APPENDIX D

Water Quality Analysis

Memorandum

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To:	Cindy Kinkade (AECOM)
From:	David Cannon (Everest International Consultants)
Copy to:	
Date:	September 30, 2014
Project Number:	P2183-03
Re:	BVLEP – Water Quality Analysis

The Buena Vista Lagoon Enhancement Project (BVLEP) is in the preliminary engineering and environmental review phase of project development. Four enhancement alternatives are currently under consideration as listed below.

I. Saltwater Alternative
II. Freshwater Alternative
III. Hybrid Alternative A (mix of saltwater and freshwater with channel in Weir Basin)
IV. Hybrid Alternative B (mix of saltwater and freshwater without channel in Weir Basin)

Under the Saltwater and Hybrid Alternatives, a tidal inlet connecting the ocean and Buena Vista Lagoon (Lagoon) would be constructed to allow tidal exchange enabling salt water habitats to establish within the Lagoon. The regular tidal exchange will result in higher salinity, as well as improved circulation and flushing of the Lagoon, which are in general considered improvements for water quality, especially for marine and estuarine species. The objective of the water quality analysis is to estimate the overall water quality condition within the lagoon under each of the enhancement alternatives and compare these conditions to existing conditions and the No Project Alternative.

Since the enhancement alternatives cover a range of hydrologic regimes from fresh to salt water, the residence times for the Lagoon are used as surrogate to compare the potential differences in water quality among the enhancement alternatives as well as potential changes in water quality from existing conditions. Residence time is commonly used as a surrogate for water quality. The potential for water quality issues is greater for areas with long residence times such as the back ends of enclosed water bodies farther away from coastlines and/or at areas far away from any fresh water inflow. These areas are generally characterized by poor flushing with low net flow exchange. Long residence times are indicative of stagnant water with poor flushing while short residence times are indicative of good water circulation and flushing. For a given level of pollutant loading, better flushing usually indicates better water quality in the water body. Since for the Lagoon, the source of pollutants are the same (mainly from stormwater runoffs) irrespective of the enhancement alternatives, residence times are a good surrogate for comparing the potential changes in water quality among the different enhancement alternatives.

The fresh water flows entering the Lagoon from Buena Vista Creek will result in salinity level decreases in the Lagoon under the Salt and Hybrid Alternatives. Substantial decreases of salinity may affect marine habitats and the associated organisms. Hence, in addition to the residence time analysis, a salinity analysis was conducted to evaluate the salinity levels in the Lagoon under the various enhancement alternatives. The residence time and salinity analyses were evaluated for both dry and wet weather conditions; and the effect of sea level rise on residence times and salinity in the Lagoon was also estimated in the analyses.

In Section 1 below, a brief description of the existing Lagoon water quality is provided. The methodology, data, and results for the residence time and salinity analyses are provided in Sections 2 and 3, respectively. A summary of the findings of the water quality analysis is provided in Section 4.

1. Existing Conditions

Overview

Water levels in the Lagoon are controlled by the sandy beach berm and weir located at the mouth of the Lagoon. The present 50-ft wide weir was constructed in 1972, which isolates the Lagoon from tidal flushing even after storm flows have eroded the beach berm, which also regulates water levels. Since the weir precludes tidal flushing of the Lagoon, freshwater runoff is the primary mechanism for flushing of the Lagoon. The primary source of freshwater inflow into the Lagoon is storm water runoff from Buena Vista Creek upstream of the I-5 Basin. The Lagoon also receives minor inflows from several local storm drains along the perimeter of the Lagoon. Storm water runoff includes wet weather runoff during storms and dry weather runoff from wastewater, nuisance water, and irrigation return water. Flow measurements from Buena Vista Creek recorded from October 1, 2007 through October 31, 2008 (MACTEC 2009) showed that the average dry weather flow from April 2008 to December 2008 was approximately 3 cfs, and the average wet weather flow between from January to March was approximately 50 cfs. These measured dry and wet weather flows were used for the residence time and salinity analyses described in Sections 2 and 3.

Even though the weir keeps ocean water from entering the Lagoon, some exchange of ocean and Lagoon water still occurs under the beach berm. Field data show that salinity in the Lagoon ranges from fresh to brackish. A recent study conducted by SCCWRP (2010) shows that salinity levels in the I-5 Basin in the range of 0 to 2 ppt and those in the Coast Highway (CH) Basin in the range of 0 to 3.5 ppt.

Buena Vista Lagoon is under the jurisdiction of the San Diego Regional Water Quality Control Board (SDRWQCB). For administrative purposes, the Lagoon is within the Carlsbad

Hydrologic Unit, which encompasses several coastal lagoons with similar water quality issues. The Carlsbad Hydrologic Unit includes four major lagoons – Buena Vista, Agua Hedionda, Batiquitos, and San Elijo Lagoons; and two smaller lagoons – Loma Alta and Canyon de las Encinas Lagoons (SDRWQCB 2011). Major water quality issues in the Carlsbad Hydrologic Unit include surface water quality degradation, sewage spills, beach closures, sedimentation, habitat degradation/loss, invasive species, and eutrophication. Pollutants of concern include bacterial indicators, eutrophic conditions, nutrients, sediments, sulfates, nitrates, and phosphates.

303(d) Listing

The Buena Vista Lagoon was placed on the State Water Resources Control Board's (SWRCB) 303(d) list of impaired waterbodies. The 2010 303(d) listing for the Lagoon includes impairments for nutrients, indicator bacteria, and sedimentation/siltation (USEPA 2011). The extent of nutrient impairment is 150 acres, and the estimated extent of bacteria and sedimentation impairments is 202 acres. All three impairments have been listed since 1996. The original 303(d) listing for nutrients, bacteria, and sediment were largely observational and qualitative. For nutrients, treated sewage was discharged directly into the Lagoon until 1967. Periodic algae blooms were observed to cause localized fish kills and nutrient buildup in the sediments have promoted eutrophication in the Lagoon. The bacteria listing was based on occasional exceedance of water quality objectives from water quality sampling in the Lagoon. Sewage spills in 1991-1995 contributed to elevated bacteria levels, and storm water runoff may also contribute to the occasional exceedance of bacteria objectives. For sediment, the Lagoon receives runoff from agricultural land erosion, construction, and channel erosion. The weir structure reduces sediment transport through the Lagoon and out the Pacific Ocean. The nesting islands in the I-5 Basin were created in 1983 from approximately 130,000 cubic meters of sediment dredged within the I-5 Basin. Urbanization of the watershed that has increased runoff during storm events and encroachment upon the floodplain that eliminated most of the riparian and marsh land buffer are considered primary factors in sedimentation of the Lagoon, particularly in the late 70's and early 80's (SWRCB 2002).

Available Water Quality Data

A recent comprehensive water quality data sampling program for the Lagoon was conducted in 2008 by MACTEC (2009). The 2008 sampling program was conducted in response to a Monitoring Order (R9-2006-0076) issued by the San Diego Regional Water Quality Control Board (SDRWQCB) requiring stakeholders to collect data for the development of TMDLs for nutrients and other contaminants (e.g., bacteria). The study was one of several sampling programs that were coordinated including ambient lagoon water quality, sediment, pore water, and macroalgae sampling programs. The Lagoon water quality sampling included collection of water quality data at one location in the I-5 Basin and one location in the CH Basin. Samples include three wet and four dry weather events between January and September 2008.

There was an early water quality sampling conducted for the Lagoon by the Coastal Environments in 1999 (Coastal Environments 2000). The 1999 program was conducted to provide the necessary physical and biological data for the development of a Land Management Plan for Buena Vista Lagoon. For that program, water quality data were collected at six locations within the Lagoon on a monthly or bimonthly basis from June to November 1999. Sampling locations included two locations in the I-5 Basin, two locations in the CH Basin, one location in the Railroad Basin, and one location in the Weir Basin. Water quality data collected from these two programs are summarized and compared with the Basin Plan Objectives in Table 1.

Nutrients: As shown in Table 1, water quality data for the Lagoon indicates that nutrients, as indicated by total nitrogen and total phosphorus, typically exceed water quality objectives, sometimes by an order of magnitude. Based on the 2008 data, nutrients were higher during winter and spring weather months compared with the summer and fall months.

The relative ratio of nutrients (nitrogen to phosphorus) can be used to characterize potential nutrient sources. The ratio of total nitrogen to total phosphorus ranged from 4.8 to 25.8 with an average of about 13.5. The higher nitrogen compared with phosphorus indicates the Lagoon is generally phosphorus-limited. In general, ratios greater than 10 are indicative of waterbodies receiving nutrients predominantly from non-point sources. Thus, nutrients loadings to the Lagoon are expected to originate primarily from non-point sources such as agricultural, open, and urban lands.

The 2008 study also included comprehensive data collection to understand the nutrient cycling within the Lagoon (SCCWRP 2010). Overall, the study found that the Lagoon exhibits symptoms of eutrophication indicated by periodic depressions in dissolved oxygen (DO) and high biomass. Differences in nutrients cycling were observed in the CH Basin compared with the I-5 Basin. Watershed loads dominate nutrient cycling in the I-5 Basin. In the Coast Highway Basin, eutrophication is greater and aquatic primary productivity and internal recycling control the nutrient cycling. Based on these findings, recommendations for reducing eutrophication included increases in flushing and decreases in residence time.

Bacteria: As shown in Table 1, water quality objectives for bacteria were occasionally exceeded. In general, REC-1 water quality objectives for bacteria are exceeded during wet weather conditions with occasional exceedances during dry weather.

Dissolved Oxygen: The DO data from the dry and wet weather sampling indicate that DO levels in the Lagoon fell below the water quality objective of 5 mg/L. This water quality objective is for inland surface waters with designated Marine Habitat (MAR) or Warm Freshwater Habitat (WARM) beneficial uses, which applies to the Lagoon. Continuous DO monitoring was also conducted in the I-5 and CH Basins from January to October 2008. The average DO concentrations were 10.1 and 7.3 mg/L in the I-5 and CH Basins, respectively (MACTEC 2009). Based on the continuous DO levels, during which DO levels periodically fell below the 5 mg/L criteria for approximately 12% and 24% of the time in the I-5 and CH

Basins, respectively. Lower DO levels typically occurred during the summer in the I-5 Basin. In the Coast Highway Basin, low DO levels occurred periodically throughout year. In general, higher DO levels corresponded to higher fresh water flow during the wet weather months (SCCWRP 2010).

Table 1. Lagoon Water Quality Sampling Results

CONSTITUENT	UNIT	1999 DATA*	2008 DATA**	BASIN PLAN OBJECTIVE(1)
Total Nitrogen	mg/L	1.0 – 4.4	0.59 – 4.48 (dry) 0.15 – 2.15 (wet)	0.25 – 1.0 (2)
Total Phosphorus	mg/L	ND (3) – 0.4	0.03 – 0.42 (dry) 0.02 – 0.26 (wet)	0.025 – 0.1 (2)
Total Coliform	MPN/100 mL	--	No exceedances (dry) 6/12 exceedances (wet)	1,000 –10,000 (4, 5)
Fecal Coliform	MPN/100 mL	One exceedance in Railroad Basin	No exceedances (dry) 10/12 exceedances (wet)	200 – 400 (4, 6)
Enterococcus	MPN/100 mL	No exceedance	2/4 exceedances (dry) 10/12 exceedances (wet)	108 (4, 7)
Dissolved Oxygen	mg/L	4.5 – 6.2 (surface) 2.5 – 5.4 (bottom)	1.0 – 26.3 (dry) 3.2 – 17.2 (wet)	5.0 (8) 7.0 (9)
Salinity	ppt	1.6 – 2.7 (surface) 1.6 – 3.0 (bottom)	0 – 3.5	None

* *Source: Coastal Environments 2000 (6 locations)*
** *Source: MACTEC 2009 (2 locations)*
Data shown as range in measured values, unless otherwise indicated.

Notes:
(1) *SDRWQCB (2011) Water quality objectives for inland surface waters not to be exceeded more than 10% of the time during any one year period*
(2) *Criteria for TP 0.1 mg/L for flowing waters and 0.025 for any standing body of water; criteria for TN assumed based on N:P ratio of 10*
(3) *ND = Non-detect*
(4) *REC-1 criteria over 30-day period*
(5) *1,000 MPN/100mL for not more than 20% of samples and no single sample 10,000 MPN/100mL*
(6) *Log mean 200 MPN/100mL and 400 MPN/100mL applies to 10% of total samples*
(7) *Freshwater, maximum single sample for moderately or lightly used area*
(8) *Inland surface waters with designated Marine Habitat (MAR) or Warm Freshwater Habitat (WARM) beneficial uses*
(9) *Annual mean DO concentration shall not be less than 7.0 mg/L more than 10% of the time*

2. Residence Time Analysis

Approach

A two-dimensional (2-D) hydrodynamic and water quality model was used to estimate residence times by simulating average hydrodynamic and mixing conditions within the Lagoon. The 2-D model used for the residence time analysis is the Environmental Fluid Dynamic Code (EFDC) developed by the U. S. Environmental Protection Agency (EPA) (Tetra Tech 2007). EFDC was used to simulate tidal exchange between the ocean and Lagoon and the freshwater inflow from Buena Vista Creek under dry weather (3 cfs) and wet weather (50 cfs) conditions under the enhancement alternatives, existing conditions (Year 2015), and the No Project Alternative (Year 2100).

Residence times within the Lagoon were determined based on the simulated transport and dilution of an initial amount of conservative dye placed uniformly throughout the Lagoon over a 30- to 60-day period. Over time, the initial dye concentrations decreased as freshwater from Buena Vista Creek and ocean water entering through the tidal inlet (Saltwater and Hybrid Alternatives) replaced the water within the Lagoon. Residence times in the Lagoon were determined as the time required for the dye concentration to drop to e^{-1} of the initial concentrations (i.e., the time it takes for an initial concentration to drop from 1 to 0.368). An example of using the simulated dye concentrations to estimate the residence times for a location near the middle of the Weir Basin and a location near the middle of the Coast Highway Basin for Hybrid Alternative A is shown in Figure 1. As shown in figure, the dye concentration oscillates with the tidal cycle. Over time, the overall dye concentration decreases exponentially with time (indicated by the black line). The residence time is determined as the time for the dye concentration to be reduced to 0.368 of the initial condition (indicated by the red line in the figure). As expected, the residence time for the Weir Basin, which is closer to the tidal inlet, is less than the residence time for the Coast Highway Basin.

Results

The simulated residence times for the Saltwater Alternative are shown in Figure 2. In the figure, the top panel shows the results for the dry weather condition, while the bottom panel shows the results for the wet weather condition. As expected, as shown in the figure, with higher freshwater inflow under wet weather compared with dry weather, the residence times in the Lagoon under wet weather are shorter (ranging from less than a day to 3 days depending on locations) than those under dry weather (ranging from less than a day to 5 days). Residence times for Hybrid A, Hybrid B, and Freshwater Alternatives are shown in Figures 3 to 5, respectively. Results for existing conditions are shown in Figure 6. Note that due to differences in the range of residence times for each alternative, different color scales are used for each alternative; however, for the same alternative, the same color scale is used for the dry and wet weather conditions.

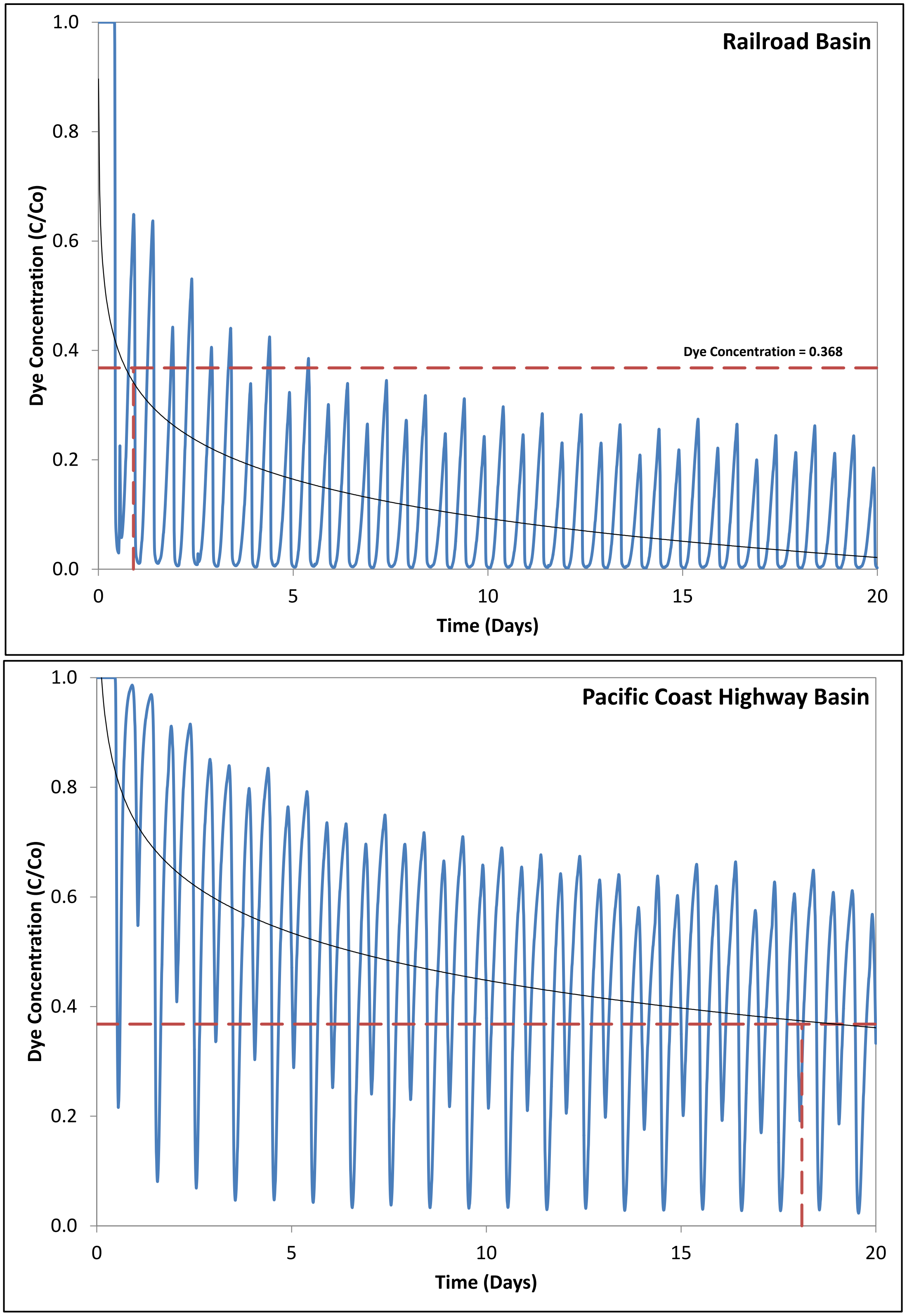


Figure 1. Concentration for Hybrid Alternative A – Year 2015

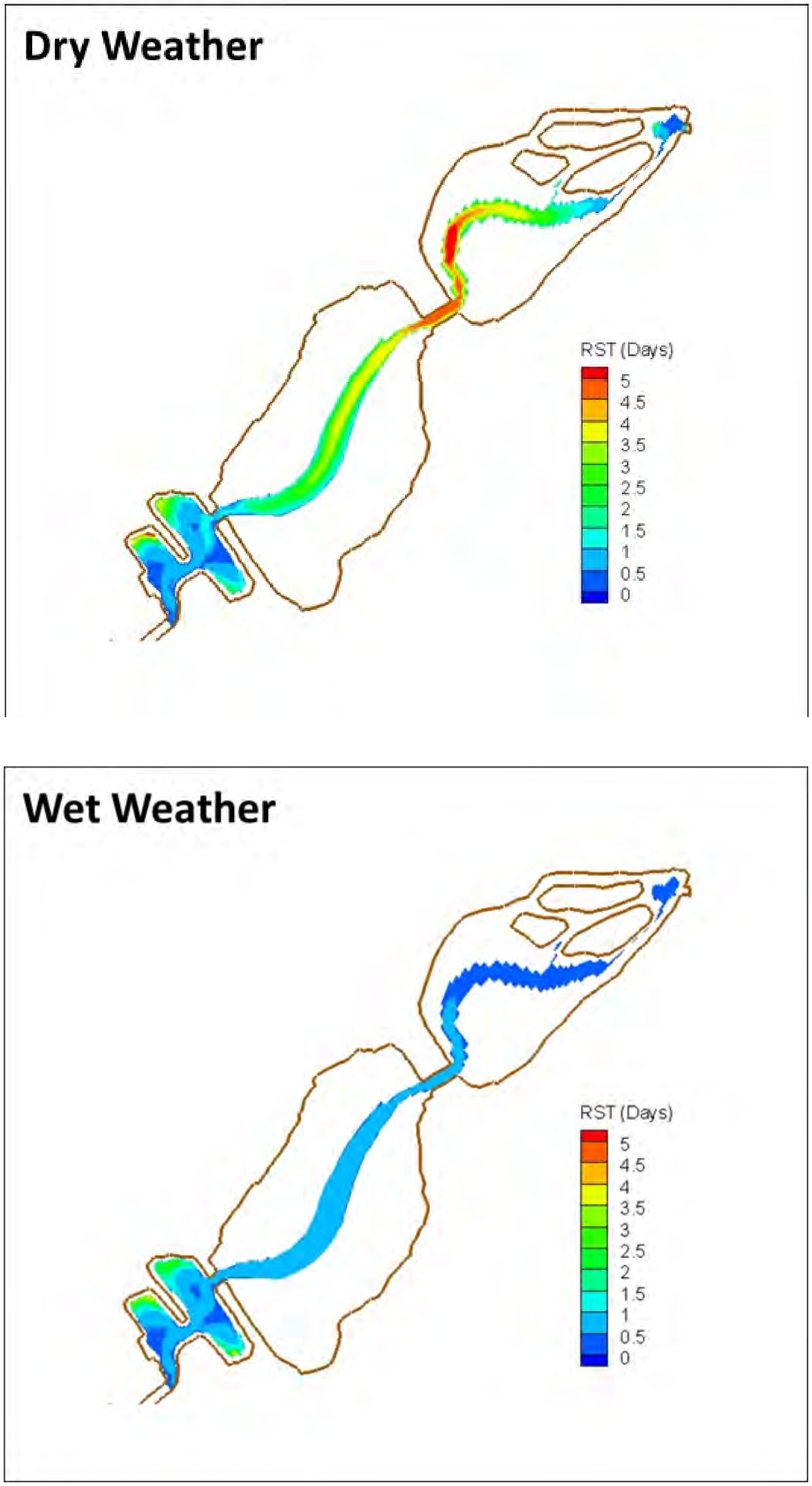


Figure 2. Residence Times for Saltwater Alternative – Year 2015

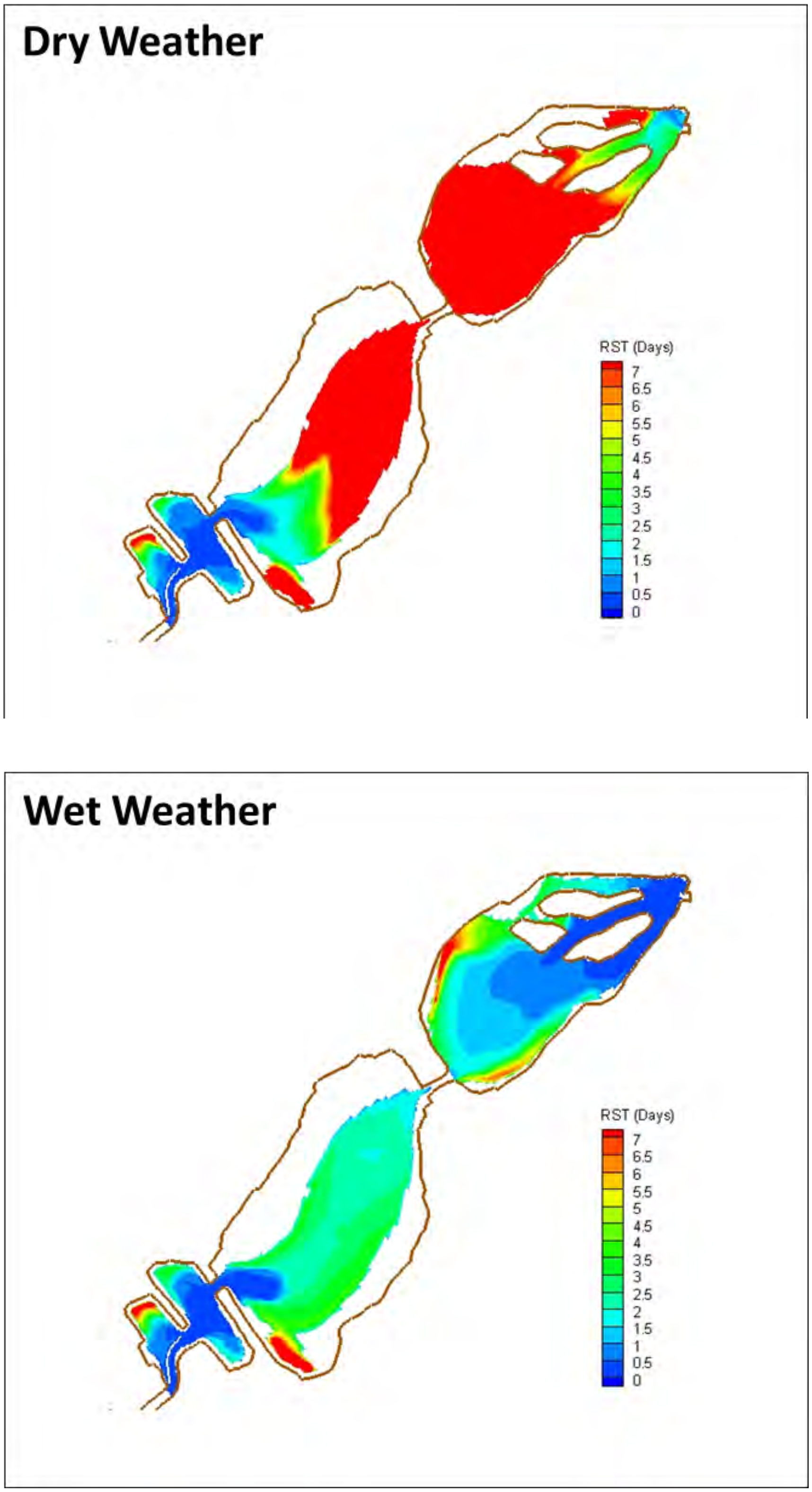


Figure 3. Residence Times for Hybrid Alternative A – Year 2015

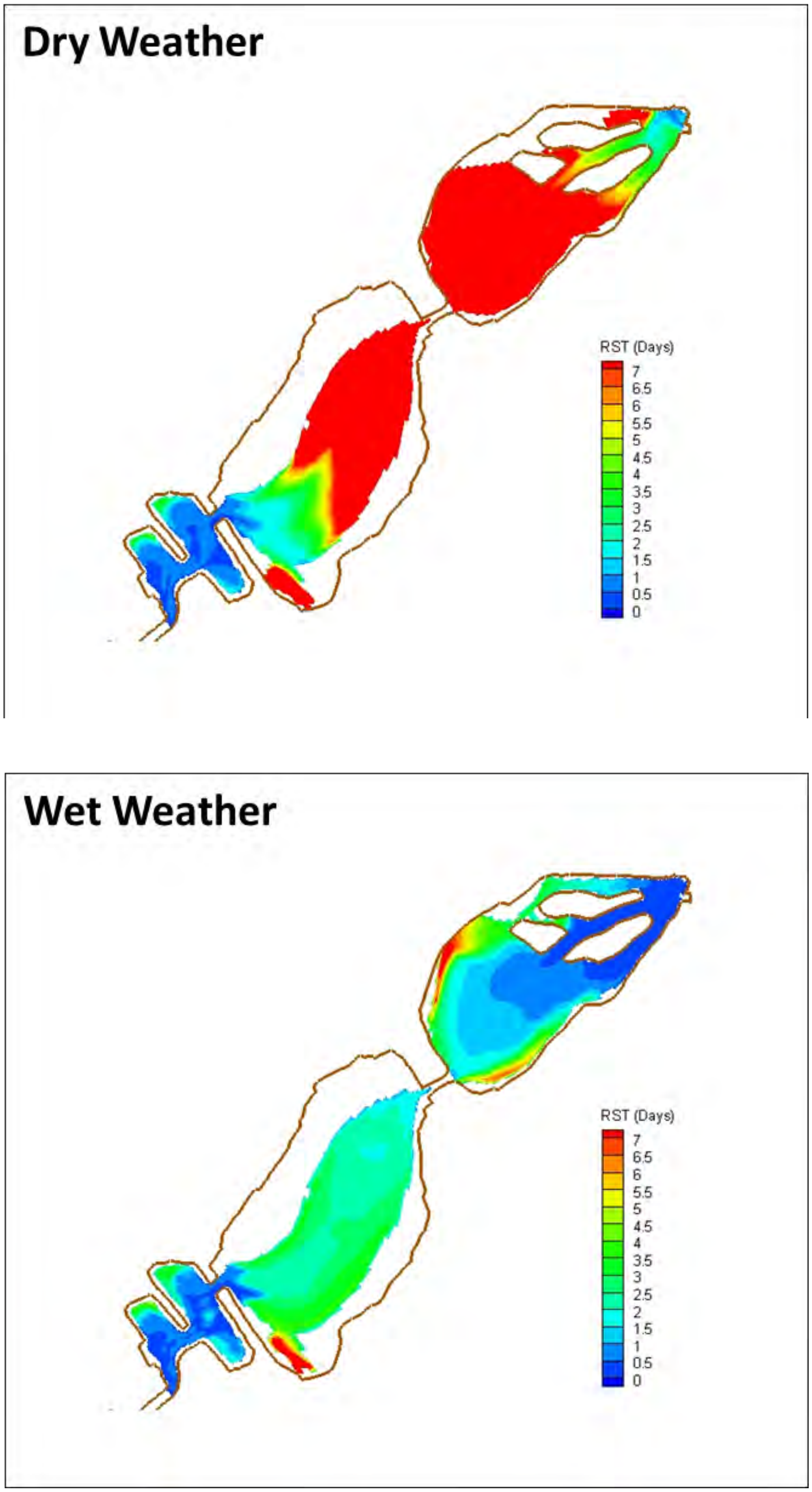


Figure 4. Residence Times for Hybrid Alternative B – Year 2015

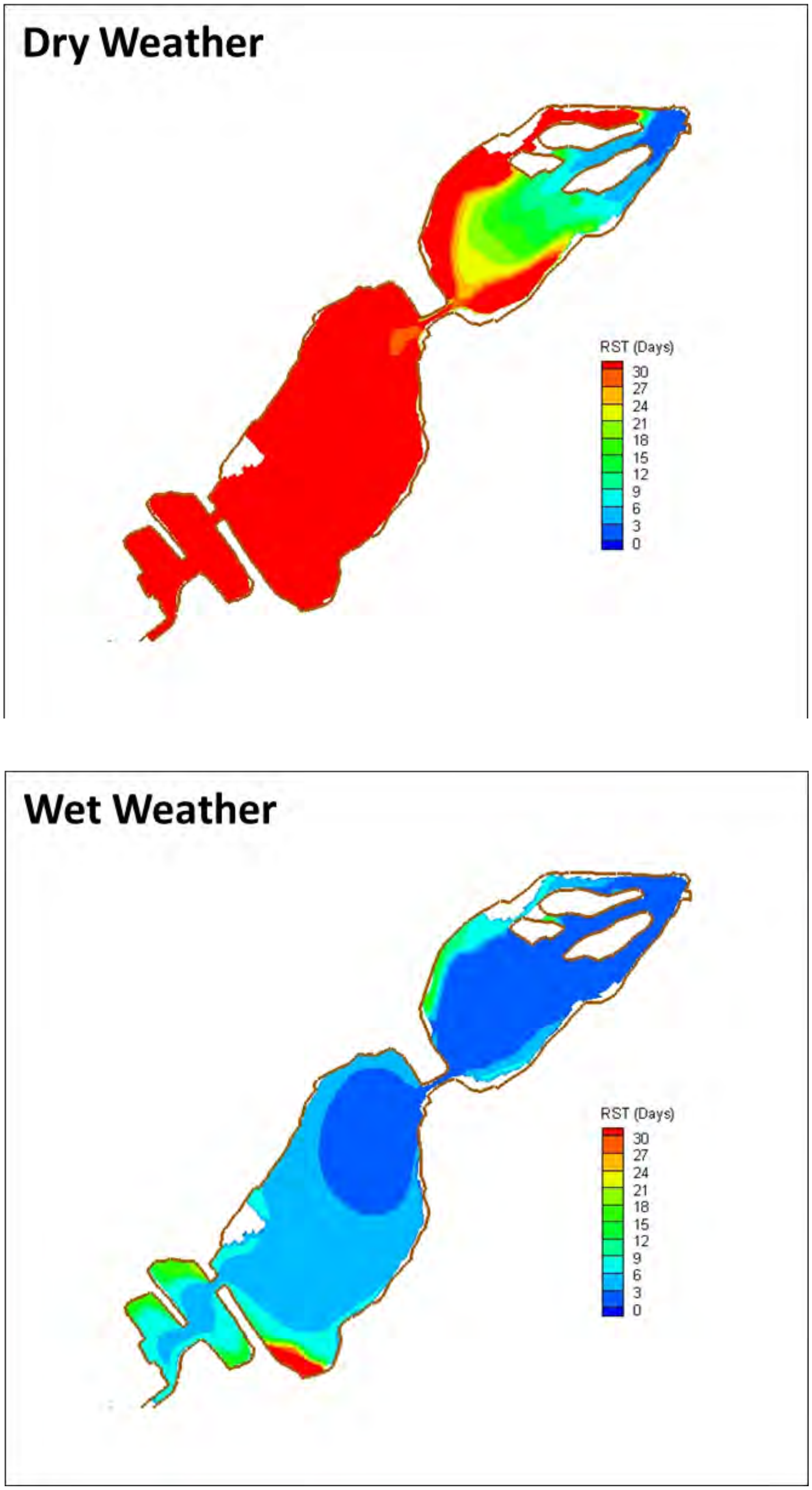


Figure 5. Residence Times for Freshwater Alternative – Year 2015

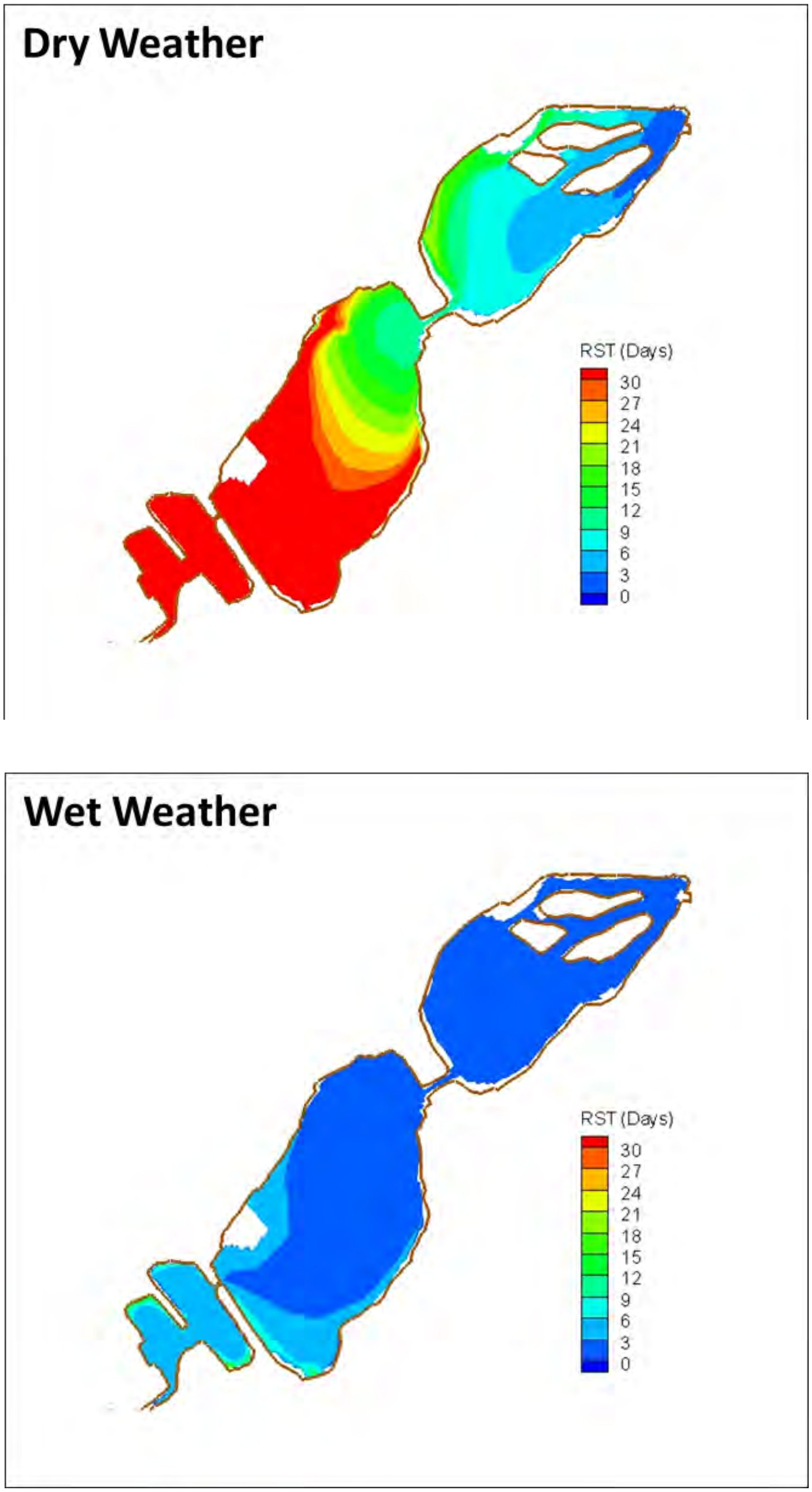


Figure 6. Residence Times for Existing Condition – Year 2015

Residence times for the enhancement alternatives are compared with those under existing Lagoon conditions in Table 2. In the table, the average residence times (rounded off to the nearest whole number) for the individual basins are shown. As expected, with the introduction of tidal exchange, residence times for the Saltwater Alternative in all the basins are significantly less than those under existing conditions. For example, under dry weather condition, the residence times for the Saltwater Alternative range from 1 day (Weir and RR Basins) to 3 days (CH and I-5 Basins), while under existing condition, residence times range from 82 days (Weir Basin) to 8 days (I-5 Basin). Similarly, for the Hybrid Alternatives, for the basins with tidal flushing (i.e., Weir, RR, and CH Basins), the residence times are significantly less than those under existing conditions. For the I-5 Basin, residence times for the Hybrid Alternatives are similar to those under Freshwater Alternative but substantially higher than those for the Saltwater Alternative. Residence times for the two Hybrid Alternatives (i.e., Hybrid A and Hybrid B) are similar except for the Weir Basin in which Hybrid A shows longer residence time compared with Hybrid B because under Hybrid A, a major portion of the basin will be isolated by a dike (i.e., less flushing).

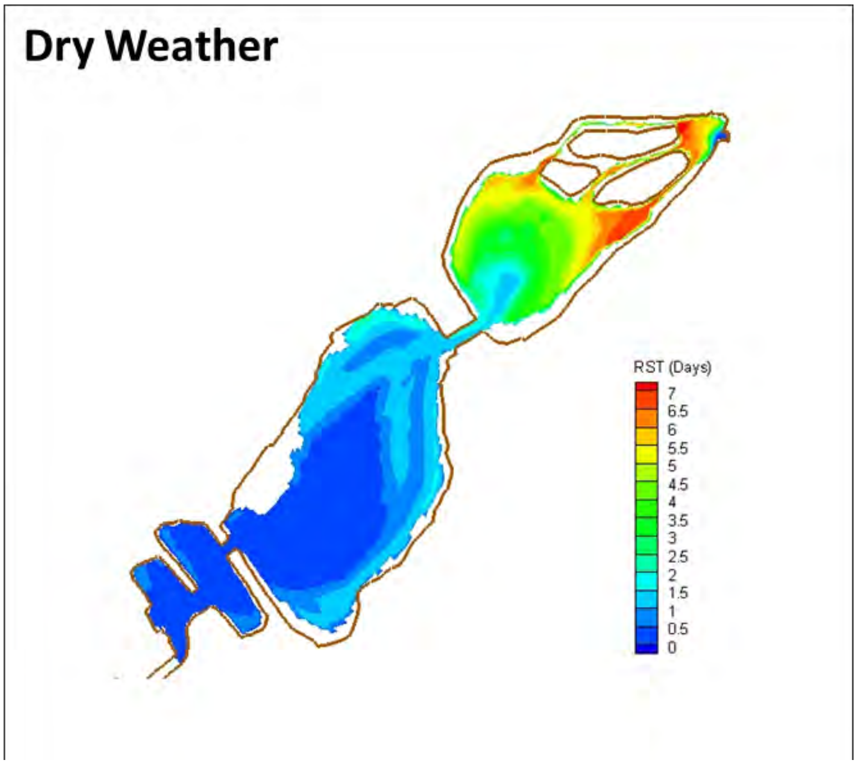
As expected, the residence times for the Freshwater Alternative (no tidal flushing) is substantially higher than those for the Saltwater and Hybrid (except I-5 Basin) Alternatives. In addition, with deeper basins, the residence times for the Freshwater Alternative is in general higher than those under existing conditions. Since flushing is only provided by freshwater inflow from Buena Vista Creek for existing Lagoon conditions and the Freshwater Alternative, there are substantial differences in residence times in the Lagoon between dry weather and wet weather conditions. A common method to qualitatively examine flushing (no hydrodynamic modeling) for a water basin is the replacement time which is simply defined as the time to replace the volume of water in the basin by the inflow. Based on the volume of the existing Lagoon, the average replacement times for the Lagoon under dry and wet weather conditions are approximately 54 and 3 days, respectively. Similarly, for the Freshwater Alternative, the average replacement times are approximately 111 and 7 days. These average replacement times compare well with the residence times shown in Table 2. The use of EFDC model for this study provides changes in residence times (i.e., relative flushing) from one basin to another that the simple replacement time calculation cannot provide.

Table 2. Average Residence Time for Year 2015

LAGOON CONDITION	BASINS	RESIDENCE TIME (DAYS)	
		DRY WEATHER	WET WEATHER
Saltwater Alternative	I-5	3	<1
	CH	3	1
	RR	1	1
	Weir	1	1
Hybrid Alternative A	I-5	23	2
	CH	18	3
	RR	1	1
	Weir	2	2
Hybrid Alternative B	I-5	22	2
	CH	17	3
	RR	1	1
	Weir	1	1
Freshwater Alternative	I-5	33	2
	CH	82	5
	RR	116	9
	Weir	118	9
Existing Conditions	I-5	8	1
	CH	36	3
	RR	75	4
	Weir	82	5

Effects of Sea Level Rise

The residence times analysis was conducted based on the sea level rise estimate for Year 2100 to evaluate the potential effect of sea level rise on tidal flushing. The results are shown in Figures 7 to 11 for Saltwater, Hybrid A, Hybrid B, Freshwater, and No Project Alternatives, respectively. The average residence times for each basin under these alternatives in Year 2100 are summarized in Table 3.


Dry Weather

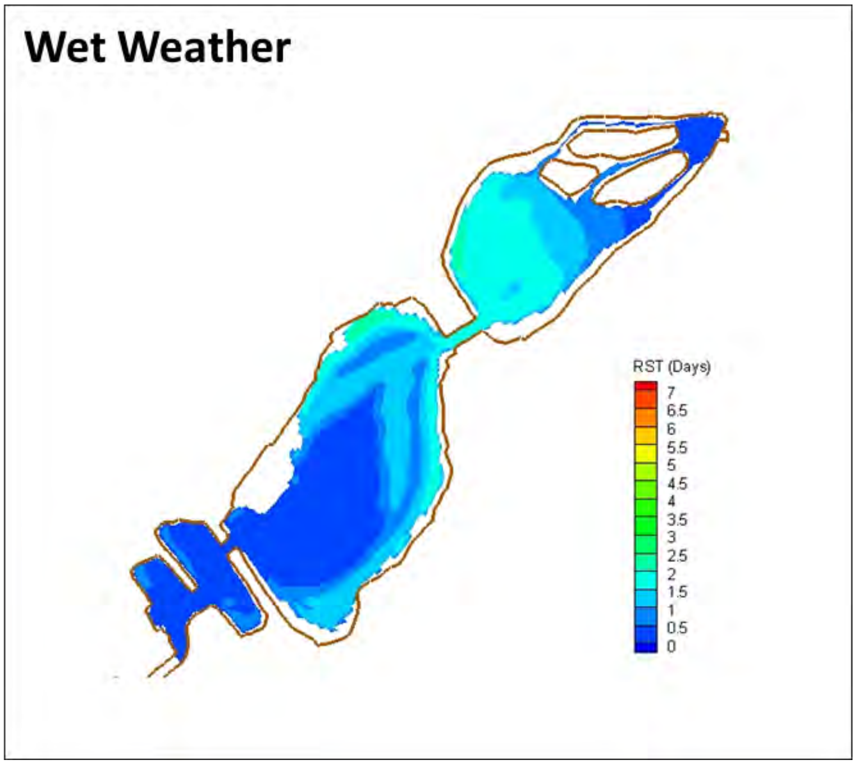

Wet Weather

Figure 7. Residence Times for Saltwater Alternative – Year 2100

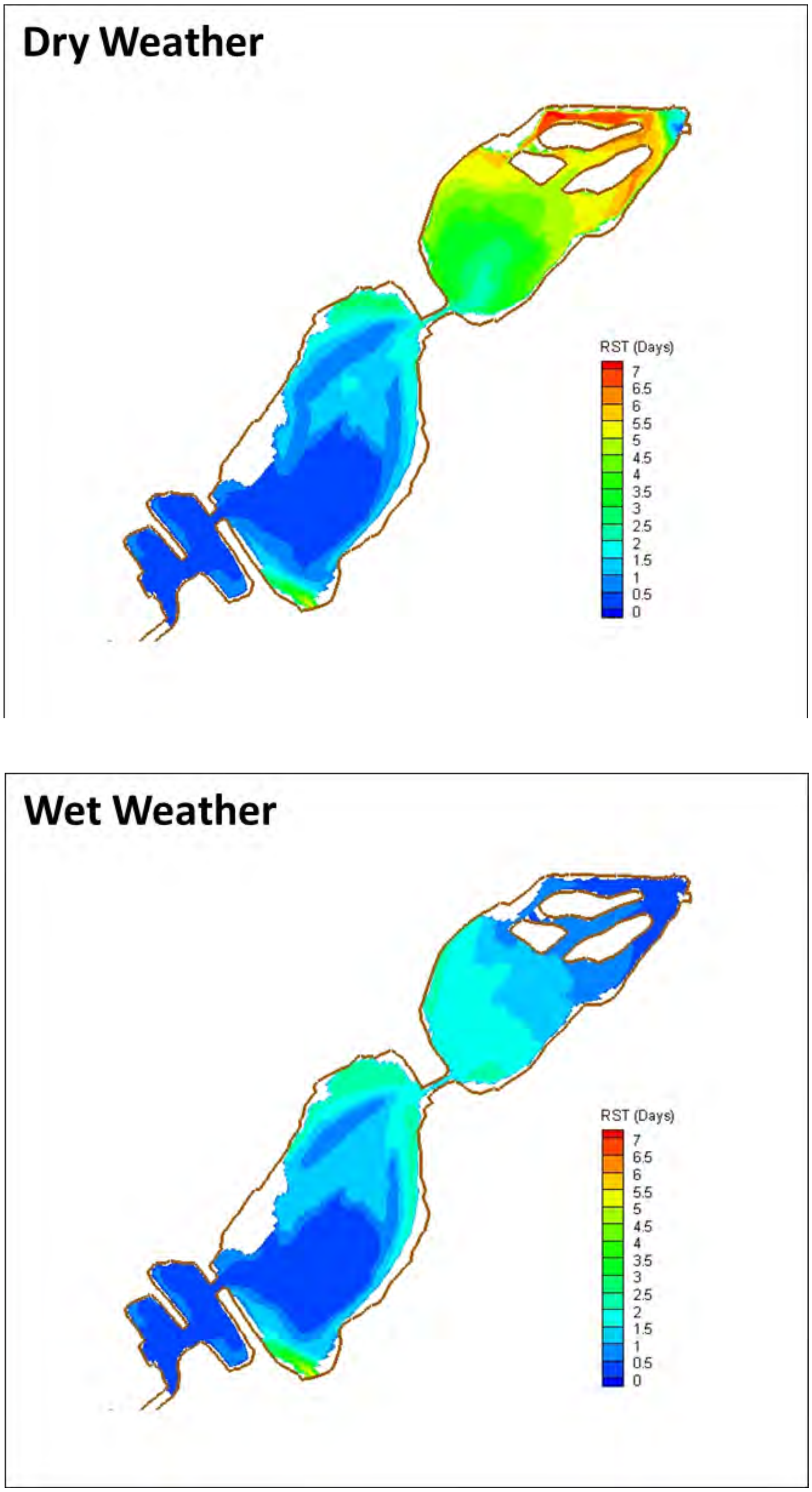


Figure 8. Residence Times for Hybrid Alternative A – Year 2100

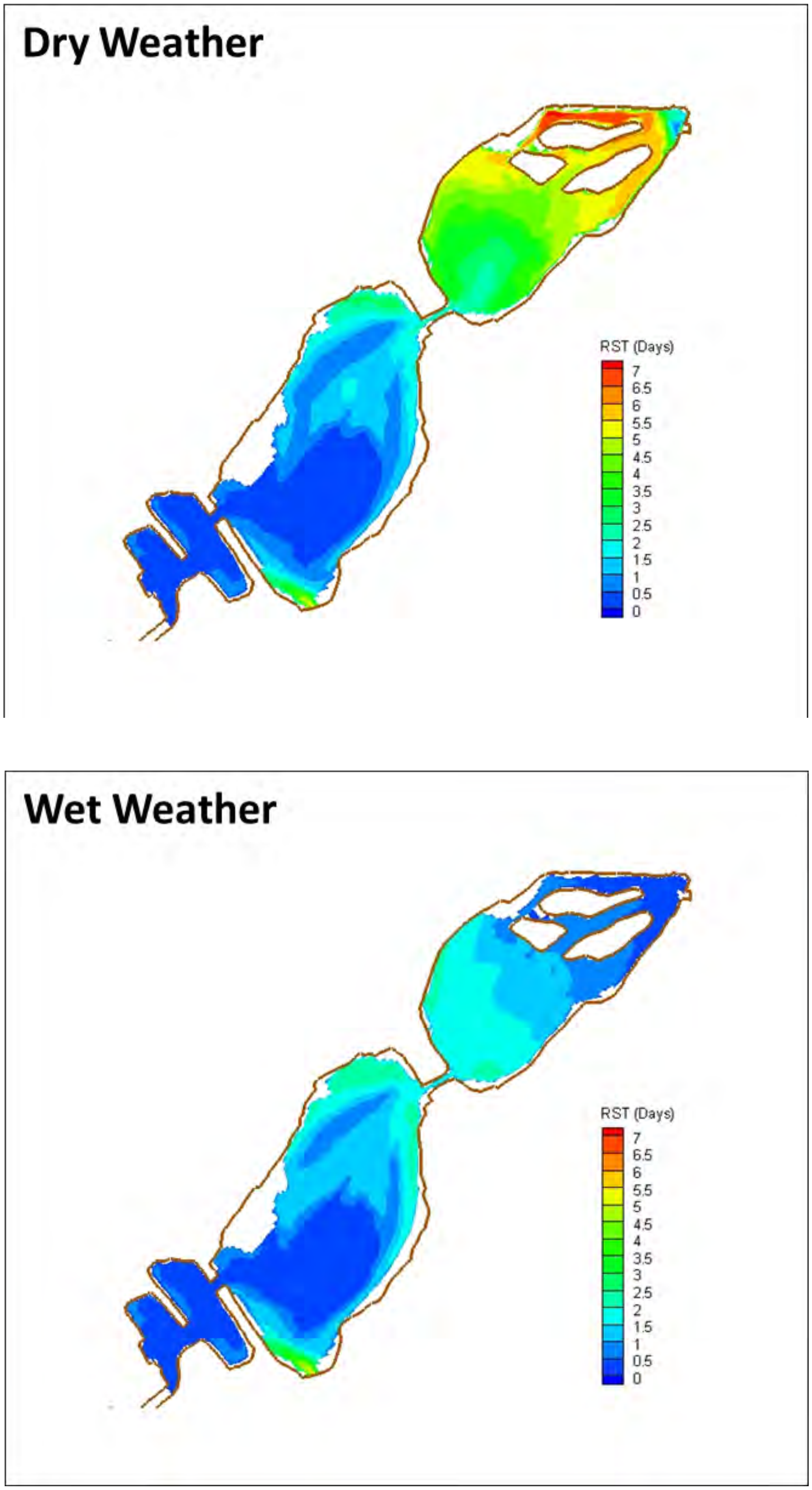


Figure 9. Residence Times for Hybrid Alternative B – Year 2100

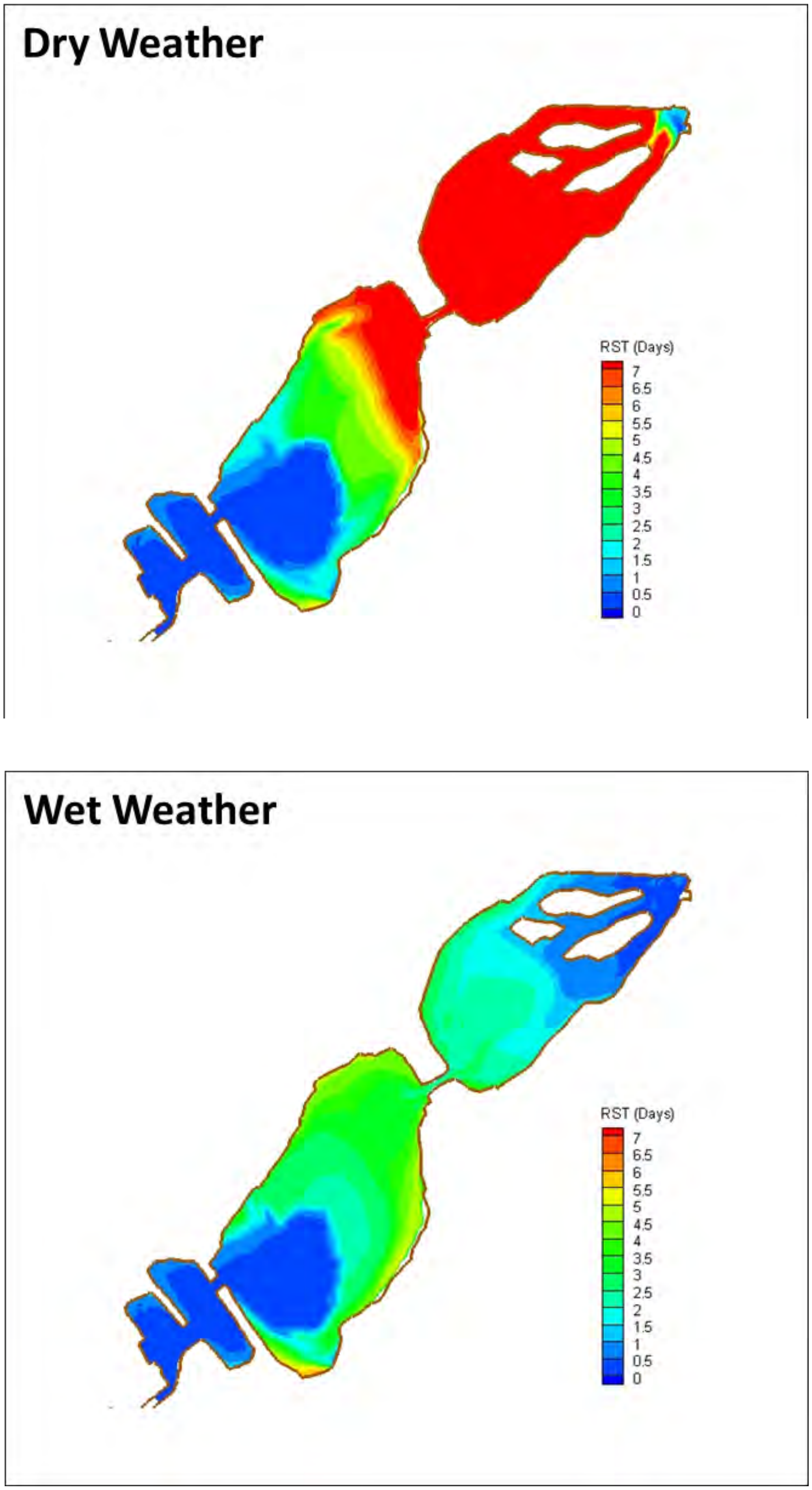
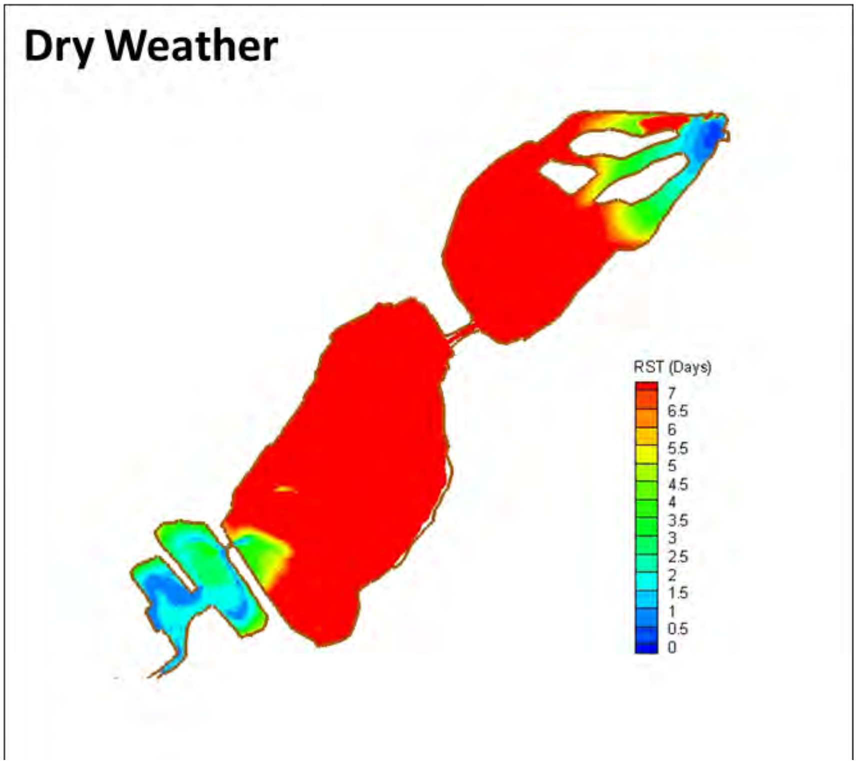


Figure 10. Residence Times for Freshwater Alternative – Year 2100



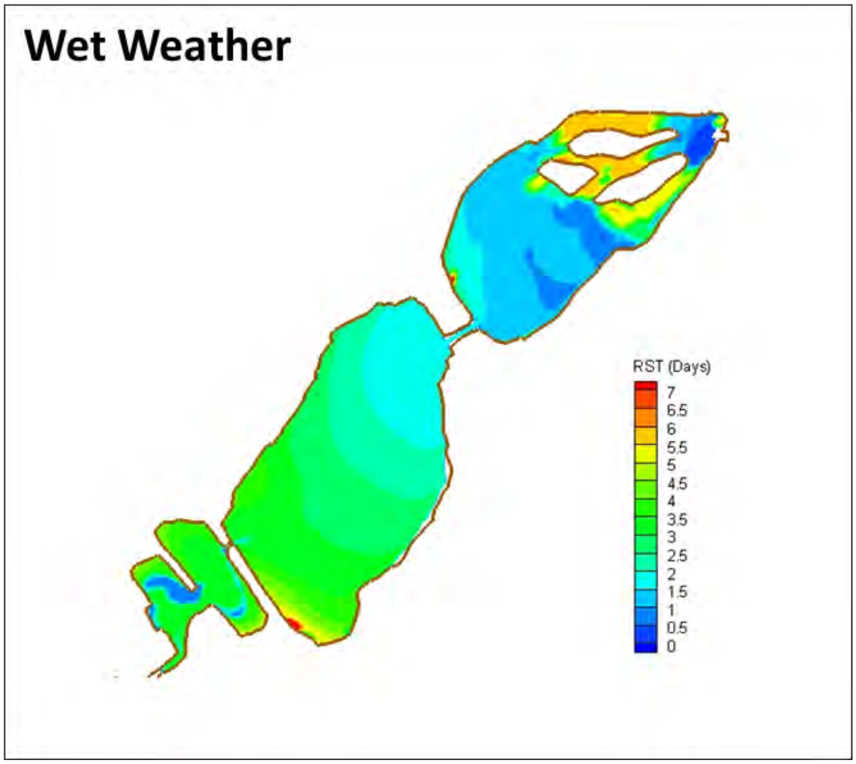


Figure 11. Residence Times for No Project Condition – Year 2100

Table 3. Average Residence Times for Year 2100

LAGOON CONDITION	BASINS	RESIDENCE TIME (DAYS)	
		DRY WEATHER	WET WEATHER
Saltwater Alternative	I-5	4	1
	CH	1	1
	RR	<1	<1
	Weir	<1	<1
Hybrid Alternative A	I-5	4	1
	CH	1	1
	RR	<1	<1
	Weir	<1	<1
Hybrid Alternative B	I-5	4	1
	CH	1	1
	RR	<1	<1
	Weir	<1	<1
Freshwater Alternative	I-5	11	2
	CH	4	2
	RR	<1	<1
	Weir	<1	<1
No Project Condition	I-5	13	2
	CH	33	3
	RR	3	4
	Weir	2	3

In Year 2100, with the estimated sea level rise, there would be some tidal flushing for the Freshwater and No Project Alternatives, leading to substantial reduction in residence times compared with those in Year 2015. For the Saltwater and Hybrid Alternatives, there would also be a reduction in residence times due to sea level rise, but those reductions are not as significant as that for the Freshwater and No Project Alternatives.

3. Salinity Analysis

Salinities within each basin were calculated using a mass-budget scheme that simulated mixing of salt water entering the Lagoon with the freshwater inflow over 24-hour tidal cycles. During each simulated tidal cycle, freshwater inflows from the upstream portion of the basin mix with saltwater inflows from the tidal inlet. TUFLOW simulations of tidal cycles were used to calculate the water elevations in the Lagoon in response of the ocean tide (see separate hydraulic report for TUFLOW model setup and results). At each tidal high and low (MHHW, MLLW, MHW, and MLW), a corresponding volume of water was calculated (tidal prism) as inflow or outflow through the tidal inlet, and these tidal prisms were used in the mass-budget scheme to calculate the equilibrium salinity in the Lagoon under the dry and wet weather conditions. A detailed description of this method is provided in the Appendix.

The results of the mass-budget analysis for the Saltwater Alternative are shown in Figure 12. In the figure, the top panel shows the results for dry weather and the bottom panel shows the wet weather results. Initially, the salt water concentration within each basin is equal to the ocean water concentration (34 ppt). Over time, as the basin water becomes diluted by freshwater inflow the saltwater concentration declines. After several tidal cycles, the range of salinity fluctuations within each basin reaches pseudo-equilibrium, and the average salt water concentration in each basin can then be calculated. Note that in the figure, salinity for the I-5 Basin is shown at two locations, namely I-5 Upstream and I-5 Downstream. The I-5 Upstream and I-5 Downstream locations are shown in Figure 13. The reason for dividing the I-5 Basin into upstream and downstream basins is so that salinity for the deep open water area just downstream of the Buena Vista Creek can be evaluated.

The results for the Hybrid A and Hybrid B are shown in Figures 14 and 15 respectively. Average salinities for each basin for the Saltwater, Hybrid A and Hybrid B Alternatives under dry and wet weather conditions are summarized in Table 4.

Table 4. Salinity Results for Year 2015

LAGOON CONDITION	BASIN	AVERAGE SALINITY (PPT)	
		DRY WEATHER	WET WEATHER
Saltwater Alternative	I-5 Upstream	20.6	3.6
	I-5 Downstream	33.0	23.6
	CH	33.8	30.4
	RR	33.8	31.5
	Weir	33.9	32.3
Hybrid Alternative A	I-5	N/A	N/A
	CH	33.5	27.4
	RR	33.6	29.1
	Weir	33.7	29.7
Hybrid Alternative B	I-5	N/A	N/A
	CH	33.5	27.4
	RR	33.6	29.1
	Weir	33.8	30.5

N/A: Not Applicable, Basin Not Subject To Tidal Flushing

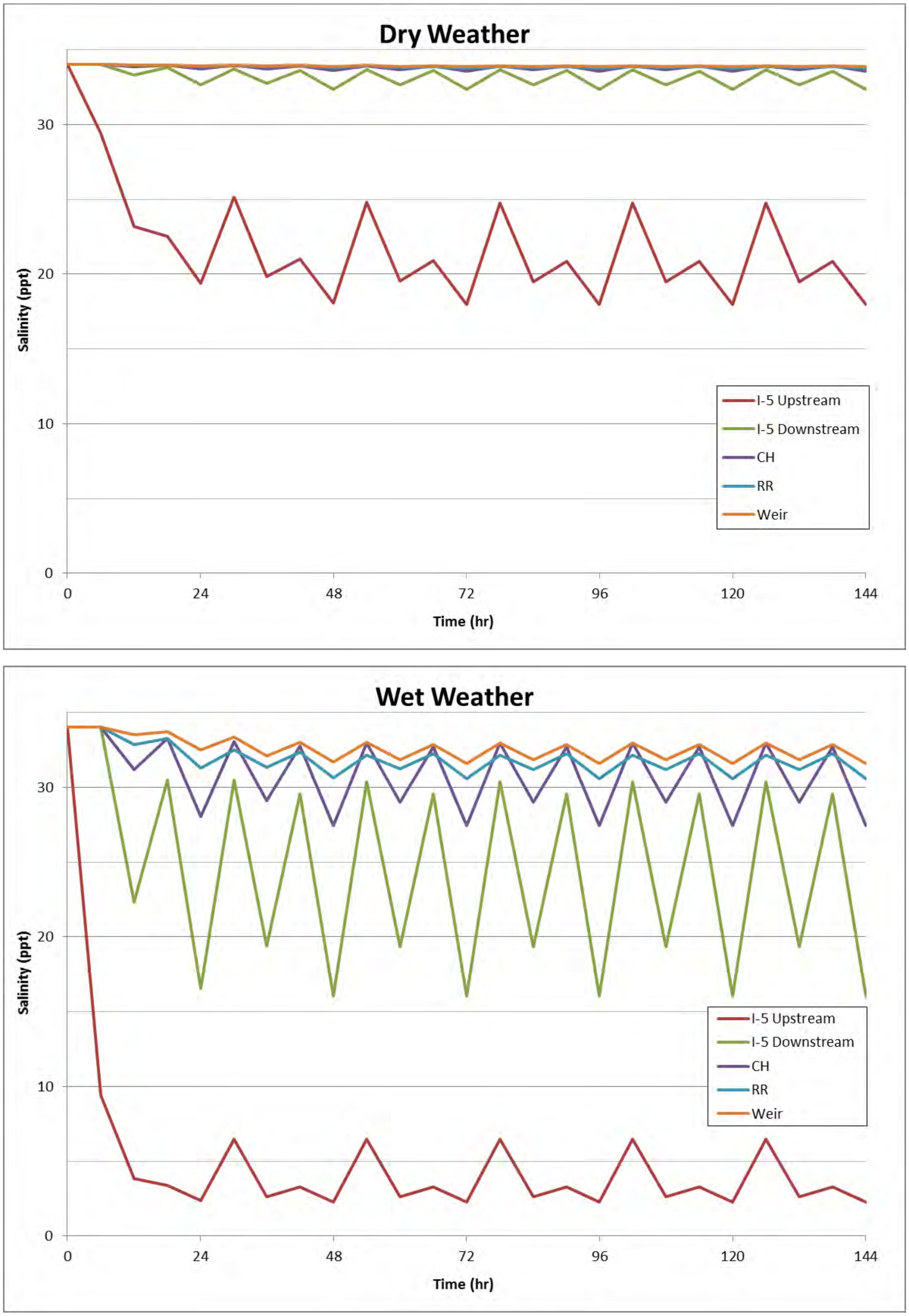
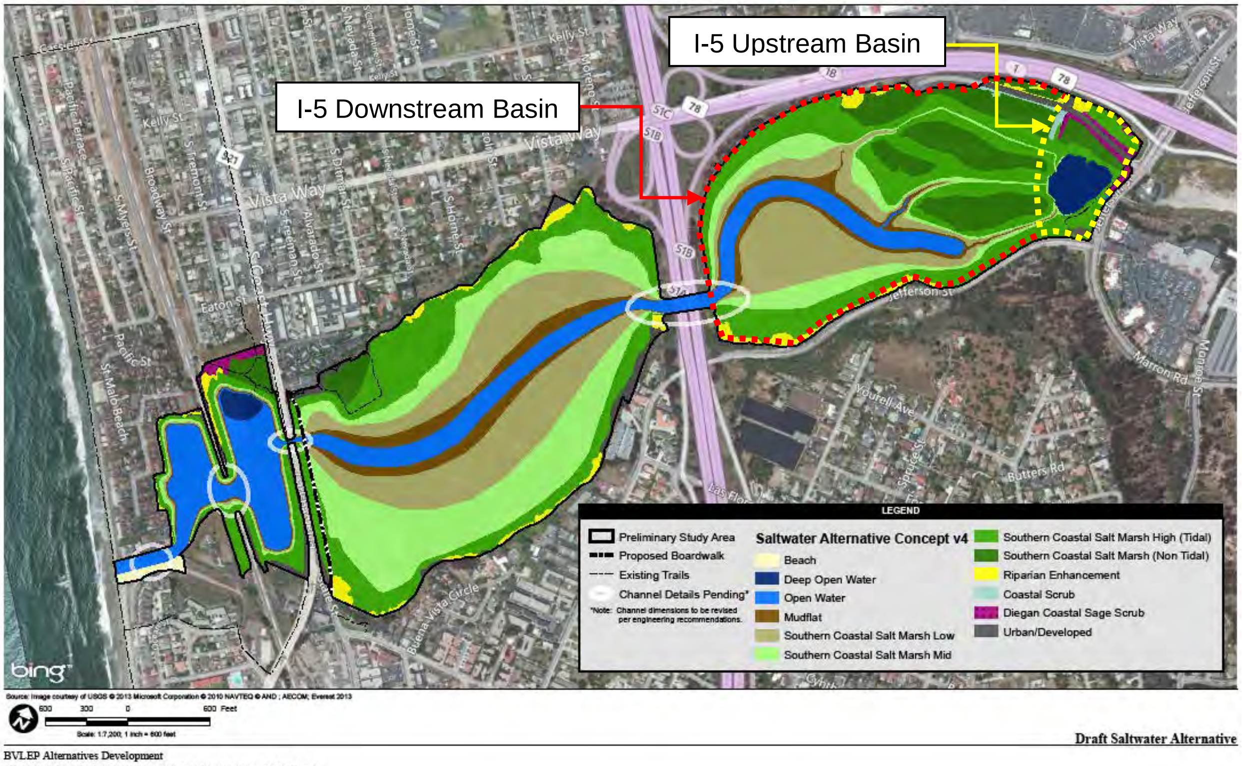


Figure 12. Salinity Time Series for Saltwater Alternative – Year 2015



Graph

Figure 13. Saltwater Alternative I-5 Basin Upstream and Downstream Locations for Salinity Analysis

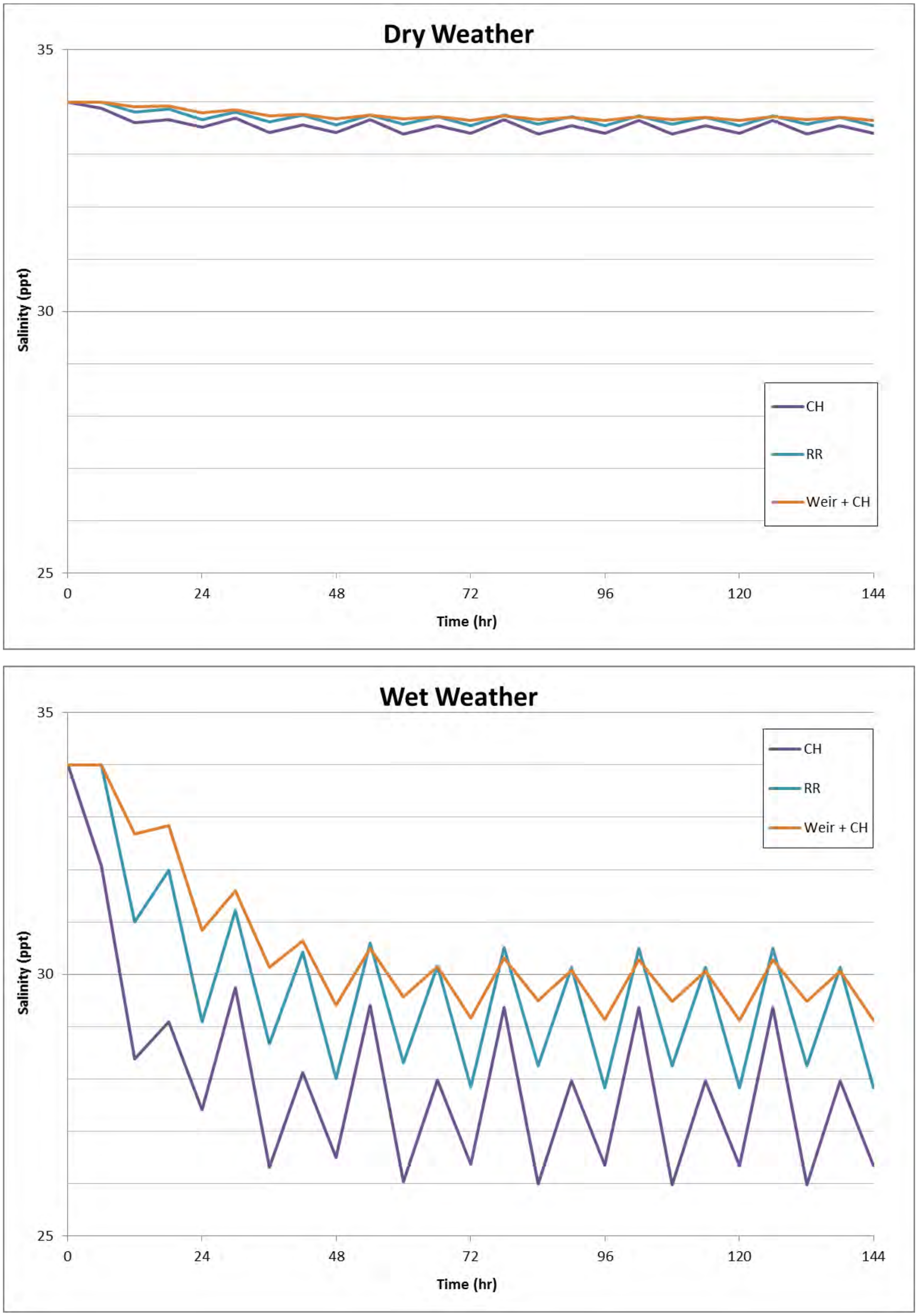


Figure 14. Salinity Time Series for Hybrid Alternative A – Year 2015

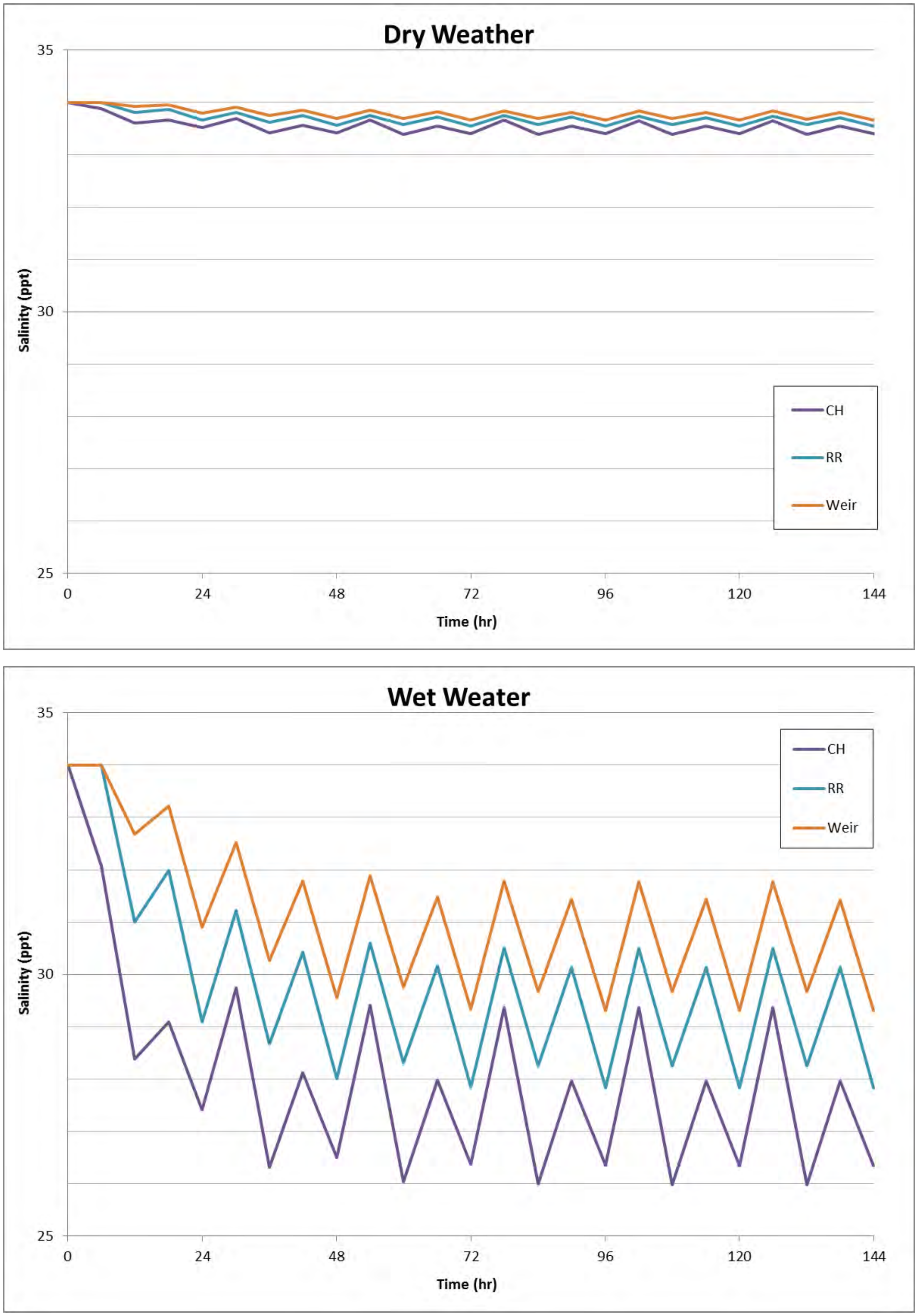


Figure 15. Salinity Time Series for Hybrid Alternative B – Year 2015

Results show that under dry weather conditions, all basins with tidal influence can be classified as saline (salinity greater than 30), except for the I-5 Upstream location, which is brackish. During wet weather conditions, the entire I-5 Basin for the Saltwater Alternative would become brackish, while the Coast Highway Basin, Railroad Basin, and Weir Basins would remain saline. For the Hybrid Alternatives, all the basins would become brackish under wet weather conditions, except for the Weir Basin for Hybrid B, which would remain saline.

Effect of Sea Level Rise

The salinity analysis was conducted based on the sea level rise estimate for Year 2100 to evaluate the potential effect of sea level rise on salinity in the Lagoon. The results are shown in Figures 16 to 20, and the average salinities in each basin are summarized in Table 5.

Table 5. Salinity Results for Year 2100

LAGOON CONDITION	BASIN	AVERAGE SALINITY (PPT)	
		DRY WEATHER	WET WEATHER
Saltwater Alternative	I-5 Upstream	31.2	14.4
	I-5 Downstream	33.8	31.0
	CH	34.0	33.2
	RR	34.0	33.4
	Weir	34.0	33.6
Hybrid Alternative A	I-5	33.2	24.6
	CH	33.9	32.1
	RR	33.9	32.7
	Weir	33.9	33.1
Hybrid Alternative B	I-5	33.2	24.6
	CH	33.9	32.1
	RR	33.9	32.7
	Weir	33.9	33.1
Freshwater Alternative	I-5	33.5	27.2
	CH	33.8	31.2
	RR	33.9	31.7
	Weir	33.9	32.2
No Project Condition	I-5	29.7	10.5
	CH	32.1	17.3
	RR	32.7	21.1
	Weir	33.0	23.7

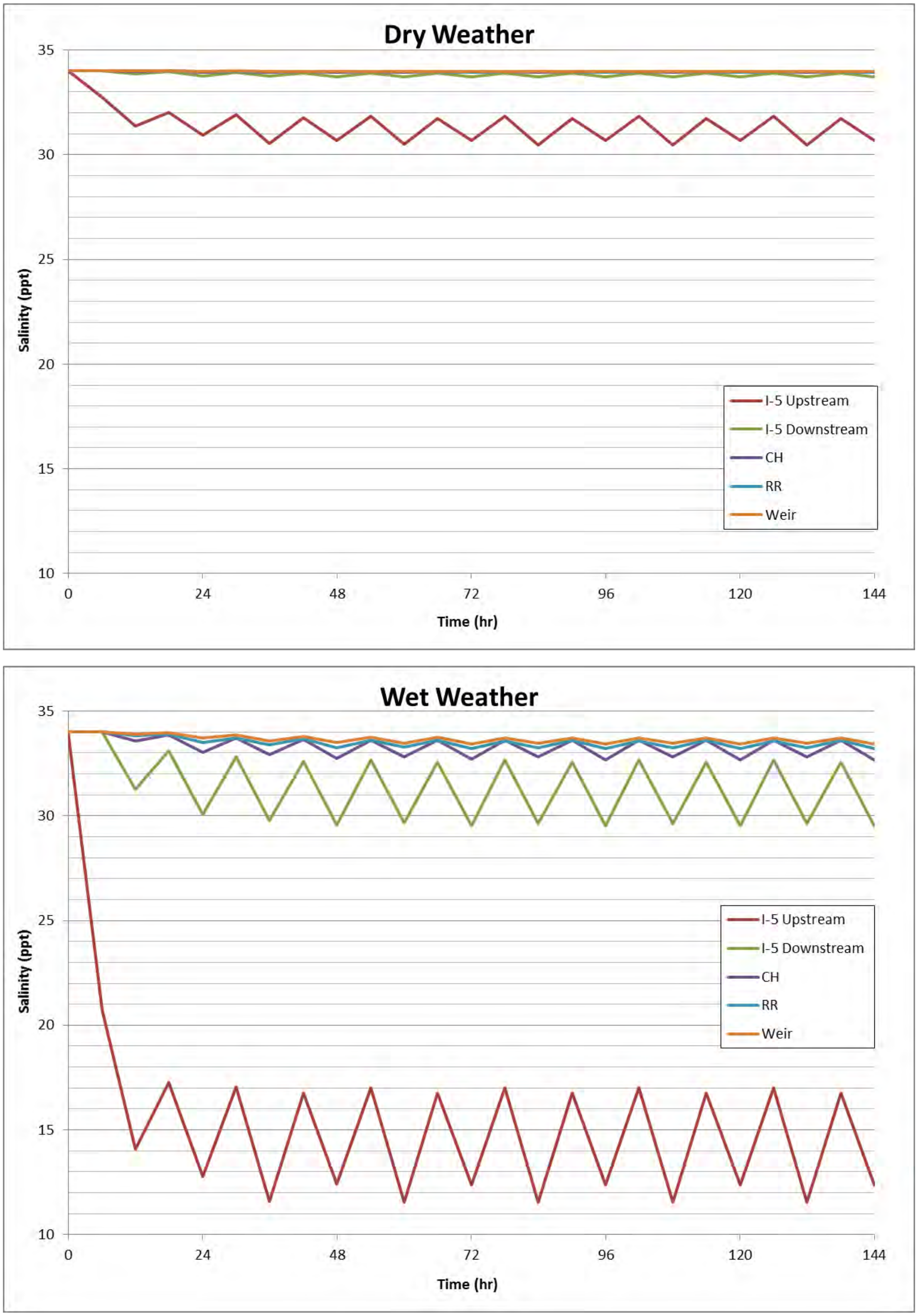


Figure 16. Salinity Time Series for Salt Water Alternative – Year 2100

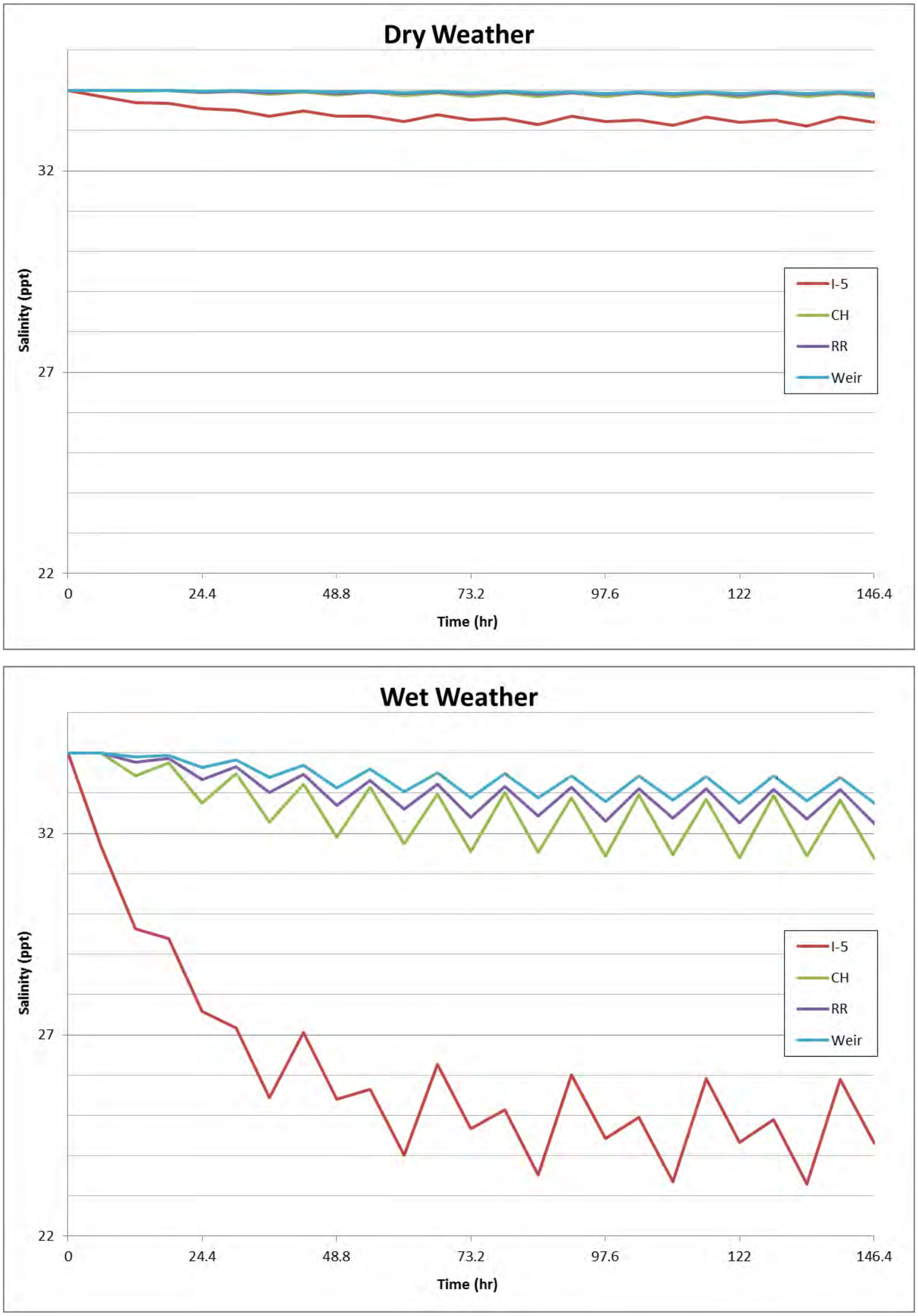


Figure 17. Salinity Time Series for Hybrid Alternative A – Year 2100

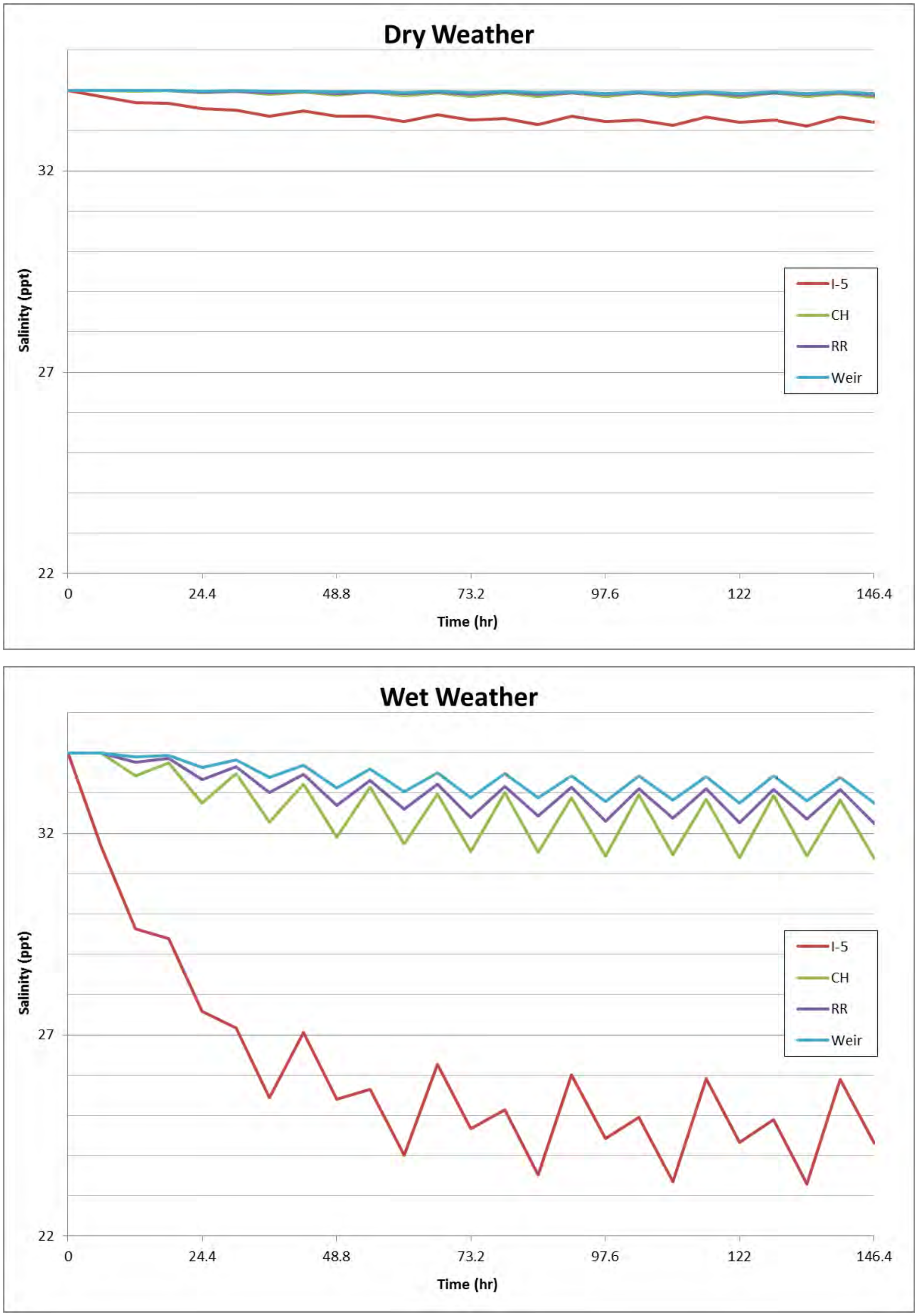


Figure 18. Salinity Time Series for Hybrid Alternative B – Year 2100

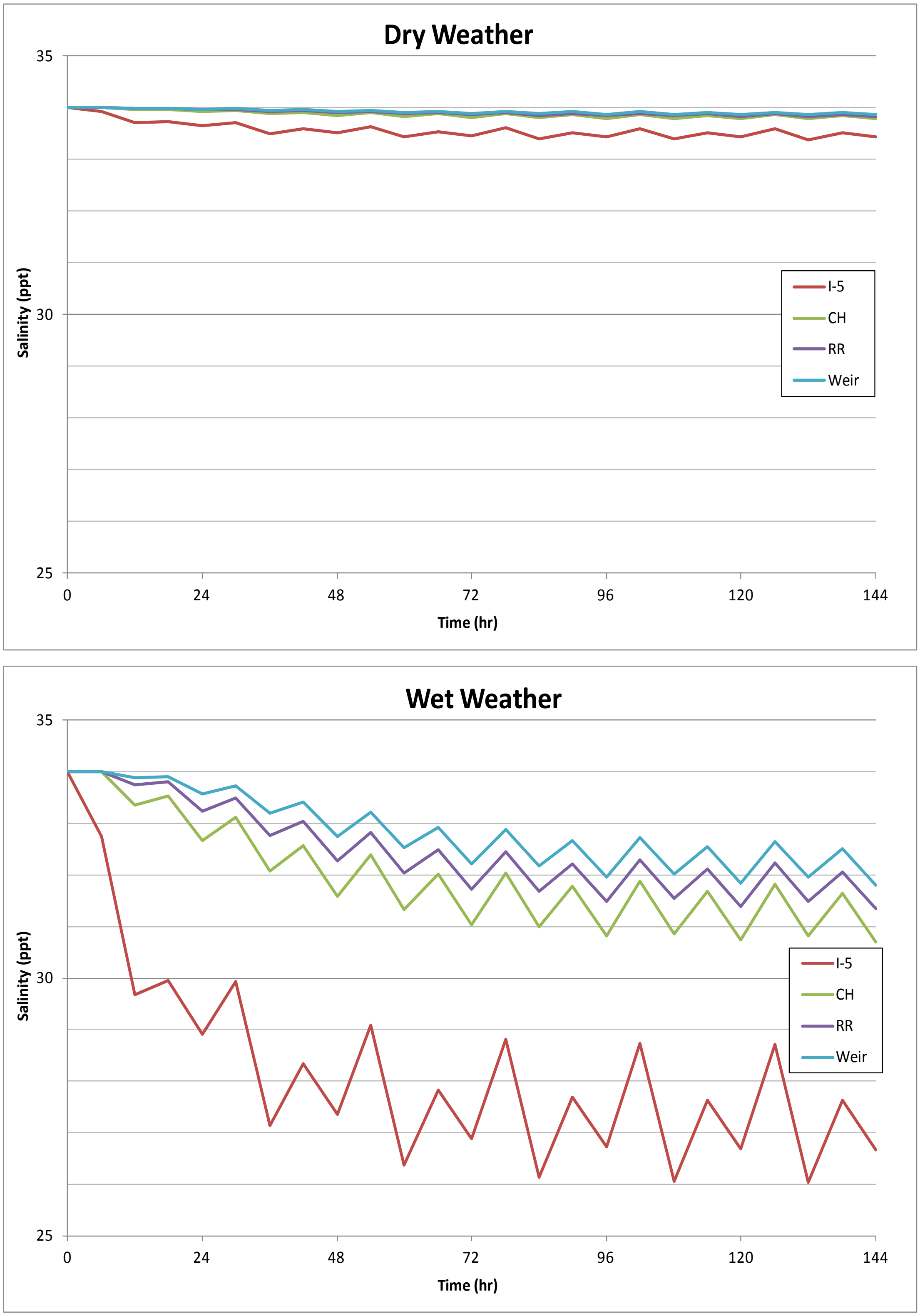


Figure 19. Salinity Time Series for Freshwater Alternative – Year 2100

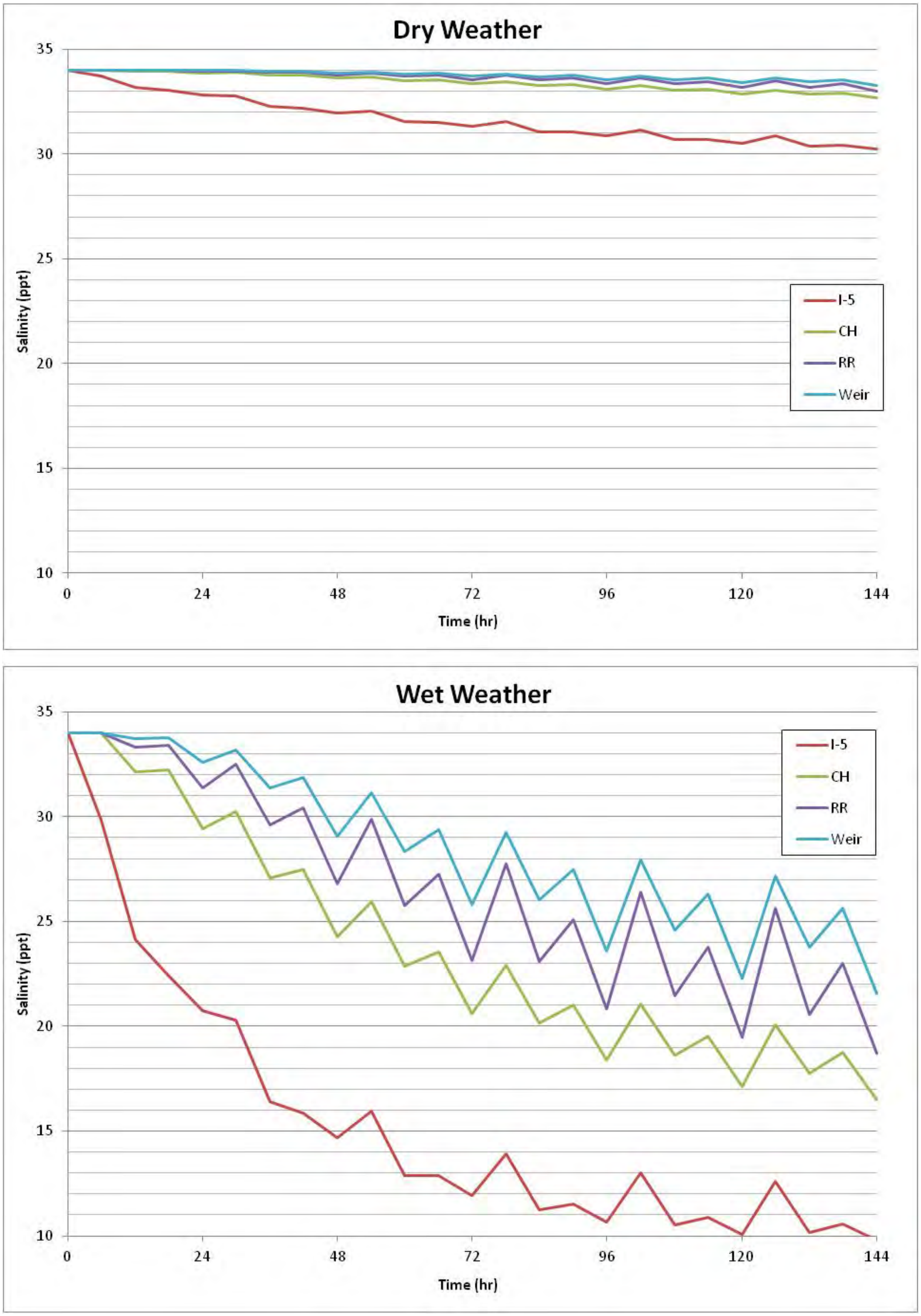


Figure 20. Salinity Time Series for No Project Alternative – Year 2100

With the projected sea level rise in Year 2100, ocean water levels will exceed the elevation of both the current outlet weir and the proposed weir at I-5 for the Hybrid Alternatives. Thus, all basins will become exposed to tidal influence, including the No Project Alternative, Freshwater Alternative, and the fresh water basin (I-5 Basin) for the Hybrid Alternatives. The results show that during dry weather in 2100, all basins would be saline (salinity greater than 30 ppt) except for the I-5 Basin under the No Project Alternative. This suggests that the Hybrid Alternative and Freshwater Alternative would likely undergo habitat transition between 2015 and 2100. Under wet conditions in 2100, except for the I-5 Basin, the Coast Highway Basin, Railroad Basin, and Weir Basin for the Saltwater and Hybrid Alternatives would likely remain saline. For the No Project Alternative, under wet weather conditions in 2100, all the basins would likely be brackish.

4. Summary of Findings

Since the enhancement alternatives cover a range of hydrologic regimes from freshwater to saltwater, the residence times for the Lagoon are used as a surrogate to compare the potential differences in water quality among the enhancement alternatives as well as potential changes in water quality from existing conditions. Since the source of pollutants for the Lagoon are the same (mainly from stormwater runoff) irrespective of the enhancement alternatives, residence times are a good surrogate for comparing the potential changes in water quality among the different enhancement alternatives. Long residence times are indicative of stagnant water with poor flushing while short residence times are indicative of good water circulation and flushing. For a given level of pollutant (e.g., nutrient and bacteria) loading, better flushing usually indicates better water quality in the water body.

Major findings for the residence time analysis include:

- With the introduction of tidal exchange, residence times for the Salt Water Alternative in all the basins are significantly less than those under existing conditions. Hence, for the same pollutant loading, water quality in the Lagoon under the Salt Water Alternative is expected to be better compared with existing conditions.
- For the Hybrid Alternatives, for the basins with tidal flushing (i.e., Weir Basin, Railroad Basin, and Coast Highway Basin), the residence times are significantly less than those under existing conditions. However, for the I-5 Basin, the residence times under the Hybrid Alternatives will be higher than existing conditions. Hence, for the same pollutant loading, water quality in the Weir Basin, Railroad Basin, and Coast Highway Basin is expected to be better compared with existing conditions but not in the I-5 Basin.
- Residence times for the two Hybrid Alternatives (i.e., Hybrid A and Hybrid B) are similar except for the Weir Basin in which Hybrid A shows longer residence times compared with Hybrid B because under Hybrid A, a major portion of the basin will be isolated by a dike (i.e., less flushing).

- The residence times for the Freshwater Alternative (no tidal flushing) is substantially higher than those for the Saltwater and Hybrid (except I-5 Basin) Alternatives. In addition, with deeper basins, the residence times for the Freshwater Alternative are generally higher than those under existing conditions.
- In Year 2100, with mean sea level rise, there would be some tidal flushing for the Fresh Water Alternative and No Project Alternative, leading to substantial reductions in residence times compared with those in Year 2015. For the Saltwater Alternative and Hybrid Alternative there would also be a reduction in residence times due to mean sea level rise, but those reductions are not as significant as that for the Fresh Water Alternative and No Project Alternative.

In addition to the residence time analysis, a salinity analysis was conducted to evaluate the salinity levels in the Lagoon under the various enhancement alternatives. Major findings for the salinity analysis include:

- Under Existing Conditions, the water in the Lagoon is primarily fresh water as evidenced by salinity measurements and vegetation type. Even though the weir keeps ocean water from entering the Lagoon via tidal exchange, some ocean water can enter the Lagoon via two mechanisms. Salt water can enter the Lagoon through the beach via groundwater flow. In addition, salt water can enter the Lagoon via wave overtopping of the weir that can occur during simultaneous high tide and large wave conditions.
- Under the Salt Water Alternative, during dry weather conditions all the basins would be classified as saline (salinity greater than 30 ppt), except for the I-5 Upstream location, which would be classified as brackish.
- Under the Salt Water Alternative, during wet weather conditions the Weir Basin, Railroad Basin, and Coast Highway Basin would be classified as saline (salinity greater than 30 ppt), while the entire I-5 Basin would be classified as brackish.
- Under the Hybrid Alternative Options A and B (Hybrid A and Hybrid B), during dry weather conditions the Weir Basin, Railroad Basin, and Coast Highway Basin would be classified as saline (salinity greater than 30 ppt), while the I-5 Basin would be classified as fresh water except for the I-5 Upstream location, which would be classified as brackish.
- Under the Hybrid Alternative Option A (Hybrid A), during wet weather conditions all four basins would be classified as brackish. Under the Hybrid Alternative Option B (Hybrid B), during wet weather conditions the Weir Basin would be classified as saline (salinity greater than 30 ppt), while the Railroad Basin, Coast Highway Basin, and I-5 Basin would be classified as brackish.
- In Year 2100, with mean sea level rise, ocean water levels would exceed the elevation of both the current outlet weir and the proposed weir at I-5 for the Hybrid Alternatives. Thus, all basins would become exposed to tidal influence, including the No Project Alternative, Fresh Water Alternative, and the fresh water basin (I-5 Basin) for the Hybrid

Alternatives. During dry weather, all basins would be saline (salinity greater than 30 ppt) except for the I-5 Basin under the No Project Alternative. This suggests that the Hybrid Alternative and Fresh Water Alternative would likely undergo habitat transition between Year 2015 and Year 2100.

- Under wet conditions in Year 2100, except for the I-5 Basin, the Coast Highway Basin, Railroad Basin, and Weir Basin for the Salt Water and Hybrid Alternatives would likely remain saline.
- For the No Project Alternative, under wet weather conditions in Year 2100, all the basins would likely be brackish.

5. References

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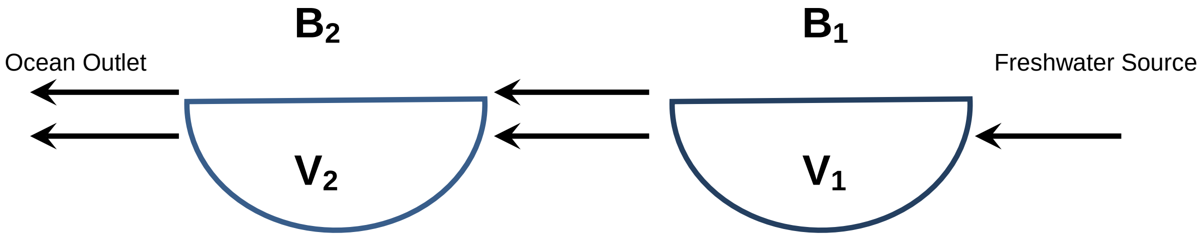
Appendix: Salinity Analysis Mass Budget Scheme

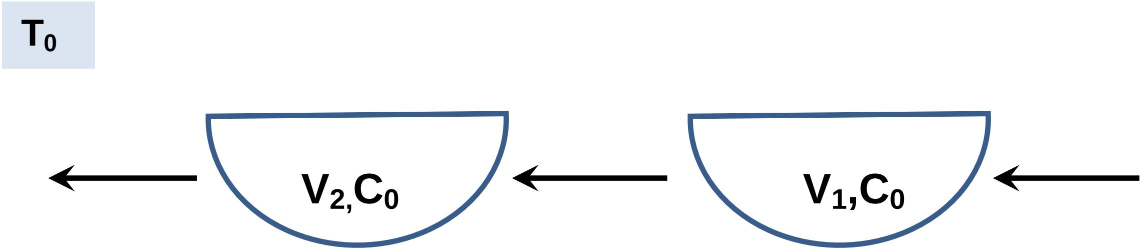
The purpose of this scheme is to calculate the average saltwater concentration of basins within a lagoon system that are influenced by tidal saltwater and freshwater flows. The basins in the lagoon system are modeled as hydraulically connected bins containing an initial volume of water (V_n). The farthest inland basin (B_1) is directly fed by a constant freshwater source (Q_f) and mixed water from B_1 flows into downstream basins (B_n) towards the ocean outlet. This method can be applied to n number of basins. For simplicity, the following figure illustrates the method with two basins (i.e., n = 2).



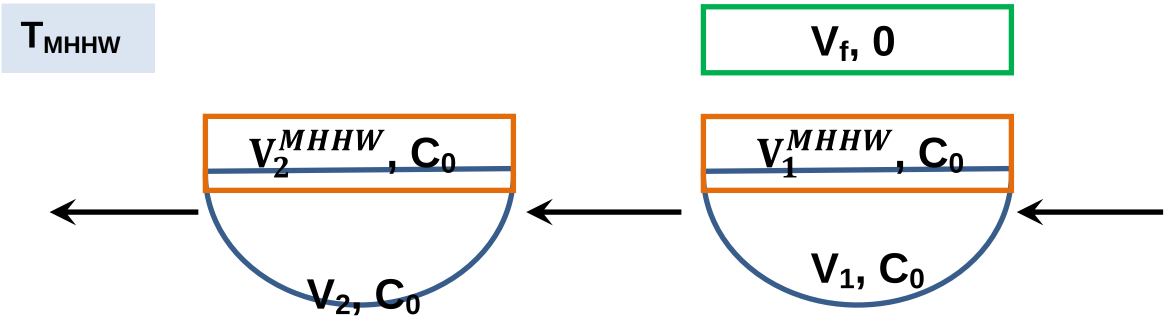
Tidal influence is modeled as a 24-hour cycle with MHHW, MHW, MLLW, and MLW represented through their respective tidal prism volume added to or removed from the system. For example, in one 24-hour tidal cycle, B_2 will receive volume at MHHW (V_2^{MHHW}) and MHW (V_2^{MHW}), while losing volume at MLLW (V_2^{MLLW}) and MLW (V_2^{MLW}). After the completion of the 24-hour tidal cycle, the volume of B_2 and B_1 will return to V_2 and V_1, respectively. Thus, mass is conserved as follows:

$$V_n^{MHHW} + V_n^{MHW} - (V_n^{MLLW} + V_n^{MLW}) = 0.$$

At the peak time of each tide level (T_{MHHW}, T_{MIW}, T_{MHW}, T_{MLLW}) the concentration of saltwater within each basin (C_n^t) is calculated until the average concentration converges. At the beginning of the first 24-hour tidal cycle (T_0), the concentration of saltwater within each basin is set equal to the concentration of ocean water (C_0):



At T_{MHHW}, the volume within each basin is updated based on the MHHW tidal inflows and constant freshwater inflows (the volume of freshwater inflows (V_f) is calculated as Q_f x T_{MHHW} hours):

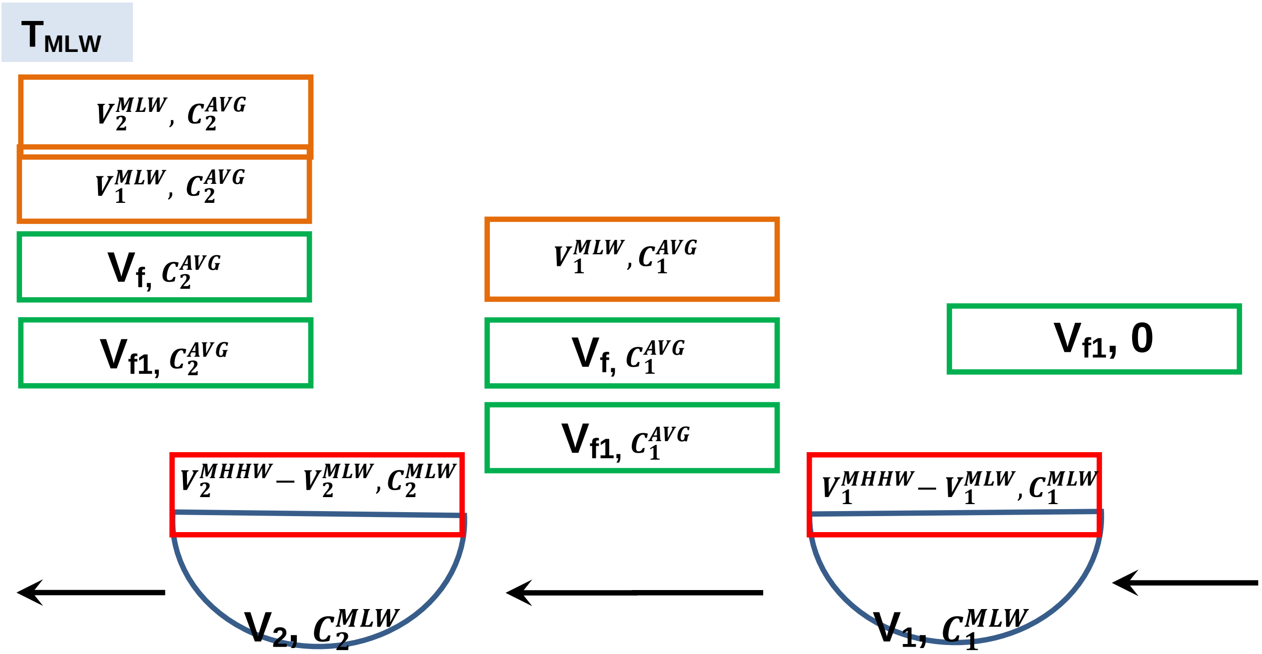


By assuming the saltwater concentration of freshwater inflows equals 0 and complete mixing occurs between T_0 and T_{MHHW}, concentrations in B_1 and B_2 at T_{MHHW} (C_1^{MHHW}, C_2^{MHHW}) are calculated as:

$$C_1^{MHHW} = \frac{(V_1)C_0 + (V_1^{MHHW})C_0 + (V_f)0}{V_1 + V_1^{MHHW} + V_f}$$

$$C_2^{MHHW} = \frac{(V_2)C_0 + (V_2^{MHHW})C_0}{V_2 + V_2^{MHHW}}$$

At T_{MLW}, the concentrations of each basin are updated again. It is assumed that between T_{MHHW} and T_{MLW}, completely mixed water from B_1 flows into B_2, and both basins lose the appropriate volume of water (V_n^{MLW}) to reach the MLW tide level. B_1 receives a new volume of freshwater (V_{f1}: calculated as Q_f x (T_{MLW} - T_{MHHW})), and V_f + V_{f2} flow from B_1 to the ocean outlet. Boxes over arrows represent volume flow between T_{MHHW} and T_{MLW}, while boxes on top of the initial volumes show updated volumes and concentrations at T_{MLW}:



First, C_1^{MLW} is calculated:

$$C_1^{MLW} = \frac{(V_1 + V_f + V_1^{MHHW})C_1^{MHHW} + (V_{f1})0}{V_1 + V_f + V_1^{MHHW} + V_{f1}}$$

Once C_1^{MLW} is known, the inflow concentration to B_2 (C_1^{AVG}) is calculated as the average concentration in B_1 between T_{MHHW} and T_{MLW}:

$$C_1^{AVG} = \left(\frac{1}{2}\right)(C_1^{MLW} + C_1^{MHHW})$$

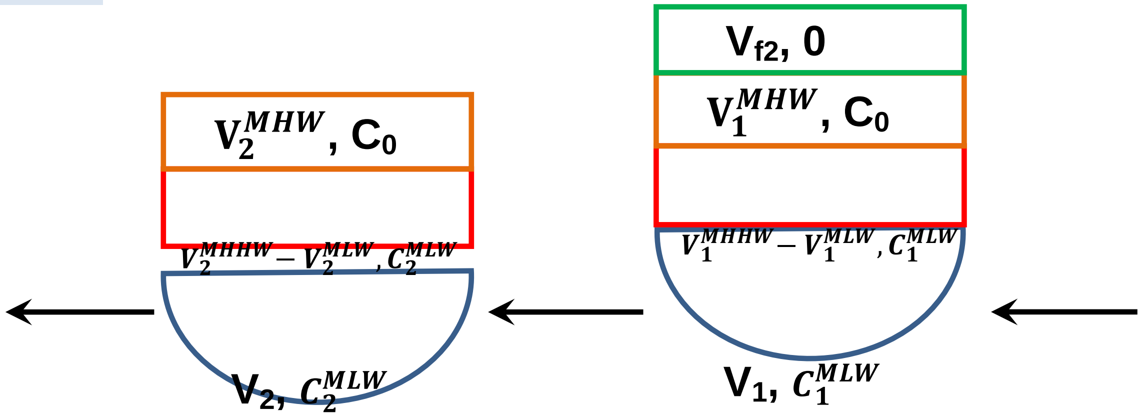
C_2^{MLW} can then be calculated:

$$C_2^{MLW} = \frac{\left(V_{f1} + V_f + V_1^{MLW}\right)C_1^{AVG} + \left(V_2^{MHHW} + V_2\right)C_2^{MHHW}}{V_{f1} + V_f + V_1^{MLW} + V_2^{MHHW} + V_2}$$

It is not necessary to calculate C_2^{AVG} unless a basin is added downstream of B_2.

At T_{MHW}, the volumes are updated similarly to T_{MHHW}, and calculations for C_n^{MHW} are similar to C_n^{MHHW}:

T_{MHW}

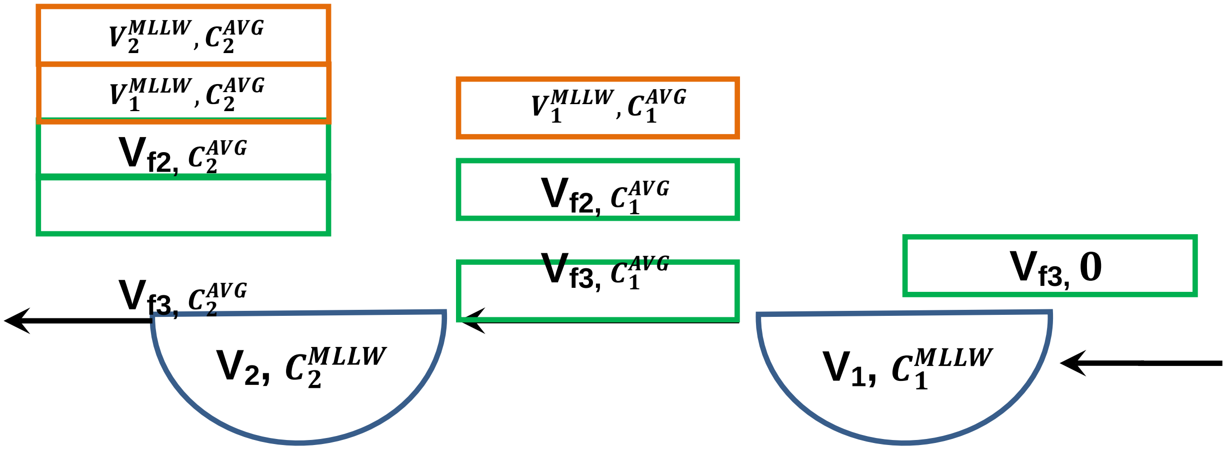


$$C_1^{MHW} = \frac{\left(V_1 + V_1^{MHHW} - V_1^{MLW}\right)C_1^{MLW} + \left(V_1^{MHW}\right)C_0 + \left(V_{f2}\right)0}{V_1 + V_1^{MHHW} - V_1^{MLW} + V_1^{MHW} + V_{f2}}$$

$$C_2^{MHW} = \frac{\left(V_2 + V_2^{MHHW} - V_2^{MLW}\right)C_2^{MLW} + \left(V_2^{MHW}\right)C_0}{V_2 + V_2^{MHHW} - V_2^{MLW} + V_2^{MHW}}$$

Lastly, at T_{MLLW}, the tide levels return to MLLW and initial volumes are restored.

T_{MLLW}



$$C_1^{MLLW} = \frac{\left(V_1 + V_1^{MHHW} - V_1^{MLW} + V_1^{MHW} + V_{f2}\right)C_1^{MHW} + \ (V_{f3})0}{V_1 + V_1^{MHHW} - V_1^{MLW} + V_1^{MHW} + V_{f2} + V_{f3}}$$

$$C_1^{AVG} = \left(\frac{1}{2}\right)(C_1^{MLLW} + C_1^{MHW})$$

$$C_2^{MLLW} = \frac{\left(V_{f2} + V_{f3} + V_1^{MLLW}\right)C_1^{AVG} + \ (V_2^{MHHW} - V_2^{MLW} + V_2^{MHW} + V_2)C_2^{MHW}}{V_{f2} + V_{f3} + V_1^{MLLW} + V_2^{MHHW} - V_2^{MLW} + V_2^{MHW} + V_2}$$

Once C_n^{MLLW} is calculated, the tidal cycle and corresponding calculations are repeated starting at T_{MHHW}. At the start of each cycle, C_0 in V_n is replaced with the previously calculated C_n^{MLLW} value. The process is repeated until the average concentration in each basin converges.