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TERRESTRIAL SALTS AND THE ST. JOHN'S RIVER, FLORIDA

Joseph Stewart[1] , Peter Sucsy[2], Getachew Belaineh[3], Ed Carter[4]

ABSTRACT

As part of the ongoing study to assess the potential impacts of withdrawals of surface water from the Saint Johns River, Florida, an evaluation of the terrestrial sources of salt and their influence on hydrodynamics was conducted. The intent of this effort was to assist with the development of a hydrodynamic model using the Environmental Fluid Dynamics Code (EFDC) along the River. Terrestrial salts are defined for this effort as salts of geologic origin that enter the system through flushing and dissolution and not directly from the Atlantic Ocean through its exchange with the river at the mouth. The St Johns River watershed owes its geologic structure to the variability of sea level over millions of years. The substrates of the SJR valley and adjacent uplands contribute the majority of chlorides and other salts that are entrained in surface flows through surface runoff, direct spring discharge, diffuse groundwater contribution. The primary source for monovalent salts such as chloride comes from the flushing of relict seawater, while the primary source of divalent compounds such as carbonates and sulfates are derived through dissolution of relict substrates. The principal anthropogenic influence on the terrestrial salt characteristics of the system comes from artesian pumping and drainage modifications. The input of salinity from springs and diffusive flux is the major salt load from terrestrial sources to the river.

1. INTRODUCTION

As part of the Water Supply Impact Study (WSIS), an evaluation was conducted to quantify salt sources along the St Johns River (SJR). At the downstream end of the lower SJR, salinity is dominated by exchange with the Atlantic Ocean. Upstream of the areas of ocean-influence, salinity is typically greater than 0.5. These functionally oligohaline waters have chloride levels distinctly higher than typical freshwaters (Odum, 1953). The principle sources of salt in upstream oligohaline zones are the inflow of relict seawater as diffusive groundwater and the chemical dissolution of rock in the Upper Floridan Aquifer (UFA).

Upstream of the areas of ocean-influence, the lower and middle SJR are functionally oligohaline waters with chloride levels distinctly higher than typical freshwaters, due to the inflow of relict seawater as diffusive groundwater and the chemical dissolution of rock in the UFA. The continuous influx of relict seawater and spring discharge moderates salinity along the length of the

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river and buffers salinity variability against the influences of runoff and drought. The natural variability and influence on salinity due to runoff and drought is greater than the effect of withdrawals analyzed for the WSIS in the middle St Johns River (MSJR).

Use of salinity as a conservative tracer for hydrodynamic modeling studies is generally restricted to areas having diluted seawater (waters with salts predominately derived from ocean waters). A conservative tracer is a substance that does not diminish or decay by chemical or biological processes when carried by and mixed within a fluid. The principle ionic constituents of seawater, mostly sodium and chloride, contributing to salinity are themselves conservative, so that salinity of dilutions of seawater is also conservative. Salinity of upstream freshwaters is often omitted from use as a tracer because the ions accounting for the salinity in these areas may not be conservative (particularly those contributing alkalinity)— they may be lost or gained by chemical or biological transformation. For this study, salinity is used as a conservative tracer throughout the entire study area because of the unique oligohaline character of the upstream waters. Use of salinity as a conservative tracer required careful analysis of salt composition of both the St. Johns River main stem and predominate inflows from tributaries, springs, and diffuse groundwater.

Salinity in the SJR varies from fresh ($S < 0.5$) to marine ($S > 30$). Salinity ecological zones were derived by classifying observed mean salinity according to the Venice Salinity Classification. The downstream oligohaline zone is due to mixing with seawater. Upstream areas have broad expanses of oligohaline (salinity between 0.5 and 5) conditions. Upstream intrusion of salinity in the lower SJR as a result of proposed water withdrawals in the middle SJR would not significantly affect the position of the salinity zones. Several marine species, including Atlantic Stingray and Striped Mullet, have permanent breeding populations all along the lower and middle SJR. Many others, including Striped Bass, American and Hickory Shad, are able to seasonally migrate hundreds of kilometers inland due to the oligohaline character of the river.

The presence of relict seawater in the MSJR is related to geomorphology (Tibbals, 1990). Reef structures built during the Eocene and Oligocene now form the limestone substrates of the Floridan Aquifer. The principal confining unit of the Floridan Aquifer is the Hawthorn Formation, deposited during the Miocene. Younger deposits that form surficial aquifers covered the Hawthorn Formation to varying depths in the Pliocene and Pleistocene age. Geologic and erosional processes have left the Hawthorne virtually absent as a confining unit in the MSJR, allowing for increased interaction between the UFA and surface waters. The SJR now rests in erosional Hawthorn Formation and younger deposits. The rise and fall of sea level during the Pleistocene epoch caused repeated inundation and exposure of the SJR valley. It was during periods of inundation that seawater penetrated the UFA below the SJR.

Tributaries discharging from above an elevation of 25 ft NGVD are typically bicarbonate dominated. In general they have concentrations of chloride a magnitude lower than the SJR. Smaller tributaries that drain locally, mostly below 25 ft NGVD, are typically dominated by relict seawater (chloride). Creeks draining urbanized areas tend to be mixed in character, due to the addition of water from municipal /anthropogenic sources. Creeks with major spring sources tend to be similar in salt character to their contributing springs.

Spring salinity is directly influenced by the presence of relict seawater and the type of rock present in contributing sources. Several District springs analyzed and compared to the major constituents in ocean standard salinity. When concentrations were normalized and sorted on chloride, the plot reveals a general distribution based on the approximate elevation of the source pool for each spring, with relative abundance of chloride increasing with decreasing elevation.

2. BACKGROUND

2.1 Geomorphology and Relict Seawater

During the Eocene and Oligocene Epochs of the Tertiary Period, the Florida Platform was a shallow sea. Reefs grew over millions of years and were then covered in sand as Florida emerged from the water (White, 1970). These reefs now form the limestone substrates that contain the Floridan aquifer (Johnson, 1982). Limestone in the Floridan aquifer is overlain by the less permeable sediments of the Hawthorn Formation. These sediments were deposited in the Miocene and are the Floridan aquifer's principal confining unit (Hoenstine, 1984). Younger deposits that form surficial aquifers covered the Hawthorn Formation to varying depths in the Pliocene and Pleistocene age (Johnson, 1982). The St. Johns River now rests in erosional Hawthorn Formation and younger deposits (White, 1970).

The transgression (sea level rise) and regression (sea level fall) due to glacial geology (Flint, 1947) has reoccurred at least 8 times during the past 2 million years (Vail, 1978). Transgressions at 100,000-year plus scales have occurred at least 4 times (Zelmmer, 1979). Smaller oscillations in sea level also occur at 1,000-year scales. Starting from the last glacial maximum 22,000 years ago sea level began increasing from a low stand about 350 feet below present and reached present sea level 6000 years ago (Balsillie, 2004). Since that time, sea level has oscillated between several feet above and below present sea level at least 4 times, with a present trend of increasing sea level. With previous inundation of the SJR valley, Eocene substrates that comprise aquifer-bearing formation such as the Upper Floridan Aquifer were saturated with Pleistocene seawater. This water has been flushing out of the system to varying degrees since the last low stand (Stringfield, 1951).

Variations in thickness of the Hawthorn Formation largely determine the extent of interaction between groundwater and surface waters. Groundwater interactions are least where the Hawthorn Formation is thickest, in the lower St. Johns River and upper portions of the upper St. Johns River. In the lower St. Johns River, the Hawthorn Formation thickens to a maximum of 500 ft downstream of State Road (SR) 40 (Scott, 1983). In the upper St. Johns River, the Hawthorn Formation thickens to 400 ft upstream of SR 520. Most of the lower St. Johns River and upper St. Johns River occupy a surface feature known as the Eastern Valley (White, 1970). In the area now occupied by the lower St. Johns River, episodes of faulting and warping resulted in a downward flexure that deepened this portion of the Eastern Valley (Scott, 1983). The deepening resulted in a thick Hawthorn Formation that contributes to the general lack of springs and overall lack of diffuse groundwater discharge (Spechler, 1994).

The Hawthorn Formation is thin or absent in the middle St. Johns River and lower portion of the upper St. Johns River, ranging in thickness from 0 to 50 ft (Johnson, 1982). In these areas the river receives groundwater inflows from numerous springs and diffuse groundwater discharge. These groundwater inflows flush relict seawater from the underlying Floridan aquifer to the river. The thinning of the Hawthorn Formation in this area primarily resulted from geological uplift followed by erosion of the uplifted Hawthorn Formation sediments. Uplifted features are generally associated with minimal overburden where the Floridan aquifer is closest to the surface (Opdyke, 1984).

2.2 The Offset Course of the St. Johns River

The present course of the middle St. Johns River, from Lake Harney to Palatka, flows through a valley older than the Eastern Valley. The offset course of the St. Johns River has distinct hydrogeologic features that cause this reach of the river to be strongly influenced by the Upper Floridan aquifer. Because the Upper Floridan aquifer in this reach of the river contains relict seawater, the middle St. Johns River has high chloride levels and a distinct oligohaline salinity regime.

The path of the river is diverted west around the Volusia Block Fault (Wyrick, 1960). The Volusia Block Fault underlies western Volusia County and emerged in the late Tertiary or early Pleistocene period (White, 1970) and was likely influenced by the glacial eustatic fluctuations of sea level during the Pleistocene (Alt, 1965). It now forms the DeLand Ridge, an important recharge area for springs that lie along its base (Figure 1). There is evidence for a relict path of the St. Johns River to the east of the Volusia Block Fault that extends directly from Lake Harney to Crescent Lake through the Eastern Valley (Pirkle, 1971). The offset course of the St. Johns River may have originated as a spring-fed river starting near the headwaters of the present Wekiva River. The presence of substantial artesian inputs through springs and diffuse groundwater discharge has helped maintain the present course of the middle St. Johns River through this ancestral valley (Pirkle, 1971).

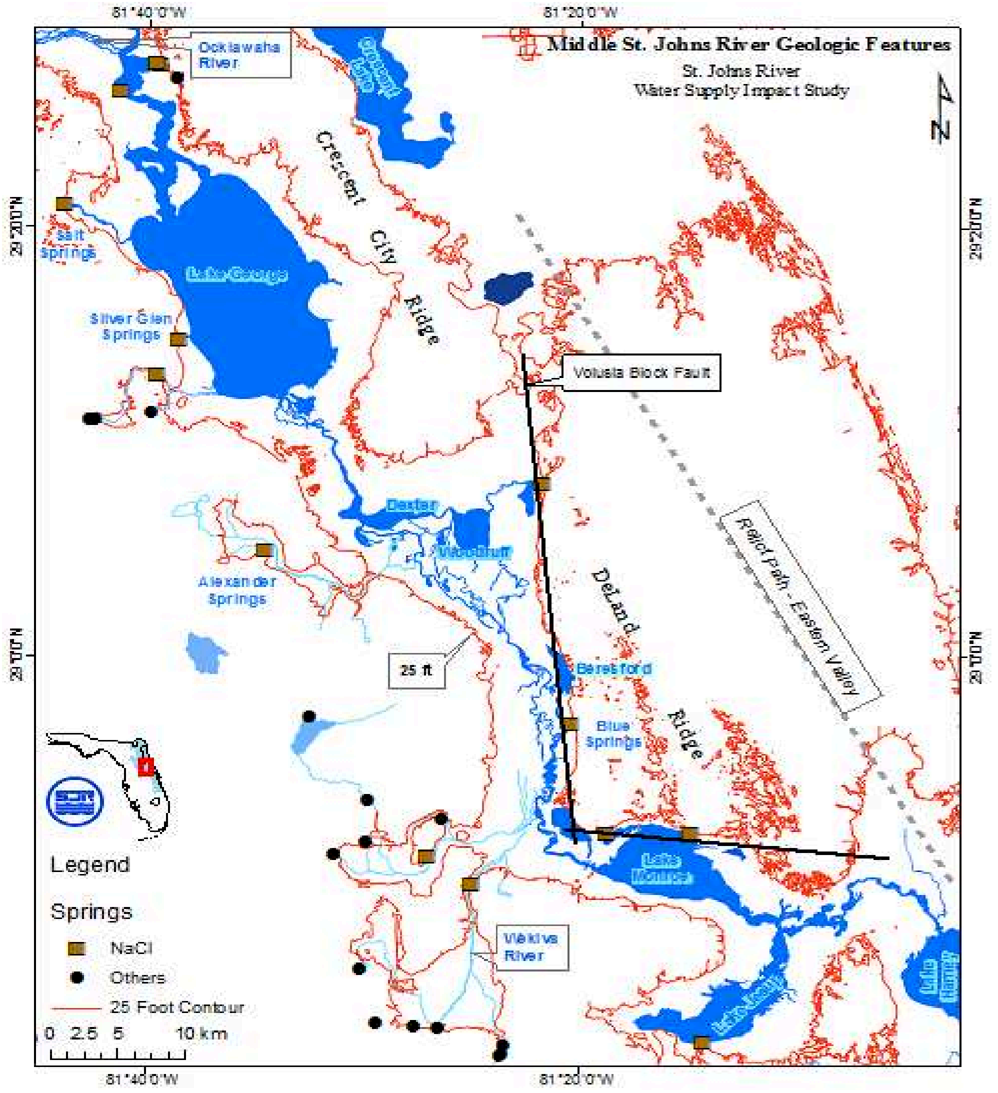


Figure 1 Topography and geology of the St. Johns River Basin between Lake Harney and the Ocklawaha River. The river enters a geologically older valley downstream of Lake Harney as it flows around the Volusia Block Fault.

2.3 Springs

Probably the most charismatic expression of the connection between ground and surface waters within SJRWMD is spring discharge (Ferguson, 1947). Springs are primarily found in the middle St. Johns River downstream of Lake Monroe and along the west shore of Lake George (Figure 2). The largest spring within SJRWMD is Silver Springs that flows to the St. Johns River through the Ocklawaha River.

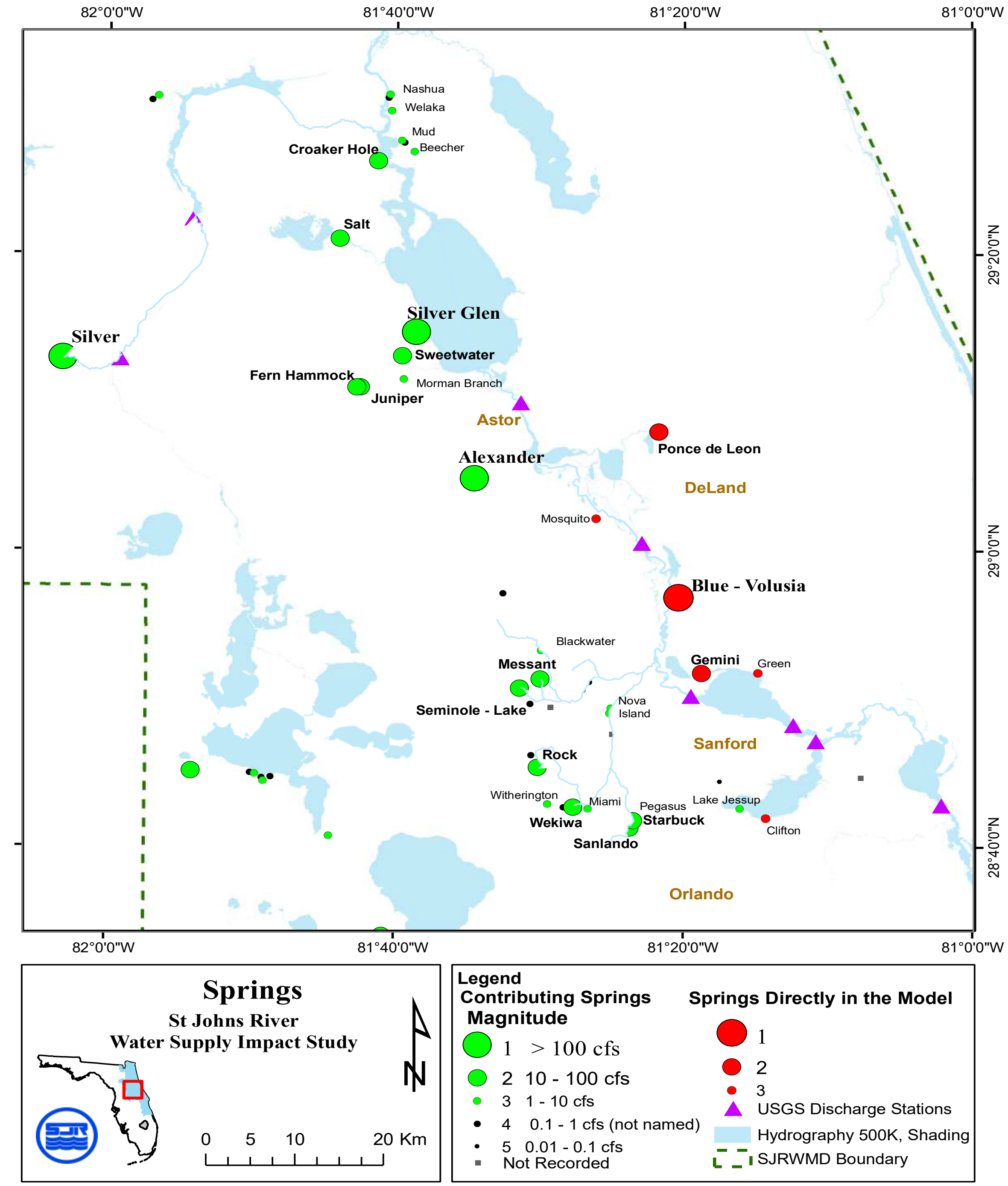


Figure 2 Location and magnitude of St. Johns River Water Management District springs with measured discharge.

There is substantial variation in the quantity, type, and time scale of data available for each spring (Copeland, 2009). Mean discharge of springs varies over four orders of magnitude and conductivity (a measure of salinity) varies over two orders of magnitude (Figure 3).

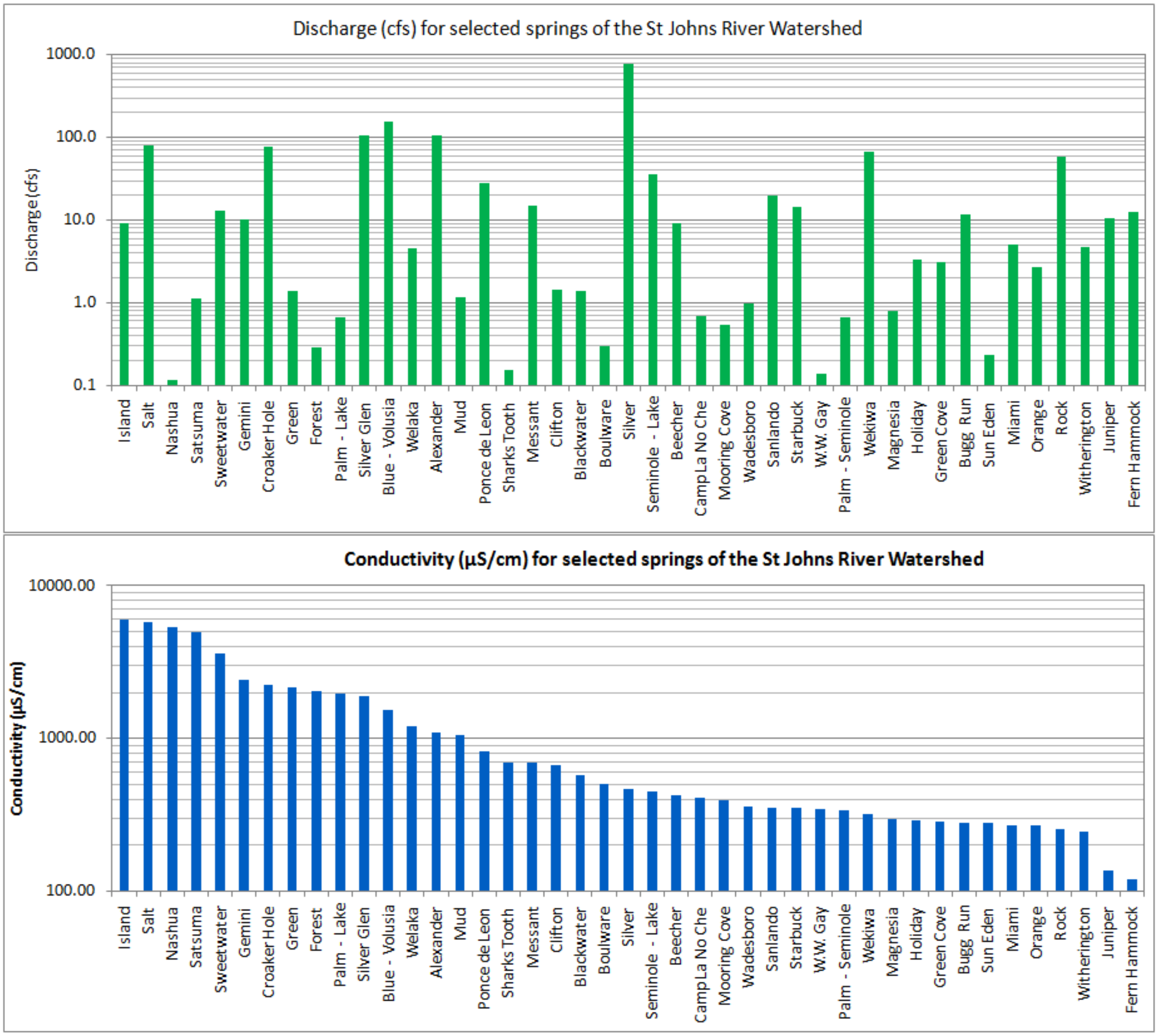


Figure 2 Mean discharge and conductivity of selected SJRWMD springs sorted by discharge.

The mass loading rate of salts from a spring to the river is determined by the product of discharge and salinity. The total discharge from the springs in Figure 3 was 1053 mgd, and the chloride load was 1040 $t\ d^{-1}$. Silver Springs has the greatest discharge among all springs but a relatively low salinity (conductivity). The total mass contribution of salts from Silver Springs is relatively small, although it is the largest single point source of bicarbonate alkalinity (HCO_3) to the St. Johns River. Salt Springs is the largest single point source of salt load to the St. Johns River. The salt load from Salt Springs is greater than the combined salt load of all surface runoff downstream of that point.

Springs that contribute relict seawater to the river are identifiable by high chloride concentration(> 250 $mg\ L^{-1}$), high conductivity (>1000 µs/cm), and a salt composition similar to seawater. These springs occur at lower elevations near the river and are symbolized as sodium chloride (NaCl) springs in Figure 1. Springs with pool elevations above 25 ft NGVD29 (National Geodetic Vertical Datum of 1929) have low levels of chloride, while springs below 25 ft have consistently high levels of chloride. Salt composition of springs with pool elevations below 5 ft is similar to ocean water and dominated by NaCl, while springs with pool elevations above 25 ft are dominated by bicarbonate, HCO_3, (Figure 4). The eight ions in Figure 4 comprise a majority of the salts found in seawater.

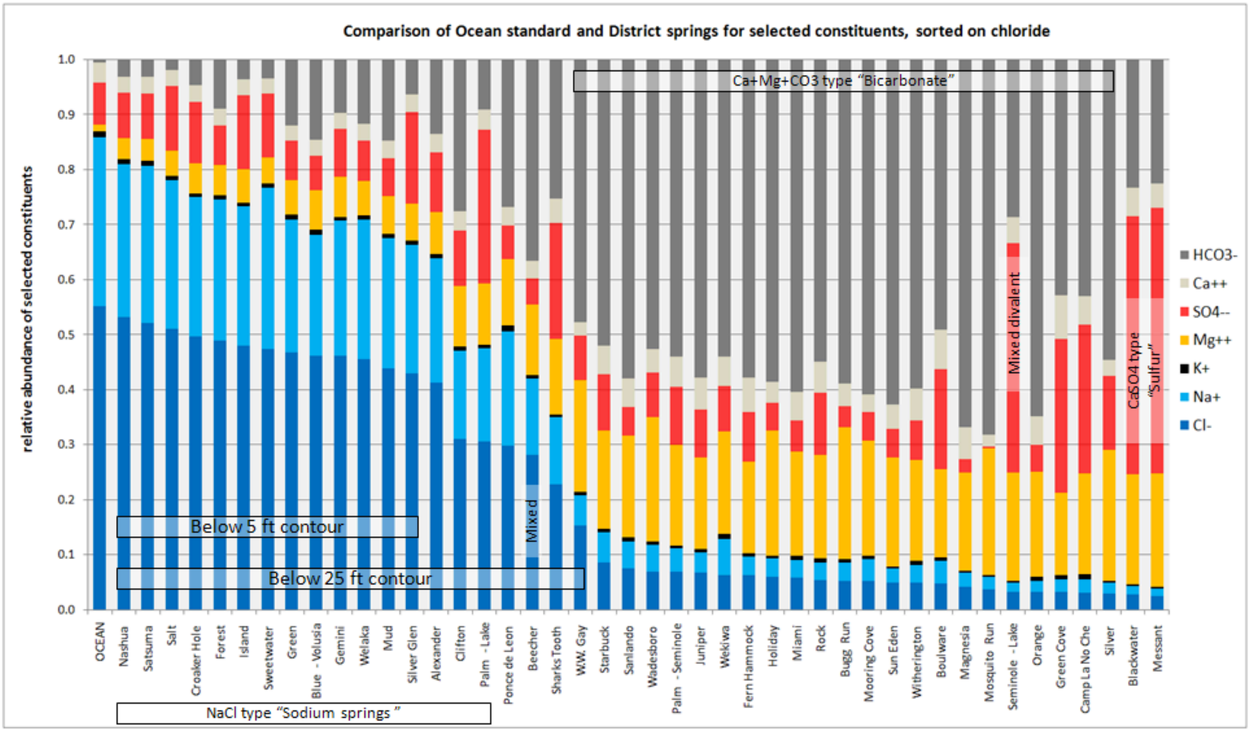


Figure 3 Salt composition of selected springs compared to the Ocean Standard. Springs are sorted by chloride abundance. Springs most similar to ocean water lie below an elevation of 5 ft NGVD29 and have salts dominated by relict seawater.

2.4 Diffuse Groundwater Discharge

In addition to spring discharge, diffuse groundwater discharge is an important source of relict seawater to the river (Belaineh, 2012). The middle St. Johns River, because of its thin Hawthorn Formation, has high diffuse groundwater discharge that contains appreciable quantities of relict seawater. Groundwater chloride concentrations are highest directly beneath the middle St. Johns River channel (Figure 5). High diffuse groundwater discharge and chloride coincide because the same factors that now allow groundwater exchange to the river also allowed seawater to inundate the underlying aquifers during past periods of higher sea level stand. The factors allowing groundwater exchange include a thin or absent Hawthorn Formation, faulting along the Volusia Block Fault, and previous channel incision at lower sea level stands (Belaineh, 2012). Finally, because the upper limit of Pleistocene sea level inundations were near the present 25 ft contour, relict seawater is only found below that elevation.

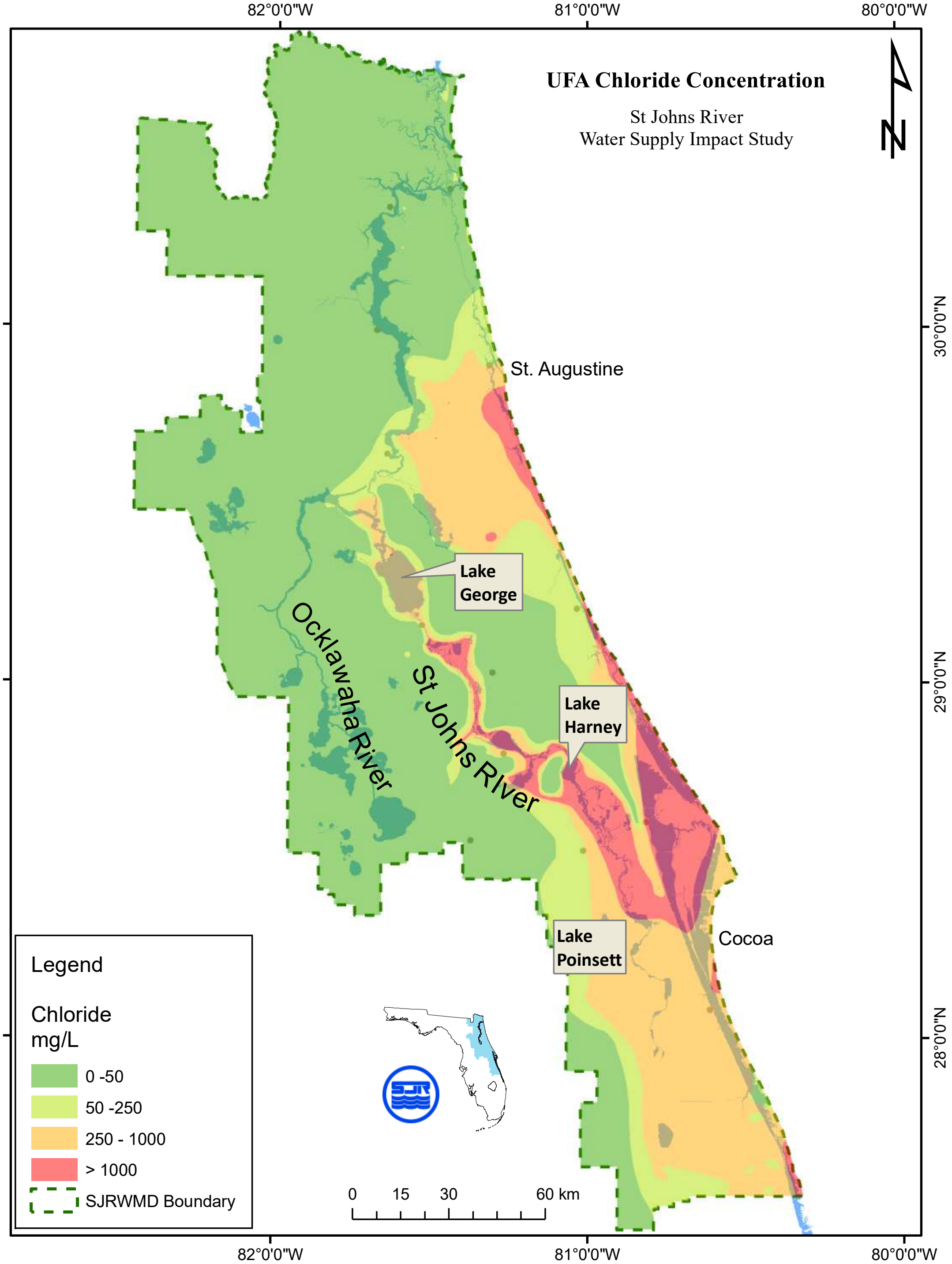


Figure 4 Chloride concentration in the Upper Floridan aquifer (UFA) within the St. Johns River Water Management District (SJRWMD). High chloride concentrations occur directly along the path of the SJR between Lake Poinsett and Lake George.

Simulated chloride load from diffuse groundwater discharge is required as a boundary condition for the EFDC model because of its importance to the total chloride budget of the middle St. Johns River, and because there are no direct observations of chloride load (Belaineh, 2012). Chloride load could have been estimated by difference in a total chloride budget, but this methodology is compromised by dependence on the accumulated error of all components in the budget. In addition, the spatial resolution of chloride load estimated from a chloride budget would be coarse because it is limited to locations along the river with coincident observations of discharge and chloride concentration.

To resolve spatially varying groundwater chloride load, the EFDC model was subdivided into 16 sub regions. Steady-state groundwater discharge and chloride load, derived from the groundwater models, are assigned to each sub region. The total area of the EFDC model sub regions (127.8 km^2) is smaller than the total area of the five middle St. Johns River groundwater segments (280 km^2) because the surface water and groundwater models differ in resolution and configuration, the EFDC model was configured to the geometry of the open waters of the middle St. Johns River and resolves the narrow channels between lakes. The differences in model resolution require that output from the groundwater models be adjusted to properly represent diffuse groundwater flows through the EFDC model cells. The estimated load from diffusive groundwater flux is presented for two reaches from SR 46 above Lake Harney to US 17-92 downstream of Lake Monroe, including offset Lake Jesup; and US 17-92 to SR 40 at Astor including offset Lake Woodruff (Table 1).

Table 1 Estimation of diffusive groundwater flux from the Upper Floridan Aquifer directly to the bottom of the SJR, SR 46 to SR 40.

River Reach	Area (km^2)	Diffuse Groundwater Discharge (mgd)	Chloride Load (t d^{-1})	Salinity
SR 46 to US 17-92	97	65.4	259.8	1.82
US 17-92 to SR 40	30.8	59.1	200.2	1.63

3. METHODS

Water quality data are used for setting salinity boundary conditions for tributaries, springs, and diffuse groundwater discharge. In order to establish that salinity can be treated as a conservative tracer (a substance that does not undergo transformations), we needed to examine the relationships between salinity, chloride, and salt composition. Water quality stations containing observations of the concentrations of major salt ions are used for this purpose (Figure 6). Water quality data were primarily obtained from SJRWMDs Water Quality Monitoring Network (Winkler, 2004) and supplemental data were obtained from FDEP, USGS, Orange County, City of Orlando, and City of Titusville. Water quality data are collected by SJRWMD at monthly to quarterly intervals and data collection methodologies are described by Winkler (2004). USGS collects water quality data as part of the National Water Information System (USGS, 2010) and data collection methodologies follow a standard protocol (Hem 1992). Kroening (2004) provides an excellent summary of water quality data available from both USGS and SJRWMD within the middle St. Johns River.

Summary statistics for chloride (Table 2) illustrate the generally high levels of salt concentrations found throughout the St. Johns River main stem relative to typical fresh surface waters. The source of high chloride over the lower 100 km of the river is seawater. The bulk of the river, from river km 100 to 400, is predominately oligohaline, with the source of chloride being groundwater entering the river through springs and as diffuse groundwater discharge. A relative maximum for chloride levels occurs near river km 330 in the upper St. Johns River (Figure 12).

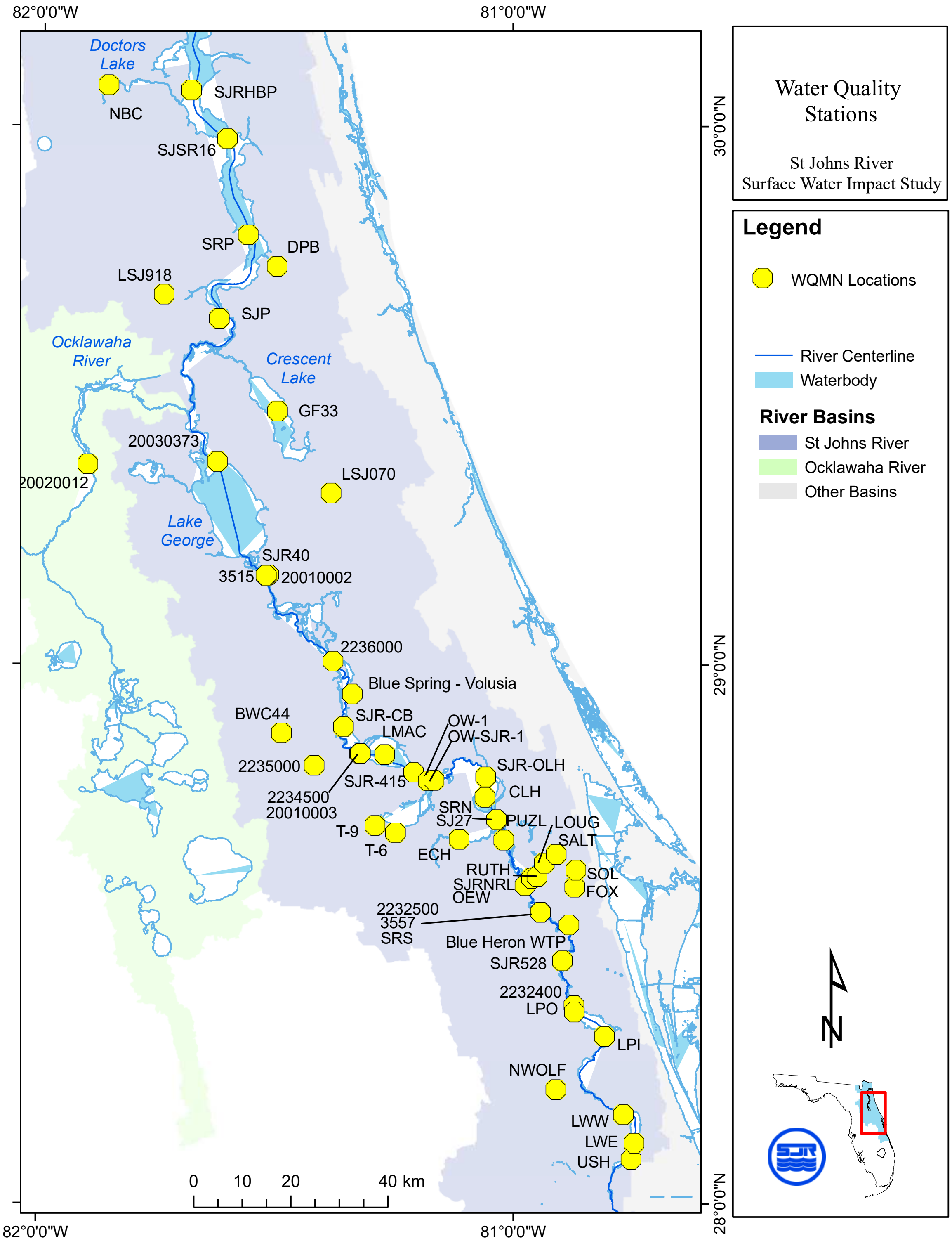


Figure 6 Water Quality Monitoring Network (WQMN) stations used for examination of salinity, chloride, and salt composition.

Table 2 Water quality sites along the St. Johns River main stem with summary chloride statistics.

Station ID	**River km**	**Agency**	***NRECS***	**Period of Record**	**Chloride (mg L^{-1})**		
					Min	***Mean***	***Max***
SJRHBP	68.7	SJRWMD	435	1995–2007	20	925	9,870
SJSR16	81.8	SJRWMD	201	1995–2007	83	425	4,944
SRP	102.7	SJRWMD	205	1995–2007	83	220	1,283
SJP	126.7	SJRWMD	254	1995–2007	86	194	353
20030373	176.8	SJRWMD	79	1995–2007	96	248	431
SJR40	204.3	SJRWMD	47	1999–2007	77	227	382
20010002	204.3	SJRWMD	136	1995–2007	78	225	380
3515	204.3	FDEP	83	1998–2006	78	212	380
2236000	232.3	SJRWMD	94	1995–2007	21	223	393
SJR-CB	251.0	SJRWMD	18	2002–2007	103	181	388
2234500	262.2	USGS	72	2000–2002	81	285	560
20010003	262.2	SJRWMD	49	1995–2001	85	257	580
LMAC	267.4	SJRWMD	82	1995–2007	69	250	573
SJR-415	274.6	SJRWMD	67	2002–2007	79	267	647
OW-1	279.7	SJRWMD	64	1995–2007	101	224	623
OW-SJR-1	281.4	SJRWMD	144	1996–2007	68	300	835
SJR-OLH	299.7	SJRWMD	63	2002–2007	77	282	700
CLH	303.9	SJRWMD	39	2001–2007	63	273	662
SRN	309.9	SJRWMD	167	1995–2007	15	272	866
SJ27	309.9	Orange County	13	1995–2000	126	246	523
PUZL	315.4	SJRWMD	2	1990	367	488	609
SJRNRL	330.0	SJRWMD	76	1996–2001	103	803	4,530
2232500	343.5	USGS	72	2000–2002	57	339	1,150
SRS	343.5	SJRWMD	217	1995–2007	12	329	3,750
3557	343.5	FDEP	83	1998–2006	49	243	940
SJR528	364.2	SJRWMD	77	1996–2001	44	196	595
2232400	378.0	USGS	87	2000–2006	30	209	647
LPO	379.5	SJRWMD	157	1995–2007	12	161	708
LPI	388.0	SJRWMD	159	1996–2007	11	142	612
LWW	413.9	SJRWMD	160	1996–2007	24	71	166
LWE	422.0	SJRWMD	171	1996–2007	18	63	160
USH	425.8	SJRWMD	63	2003–2007	17	67	138

Water quality sites off the St. Johns River main stem are shown separately in Table 3. These sites include representative tributaries, a spring, several offline lakes, and two wastewater treatment plants. In general, tributaries have low chloride levels, more typical of fresh surface water. Station DPB is an exception because it is located in a tributary that receives reject water from a reverse osmosis plant and agricultural discharge from saline wells (Munch, 1970). The offline lakes tend to have high chloride levels because they have low flushing and receive salt loading from groundwater. Blue Spring has high chloride typical of springs near the St. Johns River main stem. Wastewater treatment plants discharge low chloride waters because the sources of this water are primarily from domestic supply that necessarily requires low chloride levels as a secondary water quality standard. In summary, tributaries and wastewater treatment plants discharge low chloride waters to the river, generally a magnitude lower in concentration than the St. Johns River, but main stem of the St. Johns River generally maintains its oligohaline character because of salt loading from relict seawater derived from groundwater.

Table 3 Water quality stations off the St. Johns River main stem, with summary chloride statistics.

Station ID	**Type**	**River km**	**Agency**	***NRECS***	**Period of Record**	**Chloride (mg L^{-1})**		
						Min	***Mean***	***Max***
NBC	Tributary	71.0	SJRWMD	159	1995–2007	1	15	172
DPB	Tributary	106.4	SJRWMD	160	1995–2007	18	299	794
LSJ918	Tributary	121.4	SJRWMD	100	1995–2007	11	31	59
20020012	Tributary	162.7	SJRWMD	138	1995–2007	7	13	73
GF33	Lake	144.7	SJRWMD	82	1999–2007	29	119	236
LSJ070	Tributary	144.7	SJRWMD	72	1995–2007	8	16	57
Blue Spring–Volusia	Spring	243.2	USGS	76	1996–2007	161	353	553
BWC44	Tributary	253.2	SJRWMD	78	1995–2007	9	13	18
2235000	Tributary	253.2	SJRWMD	88	1995–2007	18	37	92
T-9	Tributary	279.6	SJRWMD	61	1995–2000	12	24	35
T-6	Tributary	279.6	SJRWMD	63	1995–2000	15	26	38
ECH	Tributary	311.4	SJRWMD	160	1995–2007	12	48	111
RUTH	Lake	330.4	SJRWMD	2	1990	204	450	696
LOUG	Lake	330.4	SJRWMD	2	1990	1,360	1745	2,130
SALT	Lake	330.4	SJRWMD	2	1990	1,200	1716	2,232
SOL	Lake	337.5	SJRWMD	11	1989–1991	172	214	289
FOX	Lake	337.5	SJRWMD	11	1989–1991	231	337	504
OEW	WWTP	331.2	Orlando Utilities Commission	137	1995–2006	23	74	100
Blue Heron	WWTP	353.1	City of Titusville	55	1998–2007	85	167	356
NWOLF	Tributary	399.7	SJRWMD	373	1996–2007	6	16	30

3.1 The Practical Salinity Scale 1978

Salinity is calculated from specific conductivity collected using water quality sondes. Different manufacturers use different algorithms for this calculation, and the algorithm used by a company may change through time. For this report, salinity is recalculated from observed specific conductivity data to ensure uniformity between measurements.

Salinity derived from conductivity measurements is defined by a unitless scale called the Practical Salinity Scale (PSS78) (Lewis, 1978). The Scale was established to provide a practical means of measuring salinity by conductivity that is reproducible, conservative, and provides accurate computation of density differences (Lewis, 1978). PSS78 defines salinity as a unitless number based on a conductivity ratio between the conductivity of a water sample and conductivity of a standard solution. PSS78 salinity provides accurate calculation of density differences for simulation of dynamic effects within the hydrodynamic model application regardless of shifting salt composition when waters dominated by ocean salts are mixed with waters dominated by terrestrial salts. PSS78 salinity can be used as a conservative tracer even with shifting salt composition as long as the ions predominately contributing to the salinity are themselves conservative. In this case, salinity is superior to chlorinity because of the greater accuracy in measuring salinity compared with chlorinity by means of conductivity. The caveat that the major ions accounting for salinity are themselves conservative is addressed by examination of the salt composition of the St. Johns River main stem over varying flow conditions.

4. RESULTS AND DISCUSSION

4.1 Observed Salinity in the St Johns River Mainstem

Observed salinity is available from both continuous and synoptic stations. Eight continuous stations are maintained by USGS and record hourly salinity. There are 29 synoptic stations observed at (usually) monthly intervals as part of SJRWMDs Water Quality Monitoring Network (WQMN). The synoptic stations have high spatial resolution, while the continuous stations provide high temporal resolution. Together these two networks capture salinity variability of the lower and middle St. Johns River over ecologically relevant time scales. Salinity gauges cover both the lower (Figure 7) and middle (Figure 8) St. Johns River. The synoptic stations were selected from a larger set of stations based on record length and location. Metadata (Table 4) and descriptive statistics (Table 5) for each station are provided below. All salinity observations used for the WSIS are derived from conductivity measurements (APHA, 1995).

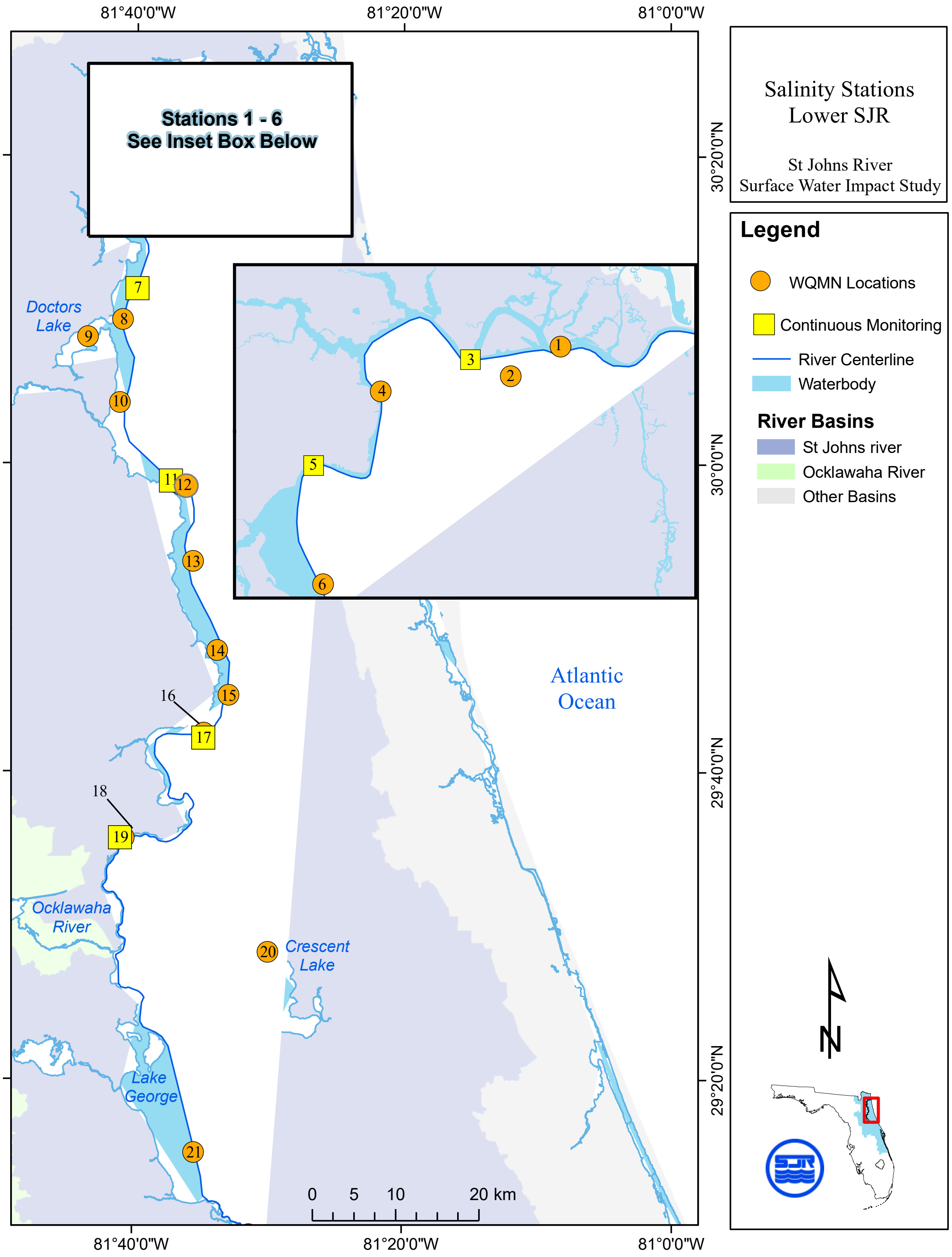


Figure 7 Locations of observed salinity stations (#1 to 21) in the lower St. Johns River. Orange circles denote Water Quality Monitoring Network (WQMN) locations and yellow squares denote locations of continuous monitoring. SJR = St. Johns River.

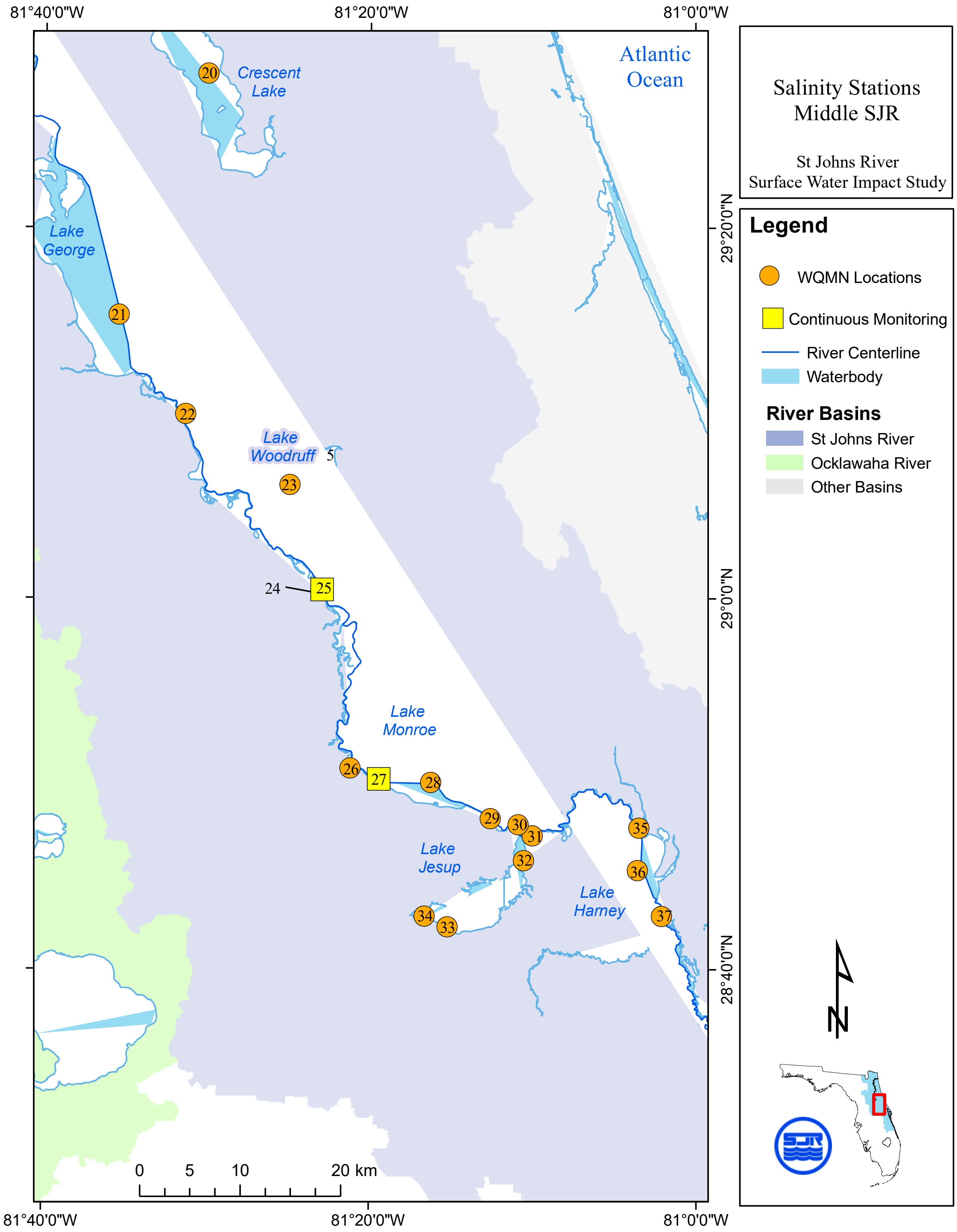


Figure 8 Locations of observed salinity stations (22 to 37) in the middle St. Johns River. Orange circles denote Water Quality Monitoring Network (WQMN) locations and yellow squares denote locations of continuous monitoring. SJR = St. Johns River.

Table 4 St. Johns River salinity stations arranged in downstream to upstream order. Map numbers refer to Figure 7 and Figure 8.

Map #	**Station ID**	**Agency**	**Period of Record**	**Lat**	**Long**	**River km**
1	JAXSJR04	SJRWMD	1998–2007	30 23.6	81 29.8	11.1
2	SAVMILCO	SJRWMD	1998–2002	30 23.6	81 31.8	17.2
3	Dames Point	USGS	1995–2006	30 23.2	81 33.5	17.3
4	JAXSJR17	SJRWMD	1998–2007	30 22.0	81 37.1	29.0
5	Acosta Bridge	USGS	1995–2003	30 19.2	81 39.5	38.1
6	JAXSJR40	SJRWMD	1997–2007	30 15.1	81 39.1	47.0
7	Buckman Bridge	USGS	1995–2003	30 11.5	81 41.4	55.0
8	MP72	SJRWMD	1993–2007	30 9.4	81 41.0	58.2
9	DTL	SJRWMD	1984–2007	30 8.3	81 39.1	63.1
10	SJRHBP	SJRWMD	1991–2007	30 4.0	81 41.2	68.9
11	Shands Bridge	USGS	1995–2001	29 59.0	81 38.0	79.3
12	SJSR16	SJRWMD	1991–2007	29 58.6	81 36.6	81.7
13	SJWSIL	SJRWMD	1997–2007	29 53.7	81 35.7	91.7
14	SRP	SJRWMD	1986–2007	29 47.9	81 33.9	101.6
15	SJM37	SJRWMD	1993–2007	29 45.0	81 33.0	108.8
16	FP42	SJRWMD	1993–2007	29 42.6	81 34.8	114.7
17	Dancy Point	USGS	1998–2005	29 42.6	81 34.8	115.0
18	BB22	SJRWMD	1993–2007	29 35.6	81 40.9	145.3
19	Buffalo Bluff	USGS	1995–2002	29 35.6	81 40.9	145.3
20	GF33	SJRWMD	1978–2007	29 28.3	81 30.0	160.0
21	LAG	SJRWMD	1989–2007	29 15.3	81 35.5	190.7
22	20010002	SJRWMD	1996–2007	29 10.6	81 31.4	204.4
23	LKWOOD	SJRWMD	1992–2006	29 3.7	81 14.7	223.1
24	2236000	SJRWMD	1996–2006	29 0.5	81 23.0	231.4
25	02236000	USGS	2000–2002	29 0.5	81 23.0	231.4
26	SJR-DPP	SJRWMD	2003–2007	28 50.9	81 21.3	258.6
27	02234500	USGS	2000–2002	28 50.3	81 19.5	262.0
28	LMAC	SJRWMD	1995–2007	28 50.1	81 16.3	267.2
29	SJR-415	SJRWMD	2003–2007	28 48.2	81 12.6	274.5
30	OW-SJR-2	SJRWMD	1996–2003	28 47.8	81 10.9	278.4
31	OW-SJR-1	SJRWMD	1996–2007	28 47.2	81 10.0	281.3
32	OW-2	SJRWMD	1995–2007	28 45.9	81 10.6	282.1
33	OW-4	SJRWMD	1995–2007	28 42.3	81 15.2	292.8
34	OW-6	SJRWMD	1995–2007	28 42.9	81 16.7	295.6
35	SJR-OLH	SJRWMD	2003–2007	28 47.6	81 3.6	299.6
36	CLH	SJRWMD	2002–2007	28 45.4	81 3.6	300.6
37	SRN	SJRWMD	1995–2007	28 42.8	81 2.1	310.1

Table 5 Descriptive statistics for St. Johns River salinity stations. Map numbers refer to Figure 7 and Figure 8.

Map #	**River km**	**Station ID**	***NRECS***	***Mean***	***STDEV***	**5%**	***1Q***	***Median***	***2Q***	**95%**
1	11.1	JAXSJR04	1,110	25.0	7.9	9.4	20.3	27.0	31.3	34.4
2	17.2	SAVMILCO	101	16.6	8.4	2.9	9.3	16.7	22.8	29.8
3	17.3	Dames Point	173,765	22.8	6.8	10.1	18.6	23.7	27.9	32.3
4	29.0	JAXSJR17	1,085	13.8	8.5	1.0	6.4	13.8	20.2	28.3
5	38.1	Acosta Bridge	190,765	6.9	6.3	0.29	1.6	5.2	10.8	19.3
6	47.0	JAXSJR40	661	5.5	5.7	0.26	0.61	3.3	8.5	16.2
7	55.0	Buckman Bridge	170,075	3.0	3.8	0.27	0.40	1.0	4.4	11.1
8	58.2	MP72	588	3.1	3.9	0.24	0.32	0.64	4.8	10.9
9	63.1	DTL	686	2.8	3.0	0.27	0.51	1.3	4.7	8.9
10	68.9	SJRHBP	727	2.0	2.7	0.21	0.30	0.44	2.8	8.1
11	79.3	Shands Bridge	144,758	0.84	1.2	0.27	0.38	0.44	0.60	4.1
12	81.7	SJSR16	454	1.0	1.5	0.26	0.33	0.42	0.66	4.6
13	91.7	SJWSIL	355	0.67	0.72	0.26	0.35	0.44	0.63	2.2
14	101.6	SRP	614	0.51	0.31	0.27	0.35	0.46	0.60	0.75
15	108.8	SJM37	351	0.48	0.18	0.27	0.35	0.45	0.59	0.71
16	114.7	FP42	213	0.48	0.13	0.27	0.38	0.47	0.57	0.71
17	115.0	Dancy Point	115,557	0.47	0.13	0.27	0.37	0.44	0.58	0.70
18	145.3	BB22	558	0.49	0.15	0.28	0.36	0.47	0.63	0.75
19	145.3	Buffalo Bluff	57,420	0.49	0.13	0.28	0.39	0.48	0.59	0.72
20	160.0	GF33	203	0.25	0.13	0.10	0.14	0.22	0.36	0.48
21	190.7	LAG	158	0.53	0.18	0.26	0.36	0.55	0.68	0.84
22	204.4	20010002	255	0.50	0.21	0.23	0.34	0.50	0.63	0.76
23	223.1	LKWOOD	127	0.42	0.15	0.20	0.30	0.42	0.55	0.69
24	231.4	2236000	131	0.47	0.18	0.20	0.32	0.47	0.63	0.75
25	231.4	02236000	621	0.58	0.64	0.22	0.42	0.64	0.73	0.86
26	258.6	SJR-DPP	63	0.49	0.23	0.18	0.28	0.49	0.63	0.91
27	262.0	02234500	829	0.65	0.70	0.22	0.40	0.70	0.83	1.12
28	267.2	LMAC	112	0.52	0.25	0.20	0.30	0.47	0.73	0.93
29	274.5	SJR-415	67	0.58	0.32	0.19	0.30	0.52	0.82	1.13
30	278.4	OW-SJR-2	348	0.54	0.27	0.20	0.34	0.49	0.73	1.08
31	281.3	OW-SJR-1	282	0.58	0.32	0.19	0.34	0.53	0.80	1.18
32	282.1	OW-2	240	0.50	0.24	0.25	0.31	0.41	0.60	0.98
33	292.8	OW-4	280	0.39	0.17	0.19	0.25	0.36	0.49	0.77
34	295.6	OW-6	280	0.34	0.16	0.15	0.21	0.31	0.38	0.53
35	299.6	SJR-OLH	63	0.60	0.32	0.17	0.32	0.52	0.84	1.17
36	300.6	CLH	73	0.60	0.32	0.17	0.32	0.51	0.84	1.14
37	310.1	SRN	168	0.53	0.35	0.11	0.23	0.43	0.83	1.11

NRECS = Number of records
1Q = first quartile of distribution (25th percentile)
2Q = second quartile of distribution (75th percentile)

4.2 Upstream Extent of Ocean Salinity

The farthest observed upstream extent of ocean salinity over the period 1986 to 2007 was to river km 108.8 during May 2007. Salinity for stations between river km 81 (Shands Bridge and SJSR16) and river km 145.3 (BB22 and Buffalo Bluff) show the high salinity event of May 2007 (Figure 9). The salinity event is clearly an intrusion of seawater at both SJSR16 (river km 81.7) and SRP (river km 101.6) because salinity at these locations rises above 2. During this same period the background upstream salinity level at BB22 (river km 145.3) was unaffected by the intrusion. Salinity for a few observations at SJM37 (river km 108.8), however, are above the upstream background level and correlated with the intrusion event. By inference, these observations likely resulted from the intrusion event and place the farthest upstream extent of ocean salinity to river km 108.8.

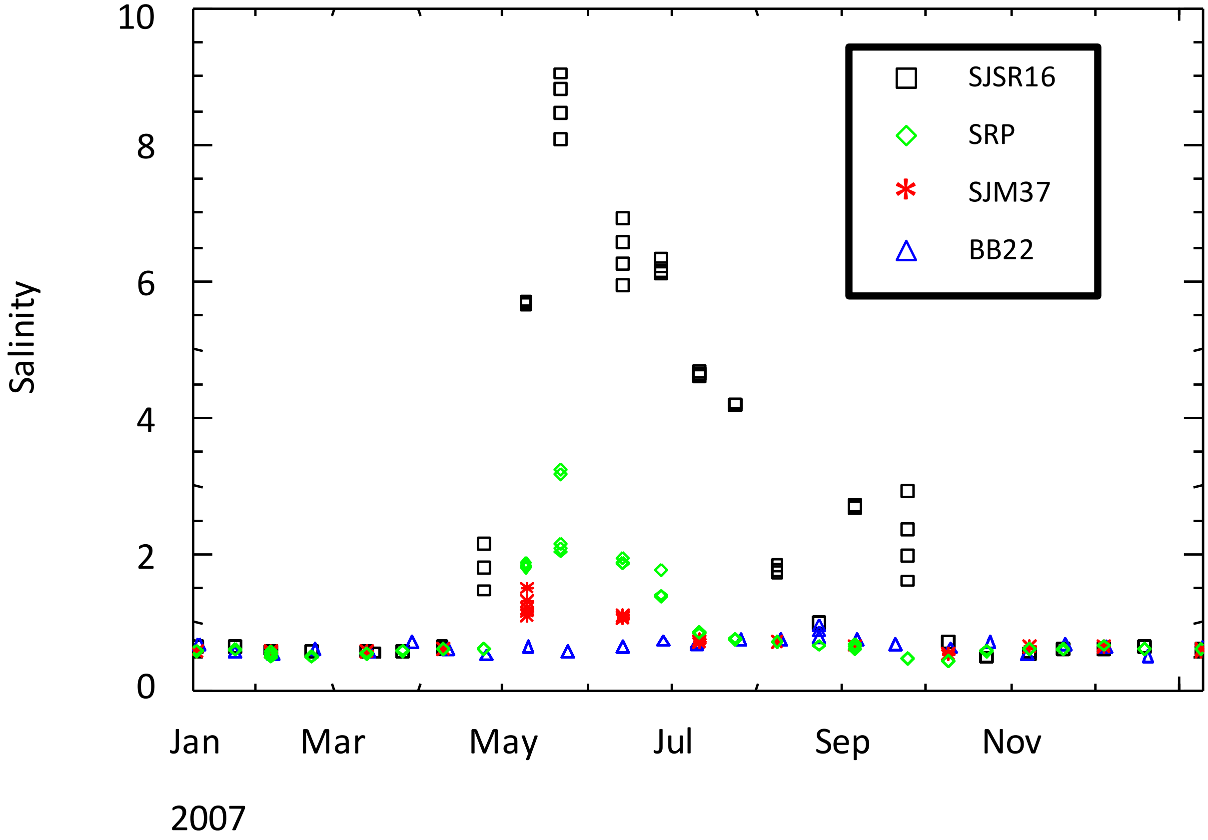


Figure 9 Comparison of salinity between Shands Bridge and Buffalo Bluff during the greatest observed upstream extent of salinity in May 2007. SJSR16, SRP, SJM37, and BB22 are salinity stations.

4.3 Seasonal Variation of Salinity

On average, salinity in the St. Johns River is highest in summer and lowest in winter (Table 6). Seasonal variation of salinity is characterized by calculating mean values for all observations at a station falling within a given month irrespective of year. The station indicated as “MSJR” is a composite of data taken from stations 2236000, LMAC, and OW-SJR-1. These three stations are all upstream of the confluence of the St. Johns River with the Wekiva River and together represent salinity conditions in the uppermost reach of the study area. Aggregating data from these stations was required to have a sufficient number of records within a selected month to produce a meaningful mean value.

Table 6 Monthly averaged salinity for all months available within station record. The middle St. Johns River (MSJR) is calculated from pooled observations using stations 2236000, LMAC, and OW-SJR-1.

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Dames Surface	21.1	21.5	21.0	20.9	24.4	25.1	22.2	22.8	21.6	19.5	19.4	19.9
Acosta Surface	4.6	6.1	6.9	8.2	11.6	10.8	7.8	8.0	6.6	4.8	3.8	4.0
Buckman Surface	0.9	1.2	2.0	3.3	4.6	5.7	8.3	2.7	2.2	1.6	0.9	1.3
Shands Surface	0.4	0.4	0.5	0.5	1.2	1.6	1.2	0.9	1.1	0.6	0.4	0.4
Dancy Point	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
Buffalo Bluff	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.4
MSJR	0.4	0.5	0.6	0.7	0.7	0.8	0.6	0.5	0.4	0.3	0.4	0.5

Salinity in the St. Johns River varies from fresh ($S < 0.5$) to marine ($S > 30$). Salinity ecological zones, derived by classifying observed mean salinity according to the Venice Salinity Classification (Venice Symposium 1958), show polyhaline (salinity between 18 and 30) conditions to Dames Point and mesohaline (salinity between 5 and 18) conditions to Buckman Bridge (Figure 10). Salinity in these areas results from mixing of fresher river waters with seawater. Upstream areas have broad expanses of oligohaline (salinity between 0.5 and 5) conditions.

Salinity in the St. Johns River varies with river flow and meteorological tide. In the polyhaline zone, large river discharge can lower salinity to 10 (Figure 11). The downstream oligohaline zone, between Buckman Bridge and Racy Point, is due to mixing with seawater. Intrusions of seawater can raise salinity to 10 at Buckman Bridge. Upstream of the areas of ocean-influenced salinity, salinity is regularly above 0.5 (Figure 12). Salinity in upstream oligohaline zones result from the inflow of relict seawater from underlying groundwater. These waters have chloride levels distinctly greater than typical freshwaters so that all these areas are functionally oligohaline.

Astronomical tide extends to Lake George, so it is physically possible that ocean salinity and relic seawater can mix in the lake, but the Ocklawaha River and Dunns Creek enters the St Johns River downstream, bringing with it a substantial freshwater input that inhibit the upstream transport of ocean salinity. The overlap defines a lower tidal estuarine zone and a tidal freshwater zone.

Astronomical tide is absent upstream of Lake George, but meteorological tide extends through Lake Harney. The salinity throughout this reach (Lake George to Lake Harney) is dominated by relict seawater. The areas upstream of Lake Harney are not affected by ocean tide. These areas are divided by relict seawater-dominated waters downstream of Lake Washington and fresh, low-chloride waters upstream of Lake Washington.

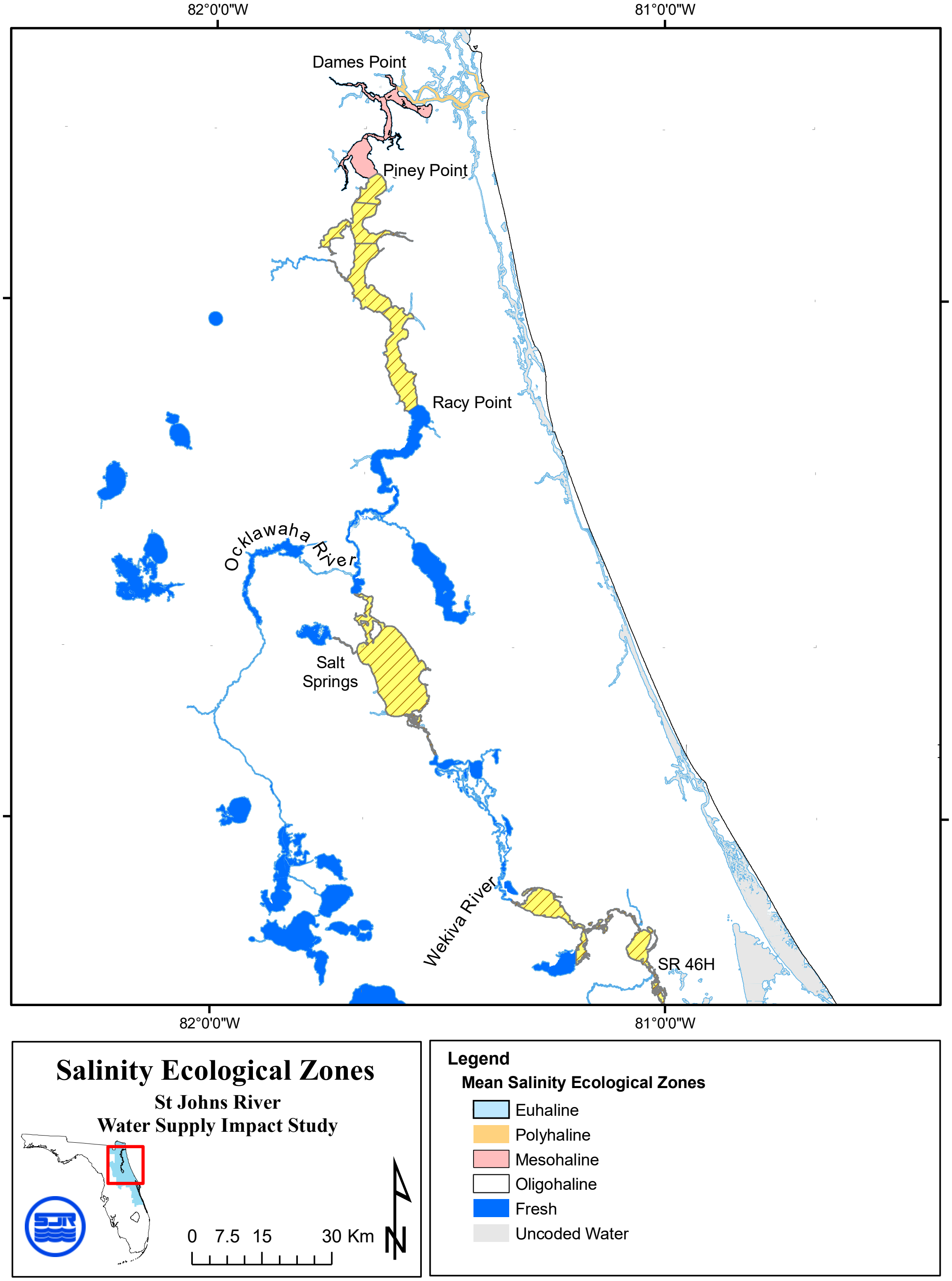


Figure 10 Salinity ecological zones based on the Venice Salinity Classification for the St. Johns River using observed mean salinity. Salinity ranges by zone are as follows: euhaline (30 to 40), polyhaline (18 to 30), mesohaline (5 to 18), oligohaline (0.5 to 5), and fresh (< 0.5). SR46H = State Road (SR) 46 above Lake Harney.

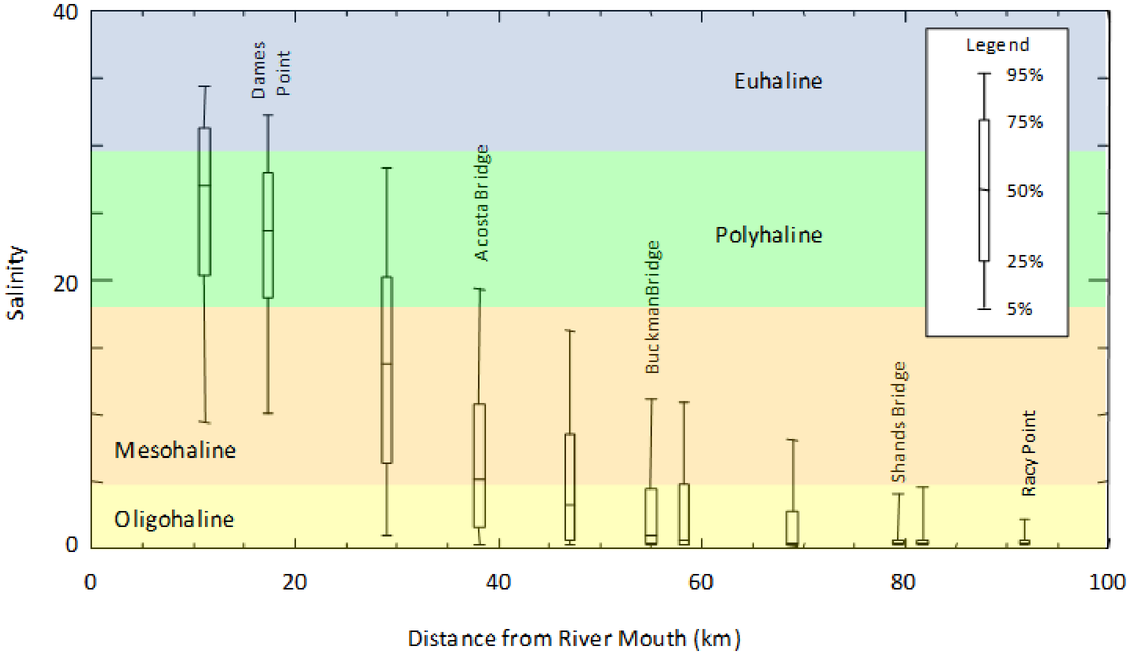


Figure 11 Five-point plots of observed salinity distributions in the St. Johns River over the first 100 river kilometers.

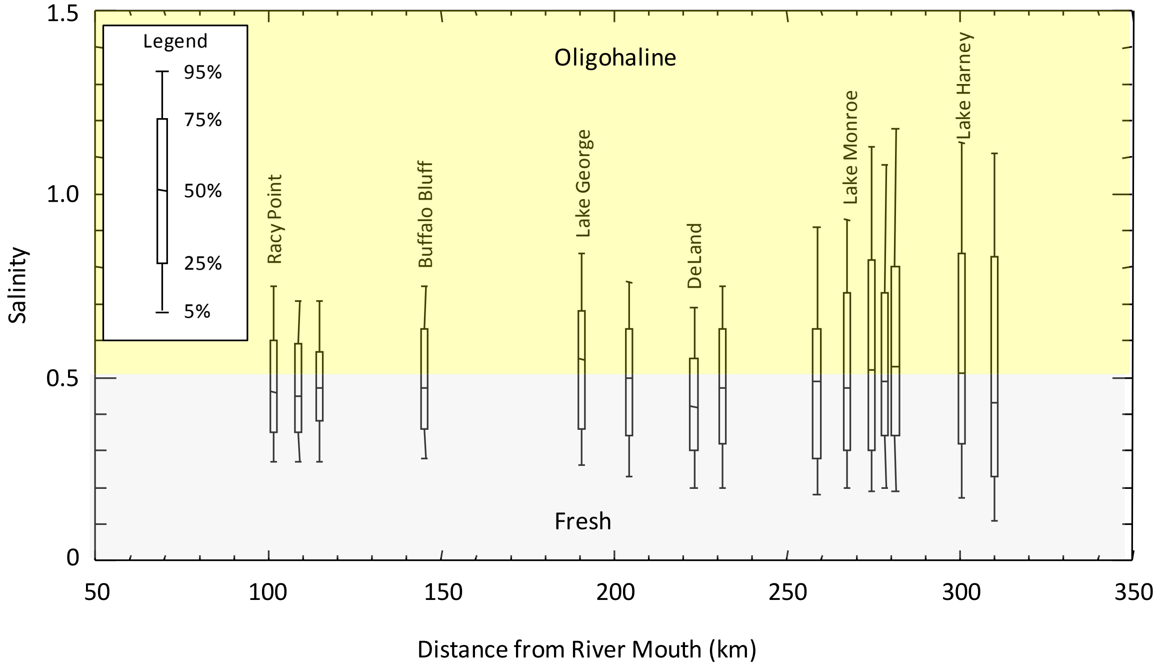


Figure 12 Five-point plots of observed salinity distributions in the St. Johns River for river kilometers 100 to 310, Racy Point to Lake Harney.

4.4 Salt Composition of the St. Johns River Main Stem

Salinity along the lower and middle St. Johns River main stem ranges from 0.1 in upstream areas under high flow conditions to over 36 near the mouth. High salinity waters near the mouth are derived from ocean salts and salt composition is nearly identical to seawater. Of particular interest here are upstream oligohaline waters where salinity ranges from 0.1 to 1.5. High salinity in these upstream areas occurs during extended periods of low flow when river water is most affected by groundwater inflow and the associated flux of chlorides from relict seawater (Odum, 1953). However, salinity can decline 80% to 90% during the transition from low to high flow conditions and the question of whether this rapid dilution by surface water runoff shifts salt composition away from sodium-chloride dominance to the typical calcium-bicarbonate dominance of fresh surface waters is important for use of salinity as a conservative tracer. Sodium and chloride are conservative, while carbonate and bicarbonate, because they participate in acid base reactions, are not conservative.

4.5 The Maucha Diagram

Salt composition at 13 mainstem locations under low, median, and high discharge conditions is examined using Maucha diagrams to show relative abundance of major ions. The analysis extends upstream of the study area to include the upper St. Johns River for a better understanding of salt composition and sources entering the upstream model boundary. The examination of salt composition showed that the St. Johns River main stem is dominated by sodium, chloride, and sulfate ions over a wide range of discharge conditions. Because these are conservative ions, the associated salinity is also conservative.

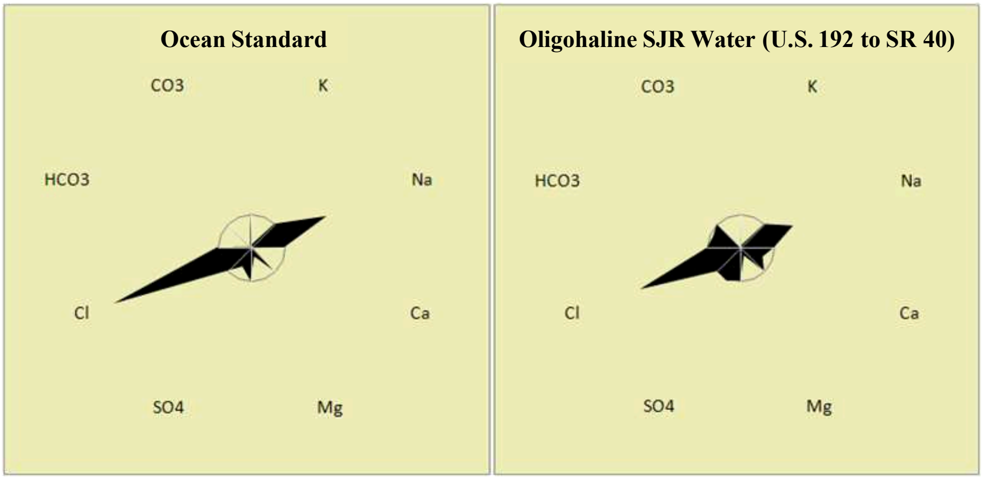
The Maucha diagram, or ionic polygonic diagram, shows the relative abundance of the major cations and anions in water (Maucha, 1932). Relative abundance is the ratio or percent of each constituent in solution. The same eight major cations and anions are found in both ocean and fresh waters—chloride (Cl^-), sulfate (SO_4^2), potassium (K^+), sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}). (For the remainder of this chapter the charge is omitted.) The Maucha diagram is a useful method of comparing the relative abundance of ions for locations with widely varying concentrations (Wetzel, 2001; Silberbauer, 1991).

Creation and use of the Maucha diagram is illustrated by comparing the average salt composition of the middle and upper St. Johns River to the salt composition of ocean water. Mean concentrations of the eight major ions from 612 samples between U.S. 192 and SR 40 is compared to the ocean standard in the top of Table . CO_3 and HCO_3 concentrations were calculated from observed alkalinity and pH (Sawyer, 1994). Ocean concentrations generally exceed the mean concentrations of the oligohaline reach of the St. Johns River by one to two orders of magnitude.

Relative abundance is shown by normalizing a set of eight concentrations by the average of the eight concentrations. The average of a set of normalized values, then, equals one and the sum of a set of normalized values equals eight. Normalized values for the ocean standard and oligohaline reach of the St. Johns River are shown in the bottom of Table 7. The normalized values show similarities between the relative abundance of ions in ocean water compared with the waters of the oligohaline reach of the St. Johns River. Finally, the normalized values are used to create Maucha diagrams for visual comparison of the relative abundance of salts between these two data sets (Figure 13).

Table 7 Comparison of eight main salt constituents in the ocean standard to average values for the St. Johns River.

	Observed Concentration (mg L^{-1})						Calculated Concentration (mg L^{-1})	
	Cl	**SO_4**	**K**	**Na**	**Mg**	**Ca**	**HCO_3**	**CO_3**
Ocean Standard	19,354	2,712	399	10,770	1,290	412.1	140.67	1.66
Average U.S. 192 to SR 40	222.4	73.7	5.5	116.4	17.4	48.8	60.18	0.09
	Observed (Normalized)						**Calculated (Normalized)**	
	Cl	**SO_4**	**K**	**Na**	**Mg**	**Ca**	**HCO_3**	**CO_3**
Ocean Standard	4.4138	0.6185	0.0910	2.4561	0.2942	0.0940	0.0321	0.0004
Average U.S. 192 to SR 40	3.2684	1.0825	0.0811	1.7098	0.2551	0.7176	0.8843	0.0013


Ocean Standard

Oligohaline SJR Water (U.S. 192 to SR 40)

Figure 13 Maucha diagrams comparing relative abundance of eight major ions in ocean water with the oligohaline reach of the St. Johns River (U.S. 192 to SR 40).

The Maucha diagram shows that Cl, Na, and SO_4 are the dominant constituents of both ocean water and waters of the oligohaline reach of the St. Johns River. This similarity exists even though the salts of the oligohaline reach of the St. Johns River are terrestrial in origin and not derived from mixing with seawater. The St. Johns River water contains some Ca and HCO_3, whereas the ocean water contains almost none. Still, the dominance of the conservative Na, Cl, and SO_4 ions in the St. Johns River water is clearly shown.

4.6 Relative Abundance Over a Range of Flow Conditions

Salt composition along the St. Johns River main stem was evaluated over a range of flow conditions to determine whether relative abundance of salts shifts within any portions of the river because of dilution by surface water runoff. Specific months representing low-, median-, and high-discharge conditions were selected for analysis. The low-flow condition (April 2001) represents a period of extended drought when flow was primarily derived from groundwater and springs, making salinity correspondingly high. The median flow condition (April 2003) had a monthly median discharge at SR 46 above Lake Harney similar to the median discharge for the period 1996 to 2006 (USGS, 2004). Flow during this period is nearly equally derived from groundwater, springs, and surface water runoff. The high-flow condition (November 2004 and March 1998) represents a period following a major precipitation event when surface water runoff dominates flow and salinity is correspondingly low. (March 1998 was used to replace unavailable data for the four northern sites.) Maucha diagrams were created at 13 locations for each of these flow conditions to show the spatial and temporal variability of salt composition (Figure 14).

Salt composition within the study area, from SR 46 northward, is dominated by Na and Cl under all flow conditions. The only location where HCO_3 is dominant is for the median- and high-flow conditions at U.S. 192 in the upper St. Johns River. The river reach from U.S. 192 to SR 46 exhibits a mixed character of salt composition under high-flow conditions with a significant fraction of Ca and HCO_3 in addition to Na and Cl. Downstream of SR 46 chloride dominates for all flow conditions.

The spatial shift in relative abundance of salts along the river is due to the principle source of salts within each river reach. At U.S. 192, the salt composition is characteristic of surface water runoff. Just upstream of U.S. 192, at an elevation of about 6 m above sea level, the St. Johns River becomes a defined surface drainage feature. The salt composition is dominated by dissolution of $CaCO_3$ and, to a lesser extent, $MgSO_4$. Salt composition changes abruptly to NaCl dominance between SR 50 to SR 46. Because this reach has minimal tributary contribution of chlorides, and no springs at all, the source of this chloride can only come from diffuse groundwater discharge and associated flux of chlorides from relict seawater. The Georgetown site shows a consistent decrease in relative abundance of HCO_3 compared with SR 40 and this feature is due to the proximity of Salt Springs, *the* major contributor of terrestrially derived NaCl mass to the river. HCO_3 abundance increases at US17 (near Palatka) due to the addition of Silver Springs waters by way of the Ocklawaha River. Silver Springs is the largest point source for bicarbonate to the St. Johns River. Downstream of SR 16, ocean salts begin to dominate relative abundance. The salt composition at SJRHBP during low flow conditions is essentially that of seawater.

Relative abundance of salts in Crescent Lake is similar to the adjacent St. Johns River, yet Stewart (2008) demonstrated that mixing of Crescent Lake waters with St. Johns River waters through Dunns Creek is insufficient to control salt composition of the lake. Crescent Lake instead derives its salts from local runoff. The salt composition of Crescent Lake is similar to that of Little Haw Creek, which drains north from the DeLand Ridge along the relict path of the St. Johns River through the Eastern Valley (Figure 1). The importance of local sources of salt to determining salt composition of such a large lake illustrates the importance of examining the salt composition of surface tributaries to the St. Johns River for the purposes of establishing proper salinity boundary conditions for the hydrodynamic model.

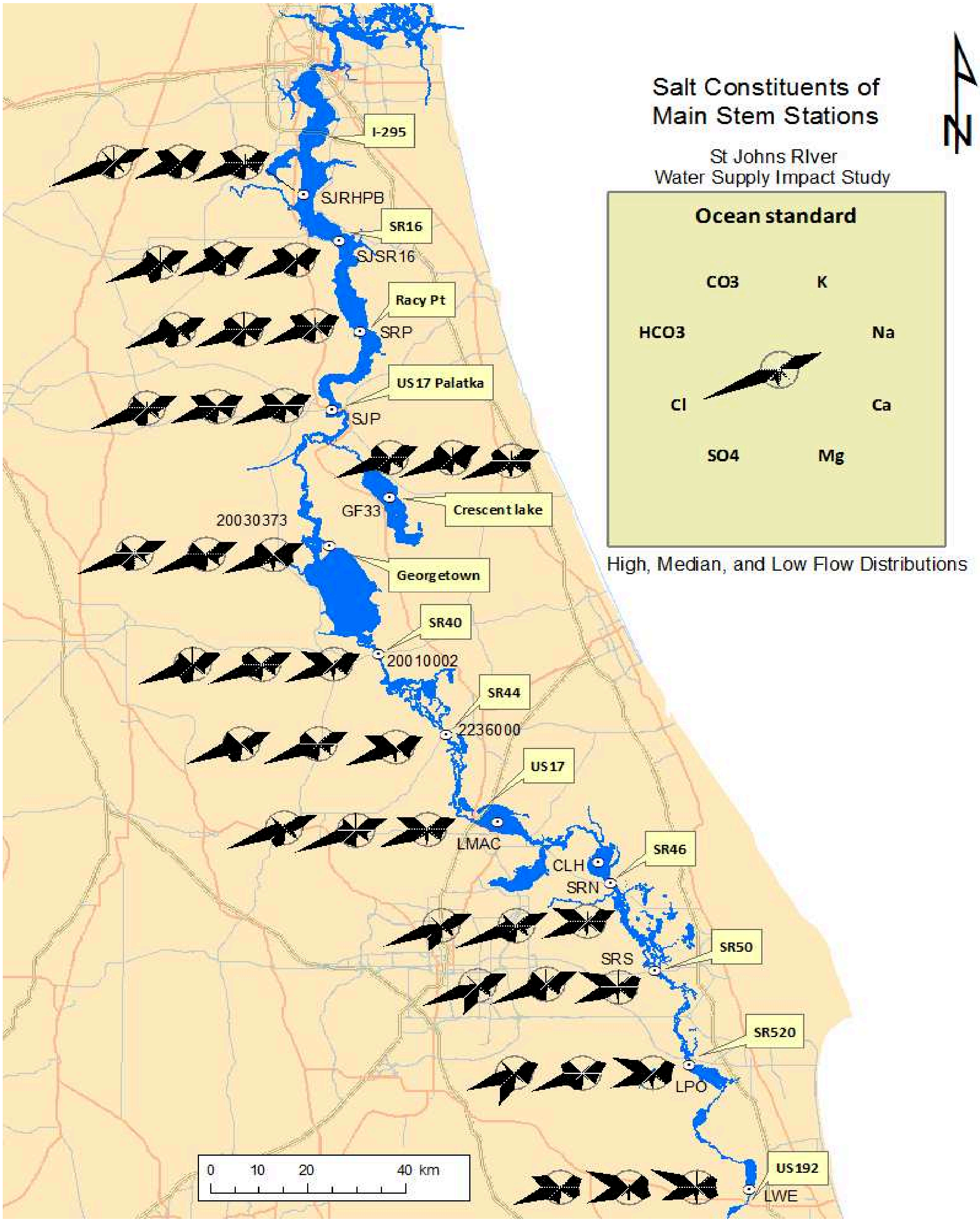


Figure 14 Maucha diagrams for the St. Johns River main stem. For each location the Maucha diagrams show, from left to right, relative salt abundance under low-, median-, and high-flow conditions.

4.7 Conductivity–Chloride Relationships in the Oligohaline Reaches

Although chloride is not used as an independent variable in the hydrodynamic model, chloride has importance to biological processes. Conductivity–chloride relationships were examined as part of the model development process to understand the possible utility of chloride as a direct conservative tracer and to develop an understanding of the sources of salinity to the study area. The conductivity–chloride relationships for the oligohaline river are summarized here to demonstrate that chloride concentrations in the river main stem can be reasonably estimated from conductivity observations. These results have general applicability to future studies of the chemical and biological characteristics of the river system.

Matched pairs of conductivity and chloride taken from 20 locations between U.S. 192 and SR 40 have a strong linear relationship with a slope less than that of diluted ocean water (Figure 15). The Seawater Line in Figure shows the conductivity–chloride relationship of diluted seawater estimated from the salinity:chlorinity ratio of 1.80655 for seawater (Lewis, 1980). The Seawater Line is the line for which the ratio of conductivity to chloride is identical to that of diluted seawater. The conductivity–chloride curve for seawater actually has a slightly increasing slope for increasing conductivity. Over the range of conductivities shown, the Seawater Line has a slope of 0.27 to 0.30. The pooled conductivity–chloride pairs for the oligohaline St. Johns River have a slope of 0.25.

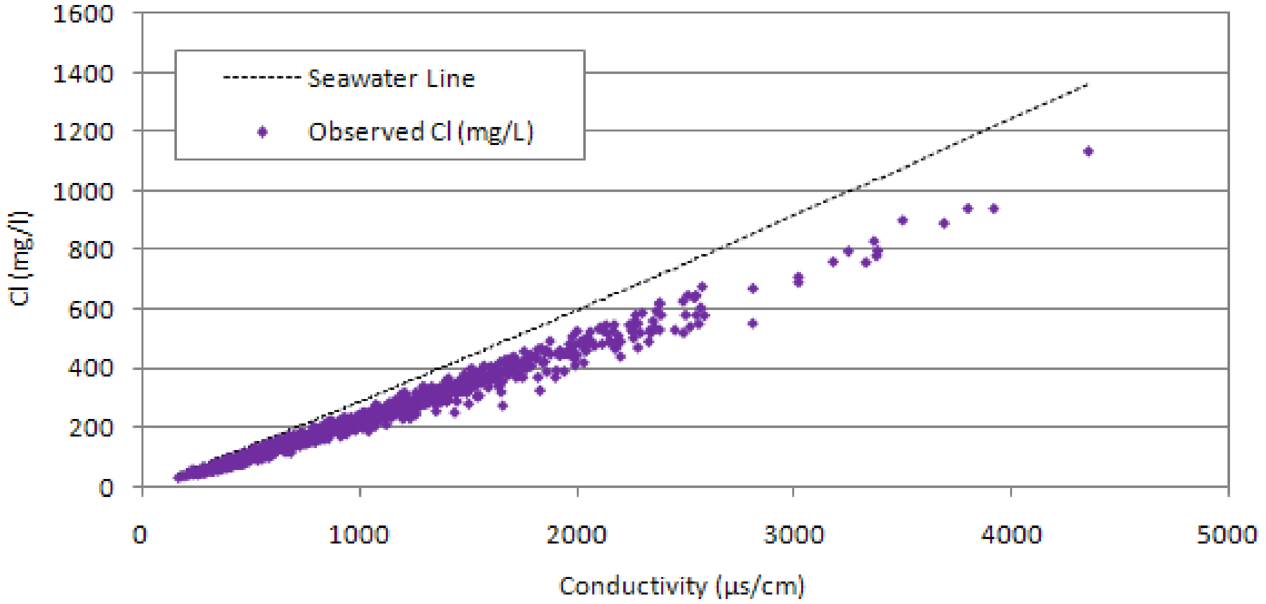


Figure 15 Observed conductivity and chloride,U.S.192 to SR 40, compared with chloride of diluted seawater at the same conductivity (Seawater Line).

The lower slope for the observed St. Johns River data compared with the Seawater Line is due to a greater proportion of divalent ions in the St. Johns River waters, primarily from the dissolution of limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and gypsum ($CaSO_4$). Use of a chloride:conductivity ratio of 0.25 provides a reasonable estimate of chloride from observed conductivity for the oligohaline St. Johns River. This site-specific ratio improves the estimate of chloride concentration from conductivity about 20% compared with estimating chloride by assuming chloride is in proportion to diluted seawater.

4.8 Spatial Variation of Conductivity–Chloride Relationship in Upper and Middle St. Johns River

The estimation of chloride from conductivity along the St. Johns River can be slightly improved over the constant ratio shown above by considering spatial variation of the chloride:conductivity ratio. Chloride:conductivity ratios for each of the observed locations vary from 0.21 to 0.30 (Figure 16). The spatial variation of the chloride:conductivity ratios are also indicators of notable shifts in salt composition caused by local salt sources or the diluting effects of tributary inflows.

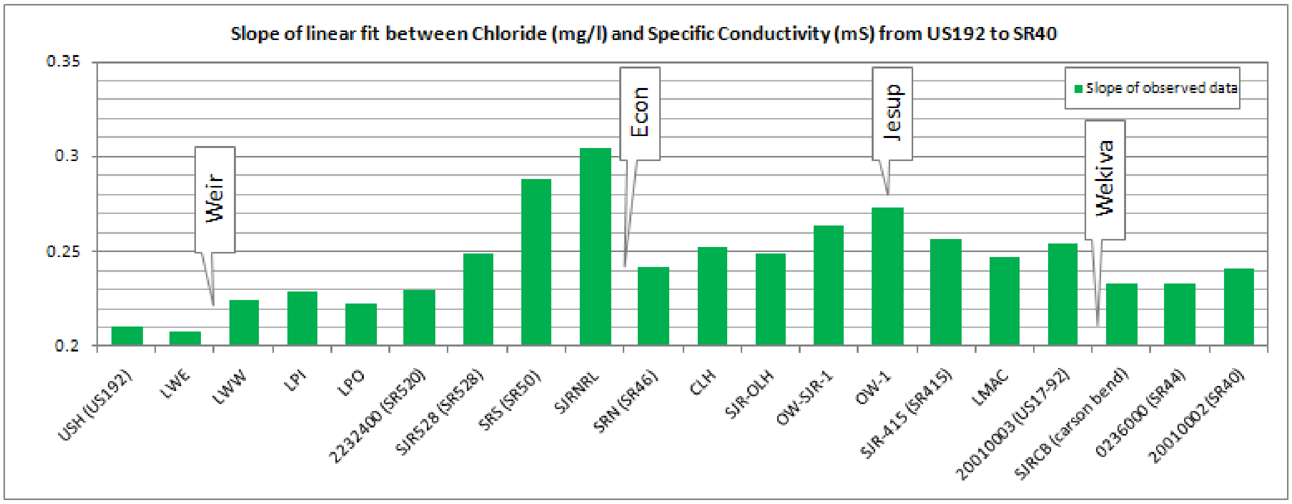


Figure 16 Spatial variation of chloride:conductivity ratio along the St. Johns River from U.S.192 to SR 40. The ratio for diluted seawater ranges from 0.21 to 0.30 for the ranges of conductivity considered.

A weir controlling the water level (stage) of Lake Washington exists between LWE and LWW and low conductivity:chloride ratios occur upstream of the weir. The conductivity:chloride ratio increases abruptly between SR 520 and SJRNRL in an area of high groundwater discharge. The conductivity:chloride ratio here reaches that of diluted seawater. The decline in the ratio at SRN is due to the introduction of low chloride water from the Econlockhatchee River. The ratio increases to a relative maximum near the mouth of Lake Jesup. A notable decline in the ratio occurs at the confluence of the Wekiva River near SJRCB, where a substantial amount of bicarbonate-rich water enters the system through spring discharge.

The conductivity:chloride ratio varies spatially along the upper and middle St. Johns River. The spatial-variability of the ratio is consistent with major sources of salt or the diluting effects of tributaries along the river. The site-specific chloride:conductivity ratios are sufficient to calculate chloride from conductivity to within a few percent of observed values. Then, based on seasonal relative abundance, reasonable estimates for the other major salts can be determined.

5. CONCLUSION

Relict seawater is a dominant source of salts to the St. Johns River main stem and quantification of the inflow of relict seawater to the river is required for setting model boundary conditions that account for the river's salt budget. Relict seawater enters the river through spring discharge, diffuse groundwater discharge entering the river directly, and diffuse groundwater discharge entering the river from tributaries as pick-up water. This latter source is accounted for in the hydrodynamic model by use of a power law describing the chloride-discharge relationship for low-lying tributaries. Use of the power law relationship allows for the estimation of daily salinity for a tributary from either observed or simulated daily discharge. The estimated salinity accounts for the salt contribution of diffuse groundwater discharge to low-lying tributaries that ultimately enters the St. Johns River main stem as tributary discharge.

This modeling study used salinity determined from conductivity as defined by the Practical Salinity Scale 1978 (PSS78). Salinity thus defined is unitless, but is numerically equivalent (in practice) to the conventional limnological definition as the total concentration of salt ions in mg L^{-1}. Conductivity-derived salinity (defined using PSS78) is used because of its ease of measurement, accurate determination of water density differences within the model, and applicability as a conservative tracer. Conductivity-derived salinity as a conservative tracer in low-salinity areas (such as the middle St. Johns River) depends on salt composition. Salinity in the middle St. Johns River is shown to be conservative because the salt composition of the middle St. Johns River is chloride-dominated under all flow conditions due to the presence of relict seawater. Analysis of salt composition of inflows to the river, tributaries and springs, is useful for setting model boundary conditions. This information is used in two ways: first, to infer properties of salt composition and salinity levels for ungauged areas and second, as a means to create discharge-salinity relationships to estimate salt loads derived from pick-up water in tributaries.

The salt composition of the St. Johns River main stem and major lakes throughout the study area—the middle St. Johns River, Lake George, Crescent Lake, and lower St. Johns River—is dominated by Na and Cl under all flow conditions. NaCl dominance is maintained even when salinity in the upstream oligohaline river declines over 80% during periods of high tributary discharge. The stable salt composition dominated by conservative ions justifies the use of salinity as a conservative tracer for hydrodynamic modeling of the oligohaline reaches of the St. Johns River.

The greater similarity of the salt composition of the St. Johns River main stem to seawater compared with either springs or tributaries indicates, by inference, the importance of a third source of salts, in this case, relict seawater entering the river by diffuse groundwater discharge. If the dominant source of salts were from springs or tributary runoff alone, then the salt composition of the St. Johns River main stem would be characteristically like those sources in both composition and concentration.

An understanding of the salt composition of various sources of salt to the river is useful for setting model boundary conditions in areas lacking sufficient direct observations of salinity. For springs, salt composition is closely associated with spring elevation, and both concentration (salinity) and composition of salts from springs can be inferred, in the absence of observed data, from spring elevation. Given the wide range of salt characteristics of the tributaries shown here, and need for estimating salinity of ungauged watersheds for model boundary conditions, a further understanding of the salt composition of tributaries is needed, particularly in areas where tributaries supply relict seawater. The nearly identical salt composition of relict seawater and modern seawater means that groundwater salinity can be calculated from observed chloride where that is the only measured parameter.

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