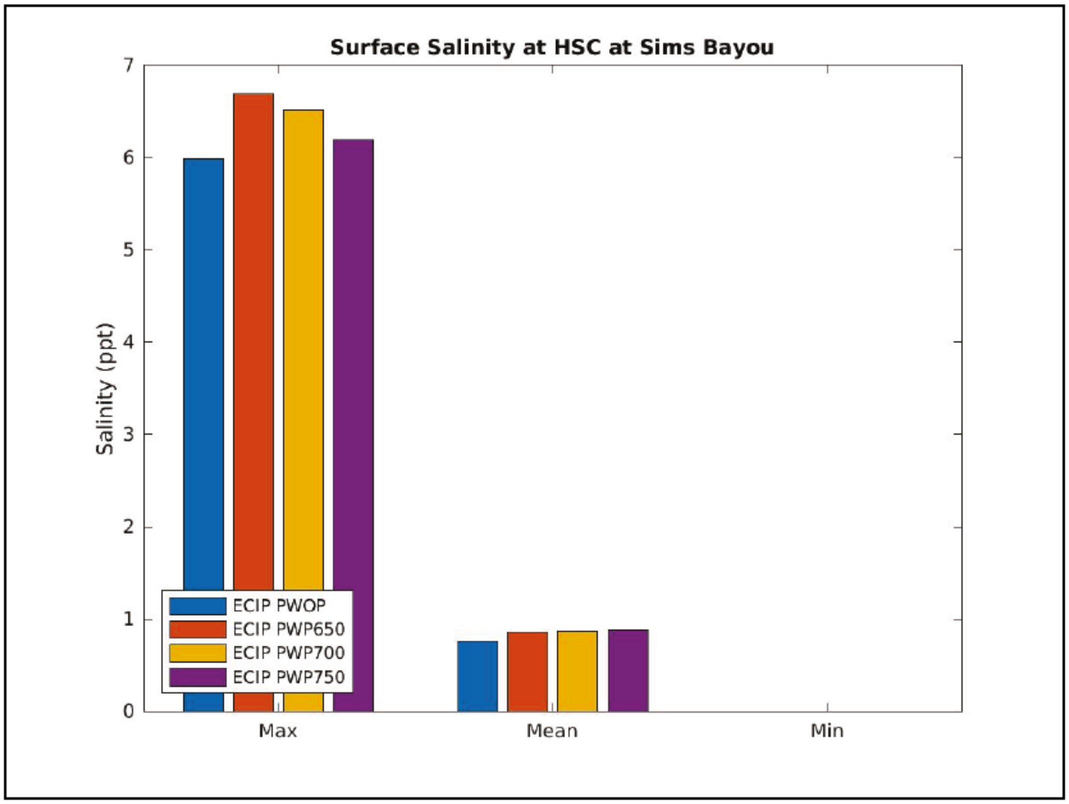

Bottom Salinity at HSC at Greens Bayou
Salinity (ppt)
0
2
4
6
8
10
12
14
16
18
20
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

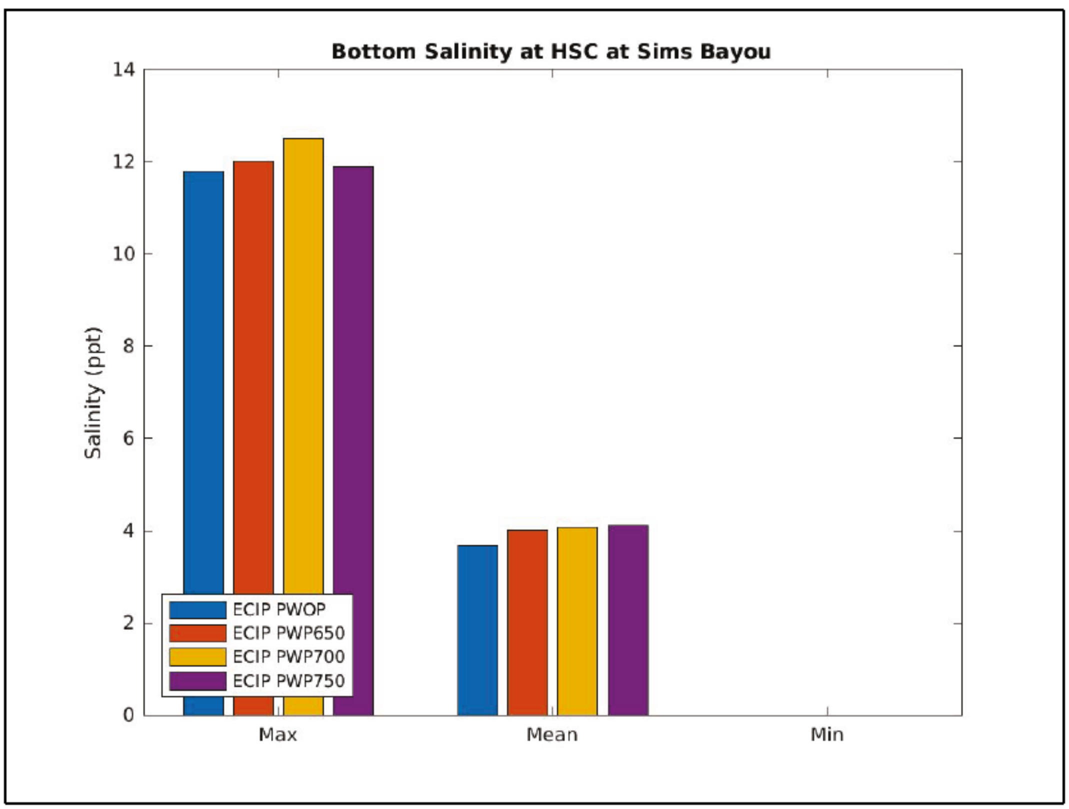

Surface Salinity Percentiles at HSC at Greens Bayou
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

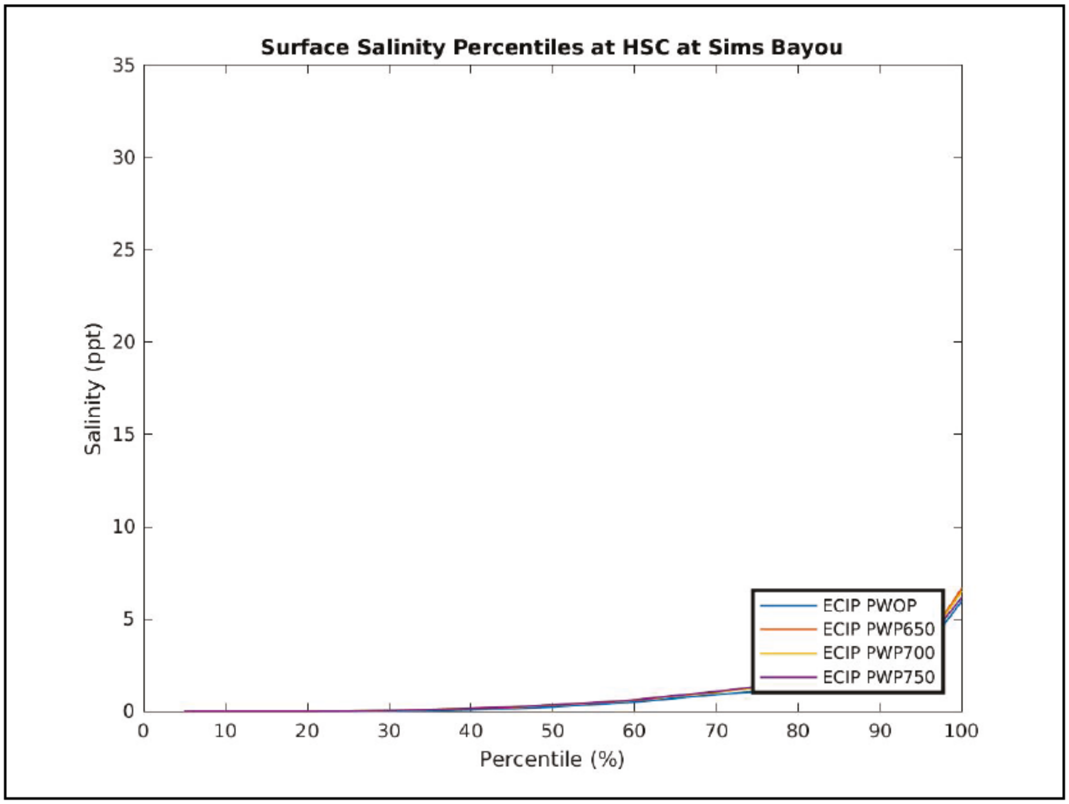

Bottom Salinity Percentiles at HSC at Greens Bayou
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

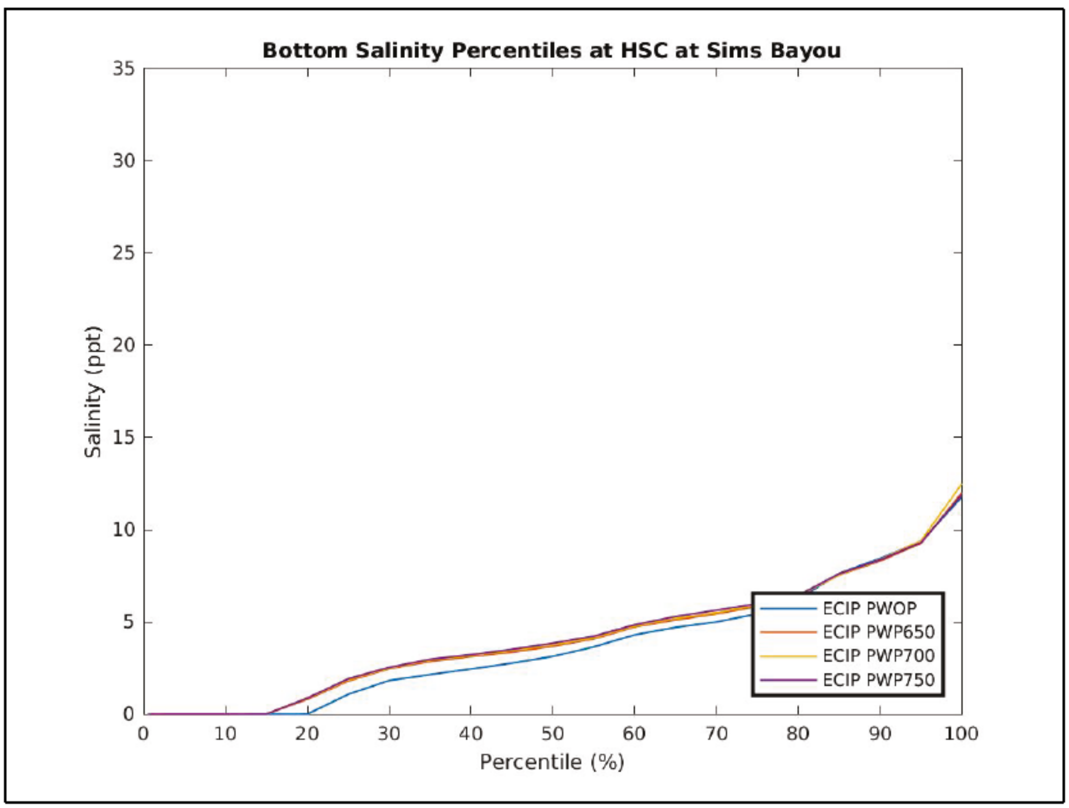

Mean Salinity Profiles at HSC at Greens Bayou
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
-16
Salinity (ppt)
0
2
4
6
8
10
12

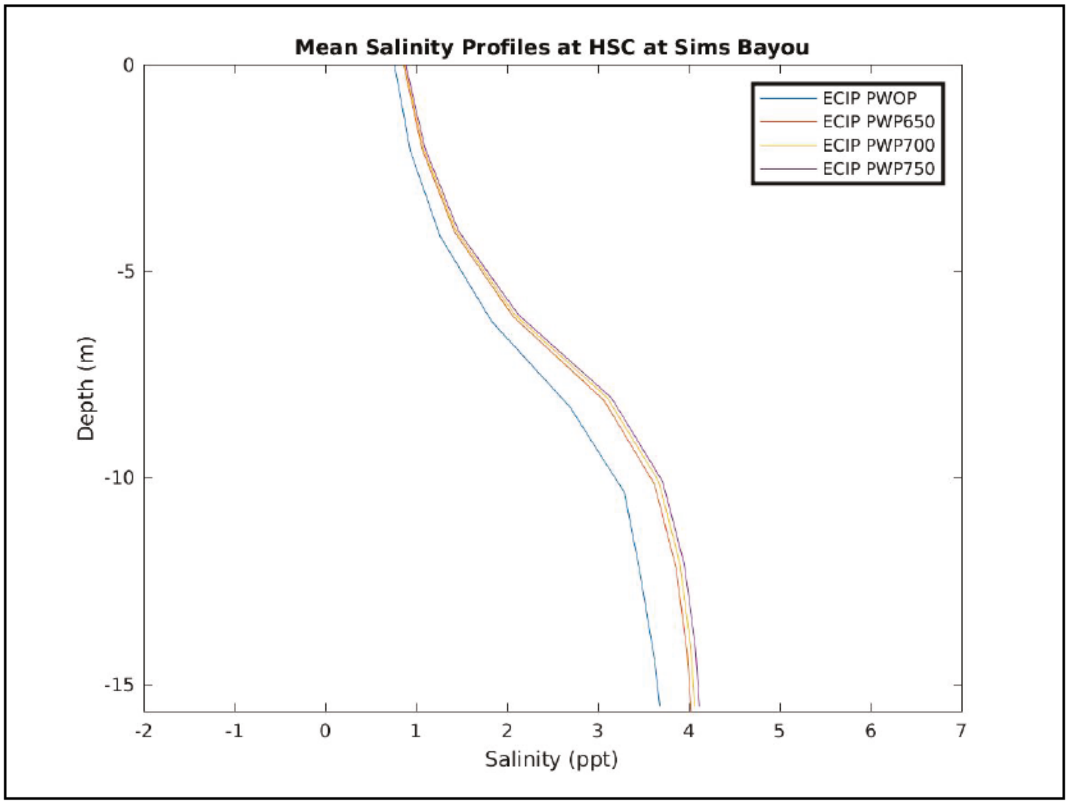

Salinity at HSC at Sims Bayou
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Salinity (ppt)
40
35
30
25
20
15
10
5
0
Date (mm/dd)
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16

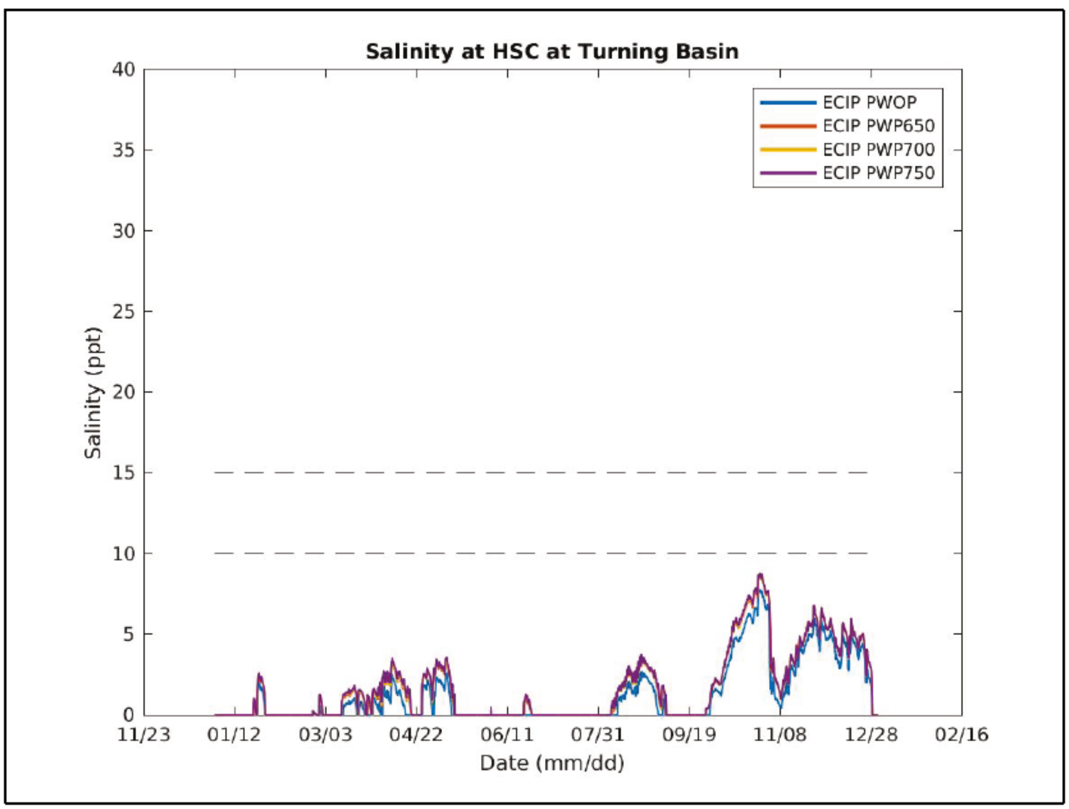

Surface Salinity at HSC at Sims Bayou
Salinity (ppt)
0
1
2
3
4
5
6
7
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

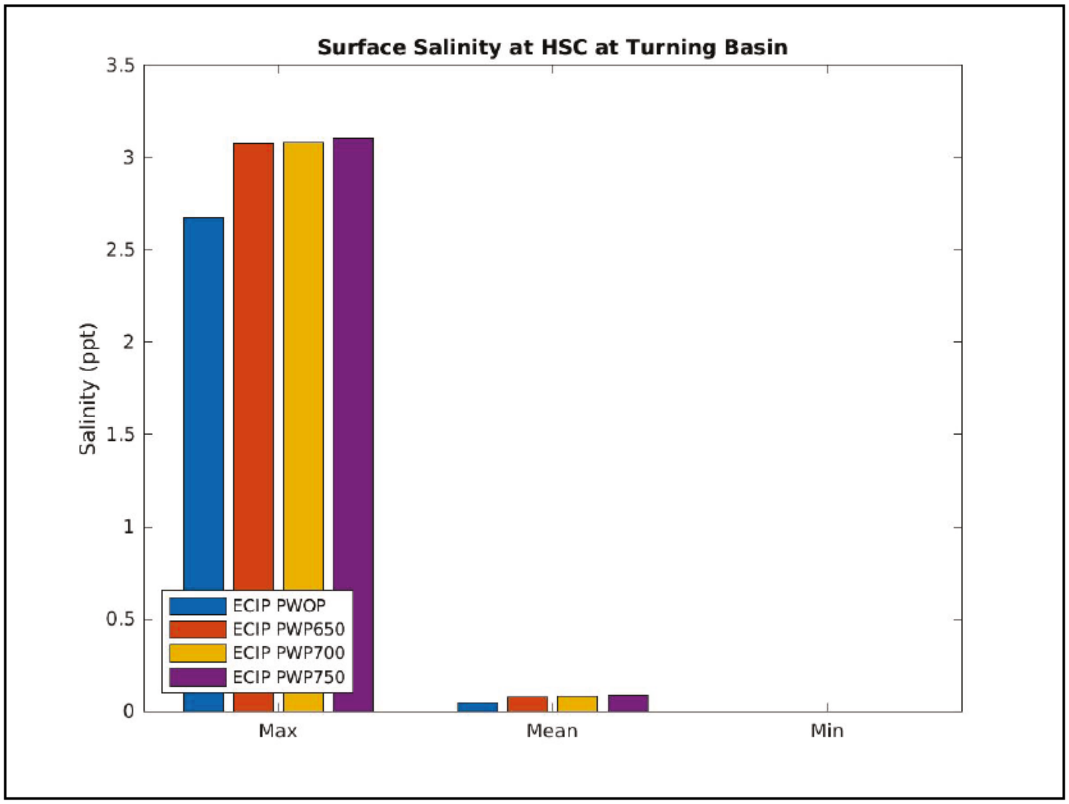

Bottom Salinity at HSC at Sims Bayou
Salinity (ppt)
0
2
4
6
8
10
12
14
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

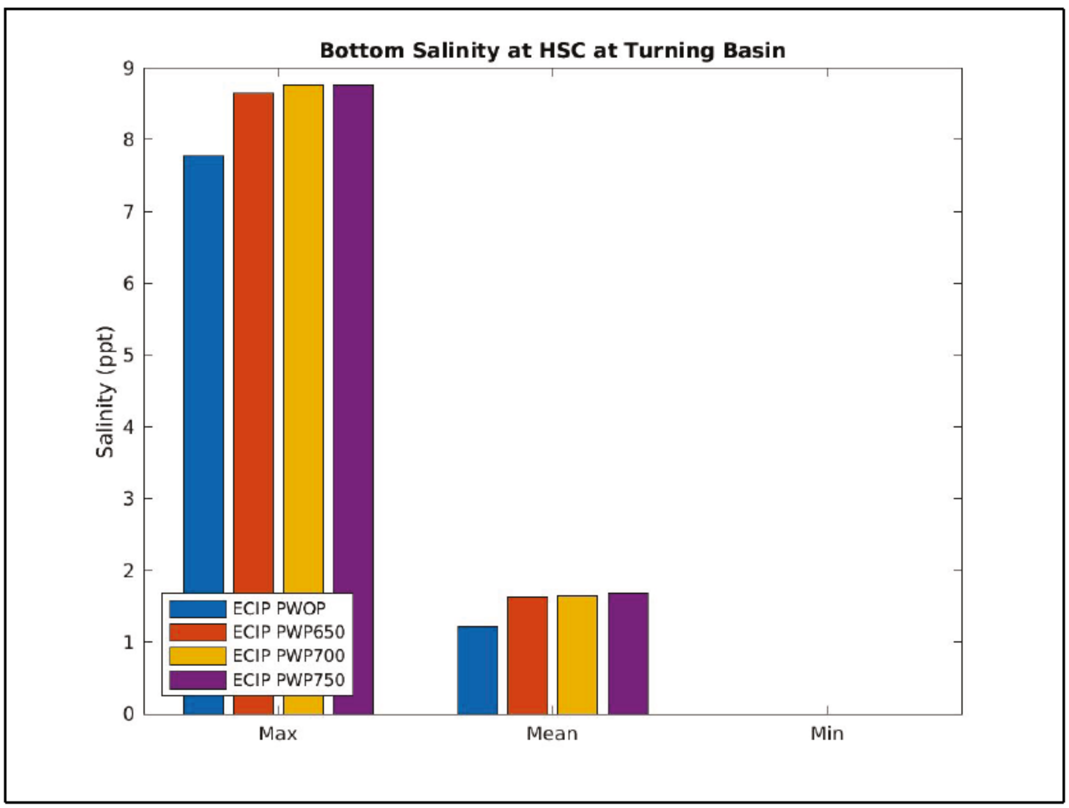

Surface Salinity Percentiles at HSC at Sims Bayou
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

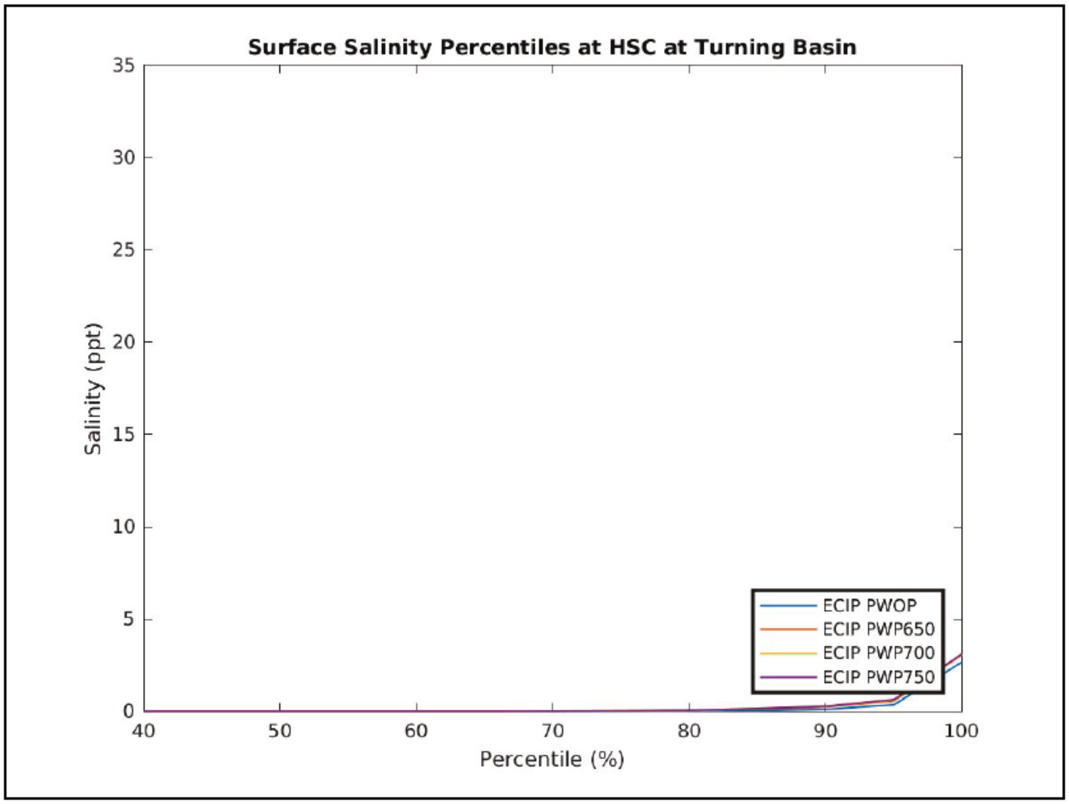

Bottom Salinity Percentiles at HSC at Sims Bayou
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100

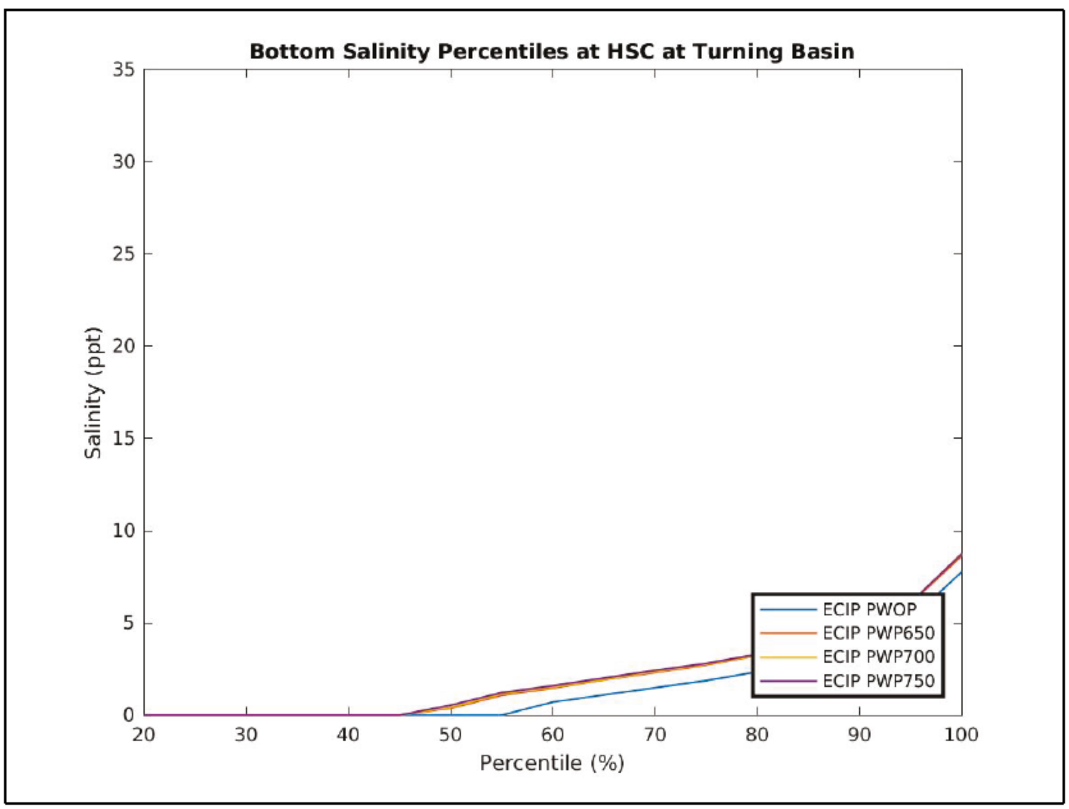

Mean Salinity Profiles at HSC at Sims Bayou
Depth (m)
Salinity (ppt)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
0
-5
-10
-15
-2
-1
0
1
2
3
4
5
6
7

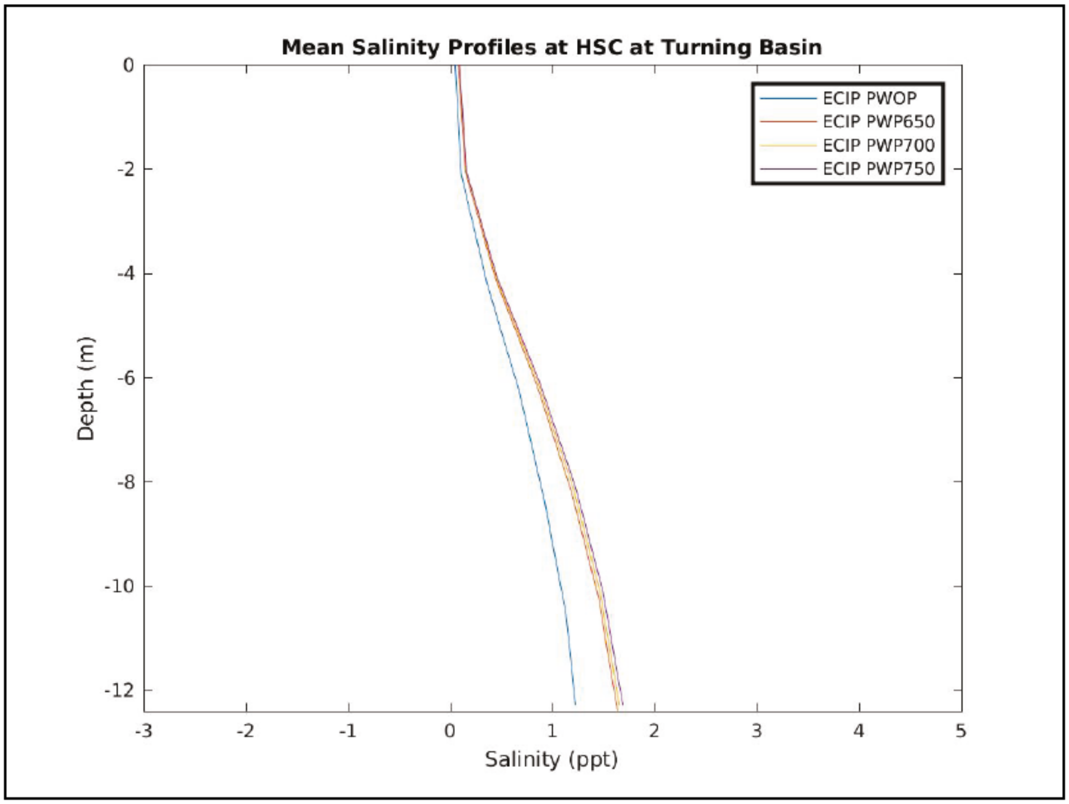

Salinity at HSC at Turning Basin
Salinity (ppt)
Date (mm/dd)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
40
35
30
25
20
15
10
5
0
11/23
01/12
03/03
04/22
06/11
07/31
09/19
11/08
12/28
02/16


Surface Salinity at HSC at Turning Basin
Salinity (ppt)
3.5
3
2.5
2
1.5
1
0.5
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750


Bottom Salinity at HSC at Turning Basin
Salinity (ppt)
9
8
7
6
5
4
3
2
1
0
Max
Mean
Min
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

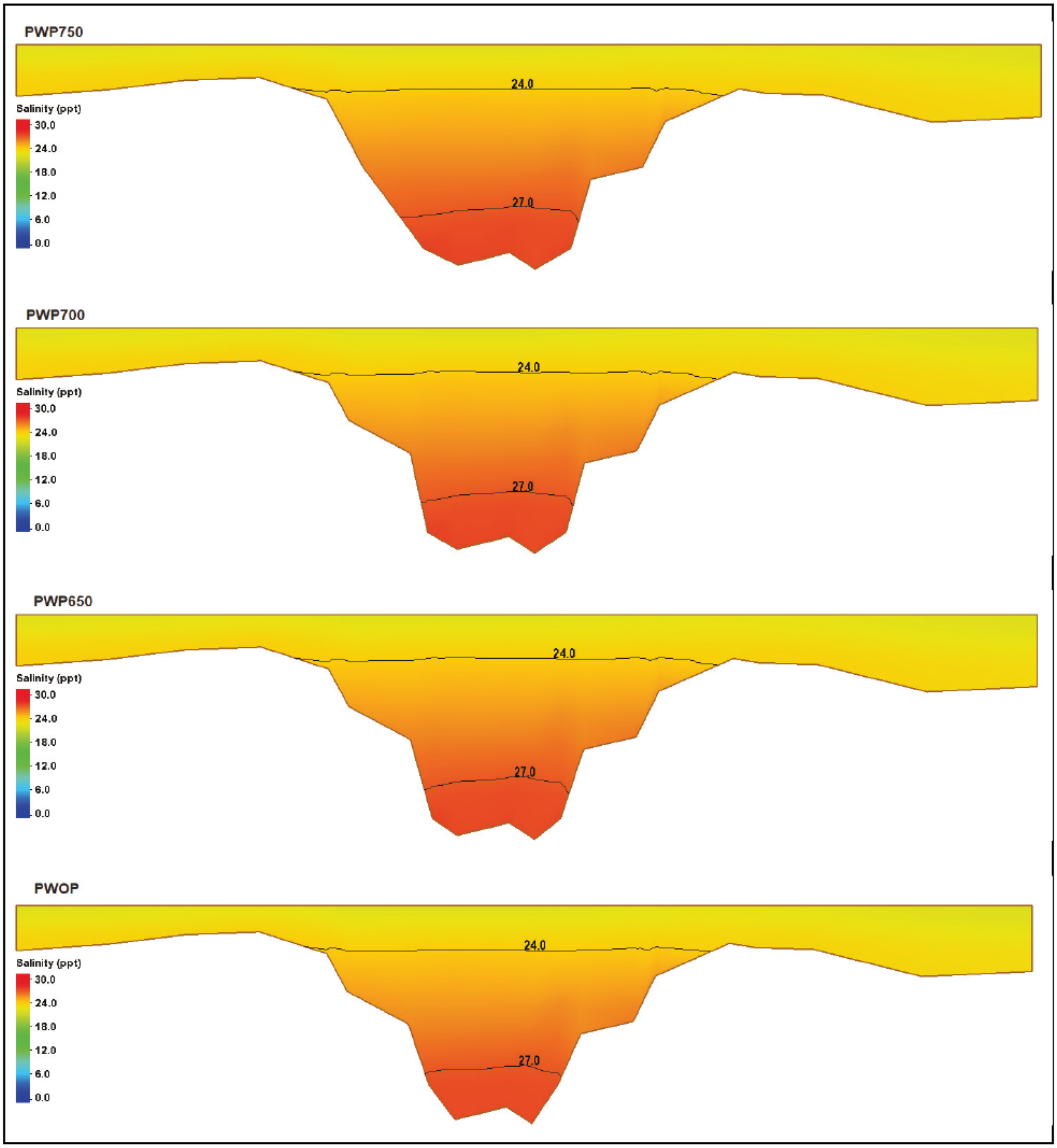

Surface Salinity Percentiles at HSC at Turning Basin
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750


Bottom Salinity Percentiles at HSC at Turning Basin
Salinity (ppt)
Percentile (%)
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750

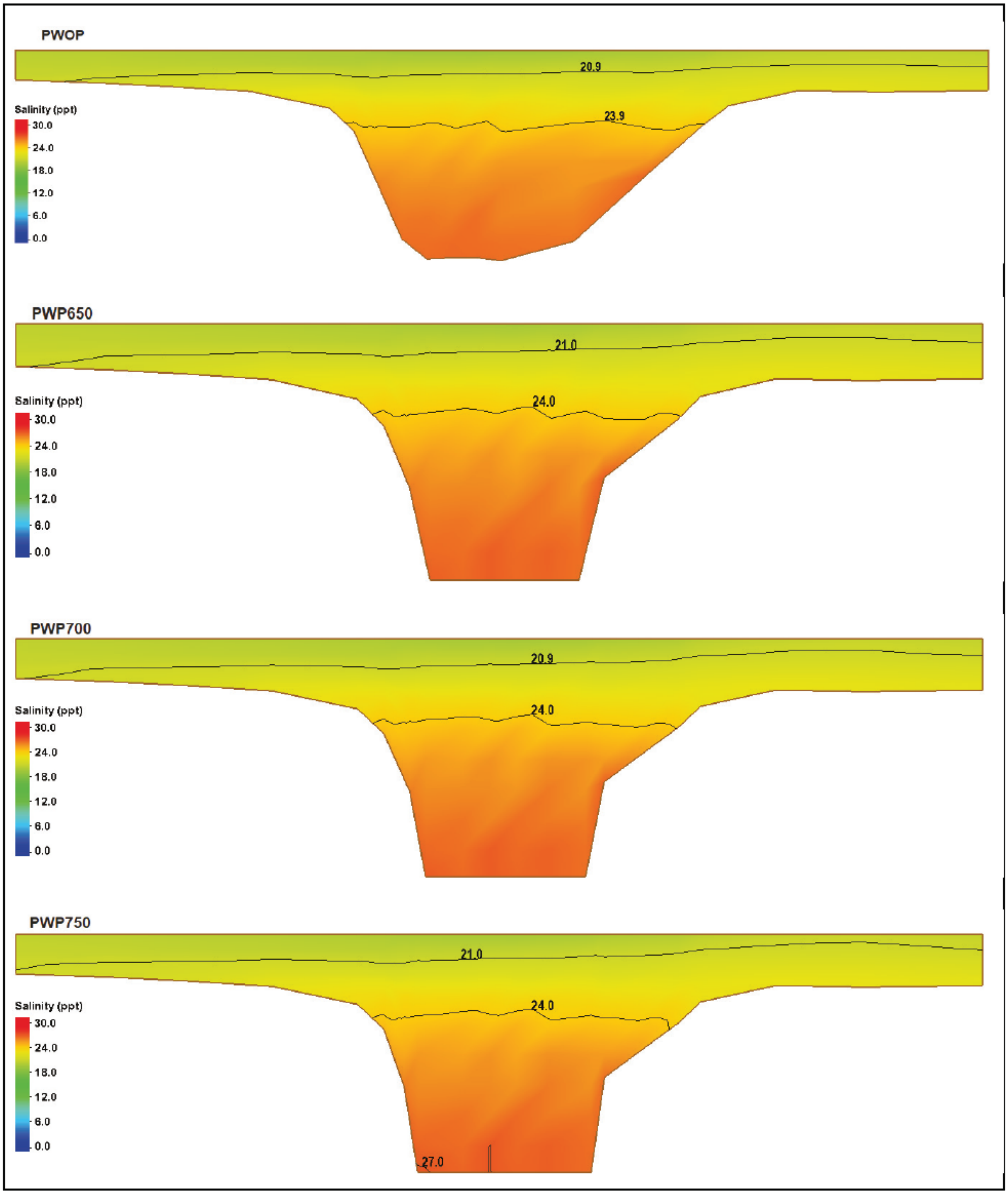

Mean Salinity Profiles at HSC at Turning Basin
ECIP PWOP
ECIP PWP650
ECIP PWP700
ECIP PWP750
Depth (m)
0
-2
-4
-6
-8
-10
-12
-3
-2
-1
0
1
2
3
4
5
Salinity (ppt)

## Cross-Sectional Salinity Analysis

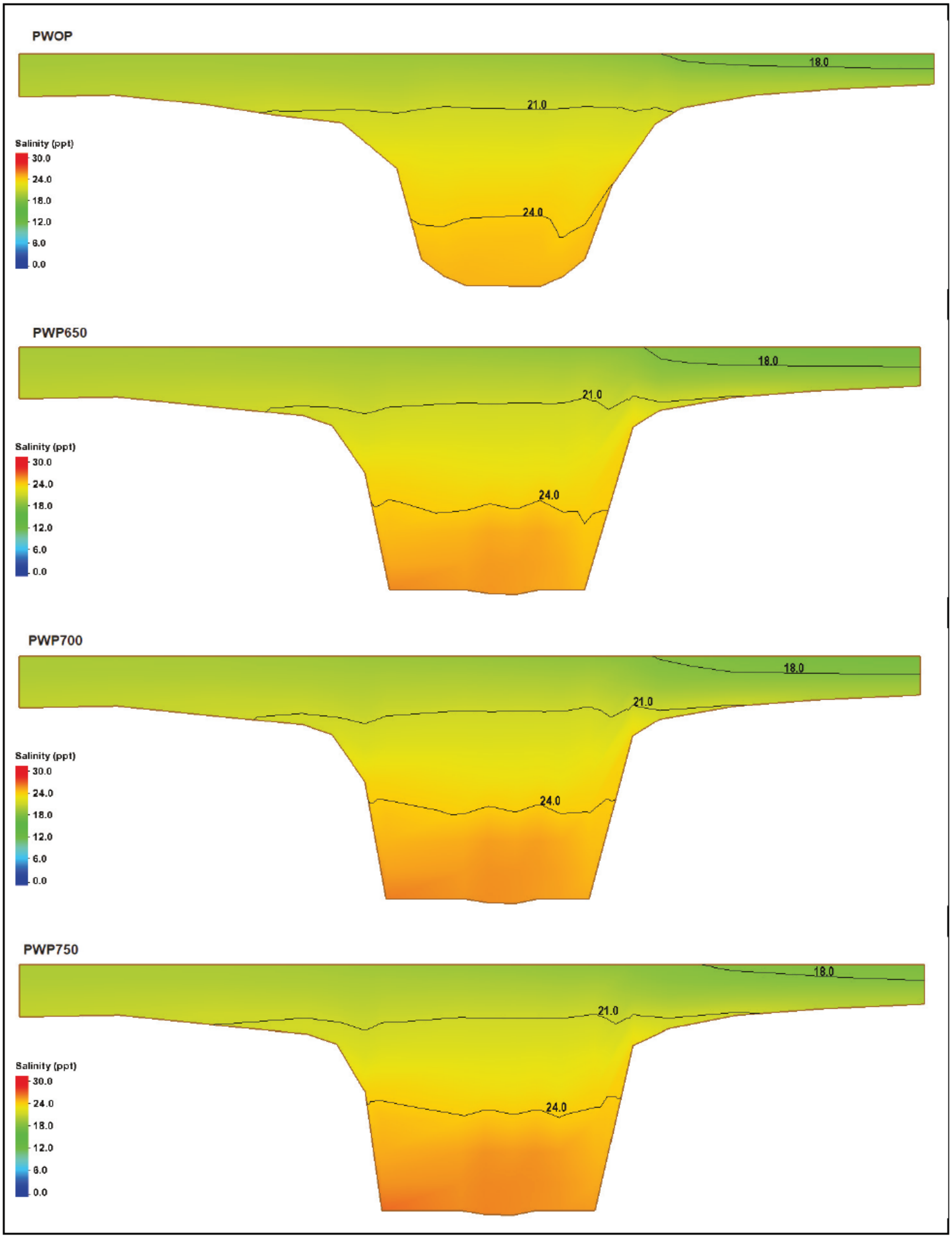
## Cross Section 1



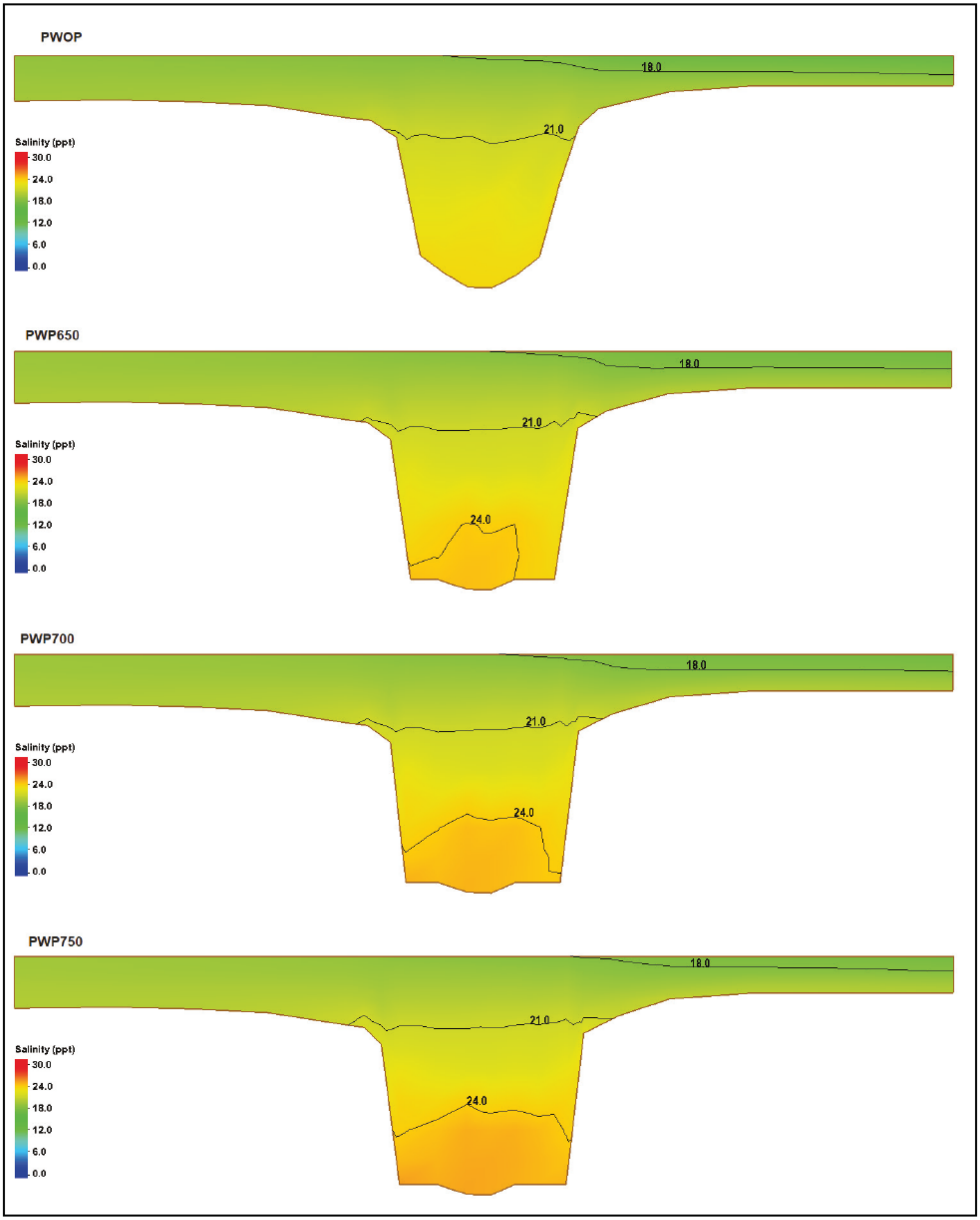
## Cross Section 2



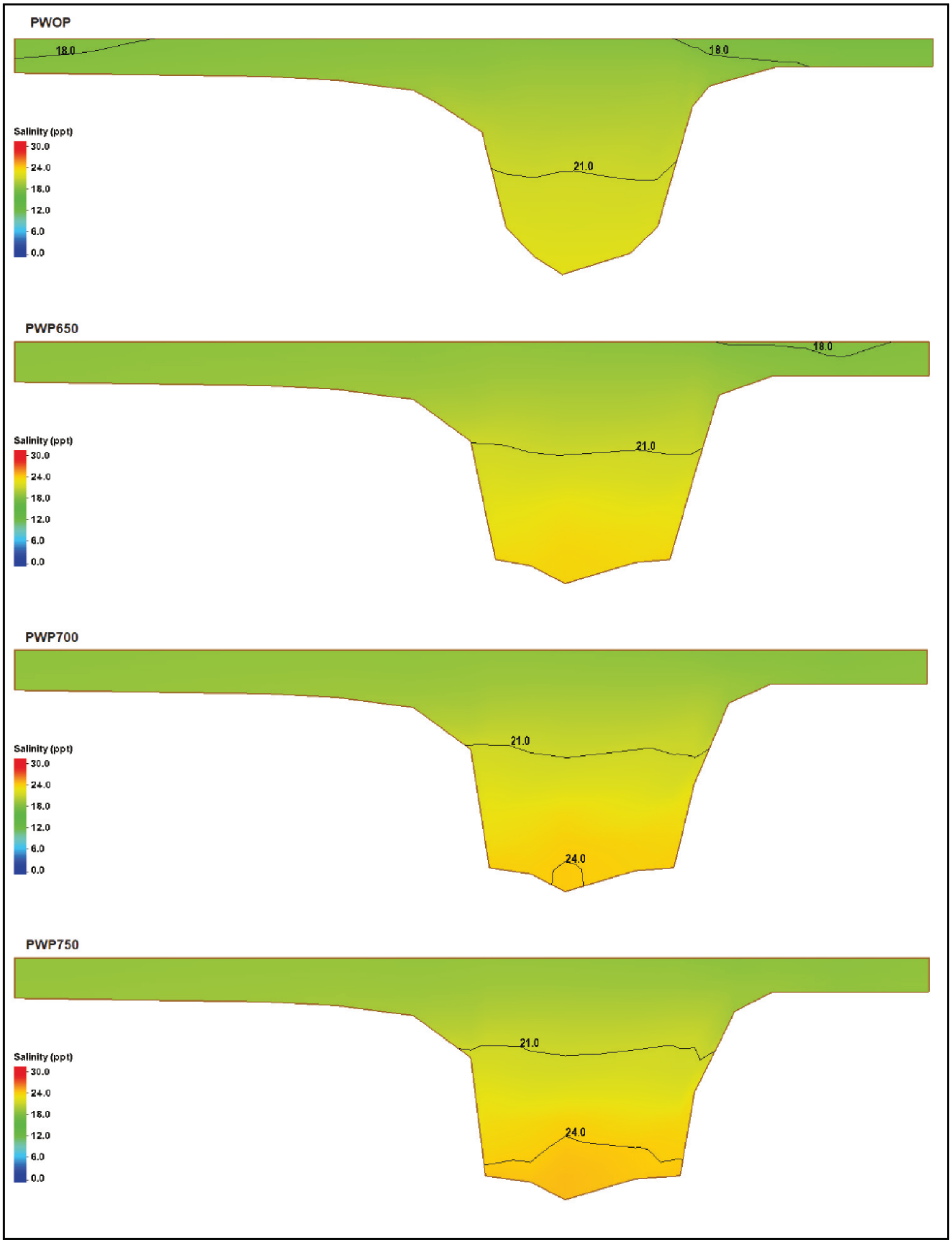
## Cross Section 3



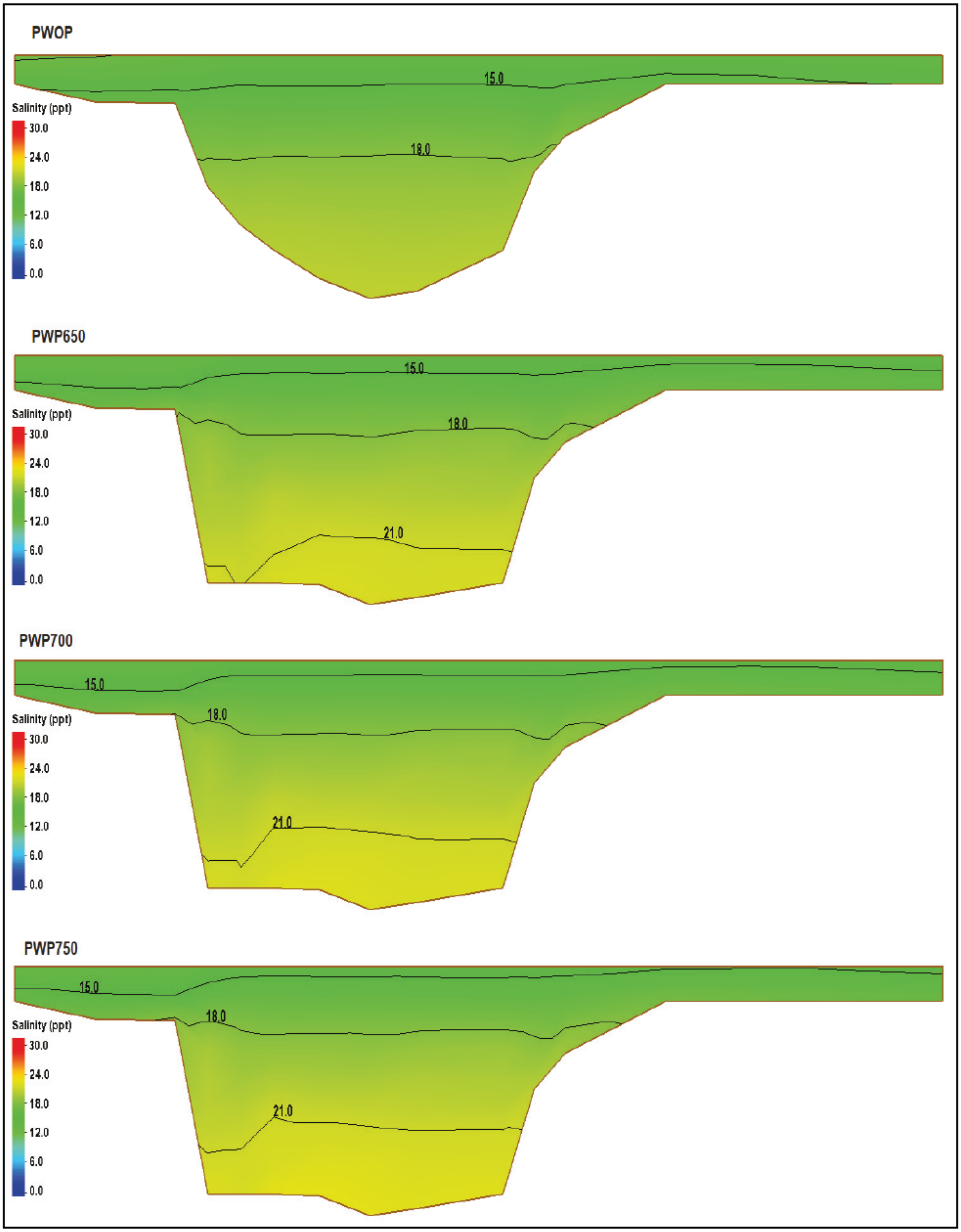
## Cross Section 4



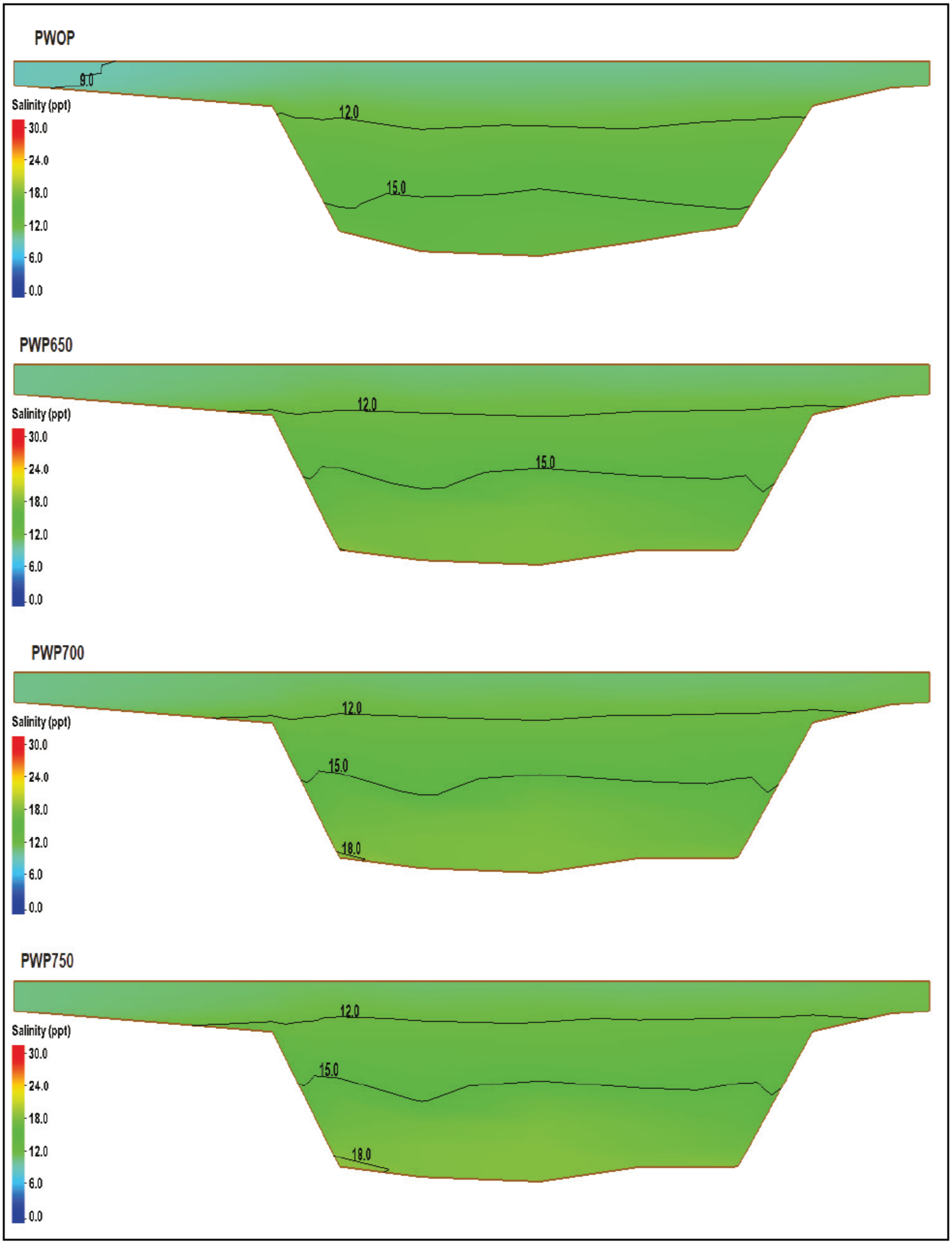
## Cross Section 5



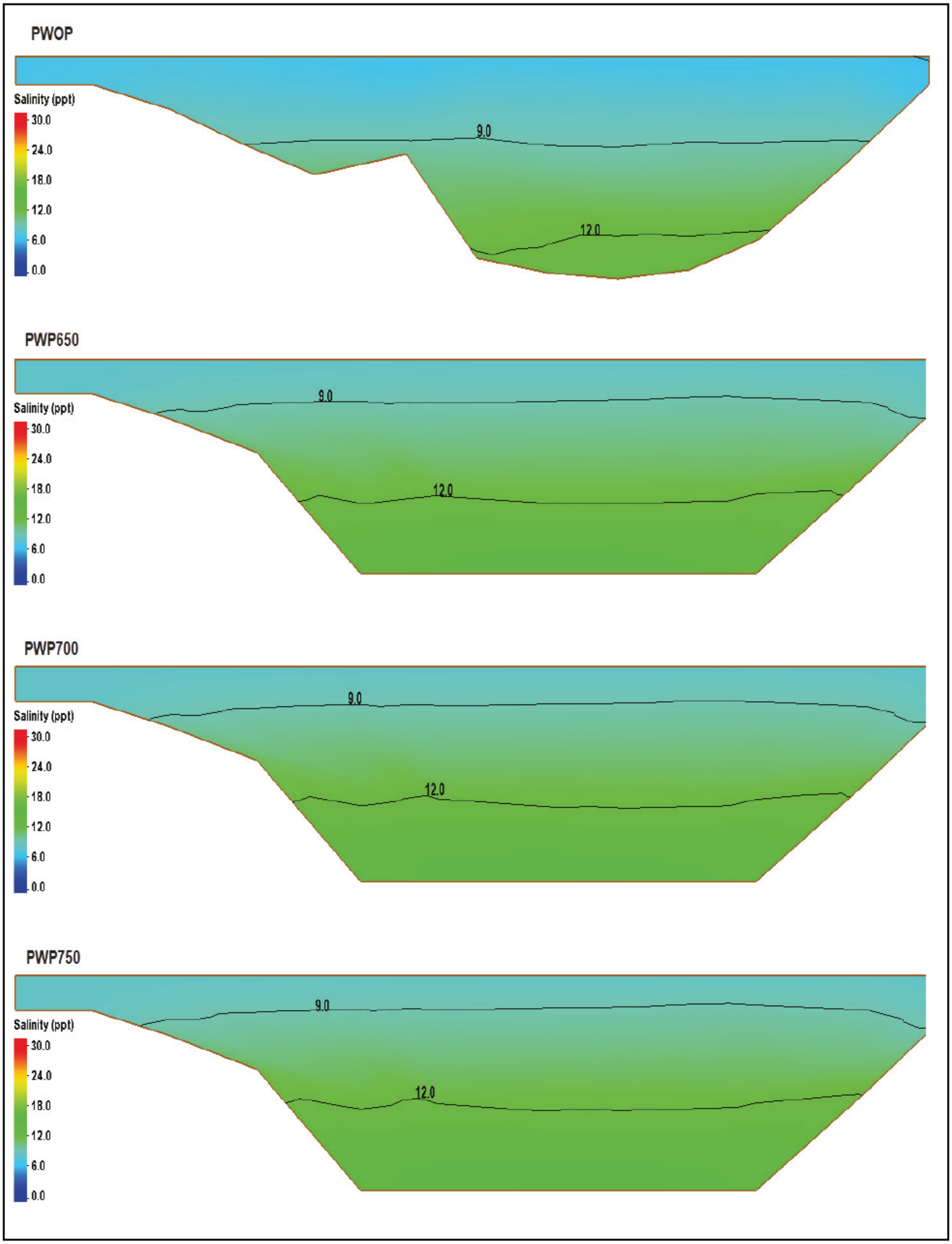
## Cross Section 6



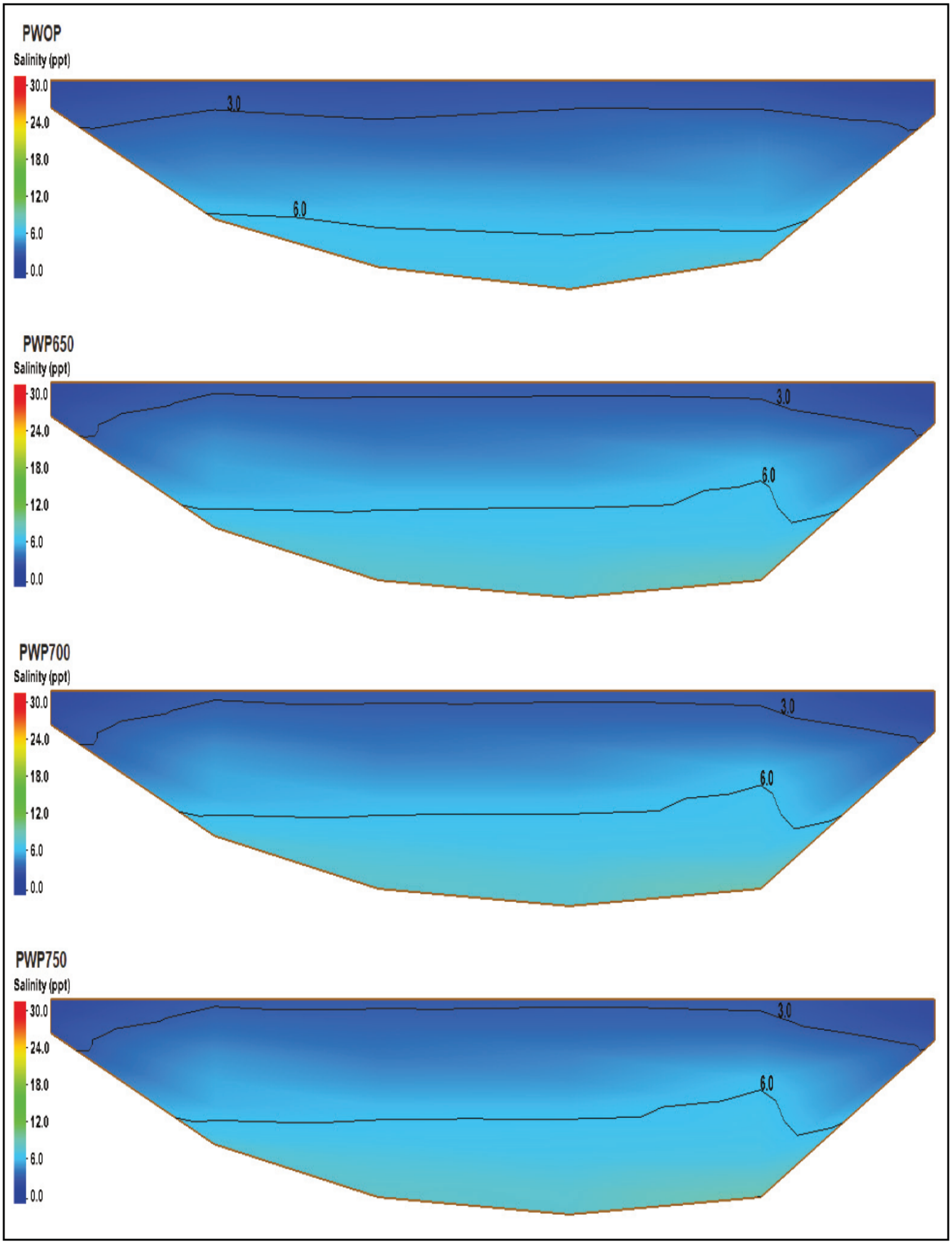
## Cross Section 7



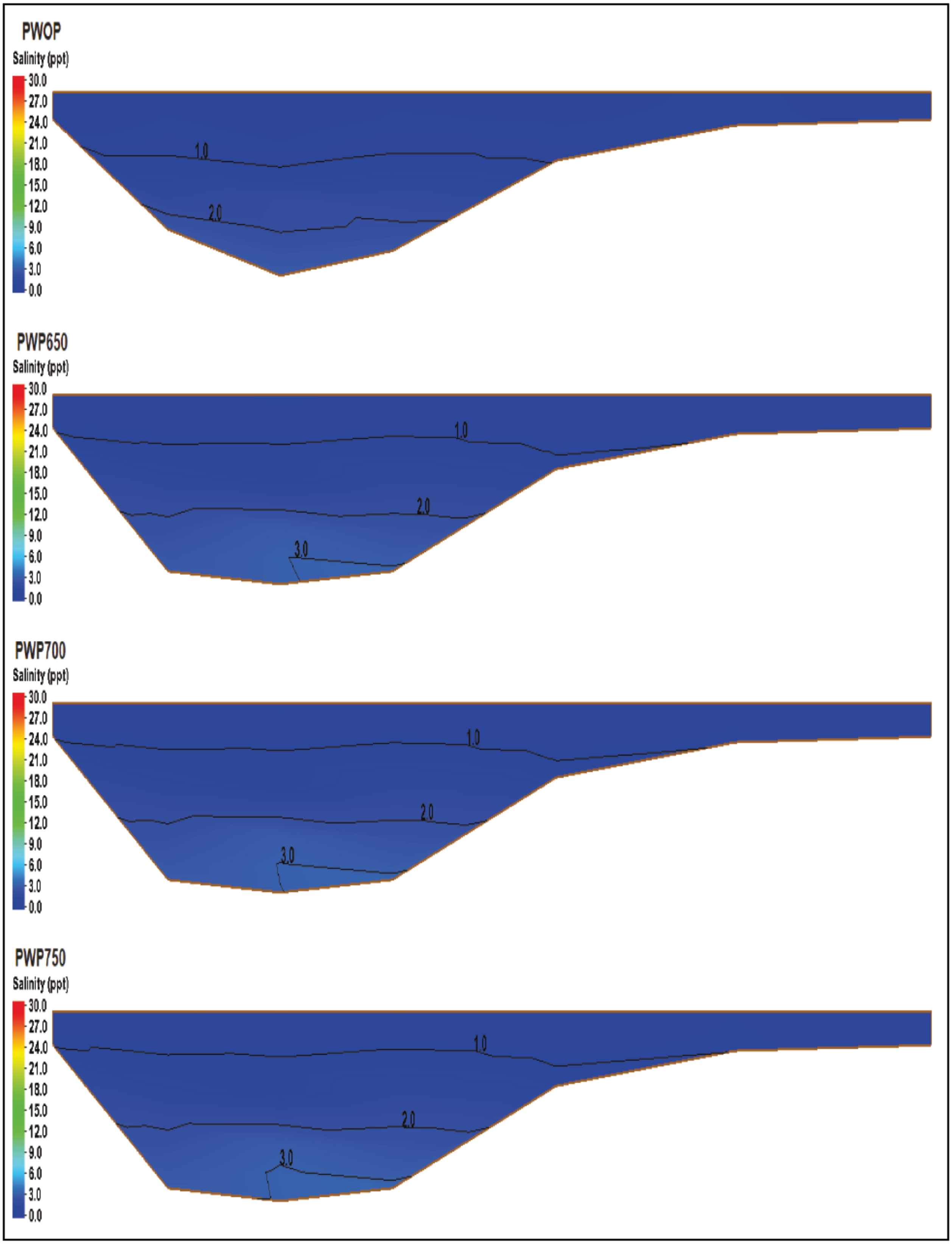
## Cross Section 8



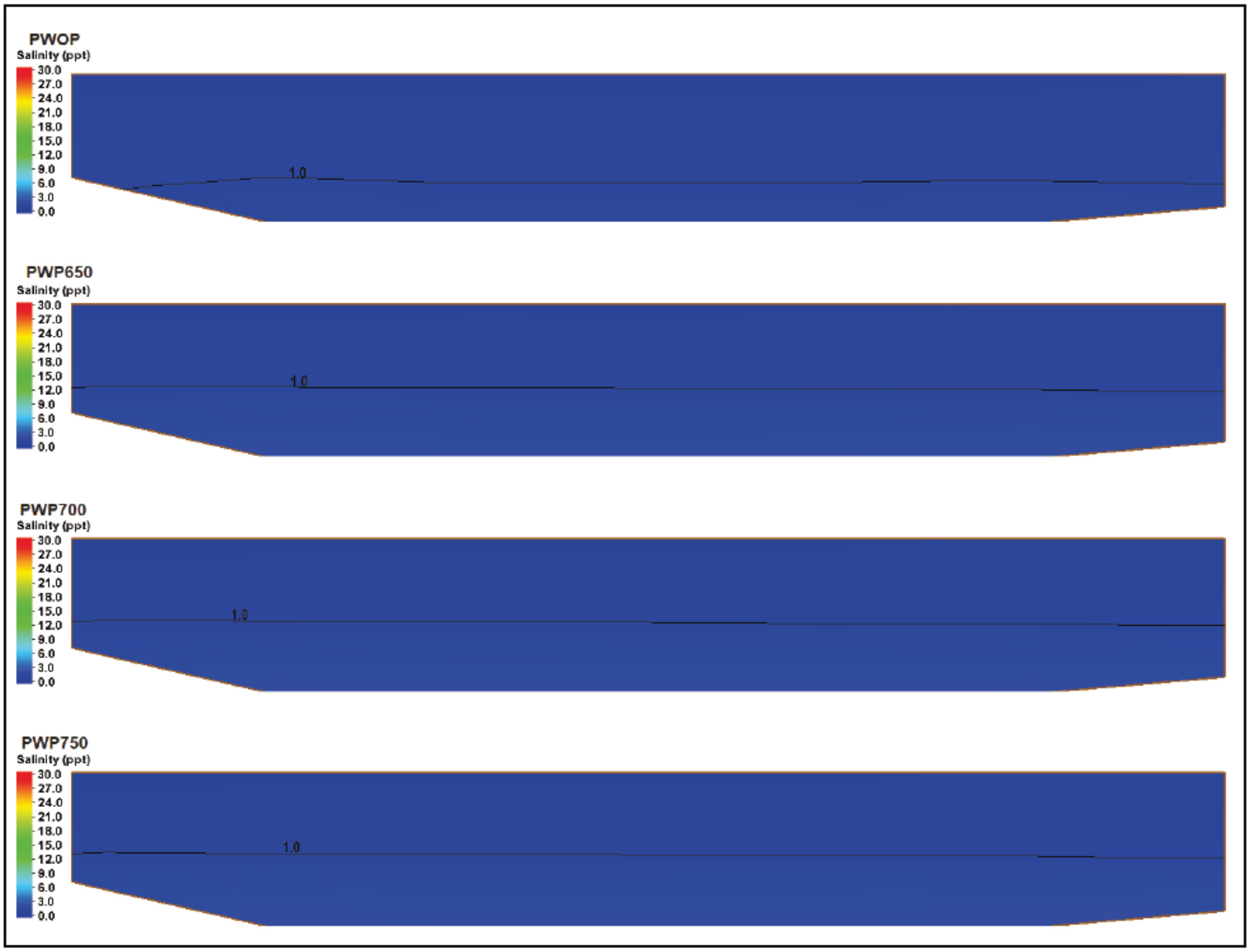
## Cross Section 9



## Cross Section 10



## Cross section 11



# 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 |

# Acronyms and Abbreviations

| | |
|---|---|
| 3D | three-dimensional |
| AdH | Adaptive Hydraulics |
| AM | advanced maintenance |
| AO | allowable overdepth |
| CHL | Coastal and Hydraulics Laboratory |
| ERDC | U.S. Army Engineer Research and Development Center |
| HSC | Houston Ship Channel |
| PWOP | present without project |
| PWP650 | present with 650 ft width project |
| PWP700 | present with 700 ft width project |
| PWP750 | present with 750 ft width project |
| SWG | Galveston District |
| TSP | tentatively selected plan |
| TWDB | Texas Water Development Board |
| USACE | U.S. Army Corps of Engineers |

**Units of Measure**

| | |
|---|---|
| ft | feet |
| m | meters |
| $m^3$ | cubic meters |
| cms | cubic meters per second |
| m/s | meters per second |
| mi | miles |
| mg/l | milligrams per liter |
| ppt | parts per thousand |

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| February 2021 | Final Report | |

**4. TITLE AND SUBTITLE**
Houston Ship Channel Expansion Channel Improvement Project (ECIP) Numerical Modeling Report: Increased Channel Width Analysis

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Jennifer McAlpin and Cassandra Ross

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ERDC/CHL TR-21-2

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Port of Houston Authority
Houston, TX 77029

**10. SPONSOR/MONITOR'S ACRONYM(S)**
N/A

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**
Port of Houston Authority; Funding Account Code SA-2020-CHL-3562

**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. 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. After initial analysis, two additional channel widths in the bay portion of the Houston Ship Channel were requested for testing. The results of these additional channel widths are presented in this report.
The model shows that the salinity does not vary significantly due to the channel modifications being considered for this project. Changes in 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.

**15. SUBJECT TERMS**
Channels (Hydraulic engineering)—Mathematical models, Houston Ship Channel (Tex.), Navigation, Ships

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| Unclassified | Unclassified | Unclassified | SAR | 165 | Jennifer McAlpin |
| | | | | | **19b. TELEPHONE NUMBER** *(Include area code)* 601-634-2511 |