ATTACHMENT A

Tech Memo Approval Form

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0	Initial submittal for formal review.	1/14/09	All
1	Corrected some typographical errors and clarified that the brackish Cross Florida Barge Canal and Old Withlacoochee River were marine waters, consistent with FL regulations.	1/29/09	Multiple

Document Review and Approval

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Estimated Salinity Changes in the Cross Florida Barge Canal and Old Withlacoochee River Channels after Levy Nuclear Plant Intake Operation

Problem Statement

Operating the proposed ±122 million gallons per day (mgd) or ±190 cubic feet per second (cfs), Cooling Water Intake Structure (CWIS) for the Levy Nuclear Plant Units 1 and 2 (LNP) near the Inglis Locks on the Cross Florida Barge Canal (CFBC) may result in an increase in average salinity in the CFBC over time. The Florida Fish and Wildlife Conservation Commission (FWC) requested an evaluation to determine if potential changes in the CFBC could cause water quality and biological changes (primarily salinity) to the short stretch of the Old Withlacoochee River (OWR) that is located between the Inglis Dam on Lake Rousseau and the CFBC. The analysis documented in this memorandum addresses the potential water quality impacts operating the proposed CWIS would have on the water quality and biota in the OWR.

Approach

Salinity in both the OWR and the CFBC will vary depending on the salinity at the mouth of the CFBC; tidal conditions; and fresh water from groundwater seepage, subsurface springs, and releases from the Inglis Dam. Salinity measurements taken at any given time may not be representative of long term salinity levels in these water bodies and may not be a good indicator of the types of biota that they can support. A better indicator of general ambient conditions in the OWR can be obtained through a survey of biological communities.

Biological data were collected at three stations in the OWR in summer 2008. Sampling included the collection of fish, motile crustaceans, and benthic infauna, as well as water quality data. The biological data were analyzed for species composition and abundance, and salinity preference. Based on the types and preferences of the species obtained during the field sampling, segments of the OWR were classified as either fresh water, salt water, or transitional areas.

The potential for salinity changes resulting from the proposed withdrawal were also evaluated by:

- Review of existing USGS gage data to determine potential freshwater flows in the OWR
- Review of salinity data collected in the CFBC and OWR between October 18, 2007 and September 15, 2008
- Analysis of the hydraulics and salinity transport in the system

Biological Program Introduction

Biological data provide one of the best measures of long-term water quality trends at a particular location. While water quality parameters measured at a particular time and location reflect current conditions, water quality data can be highly variable, particularly on a short reach of river like the OWR that is subject to periodic releases of fresh water from the Lake Rousseau Dam and daily tidal influences from the CFBC in its lower portions.

Collections of biological organisms resident to the OWR integrate water quality conditions over time and provide a good measure of the water quality conditions. Since the primary concern with the operation of the LNP CWIS is the potential for increases in salinity in the OWR due to increased flows being drawn from higher salinity waters in the lower CFBC to the upper CFBC, the primary goal of the examination of the collected biological data was to sort the collected organisms by their known tolerances to salinity.

In particular, collections of benthic macroinvertebrates, bottom dwelling organisms inhabiting the sediments with limited mobility (benthic infauna), show which locations support benthic organisms indicative of freshwater conditions and which show organism groups that are indicative of euryhaline conditions. Euryhaline organisms are capable of tolerating a wide range of saltwater concentrations, while freshwater organisms generally will not be found in marine waters.

Sampling Methods and Locations

Three sampling stations (Stations 8, 9, and 10) were selected to examine the biological conditions in the OWR (Figure 1). Station 8 is located near the junction of the OWR with the CFBC. Station 9 is located approximately half the distance from the junction of the OWR to Lake Rousseau's Inglis Dam. Station 10 is located in the upper portion of the OWR just below the dam. One set of replicate macroinvertebrate samples was collected at each of the three stations during June to July 2008. Three discrete petite Ponar samples were collected from the sediment at each station. The data from each discrete sample were sorted, identified, and counted, and later integrated to provide data for each sampled station.

In addition to macroinvertebrates, fish and motile crustaceans (e.g., crabs and shrimp) were collected at each of the three stations using a variety of collection methods including beach seines, gill nets, minnow traps, cast nets, and crab traps. While many fish and motile crustaceans are euryhaline and tolerate a range of salinity conditions, certain fish species are strictly fresh water and are clearly indicative of water quality conditions that are essentially free of measured salinity. The collected fish and motile crustaceans were sorted and examined according to their known salinity preferences.

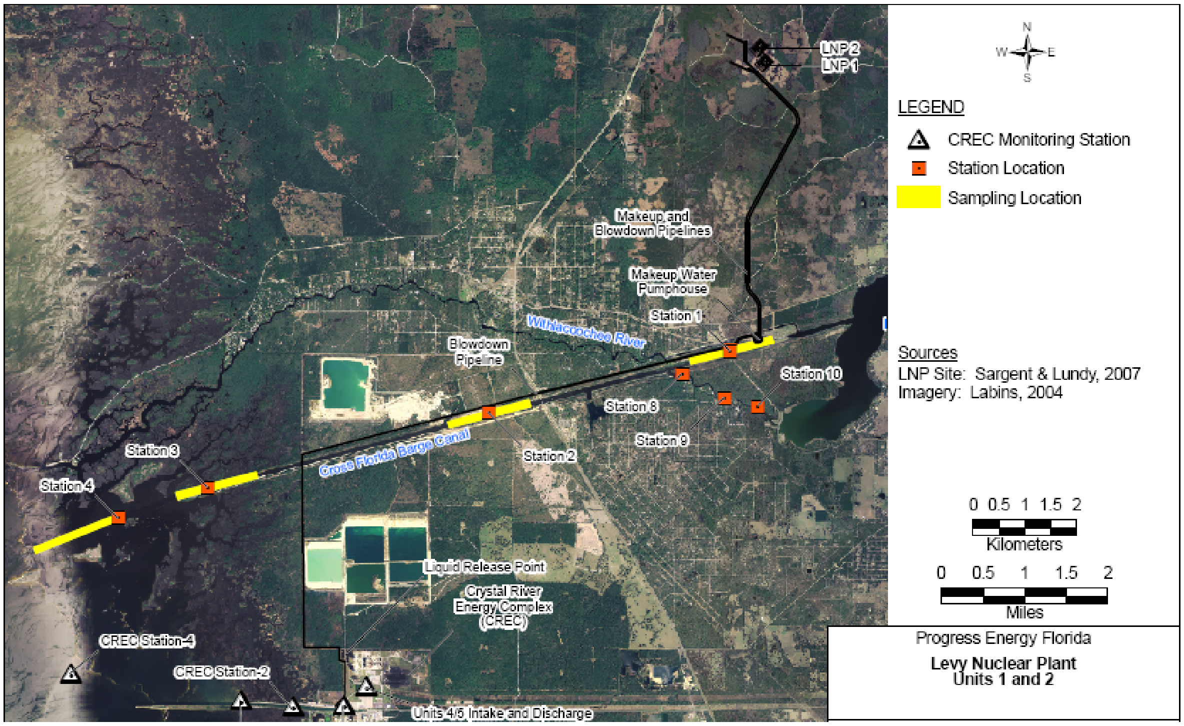

FIGURE 1
Location of Sampling Stations

Habitat Conditions in the OWR

The OWR is a meandering stream approximately 20 to 30 meters wide with deeper water near the outer shore of each bend and shallower water near the inner shore of bends. Mature vegetation overhangs the stream and Spanish moss hangs from many of the mature trees. The flow and velocity is highly variable, with dry weather flows resulting in slowly flowing water and wet weather flows that result in releases over the Inglis Dam causing strong flows. Data showing the frequency and magnitude of periodic releases of water over the dam are presented in the discussion of water quality changes below. The bottom of the channel is periodically scoured by the higher flows and the center of the channel is mostly scoured down to the bedrock. Sediment, mostly sand mixed with organic materials, lines the edges of the scoured channel; therefore, Ponar samples were collected at the margins of the channel.

The upper portion of the OWR near Station 10 contained submerged aquatic vegetation (SAV) on the margins of the stream channel; however, SAV was only sparsely present at a few locations in the stream below Station 10.

Fish

Fish sampling was conducting using beach seines, gill nets, cast nets, minnow traps, and crab traps. Trawling was not conducted and gill net sampling was limited due to the presence of manatees in the narrow OWR; the results of these sampling efforts were too sparse to provide useful data. Crab trap efforts also were ineffective, resulting in the collection of only two organisms; therefore, only beach seining, cast netting and minnow trap data are presented in this discussion of collected fish. The results of these sampling techniques are provided in Tables 1 through 3.

The fish collected using beach seines at Station 10 near the Inglis Dam (killifish, black bass, brook silversides, sunfish, shiner, mosquito fish, and sailfin molly) are each known to prefer freshwater conditions (Table 1). Only one black bass was collected at the transition station (Station 9), and the fish collected in the lower OWR channel near the CFBC (inland silverside, common mojarra, and pinfish) have been commonly collected during other CH2M HILL sampling efforts in marine waters in the CFBC and near-shore waters of the Gulf of Mexico (Gulf).

TABLE 1
Beach Seine Sampling CPUE

Common Name	Species Name	Station 8	Station 9	Station 10	CPUE Total	Percent Composition
Killifish	*NA*			10.0	10.0	33.3
Black bass	*Micropterus sp.*		1.0	8.0	9.0	30.0
Inland silverside	*Menidia beryllina*	3.5			3.5	11.7
Brook silverside	*Labidesthes sicculus*			2.0	2.0	6.7
Common mojarra	*Eucinostomus gula*	2.0			2.0	6.7
Sunfish	*Lepomis sp.*			1.0	1.0	3.3
Shiner	*NA*			1.0	1.0	3.3
Mosquitofish	*Gambusia affinis*			0.5	0.5	1.7
Pinfish	*Lagodon rhomboides*	0.5			0.5	1.7
Sailfin molly	*Poecilia latipinna*			0.5	0.5	1.7
Total		**6.0**	**1.0**	**23.0**	**30.0**	**100.0**

CPUE catch per unit effort

Fish collected using cast nets at Station 10 in the upper reaches of the OWR (catfish, Florida gar, Golden topminnow, red ear sunfish, and sailfin armored catfish) are each known to prefer freshwater conditions (Table 2). Fish collected at Stations 9 and 10 have been commonly collected in marine waters in the CFBC and near-shore Gulf.

TABLE 2
Cast Net Sampling CPUE

Common Name	Species Name	Station 8	Station 9	Station 10	CPUE Total	Percent Composition
Catfish	*Ictalurus sp. or Ameilurus sp.*			1.6	1.6	13.3
Florida gar	*Lepisosteus platyrhinchus*			1.6	1.6	13.3
Golden topminnow	*Fundulus chrysotus*			1.6	1.6	13.3

TABLE 2
Cast Net Sampling CPUE

Common Name	Species Name	Station 8	Station 9	Station 10	CPUE Total	Percent Composition
Bay anchovy	*Anchoa mitchilli*	0.5	1.0		1.5	12.8
Tidewater mojarra	*Eucinostomus harengulus*	1.5			1.5	12.8
Sheepshead	*Archosargus probatocephalus*	0.5	0.5		1.0	8.5
Redear sunfish	*Lepomis microlophus*			0.8	0.8	6.7
Sailfin armored catfish	*Pterygoplichthys sp.*			0.8	0.8	6.7
Largemouth bass	*Micropterus salmoides*	0.5			0.5	4.3
Pinfish	*Lagodon rhomboides*	0.5			0.5	4.3
Scaled sardine	*Harengula jaguana*	0.5			0.5	4.3
Total		**4.0**	**1.5**	**6.2**	**11.7**	**100.0**

CPUE catch per unit effort

The fish collected using minnow traps at Station 10 (bluefin killifish, swamp darter, and sunfish) are known to prefer freshwater conditions (Table 3). The black bass and sunfish collected at Station 9 are known to prefer freshwater conditions, possibly reflecting the variable salinity values at this transition station and no fish were collected in the minnow traps in the lower portion of the OWR.

TABLE 3
Minnow Trap Sampling CPUE

Common Name	Species Name	Station 8	Station 9	Station 10	CPUE Total	Percent Composition
Bluefin Killifish	*Lucania goodei*			19.0	19.0	94.9
Swamp darter	*Etheostoma fusiforme*			0.4	0.4	2.0
Black bass	*Micropterus sp.*		0.3		0.3	1.6
Sunfish	*Lepomis sp.*		0.1	0.2	0.3	1.5
Total		**0.0**	**0.4**	**19.6**	**20.0**	**100.0**

CPUE catch per unit effort

Across all fish sampling techniques, the fish collected in the upper reaches of the OWR near the Inglis Dam are known to prefer freshwater conditions and to be regularly collected in freshwater settings. The fish collected in the lower reaches of the OWR near its junction with the CFBC are known to be euryhaline and to be regularly collected in higher salinity marine waters. The fewer fish and species collected at the transition mid-reaches of the OWR (Station 9) reflect the variable nature of salinity levels in this stream reach. The fish data show a distinctly freshwater upper reach, a lower reach with fish populations reflective of higher salinity levels, and a mid reach with variable fish populations.

Benthic Macroinvertebrates

Because benthic infaunal organisms are unable to readily avoid transient conditions, their characterization can prove useful in assessing long-term salinity conditions. The most striking difference between the benthic infauna composition at the three stations was the dominance of freshwater oligochaete worms at Station 10 in the upper reach of the OWR and the exclusive presence of isopods and caddisflies (Trichoptera) at Station 10 (Table 4, Figure 2). The transition station (Station 9) showed fewer taxonomic groups and fewer numbers, characteristics typical of areas with more variable salinity levels. The station closest to the higher salinity waters of the CFBC (Station 8) showed higher numbers, the result of particularly high numbers of a few euryhaline species of dipteran midges. The other obvious difference between the stations is the higher numbers of marine polychate worms at both Stations 8 and 9.

TABLE 4
Benthic Infauna Abundance of Major Taxa per Station from the Old Withlacoochee River Segment

Major Taxon	Station 8	Station 9	Station 10	Total	Percent Composition
Oligochaeta			20,007	20,007	52.5
Diptera	5,009	531	4,736	10,276	27.0
Polychaeta	1,105	1,005	172	2,282	6.0
Amphipoda	115	301	1,579	1,995	5.2
Bivalvia	631	603	388	1,622	4.3
Gastropoda	57	531	144	732	1.9
Hirudinea	14		531	545	1.4
Isopoda			517	517	1.4
Trichoptera			86	86	0.2
Nemertea		57		57	0.2
Total	**6,932**	**3,028**	**28,158**	**38,119**	**100.0**

Values expressed in numbers per square meter (m^2).

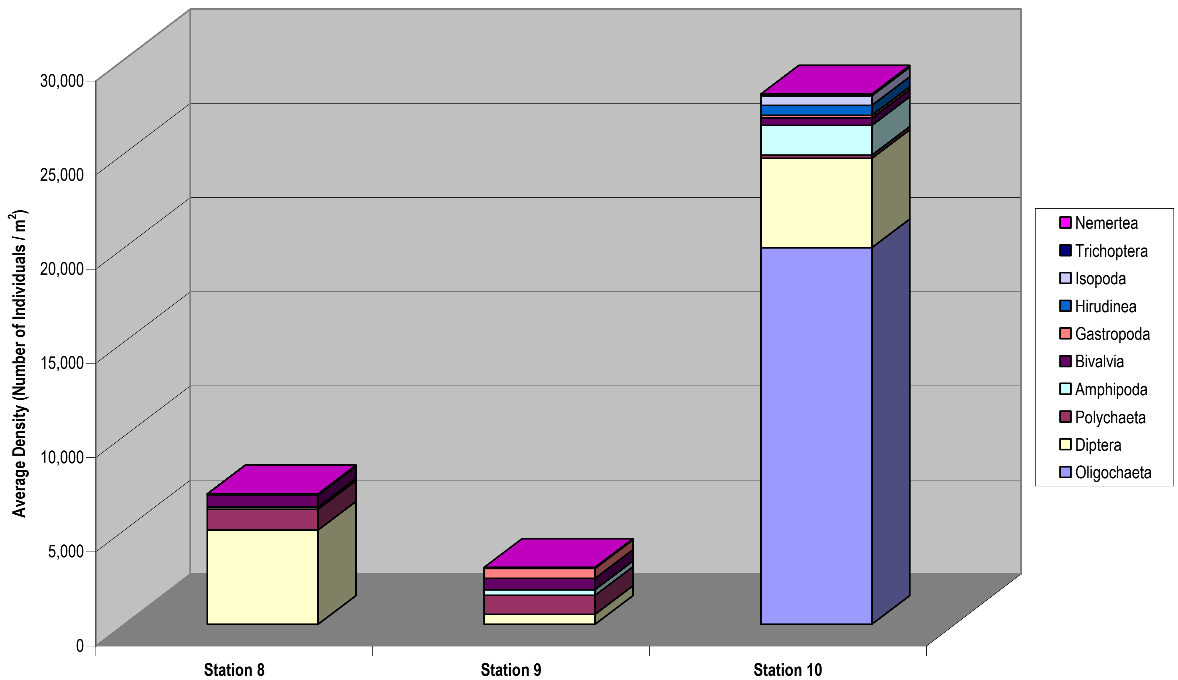

FIGURE 2
Benthic Infauna Abundance per Station in the Old Withlacoochee River Segment

The presence of certain taxonomic groups at Station 10 clearly demonstrates the infaunal characteristics of the upper freshwater reach (Table 5). The freshwater amphipod, *Hyalella azteca,* the entire complex of freshwater oligochate worms, and the freshwater caddisfly, *Oectis inconspicua,* were collected only in the upper freshwater reaches of the OWR. In addition, the number of dipteran midge species groups collected at Station 10 far exceeded the number of species groups of dipterans collected at Stations 8 and 9. The false dark mussel, *Mytilopsis leucophaeata*, typically found in brackish waters, was collected at Stations 8 and 9, but not in the upper freshwater reaches of the OWR. A total of 44 taxonomic groups were collected at Station 10, while the number of taxonomic groups collected at Stations 8 and 9 were 12 and 13, respectfully.

TABLE 5
Benthic Infauna Abundance per Species from the Old Withlacoochee River Segment

Major Taxon	Organism Name	Station 8	Station 9	Station10
Amphipoda	*Amphipoda (LPIL)*	57		
Amphipoda	*Aoridae (LPIL)*	57		
Amphipoda	*Gammarus cf. Tigrinus lecroy*		301	
Amphipoda	*Gammarus sp.*			14
Amphipoda	*Hyalella azteca complex lecroy*			1564
Bivalvia	*Corbicula fluminea*			201
Bivalvia	*Mytilopsis leucophaeata*	631	603	57
Bivalvia	*Pisidiidae (LPIL)*			129
Diptera	*Chironomidae (LPIL)*			100
Diptera	*Chironomidae pupae (LPIL)*			57
Diptera	*Chironomus decorus group epler*			273
Diptera	*Chironomus sp.*	4664	416	100
Diptera	*Cladopelma sp.*			86
Diptera	*Cladotanytarsus sp.*			43
Diptera	*Claxdotanytarsus sp. A epler*			172
Diptera	*Cryptochironomus sp.*			43
Diptera	*Cryptotendipes sp.*			57
Diptera	*Dicrotendipes modestus*			1679
Diptera	*Dicrotendipes sp.*	57		57
Diptera	*Diptera (LPIL)*			100
Diptera	*Polypedilum halterale group epler*			129
Diptera	*Procladius (holotanypus) sp.*	57		86
Diptera	*Procladius bellus var. 2 epler*			57
Diptera	*Procladius sp.*		57	
Diptera	*Pseudochironomus sp.*		57	789
Diptera	*Tanytarsini (LPIL)*			57
Diptera	*Tanytarsus sp.*	230		215
Diptera	*Tanytarsus sp. G epler*			574
Diptera	*Tanytarsus sp. K epler*			29
Diptera	*Tanytarsus sp. L epler*			29

TABLE 5
Benthic Infauna Abundance per Species from the Old Withlacoochee River Segment

Major Taxon	Organism Name	Station 8	Station 9	Station10
Gastropoda	*Cf. Pyrgophorus platyrachis*			14
Gastropoda	*Gastropoda (LPIL)*			57
Gastropoda	*Hydrobiidae (LPIL)*		158	
Gastropoda	*Pyrgophorus platyrachis*	57	373	72
Hirudinea	*Gloiobdella elongata*			344
Hirudinea	*Helobdella stagnalis*	14		187
Isopoda	*Caecidotea sp.*			517
Nemertea	*Nemertea (LPIL)*		57	
Oligochaeta	*Aulodrilus pigueti*			115
Oligochaeta	*Bratislavia unidentata*			287
Oligochaeta	*Dero digitata complex*			230
Oligochaeta	*Dero sp.*			100
Oligochaeta	*Ilyodrilus templetoni*			215
Oligochaeta	*Limnodrilus hoffmeisteri*			344
Oligochaeta	*Tubificoid naididae imm sp. A (LPIL)*			15844
Oligochaeta	*Tubificoid naididae imm sp. B (LPIL)*			2870
Polychaeta	*Boccardiella sp.*		201	86
Polychaeta	*Hobsonia florida*	115	172	86
Polychaeta	*Laeonereis culveri*	344	502	
Polychaeta	*Lumbrineris sp.*		72	
Polychaeta	*Steninonereis martini*	646	57	
Trichoptera	*Oecetis inconspicua complex pescador*			57
Trichoptera	*Trichoptera (pupae)*			29
Total		**6,932**	**3,028**	**28,158**
Number of Taxa		**12**	**13**	**44**

Values expressed in numbers per square meter (m^2).

Water Quality Field Data

CH2M HILL collected OWR water quality data on June 26, 2008 and August 27, 2008. Water quality parameters measured were temperature, dissolved oxygen, salinity, pH, and water clarity (Secchi depth). Data from these two sampling events illustrate the range of salinity levels that occur in the OWR. Table 6 presents a summary of water quality data collected during the OWR macroinvertebrate sampling event on June 26, 2008. Flows were normal and the results clearly show freshwater conditions at both Stations 9 and 10 and increased salinity at Station 8 nearest the CFBC. Note that a salt wedge was recorded at 2 meters in depth at Station 8 and that the recorded salinity level at the 2-meter depth was 12.25 parts per thousand (ppt).

TABLE 6
Summary of Average Temperature, Dissolved Oxygen, Salinity, pH, and Water Clarity Data from the Old Withlacoochee River (June 26, 2008)

Station ID	Temperature (ºC)	Dissolved Oxygen (mg/L)	Salinity (ppt)	pH (units)	Secchi depth (m)
WITH 8	29.14	3.94	4.38	7.45	1.84
WITH 9	28.98	4.62	0.15	7.78	1.65
WITH 10	28.52	4.32	0.14	7.93	0.91

Note: Salinity at Station 8 at a depth of 2 m was 12.25 ppt.
ºC degrees Celsius
mg/L milligrams per liter
ppt parts per thousand
m meters

Table 7 presents data collected during a short period in August 2008 when tropical storm flows in the upper part of the Withlacoochee River basin resulted in releases from the Inglis Dam. Essentially freshwater was present at each sampling station during this high flow period.

TABLE 7
Summary of Average Temperature, Dissolved Oxygen, Salinity, pH, and Water Clarity Data from the Old Withlacoochee River Segment (August 27, 2008)

Station ID	Temperature (ºC)	Dissolved Oxygen (mg/L)	Salinity (ppt)	pH (units)	Secchi depth (m)
WITH 8	28.05	8.86	0.35	8.39	1.19
WITH 9	28.01	8.78	0.34	8.40	1.32
WITH 10	27.77	8.12	0.34	8.26	1.18

Note: Secchi depth was collected on August 29,2008.
ºC degrees Celsius
mg/L milligrams per liter
ppt parts per thousand
m meters

Biological Summary

Fish and macroinvertebrate data collected at three stations in the OWR channel between the dam and the confluence of the OWR with the CFBC clearly indicate that the upper reaches of the remnant river, as represented by Station 10, have organism groups and species that are normally found only in freshwater conditions. Samples obtained from the lower reaches of the OWR (Stations 8 and 9) contained euryhaline organisms that are typically found in marine conditions.

The biota of the middle and lower reaches of the OWR currently show the effects of variable salinity levels. Most of the lower portions of the OWR are brackish and have a transition zone between them. It is considered unlikely that changes in salinity levels resulting from the operation of the LNP CWIS would adversely impact the biota of those river segments.

Assessment of Potential Salinity Change in the OWR

The potential for salinity changes resulting from the proposed LNP cooling tower makeup water withdrawal were addressed by:

- Review of existing USGS gage data to determine potential freshwater flows in the OWR
- Review of salinity data collected in the CFBC and OWR between October 18, 2007 and September 15, 2008
- Analysis of the hydraulics and salinity transport in the system

Freshwater Flows

Freshwater flows into the system include discharges and leakage from Lake Rousseau at Inglis Dam, which forms the headwater of the OWR, leakage from the lock into the CFBC, and groundwater, some of which is visible as boils near both the dam and the lock.

Freshwater Inputs to the OWR

Freshwater flow data for discharge from the Inglis Dam into the OWR were obtained from U.S. Geological Survey (USGS) station 02313230. Flow data were available form October 1, 1969, through December 20, 2007. Data are in the form of average daily flows from Lake Rousseau and represent flow over the spillway as well as an estimated additional 70 cubic feet per second (cfs) of groundwater downstream of the control structure that is considered to be primarily spring flow generated as leakage from the lake (USGS website, 2008).

The average daily value of freshwater discharge into the OWR based on these data is 436 cfs; however, this value is skewed by flows during high discharge periods and is not representative of the most common conditions. A cumulative distribution plot shown on Figure 3, developed after subtracting 70 cfs from the total flow values, indicates that for nearly 47 percent of the time, the dam does not discharge into the OWR and all freshwater flow into the river results from groundwater. The median value of freshwater discharge presented in the data is 87 cfs, consisting of 17 cfs discharged over the dam and an assumed 70 cfs discharged as groundwater.

Freshwater Inputs to the CFBC

No data are available for flow into the CFBC. A small amount of leakage can be observed from the locks. Groundwater also feed some freshwater springs near the headwaters of the CFBC as is evidenced by boils present in the area near the locks.

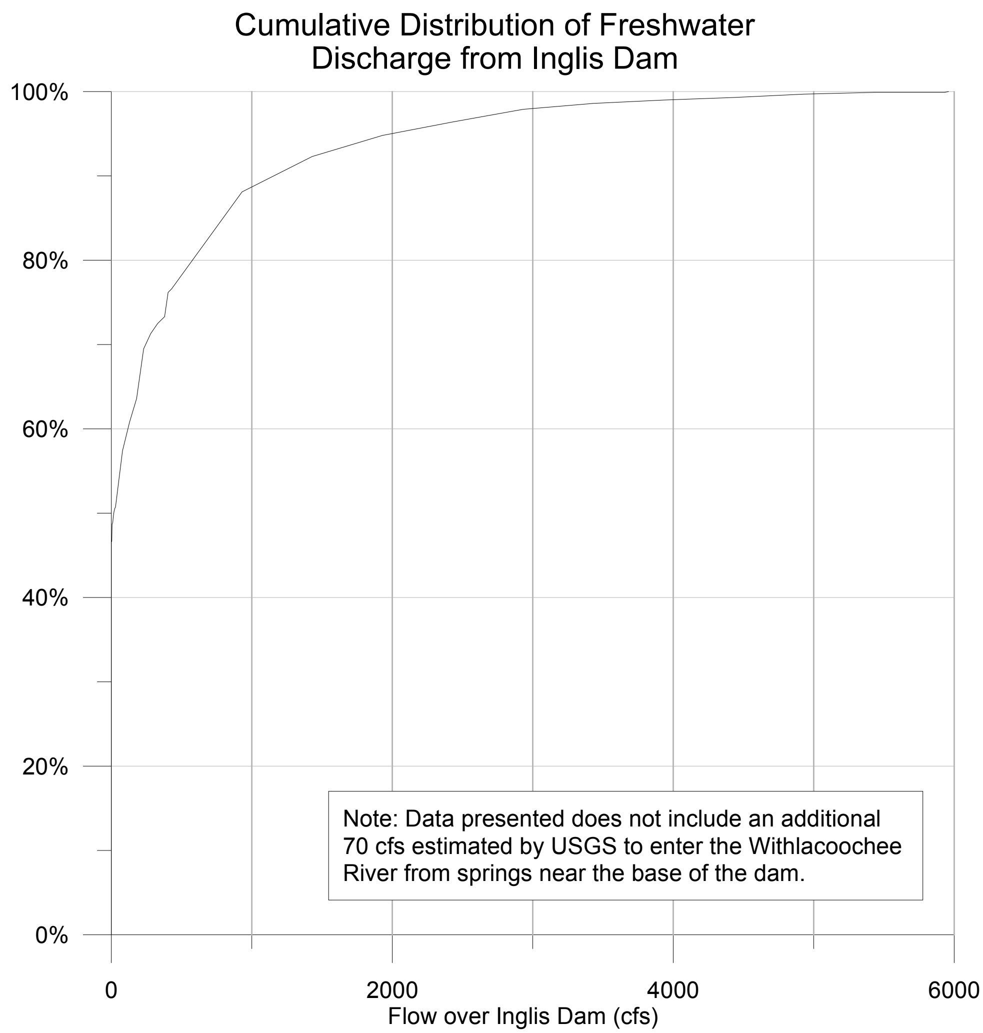

FIGURE 3
Cumulative Distribution of Freshwater Flow from Inglis Dam

Salinity Field Data

Salinity profiles were collected in the CFBC at the four stations (Stations 1, 2, 3, and 4) shown on Figure 1 on 27 different occasions between October 18, 2007, and September 15, 2008. Additionally, salinity profiles were taken every half mile along the canal, from the Inglis Lock to the Gulf of Mexico, on December 5 and 12, 2007. Data were collected from the OWR on June 25, 2008, and August 27, 2008, at the three stations (Stations 8, 9 and 10) shown on Figure 1.

Salinity Distribution in the CFBC

Figure 4 presents depth-averaged salinity data for all the sampling events on the CFBC. The grey line represents the average of all data for the four primary stations with depth averaged salinities in the canal ranging from approximately 21 primary salinity units (psu), which is equivalent to ppt, at the end of the CFBC to close to 10 psu one-half mile downstream from the Inglis Lock.

In general, the data range within ±5 psu from the average. Notable exceptions are the data points that define the minimum and maximum salinities that were recorded on August 27, 2008 and October 18/19, 2007, respectively.

Typical depth-averaged salinities near the OWR junction are on the order of 7 to 17 psu with high salinities exceeding 22 psu and low salinities likely near zero during periods of high dam discharge. Vertical profiles show that the salinity structure ranges from partially stratified to stratified. High near-bottom salinities can occur throughout the canal during periods of strong stratification as evidenced by a maximum measured salinity one-half mile from the locks of nearly 30 psu with a corresponding surface salinity of 8.5 psu and a depth averaged salinity of less than 20 psu.

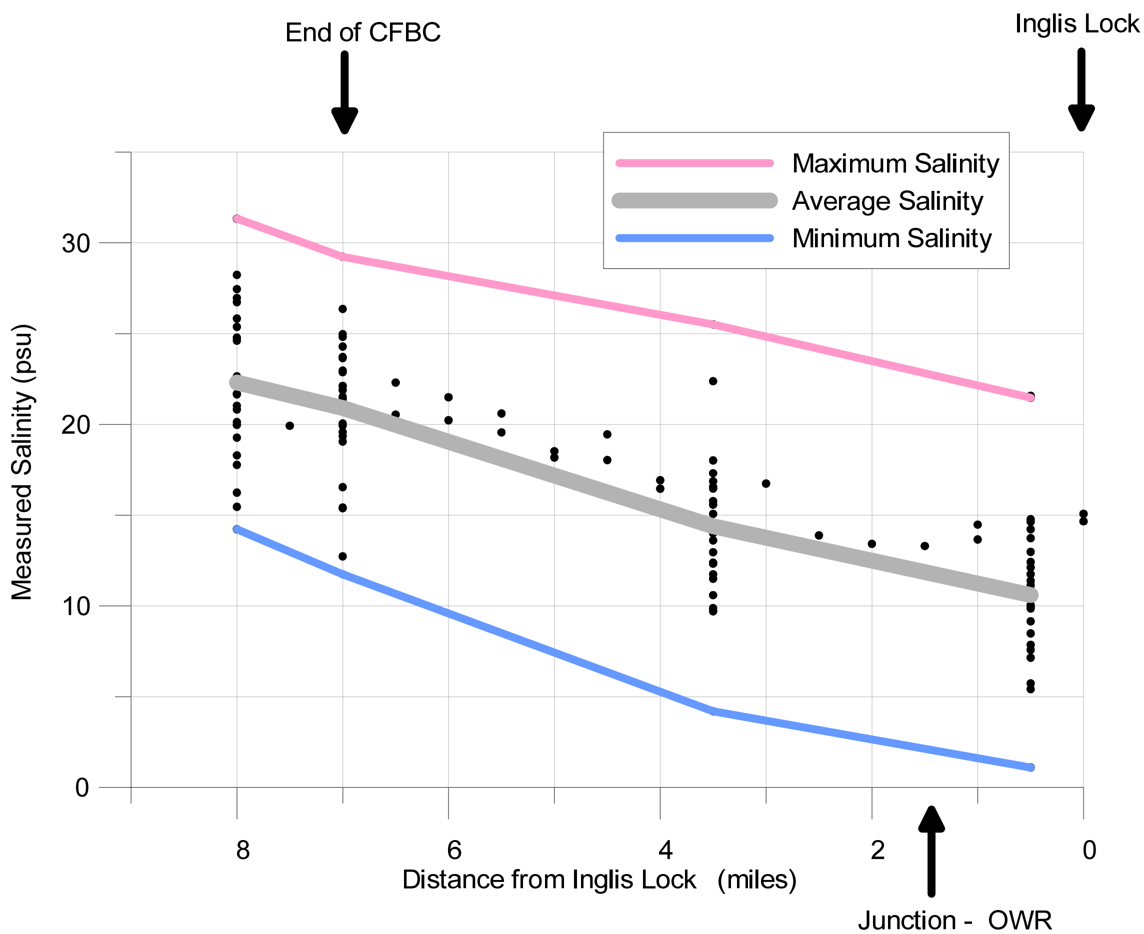

FIGURE 4
Longitudinal Salinity Distribution in the CFBC

Salinity Distribution in the OWR

Salinity data collected in the OWR on August 27 and June 25, 2008, were available at the time of this evaluation. Data collected on August 27, 2008, corresponded with a period of high discharge from the dam and all measurements taken in the OWR recorded near zero salinities. August 27 was also the date during which the minimum salinities were measured throughout the CFBC.

Measurements on June 25, 2008, also showed predominantly fresh water throughout the water column for the two stations closest to the dam, but a stratified profile near the mouth with low surface and mid-depth salinities (less than 0.5 psu) and an elevated bottom salinity of 12.25 psu.

Analysis of Potential Salinity Impacts

During high flow dam releases the OWR will be freshwater. From Figure 2, it can be seen that releases from the dam can exceed 1,000 cfs about 12 percent of the time. However, the maximum increases in salinity in the OWR would occur about 50 percent of the time when there were little or no release of water from the dam. Potential effects of withdrawing cooling water from the CFBC on the salinity in the OWR during dry periods were evaluated by applying a conceptual model of the system that identifies the primary drivers of salinity transport through the system, evaluating existing and potential future salinity levels through the CFBC, and evaluating likely changes in salinity along the OWR caused by salinity changes at the junction with the CFBC. HEC-RAS modeling was performed to support the assessment by demonstrating the expected hydraulic characteristics (elevations and flow rates) of the system.

Conceptual Model

The CFBC and OWR form a saltwater reservoir system where saltwater entering from the mouth of the CFBC during flood tides mixes with fresh water that enters the system from a number of sources including:

- Discharge and leakage from the Inglis Dam at the head of the OWR
- Groundwater discharge near the head of the OWR attributed largely to seepage under the dam from Lake Rousseau
- Groundwater that discharges into the CFBC
- Minor leakage from the lock at the head of the CFBC

Flow in the system during dry weather come from two primary drivers: tides, which cause an alternating current as the rising and falling of the tides partially fill and drain the CFBC, and freshwater inflows, which cause a net unidirectional current as the freshwater flows toward and out the mouth of the canal.

Vertical salinity profiles through the water column show a partially to strongly stratified system. During dry conditions, there is little stratification and the column is marine. Under conditions that cause the water column to stratify, the denser seawater will tend to flow into the CFBC along the bottom as a salt wedge, with less saline water flowing out along the surface. Some mixing will occur along the interface between the upper and lower layers and, under some conditions, the stratification will break down and the less saline water from the upper layer will mix vertically with the water from the salt wedge. During very large dam releases of storm water, there can be substantial flushing of the entire lower portions of the CFBC (apparently with releases greater than about 1,500 cfs). Consequently, the penetration of the saline water up the canal is largely a function of the freshwater river flow into the channel and there will be transport up the OWR only when there are small or no releases from the dam.

Salinity is transported through the canals (both CFBC and OWR) via advection with currents (both tidal and riverine) and dispersion through a number of dispersive mechanisms such as shear flow dispersion, tidal trapping, and mixing and density effects caused by the freshwater flows. Under steady-state conditions, dispersive mechanisms that transport salinity into the canals are balanced by advective transport out of the canals with riverine currents. Tidal currents average to a net zero flow over time, so for the purposes of this analysis these are assumed to be zero. The “salt balance” (i.e., the balance between advective and dispersive transport) can be expressed as:

$$U_f S = K\left(\frac{\partial S}{\partial x}\right)$$ (Ref: Fisher, et al, 1979)

where:

U_f = the net downstream velocity caused by the freshwater discharge

S = salinity

K = the longitudinal dispersion coefficient that accounts for all dispersive mechanisms

$\left(\frac{\partial S}{\partial x}\right)$ = the longitudinal salinity gradient

The salt balance equation can be applied to both the CFBC and the OWR to describe the salinity distribution through these reaches. A spreadsheet model incorporating the salt balance equation was developed for the OWR to assess potential changes to salinity through the system.

Figure 5 shows a channel segment represented by a spreadsheet cell in the model. Taking the salinity, S, for the cell to be the average of the upstream and downstream salinities, the salinity at the upstream end, S_2, can be calculated from the salinity at the downstream end as:

$$S_2 = S_1\left(\frac{2K - U_f L}{2K + U_f L}\right)$$

where L is the length of the segment. In this way, given the salinity at the downstream end of the cell, the longitudinal dispersion coefficient, and the freshwater flow, the value of salinity at the upstream end of the cell can be calculated.

Because measurements of the longitudinal dispersion coefficient are not available, a value for this application was estimated based on published values (Fischer et al, 1979) and adjusted based on the model's agreement with observed salinity gradients along the given channels.

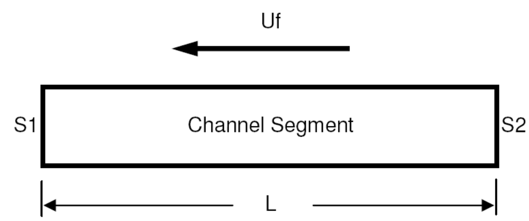

FIGURE 5
Definition Sketch of a Channel Segment Used in Salt Balance Model

If the cooling water withdrawal rate is greater than the freshwater input into the channels, then the direction of flow will reverse and there will be a net migration of Gulf seawater drawn into the channel.

The salt balance equation is applicable water bodies where fresh water flows in from rivers or other sources, and eventually flows to the ocean. The proposed cooling water intake would withdraw water from the most upstream portion of the CFBC, near the lock. If the withdrawal exceeds the inflow rates of freshwater sources, the direction of the velocity, U_f, in Figure 5 reverses and saline water from the Gulf will be drawn into the canal. Net advective and diffusive fluxes of salt would both be in the inshore direction and the salinity of the water in the channel will be equal to the salinity of the water that it is drawn from over time. From the mouth of the CFBC to the junction with the OWR, neglecting any contribution from springs along this stretch, the salinity at the junction would be equal to the salinity of the water at the mouth of the CFBC. From the junction with the OWR to the cooling water intake, the salinity would be reduced by the freshwater flow contributions from the OWR.

The following sections present analyses and conclusions of present and potential future salinities for the CFBC and the OWR based on available data, analysis, and model results.

Salinity in the CFBC

The impact to salinity in the CFBC of withdrawing cooling water from a site located below the Inglis Lock was evaluated by comparing the existing salinity levels along the canal with expected salinity levels if the withdrawal were taking place.

The USGS reports an approximate 70 cfs flow of fresh water at the head of the OWR from groundwater flow when the gates to the dam are closed, which historically occurs approximately 47 percent of the time. For the purposes of this assessment, it was assumed that 70 cfs was a typical low flow condition for freshwater flow through the OWR. This flow is expected to be largely derived from Lake Rousseau as seepage under the dam. Additional spring flow into the CFBC was assumed to be similar in magnitude, but somewhat smaller and was set to 50 cfs. This 120 cfs was considered an estimate of "typical" to low freshwater flows into the system under current conditions.

Because the proposed withdrawal of 122 mgd (190 cfs) is greater than the total freshwater inflows during periods without releases, the direction of the net flow in the CFBC will be from the mouth of the canal to the intake, and the salinity of the canal west of the OWR will be that of the water offshore from the mouth. The displacement of the CFBC water with Gulf water will take place over several days (about 5 days based on residence time estimates).

Figure 6 shows the potential impact of the cooling water withdrawal on the salinity profile along the CFBC during these dry periods. The lower line is the average observed salinity along the CFBC based on the data presented in Figure 3. The upper line represents the potential future salinity in the canal assuming salinity outside of the CFBC of 30 psu. It should be noted that the assumed salinity at the mouth of the CFBC for the future case (30 psu) is greater than that for existing conditions (about 21 psu). This is because freshwater flow from the CFBC under existing conditions reduces salinity of the water immediately outside of the canal where under future conditions, the freshwater flow will be withdrawn by the cooling water intake and the entire CFBC will be expected to be somewhat more saline on average.

Conservatively assuming small groundwater flows into the CFBC between the mouth and the junction with the OWR, the salinity along this section will be the same as the Gulf near the mouth of the CFBC. From the junction of the OWR with the CFBC to the proposed intake location, the salinity will be reduced through mixing with the freshwater flow from the OWR. For the low flow conditions assumed, the salinity along this section is on the order of 15 psu.

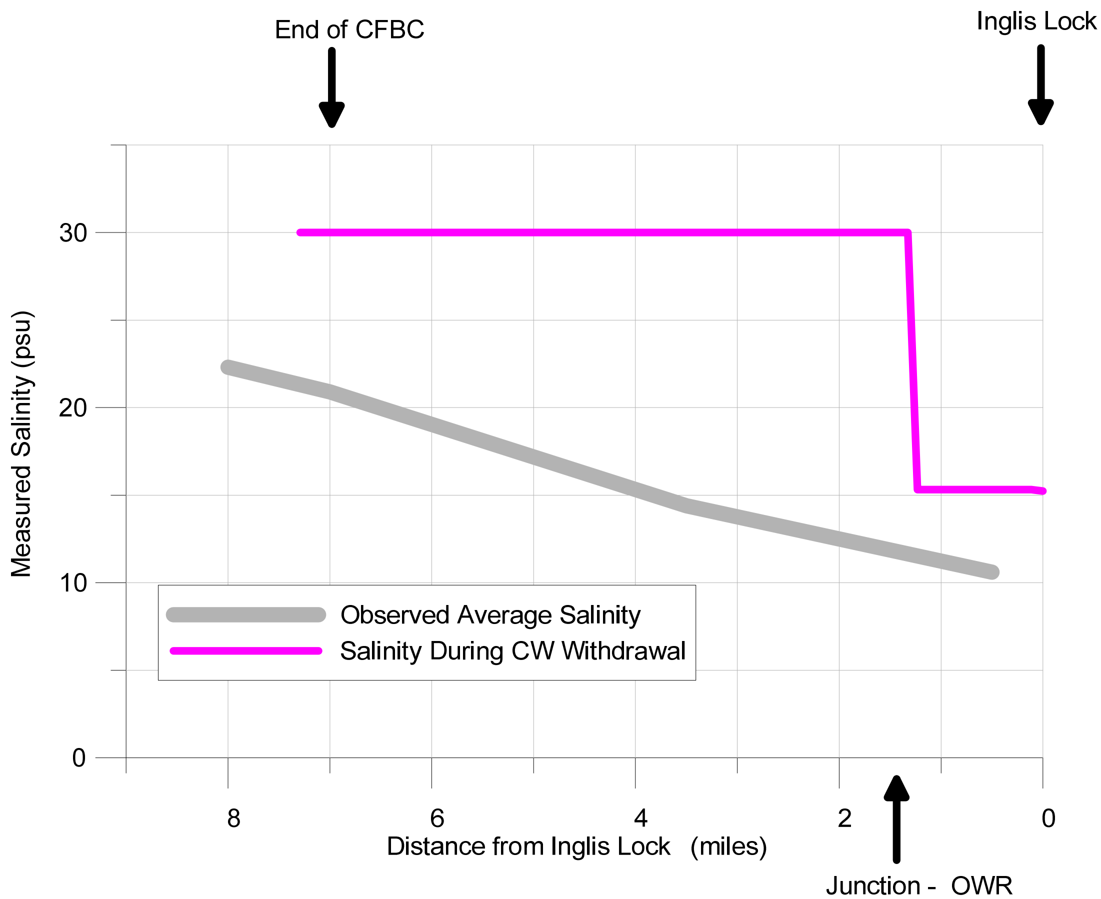

FIGURE 6
Potential Salinity Increases in the CFBC during Low Freshwater Flow Periods Resulting from Cooling Water Withdrawal

During periods of low freshwater flow, salinity in the CFBC at the junction to the OWR is expected to increase from existing levels that range from 7 to 17 psu up to levels equal to the salinity of the Gulf offshore of the mouth of the CFBC (on the order of 30 psu).

Salinity in the OWR

The potential salinity changes that may occur in the CFBC were used to evaluate salinity changes in the OWR based on available data of salinity in the OWR, results of biological field surveys, HEC-RAS model results, and spreadsheet modeling of changes to the salt balance in the OWR.

Salinity measurements taken in the OWR on June 25, 2008, and August 27, 2008, were used in this assessment. It was noted above that the August 27 sampling event occurred during a period of high release from the Inglis Dam and resulted in the lowest salinity recorded throughout the CFBC. Measurements in the OWR showed fresh water through the length of the channel (and in the vertical profile too).

Measurements in the CFBC on June 25 showed depth averaged salinities close to the average shown on Figure 4. Profiles of the CFBC exhibited stratification. Measurements in the OWR showed fresh water at all depths for Stations 9 and 10. Station 9 is located approximately mid-way from the junction to the dam and Station 10 is near the Inglis Dam. Measurements at Station 8, near the junction with the CFBC, showed a stratified water column with nearly fresh surface water and near-bottom salinities of 12.25 psu.

The salt balance equation was incorporated into a spreadsheet model as described above. The model was segmented into seven segments, as shown on Figure 7, and was consistent with geometry used in HEC-RAS modeling of the system.

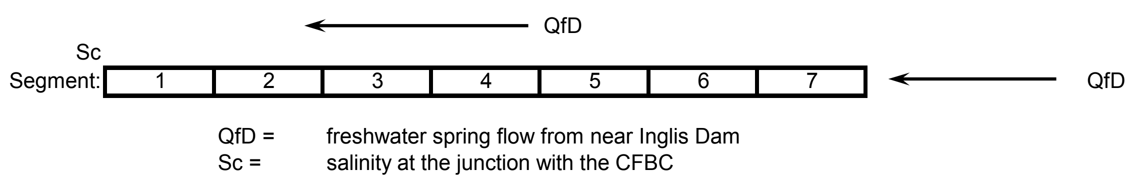

FIGURE 7
Salt Balance Model of the OWR

The salinity at the junction with the CFBC was set to 11.4 psu to represent the approximate dry weather existing condition and 30 psu to represent the potential higher dry weather salinity conditions during withdrawal of cooling water from the CFBC.

A range of longitudinal dispersion coefficients and freshwater flows were input into the spreadsheet. Results for salinities calculated at the location of Station 10 are presented in Table 8. Biological surveys of OWR indicate freshwater communities have established at Station 10. For the purposes of this analysis, it is assumed that under existing conditions the salinity at Station 10 is normally less than 1 psu. From the results presented in Table 8, if a typical low flow condition of 70 cfs or freshwater is assumed and the salinity at Station 10 were less than 1 psu, the dispersion coefficient would be on the order of 35 square meter per second (m^2/s) or lower. Similarly, if the freshwater flow was actually 100 cfs, the dispersion coefficient would be on the order of 50 m^2/s or lower to meet 1 psu at Station 10 and if the freshwater inflow were 150 cfs, the dispersion coefficient would be on the order or 75 m^2/s or lower. Salinity predictions along the OWR yield the same results for each of these three pairs of assumed freshwater flow and respective dispersion coefficient.

TABLE 8
Modeled Salinity at OWR Station 10 for Existing Conditions and with LNP for a Range of Dry Period Freshwater Flow Conditions

Freshwater Input:	70 cfs		100 cfs		150 cfs	
K (m^2/s)	Existing	LNP	Existing	LNP	Existing	LNP
20	0.1	0.2	0.0	0.0	0.0	0.0
35	0.8	2.0	0.2	0.6	0.0	0.1
50	1.8	4.6	0.8	2.0	0.2	0.5
75	3.3	8.7	1.9	5.1	0.8	2.0
100	4.5	11.8	3.0	7.9	1.5	4.0
200	7.2	17.7	5.9	15.4	4.2	11.1

Values are in primary salinity units (psu).
K Lateral dispersion coefficient in square meters per second (m^2/s)
Existing Low flow conditions in the OWR under existing conditions
LNP Existing with the LNP Cooling Water Withdrawals
cfs Cubic feet per second

Results for the predicted salinities during low flow periods (no dam releases) along the river channel are shown on Figure 8, along with field data collected along the OWR. Based on the limited field data used in this evaluation, this analysis may be predicting relatively high salinity values, but the magnitude of the potential maximum change during low flow periods is considered valid.

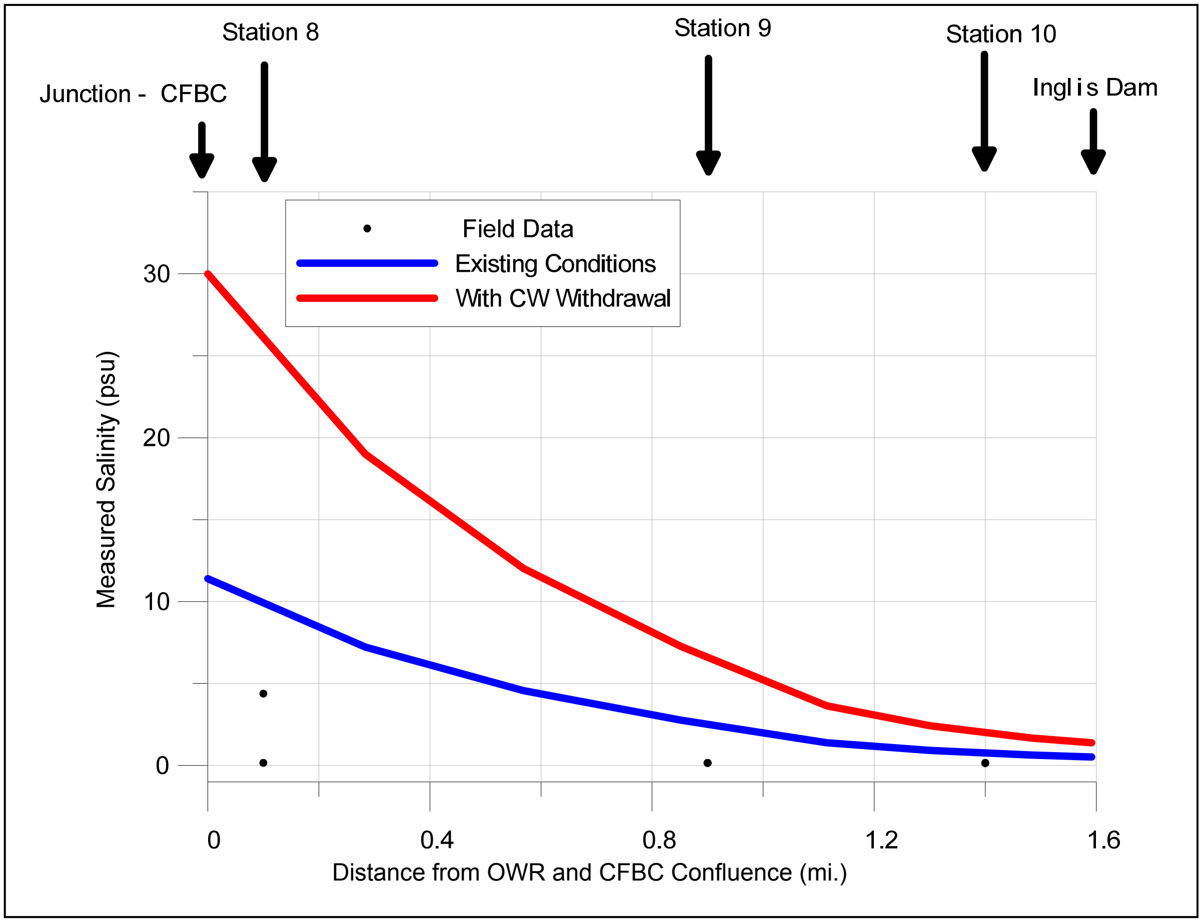

FIGURE 8
Potential Salinity Increase in the OWR during Low Freshwater Flow Periods Resulting From Cooling Water Withdrawal

Discussion of Results

Salinity profiles along the lengths of the CFBC and OWR are highly dependent on the amount of freshwater flow into the system. Based on available data, about 47 percent of the time no fresh water is released from the Inglis Dam and the only significant fresh water entering the system is from groundwater flow. (However, the number of days of dam releases varies tremendously from year to year.) The USGS assumes a groundwater flow into the head of the OWR of 70 cfs and reports this as constant with time. No similar estimate was identified for the flow into the CFBC.

The greatest increase in salinity along the CFBC will occur when freshwater flow into the system is less than the cooling water withdrawal rate (approximately 60 percent of the time). For the analysis of CFBC salinity conducted herein, the maximum increase in salinity at the junction with the OWR was assumed (30 psu). During periods with significantly greater groundwater discharge and dam releases where freshwater flows exceed withdrawals, salinity at the mouth of the OWR would be expected to be much lower than is shown on Figure 8.

The limited field measurements evaluated found fresh to brackish water through most of the OWR; however, biological surveys show communities that are normally found in marine waters as far up as Station 9, indicating that it is likely typical that salt water normally intrudes further up the channel than indicated from the limited number of field measurements reported here.

It should be noted that the field data and model results shown on Figure 8 are depth averaged values. The data collected at Station 8 on June 25, 2008, yielded an average salinity of 4.4 psu, but profiles show a stratified water column with a bottom salinity of over 12 psu at Station 8. Salinity intrusion into the OWR is typically as a salt wedge with less saline water flowing and mixing over the top (except during high dam flows). So, generally, the lower portions of the OWR are mostly saline already with periodic flushing by the freshwater releases from the dam. Based on the biological survey, it appears that the salt water intrudes on a frequent basis as far as Station 9, but that freshwater flows near the dam are sufficient to keep the saltwater wedge out of this area. Increasing the salinity at the junction of the OWR and the CFBC will result in a greater intrusion of the wedge along the bottom, but will not displace all of the freshwater.

The spreadsheet model used to assess salinity impacts in the OWR is a simplified approach, but is appropriate given the limitations in data and complexities that determine rates of mixing. Based on the model results for assumed freshwater flows of 70 to 150 cfs during periods of low flow, longitudinal dispersion coefficients of between 35 and 75 m^2/s were evaluated and they yielded similar predictions. These values are consistent with values for longitudinal dispersion coefficients used in models of semi-enclosed waterbodies as presented in Table 7.2 of Fischer, et al. (1979), which shows dispersion coefficients as low as 10 m^2/s and the majority between about 100 to 300 m^2/s. Fischer indicates that the lower values in the range of 10 to 50 m^2/s are generally found in the constant density portions of estuaries and tidal rivers where the main mechanism is primarily shear flow dispersion.

This spreadsheet model estimates changes in steady state. When releases are made from the dam, the actual salinity changes will occur over a period of several days or in a very short time period depending on the magnitude of flow. The potential and frequency of periodic high flows from the dam that will flush out the river and CFBC will remain unchanged, similar to the existing conditions, because the intake rate (about 190 cfs) is not much greater than the base seepage of 70 cfs.

A number of factors support the use of a longitudinal dispersion coefficient on the low end of observed values for this river. The straight narrow channel will minimize dispersion due to trapping along the shoreline and tidal pumping. Also, HEC-RAS modeling has shown that even for the minimum freshwater flow of 70 cfs assumed, flow will be unidirectional over the whole tidal cycle for the majority of the channel, reducing these dispersive affects further.

The salt balance model provides a simplified approach to addressing salinity levels in the OWR. Using this model, holding freshwater flows and the longitudinal dispersion coefficient constant, increases in salinity at the mouth of the river will result in proportional increases in salinity along the channel. For example, an increase from 11.4 to 30 psu will raise the calculated salinity at Station 10 by approximately the same proportion from 0.8 to 2 psu.

Conclusions

During periods with low groundwater flow and no releases from the dam (about 47 percent of the time), withdrawal of cooling water from the CFBC may affect the salinity in the canal by reversing the direction of net flow and drawing Gulf water up the canal to the point of the OWR. The magnitude of change in salinity through the OWR is expected to be roughly proportional to the change in salinity at the junction with the CFBC. Marine water at higher salt concentrations at the junction with the OWR will influence salinity levels further up the OWR with dispersive mechanisms of salt transport up the channel, balanced by the advective transport of salt out of the river with the riverine flow. The highest salinity increases will occur at the mouth of the OWR and the change will decrease moving toward the dam.

The zone in which freshwater communities transition to marine communities is linked to the frequency and distance of intrusion of the salt wedge into the OWR. The exact location of this transition zone is not known, but it appears to be between Station 9 and 10. This transition zone will move inland (upstream) somewhat with increased salinity at the mouth. However, the areas near the dam with low initial salinity are expected to see only small and infrequent increases in salinity. The modeling predicts that salinity levels will remain well below 5 parts per million (ppm) for a distance of approximately one-half mile below the Inglis Dam.

The freshwater organism community now present will continue to maintain viable populations near the dam, fed by the groundwater flow and periodically flushed with releases from the dam.

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