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# THE LOWER ST. JOHNS RIVER BASIN SEDIMENT ATLAS: RIVERBED SEDIMENT CHARACTERISTICS AND CONTAMINANT CONCENTRATIONS

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

# The Lower St. Johns River Basin Sediment Atlas: Riverbed Sediment Characteristics and Contaminant Concentrations

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# EXECUTIVE SUMMARY

Riverbed sediment contaminant assessment surveys of the Lower St. Johns River Basin were made by the St. Johns River Water Management District (District) over a period of seven years (1996 – 2003). The District collected and analyzed sediment samples from 175 sites within this downstream segment of the St. Johns River and tributaries to determine the locations and concentrations of contaminants present in the riverbed sediment. Analytical results provided preliminary screening-level assessments for 20 trace metals, 118 organic contaminants and 5 geophysical sediment characteristics.

Results were tabulated and graphed to:

- identify contaminants of potential concern.
- determine the concentrations.
- map the locations of contamination.
- delineate the spatial extent of contamination.
- evaluate detrimental influences on aquatic biota.
- infer the ecological significance of contamination.
- facilitate comparison of contaminant levels and distributions among those areas of the river that were evaluated.

The information reported in this *Sediment Atlas* validates historic contaminant information, enhances our understanding of the spatial extent of contamination in the river and the probable risk associated with this contamination to the river ecology.

Preliminary screening-level assessment results revealed highly variable contaminant concentrations in this 162 km (101 mile) segment of the St. Johns River. This high variability indicated not only differences in contaminant concentrations but also in the natural composition of the riverbed sediment. The potential toxic metal contaminants of concern include, but are not limited to, arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, selenium, and zinc. The potential organic contaminants of concern include, but are not limited to, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, chlorinated pesticides (e.g. DDTs, chlordane) and selected classes of chlorinated phenolic compounds (e.g. chlorinated phenols, anisoles, guaiacols, and catechols).

The downstream area, surrounded by the City of Jacksonville, was clearly the most contaminated part of the lower St. Johns River. Other urban areas including Green Cove Springs and Palatka also had elevated contaminant concentrations. These urbanized areas, and potentially some specific industrial activities, appear to be contributing to the elevated contaminant concentrations in the sediment in the lower St. Johns River. Concentrations of several of the organic and metal contaminants found in these locations exceeded those considered typical, based on data from various soil and crustal abundance levels, sediment quality guidelines and comparisons to sediment contaminant concentrations in other water bodies. Tributaries routinely had higher contaminant concentrations than the river main stem, and the Cedar River and Cedar-Ortega estuary were the most contaminated tributaries.

The major objectives of these assessments were to provide baseline data to identify areas in the river with potentially unacceptable levels of contaminants and to estimate their detrimental influences. The next steps in the evaluation of contamination in the lower St. Johns River will be to:

- evaluate the ecological risk, including possible bioaccumulation and biomagnification, from these measured contaminants and from more modern, currently used contaminants.
- investigate the effects of physical factors, especially salinity, organic carbon and pH on contaminant concentrations and interactions.
- examine the environmental fate and effects of these contaminants of concern.
- develop a more thorough understanding of the hydrodynamics of the basin to gain insight on the deposition, flushing and possible sources of these contaminants.

# PREFACE

This report was written primarily for scientific and management audiences. The authors chose to provide this contaminant information in a format that could be easily understood and used by the readers who may not have extensive training in environmental chemistry or toxicology. Therefore surrogate corrected data, also called recovery corrected data, were used for graphing and interpretation in this report. In addition, all non-detect data were calculated as a concentration of zero, instead of using the method detection limit which is a more conservative approach when analyzing non-detect data. The primary objective of the authors has been to make a positive contribution to the management of the river and tributary systems of the lower St. Johns River by providing information to assist resource managers in identifying contaminant concentrations and locations, assessing the contaminant risks and recommending future research.

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# 1.0 INTRODUCTION

The State of Florida is divided into five water management districts authorized by the Legislature to preserve and manage the water resources within its jurisdictional boundaries. Among these is the St. Johns River Water Management District (District) (Figure 1-1). Located in northeast Florida, it's mission is to *"…ensure the sustainable use and protection of water resources for the benefit of the people of the District and the state of Florida…"* (St. Johns River Water Management District, 2006[1]). All five water management districts, in cooperation with state agencies and local governments, were directed by the Surface Water Improvement and Management (SWIM) Act of 1987 to identify water bodies of regional or statewide significance in need of restoration and protection. Six water bodies were named for immediate action, and the Lower St. Johns River Basin (LSRJB) was included in the priority list (Campbell et al., 1993[2]). Following its mission statement and under the authority and directives of the SWIM Act, the District developed the LSJRB SWIM Plan. It identified four principal issues affecting the basin, and provided goals, strategies and objectives to address these issues (Campbell et al., 1993). The objectives included toxicological and sediment assessments to identify contamination. The sediment contaminant information described in this Lower St. Johns River Basin Sediment Atlas (Atlas) was collected and interpreted to fulfill the toxicological and sediment objectives and assist resource managers in identifying priority needs for remedial action and future research.

## Purpose

The riverbed sediment contaminant survey data collected from the LSJRB are presented in geo-spatial form in this Atlas to provide:

- identification of contaminants of potential concern.
- determination of contaminant concentrations.
- maps of the location of contaminants.
- delineation of the geographical distribution (spatial extent) of contamination in riverbed sediment.
- preliminary evaluation of the potential negative influences of contaminants on aquatic biota.
- inference of the ecological significance of the contaminants.
- comparison of inter-site differences in contaminants, levels and distributions among areas of the river that were evaluated.

This sediment contaminant survey information confirms historic contaminant information, expands our understanding of the spatial extent of contamination in the river and enhances our knowledge of the probable risks of these contaminants to the river ecology. The contaminant data also demonstrate that the vast majority of the lower St Johns River sediments are of good environmental quality and do not contain elevated levels of the contaminants measured in this survey.

The next steps in the evaluation of contamination in the lower St. Johns River will be to (a) evaluate the ecological risk, including possible bioaccumulation and biomagnification from these measured contaminants and also from more current (modern) contaminants; (b) investigate the effects of physical factors, especially salinity, organic carbon and pH on contaminant concentrations and interactions; (c) examine the environmental fate and effects of these contaminants of concern; and (d) develop a more thorough understanding of the hydrodynamics of the basin to gain insight on the deposition, flushing and possible sources of these contaminants.

## Location

The St. Johns River is the longest river located entirely in Florida, originating in the Fort Drum Marsh in its headwaters and flowing in a meandering fashion northward for approximately 500 kilometers (310 miles) through agricultural, rural, metropolitan, and industrial areas (Figure 1-1). Descriptions of the St. Johns River have been reported in *Florida's Rivers, (Boning, 2007[3]), Estuaries of the South Atlantic Coast, (Dames et al., 2000[4]), The Rivers of Florida, (Livingston, 1991[5]), Water Resource Management Plan,* (St. Johns River Water Management District, *1977[6]*), and the *Water Resources Atlas of Florida, (Fernald and Patton, 1984[7])*, among other references.

The lower St. Johns River, comprised of the northernmost 162 km (101 miles), flows from the confluence with the Ocklawaha River near Welaka, downstream (north) through Jacksonville to Mayport where it empties into the Atlantic Ocean (Figure 1-2). This lower end of the river generally ranges in width from about 0.2 to 0.8 kilometers (600 feet to ½ mile) from the Ocklawaha River to Palatka. The river widens near Palatka, and river widths range from 1.6 to 5.5 kilometers (1 to 3 ½ miles) from Palatka to Jacksonville. In Jacksonville, the river narrows again to approximately 0.4 kilometer (¼ mile) as it flows into the ocean (Spechler, 1995[8]).

The lower St. Johns River watershed or basin includes land and tributaries that contribute runoff to the river. This basin represents about 22 percent of the area within the boundaries of the District, and extends from the city of DeLand in the south to the Atlantic Ocean (Figure 1-2). The LSJRB drains approximately 6733 square kilometers (2,600 square miles) of northeast Florida, and includes parts of Alachua, Baker, Bradford, Clay, Duval, Flagler, Putnam, St. Johns and Volusia counties, as well as the cities of Jacksonville, Orange Park, Green Cove Springs, Palatka and many smaller communities.

Many tributaries flow into the lower St. Johns River (SJR) and the largest is the Ocklawaha River. Other major tributaries include Dunns, Rice, Cedar, Deep, Six-Mile, Trout, Black, Julington creeks and Doctors Inlet. The Jacksonville urban tributaries include Cedar, Ortega, Arlington, Trout, Ribault, Broward and Dunn rivers, Goodbys, Moncrief and Pottsburg creeks. Further downstream are tributaries in the Timuquana Preserve named Clapboard, Cedar Point and Hannah Mills creeks. The most downstream major tributary, Sisters Creek, flows into the lower SJR via the intracoastal waterway.

The Cedar and Ortega watershed or sub-basin is located in the urbanized southwestern area of metropolitan Jacksonville, (Figure 1-3), and the Ortega and Cedar rivers are the two tributaries that drain the majority of this watershed (Adamus et al., 1997[9]). The Ortega River is the largest tributary discharging nearly half of the total flow of this sub-basin to the St. Johns River (Freeman, 2001[10]). In the upper reach the Ortega River flows north to south, but in the downstream portion it gradually turns 180 degrees to a north-northeasterly course, flowing a total of 37.8 km (23.5 miles) before discharging into the St. Johns River (Freeman, 2001). The Cedar River is the largest tributary to the Ortega River, and flows through Jacksonville for approximately 5 km (3.1 miles) before converging with the Ortega River (Durell et al., 2005). From their confluence the merged Cedar-Ortega then flows toward the northeast for approximately 2.1 km (1.3 miles) to join with the lower SJR, and this merged segment is called the Cedar-Ortega estuary (Freeman, 2001). The Cedar River is the most polluted tributary to the SJR with the highest levels of turbidity and eutrophication in the area (Campbell et al., 1993). The LSJRB, the Cedar and Ortega sub-basin and the contaminants associated with the riverbed sediment are the focus of this Atlas.

The general characteristics of the bed sediment that underlie the river and tributaries are mainly determined by the geology and anthropogenic (human) influences within the LSJRB. These characteristics have profound influences on the fate of contaminants and their partitioning between aqueous and sediment phases. Therefore, a discussion of the general background of the geology and the human influences is helpful in understanding sediment contamination in the LSJRB.

## Geography

Land elevations in the LSJRB vary from sea level at the river mouth near Mayport, to over 60 meters (200 feet) in the west portion of the basin (Figure 1-4). Generally, the terrain over most of the LSJRB is low and flat (Spechler, 1995). Old sand dune ridge systems define the river floodplain boundaries with the Trail, Lake Wales and Mount Dora ridges forming the drainage divide in the west and the Crescent City and Deland ridges forming the drainage divide in the east (Vernon and Puri, 1964[11]). The valley between these dune ridges comprises the St. Johns River and its floodplain. The sand dune ridges tend to be well drained, while the adjacent lowlands are naturally poorly drained. These poorly drained lowlands are part of the coastal lowlands (Struthers, 1981[12]) and the river follows these coastal lowlands to the ocean.

## Hydrology

The average gradient of the main river channel is only .022 meters per kilometer (0.08 feet per mile) and due to this low gradient, tides affect the entire LSJRB (Morris, 1995[13]). The tidal amplitude at Mayport averages 1.38 meters (4.51 feet) and the tidal bore decreases by varying amounts as it moves upstream (Morris, 1995). The Atlantic Ocean tide generates a progressive tidal wave that can propagate up river extending the entire length of the LSJR, even into the lower reaches of tributaries (Spechler, 1995). The high tidal energy moves large amounts of seawater into and out of the river each day, so freshwater makes up only about 1/7th of the total average tidal flow (Anderson and Goolsby, 1973[14]). The net discharge from the river ranges from 115 to 225 kiloliters per second (4,000 to 8,000 cubic feet/second) with an average discharge estimated at 170 kiloliters per second (6,000 cubic feet/second) (Snell and Anderson, 1970[15]; U.S.G.S., 1983[16]; U.S.G.S., 1992[17]; Morris, 1995).

The mixing of salt water and freshwater forms a shallow, elongated estuary, with an extensive floodplain (Brody, 1994[18]). This salt and freshwater mixing also influences the sediment characteristics, depositional rates and areas of deposition, as well as the fate of contaminants in the river.

## Geology – Riverbed sediment

The geology of the St. Johns River Basin is largely a result of the fluctuations in sea level that have periodically flooded the St. Johns River valley and formed large sand dunes and sandy terraces (Struthers, 1981). The surficial soils in the LSJRB are mostly fine to medium sand and shell with sandy clay lenses, and can be over 150 feet thick (Snell and Anderson, 1970). In many places, another layer composed of sand, shell and silty-clay underlies the surficial soil layer. Beneath these sandy layers are dense sandy-clay and clay layers called the Hawthorn Formation, and the Hawthorn clays rest on top of limestone and dolomite rock (Struthers, 1981). In Jacksonville, the river channel has been dredged to this Ocala limestone and dolomite rock. The geologic foundation of the LSJRB is sequences of sedimentary rock, underlain by a basement complex of metamorphic rocks (Spechler, 1995). The geology of the St. Johns River Basin has been described by Struthers (1981), and summarized by Keller and Schell (1993[19]). During the Pleistocene era, oscillating sea levels allowed the St. Johns River and its tributaries to deeply incise and erode the surficial sandy soils (Struthers, 1981). In the late Pleistocene, rising sea level flooded the river valley, and this flooding has slowed erosion and reduced the gradient of the river (Struthers, 1981). Watershed runoff and erosion of tributary and river shorelines continue to contribute soil to the river, while tidal currents carry eroded ocean and beach sands into the river. Many factors combine to determine the distribution patterns of these eroded soils throughout the LSJRB estuary and the most important is the circulation of the water (Burns, 1962[20]). Water circulation is controlled by river currents, ocean tides and wind-induced waves that act to transport, distribute and deposit the eroded soils and sands to many different areas of the riverbed.

Other less dominant factors that affect the transport, distribution and deposition of eroded soil include density currents and salt induced flocculation. Density currents are formed from water that is colder, saltier, or contains more suspended sediment and therefore are heavier than the surrounding water (Britannica, retrieved 2011[21]). Density currents, like river and ocean tidal currents, convey and distribute eroded soil and runoff material along the riverbed. Unlike the river and tidal currents, density currents are kept in motion by gravitational forces and are not dependent on wind or tides. The other factor mentioned that affects estuary sedimentation is salt-induced flocculation. Salt-induced flocculation is a complex physiochemical process whereby small suspended particles and soils aggregate to form larger particles or flocs (Droppo et al. 1998[22]). The flocculation process commonly occurs when freshwater, carrying a load of suspended particles, meets marine or ocean water with a much higher ionic concentration. The salt ions in marine water electrolytically cause the small particles in freshwater to aggregate. This complex flocculation process alters the characteristics of the particles, as their size, shape, water content, density and composition change significantly during aggregation. The flocculation process is important because flocs play a significant role in the transport of fine-grained sediment and their associated contaminants. Flocs will settle much faster than their constituent particles and thereby significantly modify the fate of sediment and contaminants associated with the sediment (Droppo et al. 1998).

## Human Influences

The riverbed sediments of the St. Johns River have been influenced by humans for centuries, from the earliest influences by Native Americans to the draining of its floodplains for agricultural and urban development in the 1900s and today (Bennett, 1989[23]). Humans have altered the flow patterns of the river and tributaries by dredging, channelizing, building seawalls and bulkheads. The spatial extent and pace of these human activities have dramatically increased over time, with a resulting increase in soil erosion. The increased soil erosion has caused an increase in the buildup of sediment. Furthermore, increased sedimentation promotes development of large masses of fine-grained silt and soft mud on the riverbed. Silt and soft-mud flow with the currents, and are redistributed on the riverbed. This increased sedimentation and siltation has rapidly filled channels, marinas, and caused an increase in shoaling or sandbar development.

The composition of the riverbed sediment varies greatly over this last 101-mile stretch of the river. In areas with high river flow a hard rock bottom normally occurs. Sandy areas and shell deposits are found in lower flow areas. Fine-grained silt and soft-mud typically accumulate in the very low flow and quiescent areas, and in deep channels and depressions. Keller and Schell (1993) reported that the sediment from the St. Johns River is a poorly sorted mixture of sand, shells, silts and clays, but the major components are fine-textured silts and clays, dark in color and high in percent moisture. The tributaries of the river commonly contain sediment with a high organic material content, particularly in low flow areas. In the mainstem of the river, no spatial relationship appears to exist between the distance upstream and either sediment particle size or organic content. A complete understanding of the complexity of the river system's sediment dynamics is hindered by a paucity of information on sedimentation processes and sediment characteristics of the St. Johns River (Keller and Schell, 1993).

In addition to causing increased soil erosion, humans have used the St. Johns River and its tributaries for the disposal of many different wastes and contaminants. Direct discharges from industrial operations, such as petroleum storage and transfer facilities, power generation stations, pulp and paper industries, military installations and wastewater treatment plants introduce contaminants like toxic metals, polychlorinated biphenyls (PCBs), pesticides, oil and grease lubricants. Indirect flows include deposition from the atmosphere and from rainfall runoff. Combustion and incineration discharge tremendous quantities of pollutants into the atmosphere, and these airborne contaminants settle in terrestrial areas and can fall directly into the St. Johns River and its tributaries. Rainfall washes soil, dust, soot and contaminants from the watershed, the roads, parking lots, superfund sites, rural agricultural fields, high-density commercial and residential areas into the river and tributaries. These pollutants that are either directly discharged or are washed off the land will adsorb to suspended particles in the water, and eventually settle on the riverbed. The contaminants can become associated with suspended particles through several physical and chemical processes. The relative importance of these processes will depend on the physiochemical characteristics of the sediment, the acid dissociation constant of the compound (pKa), the hydrophobicity of the compound, and the pH and ionic strength of the surrounding water (Sonnenberg and Higman, 2001[24]). One of the most important sediment characteristic influencing the binding of contaminants is the content of organic carbon of the sediment. Fine-grained silts and soft-mud characteristically contain organic carbon so they attract and bind contaminants readily, especially the more hydrophobic organic contaminants, while sandy sediment is relatively inert and has less of a tendency to bind or retain contaminants. Generally, the higher the amount of organic carbon in sediment, the more readily the hydrophobic organic compounds will partition into it (Durell, Fredriksson and Higman. 2004[25]).

## Contaminants

Once contaminants become sequestered by the riverbed or tributary sediment, they are not easily removed from the river system, because current velocities in the St. Johns River are normally too low to move them downstream. In addition, many of these contaminants degrade very slowly, while others do not degrade at all, particularly when they are bound to particles. Even when contaminants become associated with riverbed sediment, they continue to influence the river ecology. Under certain conditions, contaminants can be resuspended with sediment particles or dissolve back into the water and contaminate the water column. In some areas, the highly contaminated sediment can often be a greater source of contamination to the water column than runoff or direct discharge sources.

The riverbed sediment is an integral component of the aquatic ecosystem providing habitat and a source of food for key components of the food web. The sediment often becomes a catchment for natural and anthropogenic toxic substances that bind to particles and settle from the water column to the riverbed. The toxicity from the buildup of these contaminants may threaten the sediment-dwelling benthic organisms, vegetative communities, and the aquatic food web that depend on them. Organisms and plants, particularly those living in the sediment, can acquire and accumulate toxic substances through epidermal contact, respiration, or by ingestion of toxins. This process of accumulating and retaining toxic substances, such as pesticides (e.g. DDT) or toxic metals (e.g. copper), by an organism or part of an organism is called bioaccumulation. Bioaccumulation results in an organism that contains higher concentrations of a toxic substance than the concentration found in the organism's surrounding environment (U.S.G.S., Retrieved 2011[26]).

As organisms bioaccumulate toxic substances they become toxic themselves. A complex interaction of the metabolism of the organism, the chemistry of the toxin and environmental variables will determine the concentration of toxins that an organism bioaccumulates (Sonnenberg and Higman, 2001). As a general rule, the lower the sediment organic carbon content and the more hydrophobic (water insoluble) the toxic substance, then the more likely it is to bioaccumulate (U.S.G.S., Retrieved 2011). The hydrophobicity of a toxic substance is correlated with its ability to partition between water and other substances, and is also related to its lipid binding ability or lipophilic nature (Sonnenberg and Higman, 2001). Organisms with higher lipid content will normally bioaccumulate higher levels of toxic organic substances. So the bioaccumulation potential of a toxic substance can be estimated by evaluating its ability to partition to different materials (Sonnenberg and Higman, 2001). It is measured in water as the octanol-water partition coefficient (Kow); in solids as the organic carbon-water partition coefficient (Koc); and in organisms as the lipid-water partition coefficient (Sonnenberg and Higman, 2001). Caution should be used with these predicted values, because not all toxic substances conform to these relationships. An example is methylmercury, which accumulates in fish to a much greater degree than predicted using its $K_{OW}$ value (Moran, et al. 2007[27] ; U.S.G.S., 1999[28]).

Sediment has been considered a permanent repository for toxic contaminants, but the relationship between sediment, contaminants and water, especially interstitial or pore water, is now understood to be much more complex (Sonnenberg and Higman, 2001; Hickey, 1999[29]). Hydrophobic contaminants (e.g. DDT, PCBs) in the sediment of estuaries, rivers and other water bodies can create the potential for continued environmental degradation, even after the contaminant source has been stopped and water column concentrations have decreased (U.S. EPA, 1997[30]). Consequently, contaminant-free sediment is critical to maintaining a healthy, contaminant-free ecosystem.

The District normally uses water quality monitoring to determine the status and condition of aquatic resources. However, the status and condition of the aquatic resources is also dependent on the sediment underlying the water bodies. The sediment integrates pollution over time and indicates a history of contamination (Durell, Fredriksson and Higman, 2004). The buildup of toxic contaminants in sediment over time can lead to chronic toxicity problems that threaten benthic communities, and due to bioaccumulation, may also threaten organisms that rely on those communities as a food source. Therefore, the inclusion of a sampling program that addresses the distribution and characterization of toxic substances in sediment is essential to developing and maintaining a comprehensive environmental assessment program (Durell, Fredriksson and Higman, 2004).

Initial contaminant assessment results established that (1) the sediment in some areas of the lower SJR had elevated concentrations of selected organic and metal contaminants, (2) many tributaries were also contaminated, and (3) some tributary contaminant concentrations exceeded the river sediment concentrations (Pierce et al., 1988[31]; Durell, Fredriksson and Higman, 2004). Results from the Ortega and Cedar rivers, tributaries of the lower SJR, showed that the sediment underlying this tributary system had elevated concentrations of a few identified contaminants including polychlorinated biphenyls (PCBs), but the extent of contamination was poorly defined, and other contaminants, such as pesticides, were not quantified (Keller and Schell, 1993). Many of these early contaminant assessments were limited spatially, only analyzed for very few contaminants or had both of these limitations. The need for a more thorough characterization of sediment contamination was apparent, so a more comprehensive and spatially complete sampling program was implemented in the LSJRB from 1996-2003. The sediment contaminant assessment results from this LSJRB sampling program have verified that the sediment in some areas of the lower SJR is contaminated with toxic organic and metal compounds. More extensive contaminant information can be found in the following reports: Evans and Higman, 2001[32]; Ouyang et al., 2002[33]; Ouyang, Higman and Campbell, 2003[34]; Evans et al., 2004[35]; Durell, Fredriksson and Higman, 2004, and Durell et al., 2005[36].

The lower SJR, its tributaries, especially the Cedar and Ortega rivers and estuary, and the contaminants associated with bed sediment underlying this part of the river are the focus of this Atlas. Its findings validate the historic information and enhance our understanding of the spatial extent of contamination in the river and the probable risk associated with this contamination to the river ecology.

# 2.0 METHODS

## Technical Approach

### Site location selection

This Atlas illustrates the locations of 175 sample sites within the LSJRB that were analyzed for sediment contamination and quality. These sample sites were selected during sediment contaminant assessments made from 1996 through 2003. The initial 110 study sites were randomly chosen following the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) probability-based sampling design protocol (Hyland et. al., 1996[37]). In subsequent assessments, the sampling strategy focused on obtaining more site-specific information and targeting areas of concern. These additional 65 sample sites were selected after review of all historical St. Johns River contaminant data, records from permitted industrial and domestic dischargers, regional land-use patterns, locations suspected of having sediment contamination or areas that had not been well characterized in the previous assessments.

Sediment physical characteristics (i.e. grain size and TOC) were also analyzed for all of these 175 sites. Seven additional sites were selected from within the Cedar River and the Cedar Ortega estuary and analyzed for physical characteristics to help elucidate the sediment variability in this tributary. A total of 182 sites were analyzed for sediment physical characteristics.

### Sampling collection methods

Riverbed sediment samples were collected by District staff during different sampling periods between 1996 and 2003. District staff used Global Positioning System (GPS) equipment to locate pre-selected sample study sites, and to record the position of the actual sample site as the sediment samples were collected. Surface sediment samples were obtained using pre-cleaned stainless steel petite Ponar dredges. A piston-core sampler was used for the collection of the sediment cores in the Cedar River, Ortega River and Cedar-Ortega estuary. Multiple sediment samples were collected at each site and each site replicate was placed in a separate 500 mL certified trace-level pre-cleaned glass jar with Teflon lined cap, chilled and shipped to the laboratory. Field Quality Assurance/Quality Control procedures were followed; the materials (e.g., clean stainless steel, glass, and Teflon materials) and practices used to collect the samples have been demonstrated to be appropriate for collecting samples for trace chemical analysis (U.S. EPA and U.S.G.S, 1994[38]). Additional information and more detailed descriptions of the sediment sample collection methods and field procedures can be found in Durell, Fredriksson and Higman (2004), and Durell et al. (2005).

## Analytical variables

Riverbed sediment samples were analyzed for multiple, carefully selected contaminant variables that included 20 trace metals and 118 non-polar organic compounds (Table 2-1). The sediment samples were also analyzed for five physical characteristics, such as grain size and organic carbon content (Table 2-1).

The contaminant variables were selected from an extensive list of chemicals following a comprehensive evaluation process. This evaluation process included as the first step, the compilation of the contaminant lists developed for major national sediment contaminant monitoring programs conducted over the last 20 years (e.g., NOAA, 1998[39]; EPA 1993[40]). The second step was to develop a sediment contaminant list from all previous lower SJR contaminant projects, outfall discharge-compliance reports, hazardous waste disposal, contaminant leachate and accidental spill information. The contaminant lists were merged, and trace metals and those organic compounds that accumulate in sediment and had demonstrated abilities to bioaccumulate in benthic and pelagic organisms were included in the lower SJR sediment contaminant assessments. This lower SJR contaminant list included the most toxic trace metals, the most prevalent 2-, 3-, 4-, and 5-ring polynuclear aromatic hydrocarbons (PAH) and alkylated PAH (27), the six most common phthalates, the 23 most prevalent polychlorinated biphenyl congeners (PCB), the most persistent chlorinated pesticides (31) and 31 industrial chemicals (Table 2-1). Sediment samples were analyzed for all contaminant variables on the lower SJR contaminant list, and the results are reported in Durell, Fredriksson and Higman (2004), and Durell et al. (2005). The results for all variables on the lower SJR contaminant list were evaluated. Not all of the variables were plotted and illustrated on the LSJRB Atlas Maps, because some were not detected in any samples while others were only measured at very low trace-level concentrations at a very few sampling locations.

## Analytical procedures

Since these types of contaminants can cause adverse affects to biota even at very low concentrations, the analyses of these chemicals had to be made using analytical procedures with very low limits of detection. For this reason, optimized versions of the National Oceanic and Atmospheric Administration's (NOAA) analytical methods (NOAA, 1998) were used for the analysis of the selected contaminant variables. Most of the metals (Al, Sb, Be, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Ni, Tl, Sn, V, and Zn) were measured, following a total digestion of the entire sample matrix, by inductively coupled plasma/mass spectroscopy (ICP/MS), but mercury was measured following the cold-vapor atomic absorption spectroscopy technique (Durell, Fredriksson and Higman, 2004). The more numerous organic contaminant concentrations were determined using three different methods each optimized for different chemical classes. These three methods included (1) high-performance capillary gas chromatography/mass spectrometry for PAH and phthalates, (2) high-performance capillary gas chromatography with electron capture detection for PCBs and pesticides and (3) high-performance liquid chromatography with ultraviolet detection for chlorophenols, anisoles and catechols. Comprehensive descriptions of these analytical procedures and information on quality assurance and quality control are given by Durell, Fredriksson and Higman (2004), and Durell et al. (2005). By using low detection limits, a comprehensive understanding of ambient or "background" conditions could be determined. These sensitive, low-level detection measurements also provided information needed to establish links between contaminant occurrence and potential biological effects or changes, and to predict the true significance of these anthropogenic contaminants.

The five sediment physical characteristics, (1) total solids (percent solids), (2) water content (percent moisture), (3) total volatile solids (percent organics), (4) total organic carbon ( percent TOC), and (5) grain size (percent sand, silt and clay) were reported with detailed analytical method descriptions in Durell, Fredriksson and Higman, 2004, and Durell et al., 2005. The analysis of samples for percent solids, percent moisture, and percent organics followed Standard Methods, 17th Edition (APHA, 1989[41]). Homogenized sediment samples were dried at 105 ºC to a constant weight and the remaining material was the percent solids. These dried sediment samples were then ashed at 550 ºC, and the weight lost, after normalization, was reported as percent volatile solids. The percent TOC was determined on dried sediment after acid treatment. The organic carbon was converted by high temperature combustion to carbon dioxide and then measured by either infrared absorbance, or by conversion to methane and subsequent flame ionization (U.S. EPA,1986. SW-846-Method 9060[42]). Grain size distributions of moist sediment were determined using a laser diffraction instrument. All sediment samples were sieved through a 2,000-µm mesh prior to diffraction analysis, and the sediments greater than 2,000 µm were assigned to the range between 2,000-2,830 µm. The total percent sand, silt and clay were calculated as the sum of volume percent between 2,830 and 62.5 µm, 62.5 and 3.91 µm, and 3.91 to 0.04 µm, respectively, using the Wentworth size scales. Only the sand, silt, and clay percentages were used in this report, but the data for each of the size intervals are available in Durell, Fredriksson and Higman, 2004; Durell et al., 2005.

## Organization of Metal, Organic and Physical Maps

The global information system (GIS) generated maps illustrated in this Atlas are organized by contaminant types (e.g. physical, metal, and organic variables) with geographical areas being subdivided into the Northern, Central and Southern regions. Expanded-scale maps illustrate the locations and results of the more intensive assessments in the Ortega River, Cedar River and Rice Creek regions.

To facilitate a clear understanding of each of the variables and their concentrations, they were grouped by type (i.e.: physical, metal or organic group). These groups were then further divided using the concentration range of each of the individual variables. (these groups are listed in the following paragraphs and in Table 2-1). Those variables with similar concentration ranges were illustrated together, allowing multiple graphs of the physical or contaminant concentrations to be presented on the same map. Illustrating multiple physical or contaminant variables together minimized the quantity maps needed to display the different contaminant concentration ranges at each site. Following this method of grouping the different variables, the physical characteristics have been divided into 2 groups, metals have been divided into 5 groups; and the non-polar organic contaminants have been divided into 8 groups (Table 2-1).

Two of the five measured physical sediment characteristics (grain size and percent total organic carbon) are illustrated graphically in this Atlas. All physical characteristics were reported as percents.

1. **Physical Group 1** includes grain size as %sand, %silt, %clay;
2. **Physical Group 2** includes %total organic carbon.

The remaining physical variables, percent moisture, percent solids, and percent organics, were not illustrated, but the data can be found in Durell, Fredriksson and Higman (2004), and Durell et al. (2005).

Concentrations of all 20 metals are individually illustrated in a graphic format in this Atlas. The metals - were measured and reported in milligrams per kilogram (mg/kg) of dry weight sediment.

1. **Metal Group 1** includes beryllium, thallium, cadmium, silver, antimony and mercury;
2. **Metal Group 2** includes cobalt, tin, and selenium;
3. **Metal Group 3** includes lithium, copper, nickel and arsenic;
4. **Metal Group 4** includes manganese, zinc, chromium, vanadium and lead;
5. **Metal Group 5** includes iron and aluminum.

Unlike the metals, many of the analytical results for the 118 non-polar organic contaminants were not displayed individually, but instead were combined into contaminant categories (e.g. chlordane, PAH, PCBs), and then expressed either as total or summation values. For example, each of the seven individual chlordane isomers and metabolites were combined, their concentrations summed and the resulting value was called the total chlordane concentration as shown in Table 2-2. Complete inventories of the individual organic contaminant variables that were summed for total categories are found in the Results section in Tables 3-9, 3-11, 3-13, 3-15 and 3-17. Some of the non-polar organic contaminants that were not included in these compound summations were not graphed, but were reviewed and are discussed in this Atlas.

The 18 non-polar organic categories are illustrated graphically in this Atlas, and were grouped by concentration ranges as previously stated. These organic contaminant variables were measured and reported in micrograms per kilogram of dry weight sediment (µg/kg). The totals and sums are included in the following:

1. **Organic Group 1** includes Total PAH, High Molecular Weight (HMW) PAH, Low Molecular Weight (LMW) PAH, and Total Phthalates (PHTH);
2. **Organic Group 2** includes Total PCB and Sum of PCB;
3. **Organic Group 3** includes Total Chlordane, and Total DDT;
4. **Organic Group 4** includes DDD, DDE and DDT; Total Endosulfans and Total Hexachlorocyclohexanes (HCHs);
5. **Organic Group 5** includes Cl-Phenols and Cl-Catechols;
6. **Organic Group 6** includes Cl-Guaiacols and Cl-Anisoles;
7. **Organic Group 7** includes Total Chlorophenolics;
8. **Organic Group 8** includes Pesticides that were not illustrated on the maps.

### Method of reporting analytical results

Sediment sample replicates were collected at each site as previously described in the "**Sampling collection methods"** section. Replicate sediment samples from each site were analyzed separately, providing two measurements from each site and for each contaminant as reported by Durell, Fredriksson and Higman (2004), and Durell et al. (2005). For the Atlas, the results from the two site-replicate analyses were averaged; these average values were reported as the contaminant concentration for each location. These site average values were then illustrated graphically on the maps. The site averages of the measured contaminant levels are represented by color-coded bar graphs, and the resulting bar graphs have been overlaid onto their corresponding geographical site locations.

All analytical results were reported on a dry-weight basis, and all non-detect data were calculated as a concentration of zero, instead of using the detection method limit which is a more conservative approach when analyzing non-detect data. Surrogate corrected data were used for graphing and interpretation in this Atlas to provide for a clear and easily understood representation of the true sediment contaminant concentrations. These surrogate corrected contaminant concentrations were not normalized to reference material in the sediment (e.g. silt-clay, organic carbon, aluminum) though these parameters often affect sediment concentrations.

### Statistical methods, natural metal abundances and sediment guidelines

General statistics, such as the maximum, median, mean and minimum concentrations, were calculated for each variable class in the physical group (i.e. % sand, % silt, % clay; % total organic carbon), metal group (e.g. beryllium) and organic chemical group (e.g. Total PAH). Those statistical calculations were evaluated and are discussed in the following Results Section.

The environmental significance of metal and non-polar organic contaminant concentrations in sediment is often evaluated by comparing the measured contaminant concentrations to measured soil and crustal abundance concentrations or to established Sediment Quality Guidelines. These comparisons can provide a method to predict the possible effects of contaminants on the riverbed sediment dwelling or benthic organisms and communities. These guidelines are based on a combination of lab and field-testing and like the results reported here, are expressed as the concentration of the contaminant per kilogram of sediment in dry weight (or the mass of the contaminant per mass of the bulk sediment).

The assessed metal contaminant concentrations that were measured in the LSJRB sediment were compared to U.S. soil concentrations (Shacklette and Boerngen, 1984[43]), average crustal abundance (Moore, 1991[44]), and estimated crustal abundance concentrations (Thomas Jefferson National Accelerator Facility [TJNAF], Retrieved 2011[45]). No soil or crustal abundance concentrations were available for the organic contaminants and many of them have only anthropogenic origins.

The metal and organic contaminant concentrations were compared to the effects-based Sediment Quality Guidelines (SQG) (MacDonald, 1994[46]; NOAA, 1999[47], MacDonald et al. 2000[48]). These SQG include the saltwater Threshold Effect Levels (TEL) and Probable Effect Levels (PEL); also the freshwater Threshold Effect Concentrations (TEC) and Probable Effect Concentrations (PEC). Adverse effects in sediment-dwelling organisms are expected very infrequently if sediment contaminant concentrations are below the TEL and/or TEC guideline levels. However, sediment-dwelling organisms are likely to be affected when sediment contaminant concentrations are at or above the PEL and/or PEC guideline levels. In the range of values between the lower TEL/TEC and higher PEL/PEC guidelines, the probability of adverse effects in sediment-dwelling organisms increases as contaminant concentrations increase. The SQG were not available for all of the metal or organic chemicals or classes of chemicals analyzed in LSJRB sediment. If the SQG for specific contaminants were available, they were compared to the individual site contaminant concentrations. These comparisons are interpreted and discussed in the following Results and Discussion Section.

# 3.0 RESULTS AND DISCUSSION

The sediment contaminant assessment results for the geophysical characteristics, metal and organic contaminant analyses were evaluated, graphed and illustrated on maps that were organized by sample variable type and geographical area. These results indicated high variability in the natural composition of the riverbed sediment and in the contaminant concentrations. In addition, all major classes of contaminants occurred in the sediment of the lower SJR and tributaries.

The sediment contaminant assessment results are divided into three sections corresponding to the organization of the Atlas maps as follows:

**Section 1** includes geophysical characteristics (grain sizes as % sand, % silt, % clay; % total organic carbon).
**Section 2** includes metal compounds (major and trace metals).
**Section 3** includes organic compounds (polynuclear aromatic hydrocarbons, phthalate esters, polychlorinated biphenyl, pesticides and chlorinated phenolic compounds).

Following an introduction to the different contaminant classes are discussions of the observed contaminant concentrations, their composition, distribution and potential risk to aquatic organisms. When available, data on concentrations of the contaminants in locations throughout the world are provided for comparison.

## SECTION 1: Geophysical characteristics

The physical characteristics include the sediment grain-size and total organic carbon (TOC) measured for each sampling location. These variables have a significant influence on contaminant distribution in the sediment of the LSJRB and are included with their corresponding geographical sampling locations to aid in the interpretation of the contaminant data.

### Grain Size Data

The grain-size composition data can be characterized as a distribution continuum of sand, silt, and clay, with each reported as a percentage of the total wet sediment volume. The total percent sand, silt, and clay were reported as the volume percent between 2,830 and 65.5 µm, 62.5 and 3.91 µm and 3.91 to 0.04 µm, respectively using the Wentworth scales (Durell, Fredriksson and Higman, 2004). Sand is relatively inert, while the %silt and %clay form a mixture of fine-grained particles that typically contain the bulk of contaminants in a sample (Durell, Fredriksson and Higman, 2004). This fine-grained mixture can be useful in normalizing metal and organic contaminant concentrations to the corresponding silt-clay fraction.

The grain-size composition of the sediment was highly variable. For example, in some locations sandbars were found that consisted primarily of coarse sand, while in other areas deposits of fine-grained silts and clays occurred. The sand fraction ranged from 15.9% to 98.7%, with an average of 50.4% (median = 48.9%). The silt fraction ranged from 0.9% to 75.9%, with an average of 45.2% (median = 47.6%). The clay fraction ranged from 0.05% to 23.7%, with an average of 4.4% (median=3.6%) (Table 3-1).

Typically, the main river channel sampling sites (e.g. LSJ37, LSJ33, LSJ39) had the highest sand concentrations (>90%), except for one site in Rice Creek (RCJU04) which had the highest percent sand value. These main channel sites could be expected to have high current flows, and these high flows wash fine-grained silts and clays away from the heavier sand and shell deposits. The sites with the highest silt concentrations were found in the Jacksonville area (e.g. LSJ06, LSJ11, BOL04), and in the Cedar-Ortega estuary [Figures 3-1 and 3-2]. The sites with the highest clay concentrations were mainly found in tributaries (e.g. CED01, CED12, BROW01) like the Cedar and Broward rivers, and the Cedar-Ortega estuary [Figures 3-1 and 3-2]. The lowest concentrations for both the silt and clay were associated with very sandy sediment (>95% sand). The Cedar-Ortega estuary and Cedar River had many sites with the lowest sand concentrations, and typically contained more silts and clays than mainstem river sites [Figure 3-2].

### Total Organic Carbon Data

In aquatic environments, total organic carbon (TOC) consists of thousands of components, including macroscopic particles (e.g. decaying leaves, grasses and plankton), colloids, particulate and low molecular weight organic and macromolecules. The organic carbon material settles on the riverbed mixing with the sands, silts and clays and contributes to the sediment composition. Organic carbon can accumulate naturally and form dark muddy deposits. The USDA term for soil with greater than 5% organic carbon is muck (Carlisle and Hurt, 2000[49]). The TOC content of mucky soils ranges from 5% to 18%, and sometimes the TOC content can even be higher (Carlisle and Hurt, 2000). The TOC data are presented in this Atlas as a percentage of the sediment dry weight. Organic contaminants will preferentially adhere to carbon-based material, so the TOC measurement can be useful in normalizing organic and some metal contaminant concentrations to the corresponding percentage of TOC in the sediment. In this way, it can be determined whether contaminant concentrations are high at a site because of the proximity of a source, or because of the nature of the sediment. Normalized information was not reported and instead the actual contaminant values for each site are graphically illustrated in this Atlas. The lower SJR contaminant data were normalized to corresponding site TOC values and reported by Durell, Fredriksson and Higman, (2004) and Durell et al., (2005)

The TOC content of the sediment varied from 0.2% (site LSJ31) to 39.6% (LSJRC06), a difference of two orders of magnitude [Figures 3-11 and 3-12]. The average sediment TOC concentration was 12.5% with a median value of 11.8% (Table 3-1). The TOC values generally tended to increase with increasing distance upstream from Jacksonville to Welaka. The highest sediment TOC values, ranging from approximately 30 to 40%, were located in the river near Rice Creek and in Rice Creek itself [Figures 3-11 and 3-12].

The sites with the lowest TOC concentrations were scattered throughout the river (e.g. LSJ31, LSJ33, LSJ37, LSJ39, LSJ10), but generally were associated with very sandy sediment (>90% sand). The TOC concentrations were consistently less than 0.7% at sites with more than 90% sand [Figures 3-5 and 3-11]. However, some sites, including DUN01 and LSJRC02, had elevated TOC concentrations (25 to 35%) with relatively high sand content (60 to 70%). The mainstem river site data indicated a lack of correlation between TOC and sediment grain size. This lack of any correlation was partially due to the elevated amounts of plant debris found in many samples that skewed the TOC concentrations. Conversely, the TOC concentrations in the Cedar and Ortega rivers, and Cedar-Ortega estuary were more typical, with most samples having a relatively high TOC content (e.g. 10 to 20% TOC) accompanied by small grain-sizes [Figures 3-8 and 3-9].

## SECTION 2: Metal compounds

Metals exist naturally in the environment as solids in the soils and small particles or dissolved in the water. Many metals are also present in dust particles in air, although these usually settle within a few days. Metal concentrations in the air can escalate due to fires and industrial activities.

Although metals occur naturally in the environment, most are geologically scarce, occurring in small or trace quantities. A few metals are geologically very abundant and therefore considered major metals (Moore, 1991; Turekian and Wedepohl, 1961[50]). Metals that naturally occur in the earth's crust, in U.S. soils and were measured in the LSJRB sediment are shown in Table 3-2 along with their average concentrations. The measured LSJR sediment metal maximum, median and minimum concentrations are also included in Table 3-2 for comparison. Most of the average U.S. soil concentrations (Shacklette and Boerngen, 1984), but not all, are lower than average crustal abundance concentrations (Table 3-2). These average crustal abundance values show that aluminum is the most abundant metal, but sources differ on whether mercury or selenium is the least abundant metal in the earth's crust (Moore, 1991; TJNAF, retrieved 2011). Based on both the crustal abundance (Moore, 1991; TJNAF, retrieved 2011) and U.S. soil concentrations (Shacklette and Boerngen, 1984), the 20 metals assessed in the sediment of the LSJRB, from highest to lowest are as follows: Al, Fe, Mn, V, Cr, Ni, Zn, Cu, Co, Li, Pb, Be, Sn, As, Ag, Tl, Sb, Cd, Se, Hg. The concentrations of these 20 St. Johns River sediment metal variables were compared to two crustal abundance values, the average (Moore, 1991) and estimated (TJNAF, retrieved 2011) crustal abundance values, and they were also compared to the average soil abundance value (Shacklette and Boerngen, 1984). These crustal and soil abundance values provided a reference level to assist in the evaluation of the metal concentrations measured in the St. Johns River sediment.

Naturally occurring metals contribute to the formation of the inorganic or mineral framework of sediment. The concentrations of naturally occurring metals vary in sediment due to geologic and environmental origins. This natural variation complicates attempts to attribute the metal concentrations to the geology of the location or to unnatural sources that would indicate metal contamination. Therefore, it is necessary when evaluating the measured metal concentrations in the LSJRB sediment to understand that elevated levels in an area may not indicate a contaminant problem but rather varying geologic sources.

All of the metals selected for analysis are toxic (Forstner, 1989[51]) at some concentration, and many are listed on the U.S. EPA's priority pollutant list, but some of the metals are much less toxic than others. It is generally assumed that most of the anthropogenic metals found in the riverbed sediment are derived from runoff and atmospheric deposition. In addition, waste disposal in the form of sewage-sludge and dredged-material can also provide a significant source of metals to the environment. Many commercially and recreationally important fin and shellfish species tend to accumulate these metals. Invertebrates, especially mollusks, concentrate metals and are excellent biomonitors of metal contamination. Fish are able to regulate many metal concentrations by induction of metallothioneins and depuration; therefore, bioaccumulation of many metals is limited.

The LSJRB sediment was analyzed for 17 trace and 3 major metals (aluminum, iron, manganese), and the results were reported in milligrams per kilogram of sediment in dry weight. These metal contaminants have been divided into 5 groups by their concentration ranges as previously described (Table 2-1). Each metal contaminant with a similar concentration range is individually illustrated in a graphic format on the same maps.

1. **Metal Group 1** includes beryllium, thallium, cadmium, silver, antimony and mercury.
2. **Metal Group 2** includes cobalt, tin, and selenium.
3. **Metal Group 3** includes lithium, copper, nickel and arsenic.
4. **Metal Group 4** includes manganese, zinc, chromium, vanadium and lead.
5. **Metal Group 5** includes iron and aluminum.

## Metals: Group 1

The Group 1 metals - beryllium, thallium, cadmium, silver, antimony and mercury - geologically occur in very small concentrations, in comparison to the other trace metals measured in the LSJRB sediment (Table 3-3). All of these Group 1 metals are toxic, accessible to aquatic organisms (Forstner, 1989) and listed as priority pollutants in water (U.S. EPA, retrieved 2011[52] ).

### Beryllium

Beryllium (Be) is one of the most toxic elements (Lenntech, retrieved 2011[53]) and is the most abundant of the Group 1 metals in the earth's crust (Moore, 1991). It is emitted during fossil fuel burning and the overwhelming source in the air is from coal combustion (Baudo et al., 1990[54], Moore, 1991). Pulp mill effluent, other industrial and municipal effluents are also sources of Be to receiving waters (Sodergren, 1991[55]). Beryllium has a very low solubility and readily precipitates or is adsorbed onto solids, therefore it is typically found in particulate rather than dissolved form in most natural waters (Callahan et al., 1979[56]). Freshwater Be concentrations are generally less than 1.0 µg/L and marine waters contain much lower levels, ordinarily less than 0.1 µg/L (Moore, 1991) Concentrations of Be measured in surface water of the lower SJR ranged from less than 0.1 to 4.977 µg/L (Florida STORET, retrieved 2011[57]). Residues in the sediment of a Louisiana estuary in a heavily populated area ranged from 0.07 to 0.48 mg/kg, and Be levels in a Japanese harbor were 2 to 3 mg/kg (Moore, 1991).

The maximum, mean, median and minimum sediment Be values calculated from the LSJRB samples are shown in Table 3-3. As expected, the mean (0.8mg/kg) and median (0.7 mg/kg) Be concentrations were the highest among all Group 1 metals (Table 3-3). The maximum Be concentration (ORT40) was over 400 times its minimum measured trace level value (ORT19). The 11 sites with the highest Be concentrations were located in the Ortega River and the Cedar-Ortega estuary, and all 11 sites had concentrations greater than 2.0 mg/kg [Figures 3-14 and 3-15]. The mainstem river sites with the highest Be values were located in the Jacksonville area (LSJ01; PTLV01; LSJ02). In general, sediment Be concentrations decreased from the highest concentrations in this northern region and the Jacksonville area to lower concentrations upstream, in the central and southern regions. Sediment Be concentrations were below detection at eight sample sites.

The highest sediment Be concentrations exceeded the average crustal abundance value of 2.5 mg/kg (Moore, 1991) at five sites (Table 3-2). All five sites were found in the Cedar-Ortega estuary and in the Ortega river and two of these five sites exceeded the estimated crustal abundance value (TJNAF, retrieved 2011) of 2.8 mg/kg [Figures 3-14 and 3-15]. Over half of the sediment samples sites exceeded the average U.S. soil concentrations of 0.63 mg/kg (Shacklette and Boerngen, 1984). Although Be is the most abundant Group 1 mineral in the earth's crust, three other Group 1 metals (mercury, silver and cadmium) had maximum concentrations that exceeded the maximum Be concentration found in LSJRB sediment (Table 3-3).

Beryllium has a high acute toxic and high chronic toxic effect on aquatic life (National Pollutant Inventory, retrieved 2011[58]). Beryllium is more toxic in soft water than in hard water, and the toxicity in soft water is comparable to cadmium and copper, with an $LC_{50}$ of 0.2 mg/L for fathead minnows (Moore, 1991). Bioconcentration is the uptake of water-borne chemicals by organisms through non-dietary means (only from direct exposure to the water column by diffusion and adsorption). Bioconcentration of Be from water by fish does not tend to occur (National Pollutant Inventory, 2011), but accumulation from food does occur, although concentration factors are low (Moore, 1991). Little information concerning biological cycling is available, but studies have shown that: a) Be is highly toxic to warm water fishes; b) guppies (*Poecilia sp.*) metabolize Be c) benthic organisms could accumulate Be from sediment and transfer the metal to higher organisms via the food web (Callahan et al., 1979).

There are no TEL/TEC or PEL/PEC SQG for Be, but both the mean and median Be concentrations were greater than the concentrations found in a Louisiana estuary in a heavily populated area. Approximately 70% of the lower SJR samples exceeded the maximum concentration found in this Louisiana estuary. The highest Be concentrations measured in the Cedar-Ortega estuary fell within the range found in the Japanese harbor mentioned previously (Moore, 1991).

### Thallium

According to the United States Environmental Protection Agency, man-made sources of thallium (Tl) pollution include emissions from coal burning power plants, cement factories and metal smelters (U.S. EPA, retrieved 2011 [59]). Thallium has a high aqueous solubility and a strong tendency to accumulate in aquatic life (Callahan et al., 1979). The surface water Tl concentrations in the lower SJR ranged from <0.10 to 49 µg/L (Florida STORET, retrieved 2011). Marine sediment has been found to contain 0.60 to 0.95 mg/kg Tl and uncontaminated sediment from lakes and small streams in various parts of Canada typically contained from 0.02 to 3.2 mg/kg Tl (International Programme on Chemical Safety – Concise International Chemical Assessment Documents [IPCS-CICAD], Retrieved 2011 [60]). In comparison, river sediment from industrialized areas contained 0.05 to 18 mg/kg Tl ([IPCS-CICAD], Retrieved 2011).

Thallium had the lowest maximum and mean sediment concentrations, and smallest variance of all Group 1 metals (Table 3-3). The five sites with the highest Tl concentrations were spread widely over the river basin, from the southern region (LSJ30), to northern region in Jacksonville (BOLL02), and in the Cedar-Ortega estuary and Cedar River (CED062; CED01D; ORT37). Therefore, no distinct pattern emerged for sediment Tl concentrations in the LSJRB. Sediment Tl concentrations were below detection in two samples.

Only five sites had concentrations greater than Moore's (1991) average crustal abundance value of 0.5 mg/kg, but none exceeded the TJNAF (retrieved 2011) estimated crustal abundance value of 0.85 mg/kg (Table 3-2). Average U.S. soil concentrations and SQG for Tl were not available.

Thallium is extremely toxic and thallium-sulfate was once used as a rat and ant poison, although it has been banned from household use in the U.S. since 1974. Thallium is more toxic to aquatic organisms than cadmium, lead, copper, nickel or zinc (Callahan et al., 1979). Since Tl is very soluble, skin contact with it is dangerous because it will absorb through the skin. Skin exposure levels should not exceed 0.1 mg/m² of skin in 8 hours (CRC, 2008[61]). It is readily available to aquatic organisms, and will quickly bioaccumulate. Thallium is as acutely toxic as copper to fish and slightly more acutely toxic to mammals than mercury (Zitko, V. 1975[62]). The high toxicity potential, and rapid bioconcentration potential, makes Tl and its compounds of particular environmental concern.

Although TEL/TEC and PEL/PEC SQG are not available for Tl, an evaluation of the LSJR sediment Tl concentrations showed they were less than the previously mentioned marine sediment literature values (0.60 to 0.95 mg/kg Tl) collected from ocean areas not contaminated by Tl (IPCS-CICAD, Retrieved 2011). The Tl levels in the lower SJR were comparable to the lower levels found in the uncontaminated sediment from Canadian lakes and streams (IPCS-CICAD, Retrieved 2011).

### Cadmium

The primary sources of cadmium (Cd) to the atmosphere are from municipal waste incineration and fossil fuel combustion (U.S. EPA. Retrieved 2011[63]). Non-point sources include domestic wastewater effluent, atmospheric deposition, leaching from landfills, and effluent from manufacturing processes such as pulp and paper, batteries, glass ceramics, electroplating, paints and plastics (Moore, 1991). Tobacco smoking is the most important source of Cd exposure in the general population.

Cadmium is routinely detected in most surface waters in both dissolved and particulate form (Moore, 1991). Mathis and Cummings (1973[64]) reported Cd concentrations from the Illinois River with an average of 0.6 µg/L, and a range from 0.1 to 2.0 µg/L. A much wider span of Cd concentrations was measured in the lower SJR surface water that ranged from <0.10 to 52.0 µg/L (Florida STORET, retrieved 2011). The most important factors in determining the aquatic fate of Cd include: complexing with organic materials, sorbing to clay minerals and/or co-precipitating with hydrous metal oxides (Callahan et al., 1979). In uncontaminated freshwater sediment, concentrations range from 0.1 to 1.0 mg/kg (Moore, 1991). Although cadmium is soluble and mobile, as salinity increases it precipitates leading to much higher sediment concentrations in estuarine and coastal environments (Moore, 1991).

The mean, median and range of Cd concentrations measured in the LSJRB are shown in Table 3-3. The highest Cd values were found at seven sites, and all seven had concentrations greater than 2.0 mg/kg. Six of the seven sites were located in the Cedar River, and the other site (PIRC01) was located in the lower SJR in the Jacksonville area [Figures 3-14 and 3-15]. Each of these seven sites had Cd concentrations that were over ten times Moore's (1991) average crustal abundance value of 0.2 mg/kg (Table 3-2). Cadmium concentrations ranged from below detection to 2.19 mg/kg in samples taken from LSJ sites, but were higher in the Cedar-Ortega estuary, Cedar and Ortega rivers. Values in the latter sites ranged from 0.14 mg/kg (ORT30) to 3.83 mg/kg (CED01). Sediment Cd concentrations were below detectable levels at ten of the 175 sites, and most of these ten sites were located in the Southern region. The spatial trend for sediment Cd concentrations was similar to Be, as sediment Cd concentrations decreased with increasing distance moving upstream.

Over 80% of the sites had Cd concentrations that exceeded Moore's (1991) average crustal abundance value of 0.2 mg/kg (Table 3-2). Crustal abundance concentrations of Be are ten times greater than the Cd concentrations, yet in the lower SJR, Cd concentrations exceeded the maximum Be concentration (Be max=3.18 mg/kg) at two sites, which indicates a local source of Cd contamination. Both of these sites were located in the Cedar River (CED01; CED02). The average U.S. soil Cd concentration was not available.

Cadmium is very toxic to plants and animals, although lethal concentrations vary over a wide range for different taxonomic groups. Very low concentrations of 0.001 to 0.03 mg/L were reported to be acutely toxic to some fish species (Moore, 1991). Cadmium although highly toxic is concentrated by most organisms, and this tendency to accumulate is great in all species (U.S. EPA., retrieved 2011). Cadmium is readily accumulated through food and water, and either source of uptake can result in the development of toxic symptoms. Cadmium has been reported to accumulate in the tissue of aquatic and marine organisms at concentrations hundreds and thousands of times higher than in the water column (Eisler et al., 1962;[65] Kinkade and Erdman, 1975[66]).

Sediment quality guidelines are available for Cd, and comparisons showed that no sediment Cd concentration measured in the lower SJR was greater than the saltwater PEL of 4.21 mg/kg (Table 3-8). However, Cd concentrations did exceed the freshwater PEC of 3.53 mg/kg at two sites in the Cedar River (CED01, CE02). Therefore, sediment dwelling organisms are probably adversely affected by the Cd levels at these two sites. The mean Cd concentration of 0.736 mg/kg (Table 3-3) exceeded both the saltwater TEL of 0.676 mg/kg, and the freshwater TEC of 0.596 mg/kg (Table 3-8). Sediment Cd concentrations were above the saltwater TEL and freshwater TEC at 75 and 85 sites, respectively. These data indicate that Cd contaminants may be adversely affecting biota at between 42 to 49% of the sampled sites.

## Silver

Silver (Ag) is a relatively rare but naturally occurring metal. Emissions from coal combustion, smelting operations, municipal waste, manufacture and disposal of certain photographic and electrical supplies are some of the anthropogenic sources of silver in the biosphere (IPCS-CICAD, Retrieved 2011). Silver is usually found in low concentrations in natural waters because of its low crustal abundance and low solubility in water. Measurements of Ag in lakes, rivers and estuaries using clean techniques showed levels of about 0.01 µg/L for pristine, unpolluted areas and 0.1 µg/L in urban and industrialized area (US EPA, 1980[67]). The clean techniques for Ag analysis were not used for lower SJR surface water, and therefore low-level detection was not possible. The Ag concentrations in the lower SJR surface water averaged 1.2 µg/L with a maximum of 810 µg/L (Florida STORET, retrieved 2011). Sediment Ag concentrations from San Francisco Bay ranged from 1 to 66 mg/kg and reflect the industrial discharge of Ag to the bay (Moore, 1991).

The maximum Ag concentration in the lower SJR (5.39 mg/kg) was over 100 times greater than the minimum measured concentration (0.011 mg/kg), and the mean, median and range of Ag concentrations are shown in Table 3-3. All of the eight sites with the highest Ag concentrations were located in tributaries in the Jacksonville area. Five of these sites were in the Cedar River, two were in the Cedar-Ortega estuary and the other site (GDBY01) was located in Goodbys Creek [Figures 3-14, 3-15 and 3-13]. Four of the sites had Ag concentrations greater than 2.0 mg/kg [Figure 3-14]. The river site with the highest Ag concentration (PIRC01) was also located in the Jacksonville area [Figure 3-13]. Silver was not detected in sediment at seven sites, and most of these sites were located in the Southern region. The Ag concentrations followed the general metal pattern of decreasing concentrations with increasing distance upstream.

Over 20 % of the LSJRB sites had Ag concentrations that exceeded Moore's (1991) average crustal abundance value of 0.7 mg/kg, while over 80% exceeded the TJNAF (Retrieved 2011) estimated crustal abundance value of 0.075 mg/kg (Table 3-2). Two sites had Ag concentrations that exceeded the maximum Be concentration (Be max=3.18 mg/kg) and, as with Cd, both were found in the Cedar River (CED01; CED02). These two sites were the same sites at which Cd was elevated compared to Be. Average U.S. soil concentrations for Ag were not available.

Silver ions are very toxic to microorganisms and uncomplexed silver ions are lethal to many species of aquatic plants, invertebrates, and fishes at nominal water concentrations of 1.0-5.0 µg/L. Adverse effects occur on the growth and development of trout fry at concentrations as low as 0.17 µg/L and on phytoplankton species composition and succession at 0.3-0.6 ug/L (IPCS-CICAD, Retrieved 2011). The ability to accumulate dissolved silver varies widely between species. Some organisms were reported to bioconcentrate silver in their tissue so that levels were hundreds to thousands of times greater than the water, while reported concentration factors from sediment were much lower (Moore, 1991).

The four highest Ag concentrations were greater than the saltwater PEL value of 1.77 mg/kg and, as previously mentioned, all were located in the Cedar River and downstream area of the Cedar-Ortega estuary. The biota are probably being adversely affected by the sediment Ag concentrations at these four sites. The saltwater Ag TEL level of 0.730 mg/kg was exceeded at 36 sites. These data indicated that biota may be adversely affected by Ag concentrations at over 20% of the sites in the LSJRB. No freshwater PEC/TEC SQG were available for Ag.

## Antimony

Antimony (Sb) is an important metal used in electronics, ammunition, as a flame-retarding agent and jet fuel additive. The U.S. EPA's Toxic Release Inventory (U.S. EPA - TRI, retrieved 2011[68]) reports that releases of antimony occur to air and water from metal processing works, mines and the burning of fossil fuels and refuse incinerators. Antimony, like mercury, will volatilize during combustion processes and be dispersed by the wind. Volatilized antimony can stay in the atmosphere for 3 to 30 days and be transported far from its source (Agency for Toxic Substances and Disease Registry -ATSDR, retrieved 2011 [69]). Antimony is relatively soluble compared to most other transition metals, and domestic wastewater and landfill leachate are potential sources to waterways.

Antimony is typically found at very low levels throughout the environment. The concentration of antimony in ambient air ranges from less than 1 nanogram per cubic meter (ng/m$^3$) to about 170 ng/m$^3$. Concentrations of total dissolved antimony are usually less than 1.0 µg/L in non-polluted waters, and ranged from 0.0003 to 2.1 µg/L in wastewater treatment plants (ATSDR, retrieved 2011). Concentrations of Sb measured in lower SJR surface water ranged from <0.10 to 30.35 µg/L (Florida STORET, retrieved 2011). Antimony concentrations in background sediment cores from open water areas of Lake St. Clair, Ontario ranged from 0.032 to 0.098 mg/kg (ATSDR, retrieved 2011). Four Chesapeake Bay tributaries, Patuxent, South, Severn and Wicomico rivers had sediment concentrations of 0.38, 0.32, 0.17, and 1.08 mg/kg respectively. Sediment samples taken from Puget Sound in Washington from non-contaminated areas ranged from 0.3 to 1.0 mg/kg, and levels rose up to 12,500 mg/kg within 1 km of a smelter (ATSDR, retrieved 2011). Antimony levels in contaminated, dredged sediment ranged from 0.5 - 17.5 mg/kg (ATSDR, retrieved 2011).

Antimony (Sb) is widespread and was one of two Group 1 metals found in all sediment samples collected from the LSJRB. The mean, median, maximum and minimum Sb concentrations are shown in Table 3-3. The highest sediment Sb concentrations were found at three sites, and all three had concentrations greater than 1.0 mg/kg. All three sites were located in the Cedar River [Figure 3-14]. The highest concentration found in the river was in Jacksonville (HSP05), near the confluence with the Cedar-Ortega estuary [Figure 3-13].

Over 90% of the lower SJR samples had Sb concentrations that were greater than the highest background concentration (0.098 mg/kg), and all sediment concentrations were greater than the low-level background concentration found in Lake St. Clair. The majority of the Sb concentrations measured in the LSJRB sediment were within the ranges found in the four Chesapeake Bay tributaries and in Puget Sound, and in the lower range for contaminated dredged sediment (ATSDR, retrieved 2011).

Over 75% of the sites had Sb concentrations that were greater than the TJNAF estimated crustal abundance value of 0.20 mg/kg (Table 3-2), however the average concentration of Sb in U.S. soils was also greater than the TJNAF estimated crustal abundance value (Retrieved 2011). Approximately 16% of the lower SJR samples exceeded the U.S. soil value of 0.48 mg/kg (Shacklette and Boerngen, 1984). Although widespread, the Sb concentrations still followed the general metal pattern, as Sb concentrations tended to decrease with increased distance upstream.

Antimony's biological role remains unknown, but clinically, antimony poisoning is very similar to arsenic poisoning. It is considered to have high acute toxicity based on short-term oral tests in rats, mice, and guinea pigs. Trivalent antimony exhibits higher toxicity than pentavalent antimony; trivalent antimony was found to be acutely toxic to fish and pentavalent antimony was acutely toxic to crustacea (RTECS, retrieved 2011[70]). No reliable chronic toxicity data were obtained for either tri- or pentavalent antimony.

Antimony can be reduced and methylated by microorganisms in anaerobic sediment, releasing volatile methylated antimony compounds into the water (ATSDR, retrieved 2011). Concentrations of antimony in selected species of algae, mollusk tissue, crustacean tissue, and fish muscle from southeastern Australia were 0.094-0.193, 0.031-0.060, 0.018-0.116, and less than 0.009-0.010 mg/kg (dry weight), respectively. The water collected at the site contained 0.17 mg/kg of antimony (ATSDR, retrieved 2011) As with many metals, antimony is generally found in greater concentrations in invertebrates than in fish. Callahan et al. (1978) reported that the bioconcentration of antimony was low, but also stated that data on bioconcentration and biomagnification are limited (Callahan et al. 1978).

No TEL/TEC or PEL/PEC SQG were available for Sb

### Mercury

Mercury is a highly toxic element that is found both naturally and as an introduced contaminant in the environment. Like many metals, mercury is released by volcanoes, hot springs and from rich geologic deposits. It is dispersed further by natural occurrences such as fires and floods. Although the release of mercury from natural sources has remained fairly constant over the years, concentrations are increasing in the aquatic environment, and this increase is attributed to human activity (Lenntech, retrieved 2011).

Humans release mercury into the environment during metal mining, by the combustion of fossil fuels especially coal, through the incineration of solid wastes, such as batteries, fluorescent bulbs, medical products, during pulp and paper manufacturing, and the production of chlorine, sodium hydroxide and cement. In addition, the application of agricultural fertilizers and pesticides, and wastewater disposal can release mercury directly into soil or water (U.S. EPA. Retrieved 2011 [71]).

Atmospheric deposition is the largest nonpoint source of mercury to both marine and freshwaters (Moore, 1990). Mercury emitted to the atmosphere will be deposited onto watersheds by precipitation. Mercury in soils or surface waters can be converted by bacteria to methylmercury, which is much more soluble than inorganic mercury (Callahan et al., 1979).

Although mercury is an extremely rare element in the earth's crust, it is recognized as one of the most widespread, toxic contaminants of industrial origin, and is found in high concentrations in the environment (Ehrlich and Newman, 2008 [72]). Atmospheric mercury contamination in outdoor urban air ranges from 0.01 – 0.02 µg/m3, but indoor concentrations usually are significantly higher (average 0.069 µg/m3). Concentrations of dissolved mercury in unpolluted freshwater are normally very low, ranging from 0.01 to 1.0 µg/L, and the average in seawater is 0.03 µg/L (Marine Chemistry, 1971 [73]). Higher acidity and dissolved organic carbon levels enhance the mobility of mercury in the environment, thus making it more likely to enter the food chain. Low-level mercury concentrations ranging from 0.088 to 0.18 mg/kg were measured in Lake Superior sediment, and much higher levels were found in the other great lakes. Lake Erie sediment mercury concentrations were highest ranging from 0.19 to 0.61 mg/kg (Environment Canada, 2011 [74]). Moore (1991) reported that total mercury concentrations in sediment typically ranged from 0.1 to 0.5 mg/kg in unpolluted areas, increasing to 5 mg/kg and higher in polluted areas.

Mercury (Hg) was another widespread Group 1 metal measured in all sediment samples collected from the LSJRB. The Hg concentrations showed the largest variance of the Group 1 metals, and the maximum Hg concentration was over 1000 times the minimum measured value. The mean, median and range of Hg concentrations are shown in Table 3-3. All 12 of the highest Hg sediment concentrations were greater than 1.0 mg/kg. Seven of the 12 sites were located in the Cedar-Ortega estuary, two in the Ortega River, one in the Cedar River and the other two were found in Rice Creek [Figures 3-14, 3-15 and 3-18].

Over 80% of sites had measured Hg concentrations above Moore’s (1991) average crustal abundance value of 0.08 mg/kg. In addition, over 89% of the sites had Hg concentrations above the average U.S. soil value (Shacklette and Boerngen, 1984) of 0.058 mg/kg (Table 3-2). The highest measured sediment concentration of 5.513 mg/kg was approximately 100 times higher than the average U.S. soil concentration, and exceeded the maximum Be concentration (Be max=3.18 mg/kg). As previously noted, Be is the most abundant Group 1 mineral, and crustal abundance values indicated that Be should be in much higher concentrations than Hg, yet the maximum Hg value exceeded the Be maximum value in the LSJRB sediments.

Mercury is widespread and elevated mercury concentrations were mainly found near urban areas of Jacksonville, Green Cove Springs and Palatka with highest values in the tributaries (Cedar-Ortega estuary, Ortega and Cedar rivers, and Rice Creek). These elevated Hg concentrations were found throughout the lower SJR, and did not tend to diminish with distance upstream as seen with the majority of other trace metals.

Mercury is a neurotoxin and is one of the most serious contaminants threatening our nation’s waters (Environment Canada. 2011). It causes damage to the brain, spinal cord, intestines, kidneys and stomach of animals and is highly toxic to plants, invertebrates and fish. Inorganic mercury concentrations above 0.05 mg/L are acutely toxic to most invertebrates, and levels between 0.1 to 1.0 mg/L are acutely toxic to marine and freshwater fish (Moore, 1990). Methylmercury is considerably more toxic to invertebrates and fish, can be absorbed quickly by most organisms and concentrates through all levels of the food web (Moore, 1990). Almost all (>95%) of the mercury in edible tissues of fish is methylated (U.S. EPA, 2001. Fact Sheet. Retrieved 2011[75]).

The saltwater PEL of 0.696 mg/kg (Table 3-8) was exceeded in sediment samples at 30 sites, and the freshwater PEC of 0.486 was exceeded at 53 sites. Mercury concentrations at these 30 to 53 sites probably are adversely affecting biota. Mercury concentrations were greater than the freshwater TEC of 0.174 mg/kg and saltwater TEL of 0.13 mg/kg at 126 and 171 sites, respectively, which indicates that biota may be adversely affected in 72 to 98% of the lower SJR sites.

## Metals: Group 2

The Group 2 metals include cobalt, tin, and selenium. The average crustal abundance of cobalt is approximately 10 times greater than tin, and 100 times greater than selenium (Table 3-2). Geologically, the Group 2 metals would be expected to be in higher concentrations in the earth's crust than the Group 1 metals, with the possible exception of selenium.

### Cobalt

Cobalt (Co) is a natural element found throughout the environment and is used to make high temperature superalloys for aircraft, corrosion resistant alloys, magnets and in pigment manufacture (ATSDR, retrieved 2011) . The radioactive isotope, cobalt-60, is used in medical treatment and to irradiate food (ATSDR, retrieved 2011). Cobalt is widely dispersed, but not often freely available in the environment.

As with many metals, fossil fuel combustion (particularly coal burning), and waste incineration account for over half of all Co in the air (Moore, 1991). The average concentration of Co in ambient air in the United States is approximately 0.0004 µg/m3, however much higher levels of 0.61 µg/m3 were measured in industrial areas. A study found average Co levels in drinking water of 0.002 mg/L, but values up to 0.107 mg/L have been reported (ATSDR, retrieved 2011). Cobalt concentrations in freshwater are generally below 0.001 mg/L, but can get much higher (>0.015mg/L) in industrial areas. In marine waters, cyanobacteria and other nitrogen-fixing organisms scavenge Co, and therefore concentrations are extremely low, often below 10 ng/L (Moore, 1991). Surface water Co concentrations were not measured in the lower SJR.

Uncontaminated freshwater sediment generally contains from 1 to 10 mg/kg of Co. Harbor and other contaminated sediment has appreciably higher residues typically ranging from 25 to 50 mg/kg with even higher levels up to 57 mg/kg found near coal-burning generating plants (Moore, 1991).

Geologically, Co would be expected to be in highest concentrations of the Group 2 metals measured in the LSJRB sediment. The mean and median Co sediment concentrations conformed to this assumption, but not the maximum value, which was exceeded by the maximum tin concentration (Table 3-4). The site with the highest Co concentration was found in the mainstem of the river, and the mean, median and range of Co concentrations are shown in Table 3-4. Six sites had Co concentrations that were greater than 6.0 mg/kg. The highest concentration was located near Point La Vista in Jacksonville (PTLV01), three of the six sites were located in the Cedar River (CED01D, CED02, CED04), and the other two sites were also found in the lower SJR (BOL04; BOLL02) in the Jacksonville area [Figures 3-19 and 3-20].

Concentrations of Co were found at all sites in the LSJRB, although none of the sites had concentrations that exceeded Moore's (1991) average crustal abundance value of 25 mg/kg. The maximum Co concentration was three times less than this average crustal value (Table 3-2). The average U.S. soil value for Co was not available. The spatial trend for sediment Co concentrations was similar to many sediment metal concentrations that showed a decreasing trend with increasing distance upstream.

Cobalt is a constituent of vitamin B12, and therefore an essential element for many organisms, but at higher levels, it is moderately toxic to most aquatic plants and animal species. It is more toxic than chromium, manganese and molybdenum, but much less toxic than aluminum, cadmium and copper (Moore, 1991).

Uptake of Co by plants appears to be extremely rapid (Moore, 1991), and some phytoplankton concentrate Co. Toxic concentrations vary extensively for invertebrates, ranging from 3 to greater than 100 mg/L depending on the species. Acute exposure to high levels of cobalt result in respiratory problems, congestion, edema, and hemorrhage of the lung. Chronic exposure can lead to respiratory irritation, pneumonia, cardiac effects, congestion of the liver, kidneys, and immunological effects (ATSDR, retrieved 2011).

All of the Co concentrations measured in the LSJRB sediment were comparable to the uncontaminated freshwater sediment concentrations discussed by Moore (1991). No TEL/TEC or PEL/PEC SQG are available for Co.

### Tin

Tin (Sn) and tin compounds are found in small amounts in the earth's crust. It is used in foil, wires, plating and in bronze and brass alloys. Inorganic Sn compounds are present in toothpaste, perfumes, soaps, coloring agents, food additives, and dyes. Tin will combine with carbon to form organotin compounds that do not naturally occur in the environment. Organotins are used in making plastics (PVC), food packages, plastic pipes, pesticides, paints, wood preservatives, antifouling paint and rodent repellants (ATSDR, retrieved 2011). Antifouling paint is highly toxic to marine life and is the primary source of organotin to the aquatic environment (Moore, 1991).

Total Sn was measured instead of organotin (or butyltins) in the LSJRB assessments because analysis costs for butyltins are 3 to 5 times greater than for total Sn, and butyltin use is restricted. Since no continual source of butyltin is suspected, the surrogate, total Sn, was used to determine areas with potentially high levels, and these areas could be assessed for butyltin sources in the future.

Tin is a natural component of many soils, and is dispersed in dusts by wind storms and farming activities. Mining, smelting, refining processes, the combustion of fossil fuels and waste incineration contribute to the atmospheric Sn concentrations (ATSDR, retrieved 2011). Particles in the air containing Sn may be transported by wind or washed out of the air by rain or snow. Most of the Sn in rainfall is in the particulate form and typically ranges from 0.1 to 10 ng/L (Moore, 1991). Tin concentrations measured in uncontaminated freshwater range from 1 to 5 µg/L (Moore, 1991), but were higher in lower SJR surface waters ranging up to 32.01 µg/L (Florida STORET, retrieved 2011). Much lower levels were found in seawater (Moore, 1991). The concentration in soil is generally between 1 to 4 mg/kg, but some soils have less than 0.1 mg/kg, while peats can have as much 300 mg/kg (Lenntech, retrieved 2011). Total Sn concentration in New Zealand sediment ranged up to 6.2 mg/kg, and the maximum values were observed adjacent to a storm water outfall (deMora, et al., 1989[76]). Mean total Sn concentrations in Antarctic sediment were 2.1 to 5.1 mg/kg (dry wt), while concentrations in Canadian sediment ranged up to 15.5 mg/kg in rivers and to 8 mg/kg in coastal waters (Moore, 1991).

The Sn concentrations in lower SJR sediment varied widely, with the maximum value approximately 100 times the minimum value. The range of Sn concentrations was the most extensive of the Group 2 metals, and the mean, median, maximum and minimum values are shown in Table 3-4. Sediment Sn concentrations above 10 mg/kg were measured at four sites in LSJRB. All four sites were located in the Cedar River [Figure 3-20].

Tin was discovered at all sites in the LSJRB, and both mean and median Sn concentrations exceeded Moore's (1991) average crustal abundance value of 2.0 mg/kg (Table 3-2). Over 60% of the LSJRB sites had Sn concentrations above Moore's (1991) average crustal abundance value, and over 80% were above the average U.S. soil concentrations of 0.89 mg/kg (Shacklette and Boerngen, 1984). The Sn concentrations followed the general metal pattern of decreasing concentrations with increasing distance upstream.

Individual atoms or molecules of Sn are not very toxic, but the organic tin compounds are extremely toxic, very persistent, not easily biodegraded and therefore will accumulate in sediment for many years. Organic tin or organotin compounds may be ingested by animals that live in water containing these compounds. The uptake of inorganic and organotin by plants is rapid, and most aquatic plants are highly sensitive to organotins, especially tributyltin (Lenntech, retrieved 2011). Tributyltin is also highly toxic to many invertebrates and fish. The acute effects of tributyltin on fish vary with species with lethal concentrations occurring as low as 1.4 to 5.2 µg/L. Chronic effects of organotin compounds were also reported at extremely low concentrations ranging from 0.2 to 2.0 µg/L (Moore, 1991).

No TEL/TEC or PEL/PEC SQG are available for Sn, but over 8% of the samples exceeded the maximum level reported in New Zealand sediment by deMora, et al. (1989). In addition, over 16% of the sampled sites had Sn concentrations that were greater than the highest average value found in Antarctic sediment (Moore, 1991).

### Selenium

Selenium (Se) is a trace element required for good health, but at high doses it can be extremely toxic

(Callahan et al., 1979). It is a potential contaminant of surface waters and it can be bioaccumulated by aquatic species to high levels (Moore, 1991). Currently, the largest use of selenium worldwide is in glass manufacturing, and in chemicals and pigments. Electronic uses for selenium, once important, have been supplanted by silicon semiconductor devices (ATSDR, retrieved 2011). Large quantities of Se are discharged as a by-product of fossil fuel combustion, metal refining, smelting and in domestic wastewater leaving residual concentrations in water and sediment. Intensive irrigation can also lead to Se contamination of surface water (Moore, 1991). Normal Se concentrations in fresh water range from <0.1 to 5 ug/L, but a lower range from <0.1 to 0.2 ug/L was found for seawater (Moore, 1991). Surface water Se concentrations in the lower SJR ranged from <0.1 to 170.2 ug/L (Florida STORET, retrieved 2011). Sediment Se concentrations are highly variable, ranging from 0.2 to 30 mg/kg in freshwater sediment, and from <0.1 to 1.0 mg/kg in marine sediment (Moore, 1991).

As expected, the maximum, mean and median sediment Se concentrations were the lowest of the Group 2 metals (Table 3-4). The range of sediment Se concentrations was also the lowest of the Group 2 metals (Table 3-4). Four sites had Se concentrations that were above 4.0 mg/kg, and 19 sites had Se concentrations over 3.0 mg/kg. The four highest Se concentrations were collected from the Welaka area (WEK021; DUNN02; LSJ40; WEK02) in the Southern region [Figure 3-23]. Selenium was not detected in five sites in the LSJRB.

The Se concentrations were above Moore's (1991) average crustal abundance at almost all of the sites (95%). Since the U.S. soil Se concentration (Shacklette and Boerngen, 1984) was higher than the crustal abundance value, 90% of the sites exceeded the soil value. Estimates of the average crustal abundance of Se vary, and some authors suggest that Se is the least abundant of the earth's crustal metals that were analyzed in the LSJRB sediment (Table 3-2). The sediment Se concentrations showed a very different spatial pattern in relation to most other metals, as Se concentrations generally increased with distance upstream. All of the ten highest selenium concentrations were found in the Southern region of the river [Figures 3-23 and 3-24]. This Se gradient in the lower SJR sediment is consistent with general trends in water column Se concentrations, where lower levels occur in estuarine waters with higher levels typically occurring in freshwater.

Selenium is toxic in high concentrations (40-60 ug/L), but trace amounts are essential for the function of at least 25 selenium-dependent enzymes in animals (Goldhaber, 2003[77]). Unlike animals, many plants do not seem to require Se for survival; however, they will incorporate it non-specifically when it is present in the soil (Lenntech, retrieved 2011). Selenium is ubiquitous, occurring in the tissues of all aquatic plants and animals in widely varying concentrations (Moore, 1991). The toxicity of Se in plants and animals is species dependent. Selenium is moderately to highly toxic to plants over a very large range (0.8 to 2,400 ug/L) depending on the plant species. Acutely toxic concentrations to invertebrates range from 0.3 to 33 mg Se/L, and for fish range from 0.01 to 5.0 mg/L. Chronic effects of Se toxicity have been found at much lower levels. Chronic levels for invertebrates were reported below 0.5 mg/L, and ranged from 0.04 to 0.10 mg/L for fish (Moore, 1991). Relatively little is known about the toxicity of organic Se, but studies have shown it is much more toxic than inorganic Se (Moore, 1991).

No TEL/TEC or PEL/PEC SQG are available for Se, but almost all (>93%) of the LSJRB sediment samples had Se concentrations above the lower marine and freshwater sediment levels reported by Moore (1991). Over 77% of the lower SJR sediment Se concentrations were also above the highest marine sediment level, but none of the sediment Se concentrations were greater than the upper freshwater sediment level reported by Moore (1991).

## Metals: Group 3

The Group 3 metals include lithium, copper, nickel and arsenic. Nickel is the most abundant of the Group 3 metals in the earth's crust, followed by copper, then lithium and the least abundant crustal metal, arsenic (Table 3-2). Nickel is approximately 40 times and lithium is approximately four times as abundant as arsenic in the earth's crust.

### Lithium

Lithium (Li) is widely distributed on Earth, but it is characteristically found in low concentrations. Lithium reacts with a large number of organic and inorganic chemicals, and many reactions may cause fire or explosion (Lenntech, retrieved 2011). It will also react very energetically with water and does not occur freely in nature (Lenntech, retrieved, 2011). Natural Li enrichment typically positively correlates with natural enrichment other metals, and this correlation can be used to compensate for the natural textural and mineralogical variability found in sediment (Aloupi and Angelidis. 2001[78]). Therefore normalizing metal contaminant concentrations to Li can be informative, although less conventional than using aluminum or the silt-clay fraction for that purpose.

Lithium has several industrial applications with the dominant use being in batteries. Lithium is also used as an algaecide, fungicide, disinfectant, sanitizer, lubricant, in medicines and as a high strength alloy in aircraft (U.S. EPA. 1993. R.E.D. FACTS.[79]) The wide application means that Li is discarded in many waste types. Due to its high solubility in water, Li can often be detected in treated wastewater and in landfill leachate. Therefore, industrial and municipal effluent discharges, leachate from landfills and coal ash ponds are potential sources of Li to the aquatic environment. Emissions of Li occur during the combustion of fossil fuels or waste and are another source to the environment (Moore, 1991).

Lithium is found at low concentrations in the major rivers of the United States averaging 2 to 3 ppb (0.002 to 0.003 mg/L), seawater contains approximately 0.17 mg/L, whereas mineral spring water contains 1 mg/L (Lenntech, retrieved 2011). Concentrations of Li in the surface and ground waters may be higher in places where Li-rich brines and minerals occur. No measurements of Li in surface waters of the lower SJR are available.

Sediment Li concentrations from the Nile delta ranged from 7 and 48 mg/kg (Mamdouh, 1973[80]), and the average found in the Bay of Bengal was 7.2 mg/kg (Sarma and Umamaheswara, 1999[81]). Leivuori (1998[82]) reported median Li concentrations from the Gulf of Finland of 60 mg/kg, Bothnian Bay of 27 mg/kg and from the Bothnian Sea of 48 mg/kg. In the U.S., the sediment Li concentrations from three non-industrial rivers ranged from 1.7 to 5.7 mg/kg, but were higher in the industrial Illinois River ranging from 0.5 to 16.3 mg/kg (Mathis and Cummings, 1973).

The highest Li concentration of 54 mg/kg, found in the Ortega River (ORT 39-1), was over 100 times the minimum concentration of 0.38 mg/kg found in Rice Creek (RCJU04). The mean, median and range of sediment Li concentrations are shown in Table 3-5. Five sites had Li concentrations greater than or equal to 50 mg/kg. Three of the five were located in the Cedar-Ortega estuary, one in the Ortega River and one in the Cedar River [Figures 3-26 and 3-27]. Eleven additional sites had Li concentrations over 40 mg/kg. Four sites were located in the Cedar-Ortega estuary and one was found in the Cedar River. The six other sites were located in the Jacksonville area: three at river sites and three in tributaries [Figures 3-26, 3-27 and 3-25]. Lithium concentrations were measured above detection limits at all sites.

Over 50% of the lower SJR site samples had Li concentrations above the estimated crustal abundance value of 20 mg/kg (Table 3-2). Although these crustal abundance values indicated that nickel could be expected to be in much higher concentrations than Li, the Li mean and median values exceeded the nickel mean and median values in the LSJRB sediments. In addition, the Li maximum concentration was equivalent to the maximum nickel concentration (Table 3-5). No U.S. soil Li concentration was available. As with many metals, sediment Li concentrations generally decreased with increasing distance upstream.

Kszos and Stewart, (2004[83]) stated that there is a general lack of information concerning the toxicity of Li, and acknowledged that the historical and current use of Li has not prompted many studies of the toxicity of this element to aquatic organisms. Trace amounts of Li have been found in some organisms, and although it is not a dietary mineral for plants, it has been shown to stimulate plant growth (Aral and Vecchio-Sadus, 2008[84]). The acute toxicity of Li is low, and the acute effect concentration measured for the water flea *Daphnia magna* was determined to range from 33 to 197 mg/L (Aral and Vecchio-Sadus, 2008). Experiments have shown that Li can promote reproductive system toxicity, and large doses (10 mg/L of blood) cause mild Li poisoning in humans (Thakur et al. 2003[85]).

No TEL/TEC or PEL/PEC SQG are available for Li, but over half of the lower SJR samples (>60%) had Li concentrations that were greater than the highest levels reported in the industrial Illinois River (16.3 mg/kg). Most, over 86%, were greater than the highest levels reported in non-industrial rivers (5.7 mg/kg) by Mathis and Cummings (1973). In addition, over 80% of the samples had Li concentrations that were above the average level measured in the Bay of Bengal and the low-level (7 µg/g) found in the Nile delta. Conversely, most lower SJR sediment Li concentrations, were lower than the high-level (48 µg/g) found in the Nile sediment (Mamdouh, 1973) and the median level reported in Bothnian Sea sediment. No sediment Li concentrations exceeded the median level of 60 mg/kg reported in the Gulf of Finland sediment by Leivuori (1998). These results suggest that Li concentrations are elevated in much of the river and tributaries. These elevated Li concentrations may be caused either by regional differences in the expected crustal abundance concentrations, or by abnormally high sediment Li concentrations.

### Copper

Copper (Cu) is used in coins, architecture ( roofing, lighting rods), household products (plumbing, cookware, flatware), electrical, biomedical and chemical applications (Lenntech, retrieved 2011). It can be released into the environment by both human activities and natural sources. Human activities that contribute to the release of Cu include the discharge of industrial and domestic wastewater, dumping of sewage sludge, metal, wood, algaecides and fertilizer production (Lenntech, retrieved 2011). Most antifouling paints contain Cu and are by design toxic to marine life. These paints also contribute to elevated Cu levels in the aquatic environment. Moore (1991) stated that over half of the atmospheric Cu deposition comes from waste incineration and fossil fuel combustion. The remaining atmospheric deposition is from natural sources like wind-blown dust, forest fires and sea spray. Because Cu is released both naturally and through human activities it is very widespread in the environment.

Although most Cu compounds will become bound to either sediment or soil particles, soluble Cu is detectable in low concentrations in most freshwaters. In Canadian freshwaters, the Cu concentrations are typically less than 20.0 µg/L and rarely exceeded 50 µg/L (Moore, 1991). In estuaries, Cu concentrations are usually higher because the increased salinity causes Cu to desorb from suspended particles (Moore, 1991). The lower SJR surface water Cu concentrations ranged up to 389 µg/L with an average of 3.8 µg/L (Florida STORET, retrieved 2011). Because it has a strong tendency to form complexes with organic and inorganic ligands, Cu accumulates in river sediment. The following sediment Cu concentrations were reported from the Great Lakes by Moore (1991): Ontario 26-109 mg/kg, Erie 5-207 mg/kg, Huron 3-78 mg/kg, Michigan 15-54 mg/kg, Superior 30-173 mg/kg. Mathis and Cummings (1973) measured similar sediment Cu concentrations in the Illinois River that ranged from 1.0 to 82.0 mg/kg, but they found a lower range from 3.5 to 11.2 mg/kg in non-industrial rivers.

Copper had the largest variance of Group 3 metals, with the maximum Cu concentration over 500 times the minimum measured value. The mean Cu concentration was greater than the other Group 3 metals, and the median and range are shown in Table 3-5. Five sites had Cu concentrations over 100 mg/kg. The highest Cu concentration was measured in Rice Creek (RICE02) sediment. Two of the five sites were located in the Cedar River, one in the Cedar-Ortega estuary, and one in Moncrief Creek [Figures 3-26 and 3-27].

Copper was found in measurable concentrations at all sites, and exceeded the crustal abundance value of 50 mg/kg at 26 sites (Table 3-2). The maximum Cu concentration was over twice the maximum nickel concentration even though Ni crustal abundance levels indicated that Ni should be in the highest concentrations of the Group 3 metals. Of the Group 3 metals, only Cu concentrations were greater than the highest nickel concentrations. Over 50% of the LSJRB sites had Cu concentrations greater than the U.S. soil value of 17 mg/kg (Shacklette and Boerngen, 1984). A mixed spatial pattern of sediment copper concentrations exists with high concentrations in both the Northern and Southern region.

Copper is an essential trace element to all higher plant and animal life. It is found in most tissues but primarily in the liver, brain, heart, kidney and muscles of vertebrates. It functions as a co-factor in various enzymes, is used for biological electron transport and is strongly bioaccumulated (Extoxnet, 1994[86]). Most mollusks and some arthropods such as the horseshoe crab use the copper-containing pigment hemocyanin rather than iron-containing hemoglobin for oxygen transport (Barnes, 1974[87]).

Copper is highly toxic at fairly low concentrations to most plants and animals, especially invertebrates and fish (Moore, 1991). The salt water TEL and PEL SQG for Cu are 18.7 mg/kg and 108 mg/kg, and the fresh water TEC and PEC are 35.7 mg/kg and 197 mg/kg (Table 3-8). The Cu concentrations at two sites exceeded the saltwater PEL of 108 mg/kg, one was located in Rice Creek (RICE02) and the other site was in Moncrief Creek (MON104). The biota probably are adversely affected by high Cu sediment concentrations at these two sites. No sites had Cu concentrations above the freshwater PEC, but 50 sites exceeded the freshwater TEC and 91 sites (>52%) were above the saltwater TEL level of 18.7 mg/kg. Sediment dwelling organisms may be adversely affected at these 50 to 91 sites.

### Nickel

Nickel (Ni) occurs in the environment normally at very low levels. It has numerous industrial applications especially as an alloy, and Ni-alloys account for approximately 75% of the total nickel use (Moore, 1991). The major sources of Ni to the environment are waste incineration, fossil fuel burning (particularly coal), industrial and municipal wastewater discharges, smelting and refining for alloy processes (Lenntech, retrieved 2011). Dissolved Ni levels in unpolluted water ranged from 1.0 to 3.0 µg/L, but increase to 20.0 µg/L in contaminated areas (Moore, 1991). Nickel concentrations measured in the lower SJR surface water ranged up to 380 µg/L and averaged 3.31 µg/L (Florida STORET, retrieved 2011) Humic acids in natural waters will influence the behavior of many metals, including Ni, by decreasing metal precipitation and increased solubility (Callahan et al., 1979). This response to humic acids may explain the apparently high Ni concentrations found in the lower SJR. Sediment Ni concentrations below 1 mg/kg are common in unpolluted areas, while concentrations greater than 100 mg/kg are typically associated with industrial and municipal waste discharges (Moore, 1991).

The five highest Ni concentrations were greater than 30 mg/kg, and all were located in Rice Creek [Figure 3-30]. The Ni maximum, mean, median and minimum values are shown in Table 3-5, and the maximum Ni concentration was over 100 times greater than the minimum measured value. Two additional sites, one in Rice Creek (RICE03) and the other near the mouth of Rice Creek (LSJRC06) had Ni concentrations above 25 mg/kg [Figure 3-30]. Only one site, near Racy Point, (RACY01), had no detectable Ni in analyzed sediment samples [Figure 3-28].

Nickel was the only Group 3 metal with measured concentrations that did not exceed either Moore's (1991) average or the TJNAF (Retrieved 2011) estimated crustal abundance values (Table 3-2). However, the Ni concentrations did exceed the average U.S. soil concentrations at over 100 sites in the LSJRB (Shacklette and Boerngen, 1984).

Nickel is an essential trace element for plants and some animals although the Ni residues in plants, soft tissues of invertebrates and in muscle tissue of fish are normally low (Moore, 1991). The nutritional importance of Ni to humans has not been determined (National Institute of Health, 2011). Elevated concentrations of Ni are highly toxic to many plants, but much less toxic to invertebrates and fish. Animals exposed to low levels on Ni over extended periods exhibited respiratory, circulatory and skeletal toxicological effects (Moore, 1991). Nickel does not appear to accumulate in fish or in other animals and is not expected to bioaccumulate (ATSDR, retrieved 2011).

The SQG are available for Ni (Table 3-8), and concentrations were greater than the saltwater PEL of 42.8 mg/kg at three sites in Rice Creek. Sediment Ni concentrations were also greater than the freshwater PEC of 35.9 mg/kg at one additional Rice Creek site (RCJU05). Biota at these four Rice Creek sites (RCJU03, RICE02 RICE021, RCJU05) are probably being adversely affected by the elevated Ni concentrations [Figure 3-30]. Thirty-two sites had Ni concentrations that were at or above the freshwater TEC of 18 mg/kg and 63 sites were at or above the saltwater TEL of 15.9 mg/kg. Sediment dwelling organisms may be adversely affected at 18 to 36% of the sites.

### Arsenic

Arsenic (As) is a rare but toxic element that is extremely mobile, cycling through land, water, sediment and living organisms, and therefore normally found only in small concentrations (Callahan et al., 1979). It is released during volcanic activity and by microorganisms, and is spread through the environment by wind-blown dust and water run-off (ATSDR, retrieved 2011). The quantities from these natural sources are relatively small when compared to waste incineration and fossil fuel combustion (Baudo et al., 1990). Arsenic is used in insecticides, rodenticides, herbicides, pharmaceuticals, detergents, in making special types of glass, as a wood preservative, in semiconductor and microchip industries (Lenntech, retrieved 2011). A major source of As to freshwaters is through municipal waste discharges and reflects its use in these household preparations (Moore, 1991). Depending on water chemistry (e.g. pH, salinity, Eh), As can potentially exist in four oxidation states in surface water and this complicates comparisons between water bodies.

Arsenic is widely distributed in surface freshwaters, and concentrations in rivers and lakes are generally below 0.010 mg/L. The magnitude of As concentrations found in natural waters is large, ranging from less than 0.010 mg/L to more than 5,000 mg/L, although typical concentrations in freshwater are less than 10 mg/L and frequently less than 1 mg/L (Smedley, P.L., and D.G. Kinniburgh, 2002[88]). Moore (1991) also reported very low levels of As in uncontaminated freshwater ranging from 0.001. to 0.005 mg/L. Arsenic levels ranging from 0.010 to 3.4 mg/L have been measured in rivers and lakes in the U.S (ATSDR, retrieved 2011). Arsenic concentrations in the surface water of the lower SJR ranged from <0.0001 to 0.0382 mg/L (Florida STORET, retrieved 2011), which is much less than the range reported by Smedley and Kinninburgh (2002), but greater than that reported by Moore (1991).

Moore (1991) stated that As is predominantly bound to sediment in most lakes and rivers. Background sediment As levels reported by Durant et al. (2004[89]) ranged from 10–40 mg/kg, but a contaminated pond in Massachusetts had elevated levels over 1,000 mg/kg. The background sediment As level of 5.3 mg/kg was reported by the ATSDR (retrieved 2011). Much higher levels were measured in dry stream sediment from a heavily contaminated mining area where As concentrations were found to vary between 29 to 28,600 mg/kg (Razo et al., 2004[90]).

As expected, As had the smallest maximum, mean and median values, and had the smallest variance of all Group 3 metals (Table 3-5). The maximum As concentration of 24.5 mg/kg, found in the Cedar River (CED01), was over 200 times greater than the minimum value of 0.120 mg/kg found in the river at the mouth of Deep Creek (LSJ31) near Federal Point [Figures 3-26 and 3-29]. Sediment As concentrations were measured above detectable concentrations at all sites in the LSJRB, and the highest concentrations, at or above 15 mg/kg, were measured at six sites. Three of the six sites were located in the Cedar River, one in the Cedar-Ortega estuary, and two were found in other tributaries Moncrief and Goodbys creeks [Figures 3-26, 3-27 and 3-25].

Unlike the majority of the metals, the average U.S. soil As concentration was higher than either Moore's (1991) average or the TJNAF (Retrieved 2011) estimated crustal abundance values (Table 3-2). Approximately 46% of the LSJRB sites had As concentrations above the average U.S. soil concentrations of 5.2 mg/kg (Shacklette and Boerngen, 1984). Over 80% of the sites had As concentrations that were greater than the average crustal abundance and estimated crustal abundance values of 2.0 and 1.8 mg/kg, respectively. Sediment As concentrations did not show a distinct spatial distribution pattern in the river.

Arsenic is one of the most toxic elements, yet despite its notoriety as a deadly poison, it is an essential trace element for many animal species because it plays a role in protein synthesis (Lenntech, retrieved 2011). Even though it is toxic, many organisms will accumulate As and biological transformations yield a large number of methylated As compounds (Moore, 1991). Plants absorb As easily so high concentrations may be present in food, and some ferns especially can accumulate large quantities of As (Brooks 1998[91]) Acutely toxic concentrations of the inorganic As range from 2 to 46 mg/L for freshwater algae, and from 7.4 to 7.5 mg/L for *Daphnia* and the American oyster. Doses of inorganic As greater than 1 mg/L have been shown to elicit acute toxic effects in most fish (Moore, 1991).

All LSJRB sediment As concentrations were within or below the background levels reported by Durant et al., (2004), and well below the levels found in a contaminated pond in Massachusetts (Durant et al., 2004). Almost half of the LSJRB sites (43%) had As concentrations that were greater than background levels reported by ATSDR (retrieved 2011).

No LSJRB sites had sediment As concentrations that exceeded the saltwater PEL SQG of 41.6 mg/kg (Table 3-8), but three sites (CED01, MON104, GDBY01) did exceed the freshwater PEC of 17 mg/kg [Figures 3-25 and 3-27]. Sediment dwelling organisms probably are adversely affected by As levels at these three sites. The As concentrations were greater than the saltwater TEL of 7.24 mg/kg and freshwater TEC of 5.9 mg/kg at 39 and 67 sites, respectively. The sediment dwelling organisms may be negatively affected by As levels at 22 to 38% of the sites.

## Metals: Group 4

The Group 4 metals include manganese, zinc, chromium, vanadium and lead. Of the metals analyzed in the LSJRB sediment, these Group 4 metals are among the most abundant in the earth's crust (Table 3-2). The crustal abundance values indicate that manganese is the most abundant of the Group 4 metals, followed by vanadium, then chromium, zinc and the least abundant of the Group 4 metals is lead (Moore, 1991; TJNAF, retrieved 2011). The manganese crustal abundance value is over 60 times greater than the average lead crustal abundance and vanadium crustal abundance values are over 10 times greater than lead (Table 3-2).

### Manganese

Manganese (Mn) is a very common element, found everywhere on earth and the total environmental flux of Mn is greater than all other metals, except iron and aluminum (Lenntech, retrieved 2011). Many metal alloys contain Mn, particularly stainless steel, and it is also used in pesticides, fertilizers and disinfectant (ATSDR, retrieved 2011). Municipal wastewater discharges are the primary source of Mn to freshwater, and the incineration of municipal wastes, metal manufacturing and coal burning also contribute to anthropogenic emissions (Moore, 1991).

Concentrations of Mn in freshwater are extremely variable ranging from 0.002 to 4.0 mg/L, but are uniformly lower in offshore marine waters (Moore, 1991). Mean Mn concentration of the bottom water in Arbuckle Lake, Oklahoma, ranged from 0.024 to 1.274 mg/L (Cover and Wilhm, 1982.[92]) Surface water Mn concentrations ranged from 0.021 to 251 ug/L (0.000021 to 0.251 mg/L) in the LSJRB (Florida STORET, retrieved 2011).

Sediment Mn concentrations ranged from 216 to 528 mg/kg in samples from the Gulf of Arabia, and from 273 to 403 in sediment off the coast of Los Angeles (Moore, 1991). In Arbuckle Lake, Oklahoma, the sediment Mn concentrations ranging from 288 to 361 mg/kg (Cover and Wilhm, 1982).

Manganese, as previously discussed, is one of the major metals in the earth's crust, and abundance values would indicate that it would have the highest concentrations of Group 4 metals (Table 3-2). Indeed, the mean and median Mn concentrations were the highest in the Group 4 metals, and are shown along with the maximum and minimum concentrations in Table 3-6. The highest Mn concentrations were greater than 400 mg/kg, and were measured at four sites. Two of the four sites were located in the river (LSJ02, LSJ11), and two were located in Rice Creek (RCJU05, RCJU02) [Figures 3-31 and 3-36].

Manganese is an essential trace nutrient for all species. As one of the toxic essential trace elements, it is necessary for human survival, but it is also toxic in high concentrations (ATSDR, retrieved 2011). For animals, Mn is an essential component of over 36 enzymes that are used for the metabolism of carbohydrates, proteins and fats. For some animals the lethal dose is quite low, which means they have little chance to survive even small doses that exceed the essential dose (Lenntech, retrieved 2011).

Not surprisingly, Mn was measured above detectable concentrations at all sites, but no sites had Mn concentrations that exceeded either Moore's (1991) average crustal abundance, the TJNAF (Retrieved 2011) estimated crustal abundance (Table 3-2), or the maximum Mn concentrations found in the Gulf of Arabia (Moore, 1991). Over 76% of the LSJRB sites had Mn concentrations that were below the minimum value reported in sediment off the Los Angeles coast, and over 84% were below the minimum value reported for the Gulf or Arabia (Moore, 1991). Average U.S. soil concentrations, TEL/TEC and PEL/PEC SQG for Mn were not available. Manganese is pervasive throughout the LSJRB and concentrations varied, but no discernible pattern emerged for sediment Mn concentrations.

## Zinc

Zinc (Zn) occurs naturally in water, sediment and soil, but concentrations are rising unnaturally, due to industrial activities, such as mining, steel processing, coal and waste combustion (Lenntech, retrieved 2011). The principal use for Zn is for galvanizing iron, and more than 50% of commercial metallic zinc goes into galvanizing. It is also important in the preparation of certain alloys, such as brass, which is an alloy of copper and zinc (Moore, 1991). Zinc is the primary metal used in making American pennies, and it is used in the automobile industry, in some electric batteries, in building construction for roofing and gutters (Lenntech, retrieved 2011).

Zinc is readily transported in most natural waters and is one of the most mobile of the heavy metals (Callahan et al., 1979). Concentrations of Zn in freshwater usually are low ranging from <0.001 to 0.05 mg/L, but levels are lower, ranging from 0.007 to 0.022 mg/L in North American peat bogs (Moore, 1991). Seawater also has lower levels of Zn than freshwater and typically less than 0.030 mg/L (Emsley, 2001[93]). Concentrations of Zn in LSJR surface waters ranged from <0.001 to 0.169 mg/L (Florida STORET, retrieved 2011). As with many metals, sediment is a primary sink for Zn, and high concentrations of 1,000 mg/kg or higher can be found near major municipalities and power plants (Moore, 1991). By comparison, uncontaminated sediment typically have Zn concentrations ranging from 5 to 50 mg/kg.

Zinc concentrations in the LSJRB sediment were the highest of the Group 4 metals, and much higher than Mn concentrations. The maximum Zn concentration of 2050 mg/kg was over four times greater than the maximum Mn concentration of 485.0 mg/kg (Table 3-6). This maximum Zn concentration was over 900 times greater than the minimum Zn concentration, and the mean, median and range of Zn values are shown in Table 3-6. Sediment Zn concentrations above 600 mg/kg were measured at five sites, and all five were located in the Cedar River [Figure 3-32]. Ten additional sites had Zn concentrations greater than 300 mg/kg, and five were located in the Cedar-Ortega estuary. Four of the ten were found in the Cedar River and the other site was located in Moncrief Creek (MON104). Measurable Zn concentrations were found at all sites.

Over 65% of the sites had Zn concentrations that were greater than the average crustal abundance value of 70 mg/kg (Moore, 1991). In addition, over 74% of the sites had Zn concentrations that exceeded the average U.S. soil Zn concentration of 48 mg/kg (Table 3-2). As with many other metals, the general trend for the sediment Zn concentrations was to decrease with increased distance upstream.

Although Zn is an essential trace mineral for all animals and plants, in excess it is toxic (ATSDR, retrieved 2011). It is important in neurological functions, reproduction, the immune response, growth and development. Zinc deficiencies can lead to growth retardation, delayed sexual maturation, and susceptibility to increased infection (NIEHS, retrieved 2011[94]). Animals deficient in Zn require 50% more food to gain the same weight as an animal supplied with adequate amounts of zinc. Excessive Zn can cause ataxia, fever, diarrhea, vomiting and suppression of copper and iron absorption that leads to the disruption of protein metabolism (NIEHS, retrieved 2011). The free Zn ion in solution is highly toxic to plants, invertebrates, and moderately toxic to fish (Eisler, 1993[95]). As an essential trace element Zn is present in all animals even in the absence of high environmental concentrations (Callahan et al., 1979).

Nine sites in the lower SJR had sediment Zn concentrations that were higher than the Florida freshwater PEC SQG of 315 mg/kg (Table 3-8). One of these sites (CED01) had over three times the PEC level and two other sites (CED02, CED01D) had over twice the PEC level. The Zn concentrations were also higher than the saltwater PEL of 271 mg/kg at 20 sites. These data indicate that sediment dwelling organisms are probably adversely affected by high Zn levels at 5 to 12 % of the sites. The sediment Zn concentrations were above both the saltwater TEL of 124 mg/kg and the freshwater TEC of 123.1 mg/kg at 78 and 79 sites, respectively. Sediment dwelling organisms may be adversely affected by Zn levels at 45% of the sites.

## Chromium

Chromium (Cr) occurs naturally as a compound, and metallic Cr is not found freely in the soil. Metallic chromium is unstable in oxygen and immediately oxidizes producing a thin layer that is impermeable to further oxidation by air (Lenntech, retrieved 2011). This corrosion resistant property has made Cr important in producing metal alloys, in particular stainless steel. Chromium is also used in leather tanning, dyes, paints, wood treatment, in colored glass and synthetic ruby production. These industrial applications along with coal combustion, waste incineration and waste disposal will increase Cr concentrations in the environment (Moore, 1991).

Total Cr concentrations in water are usually low, averaging 0.001 mg/L in the Great Lakes, 0.006 mg/L in the Mississippi River, and very low 0.0006 mg/L in offshore seawater (Moore, 1991). Average Cr concentrations of 0.00364 mg/L were measured in the lower SJR and the highest concentration was 0.250 mg/L (Florida STORET, retrieved 2011).

Total Cr concentrations in Illinois River sediment ranged from 2 to 87 mg/kg, but a lower range from 3 to 7 mg/kg was found in non-industrial streams (Mathis and Cummings, 1973). Moore (1991) compared total Cr sediment background levels that ranged from 9 to 89 mg/kg, with levels measured in the Great Lakes and found a wider range from 8 to 362 mg/kg.

Four sites in the LSJRB had Cr concentrations that were greater than 100 mg/kg, and three of the four sites were located in Rice Creek (RICE02, RICE021, RICE03) while the other site was found in the Ribault River (RIB105) [Figures 3-36 and 3-31]. The maximum and mean Cr concentrations were the lowest for the Group 4 metals, and are shown with the median and minimum Cr values in Table 3-6. The Cr concentrations also showed the smallest variance of the Group 4 metals (Table 3-6).

The four sites with the highest Cr concentrations exceeded Moore's (1991) average crustal abundance value (Table 3-2), background levels and the Illinois River levels (Mathis and Cummings, 1973). Over half of the Cr concentrations (68%) were greater than the average U.S. soil Cr concentration of 37 mg/kg. No discernible pattern was apparent in sediment Cr concentrations measured in the LSJRB.

Chromium exhibits a wide range of possible oxidation states, with trivalent Cr (III) and hexavalent Cr (VI) being the most stable. Trivalent Cr(III) is an essential nutrient required for normal energy metabolism but too much could cause respiratory and immunological problems (ATSDR, retrieved 2011). In contrast, hexavalent Cr (VI) is very toxic, mutagenic and some compounds are carcinogenic (Lenntech, retrieved 2011). Hexavalent Cr(VI) has been shown to be acutely toxic to numerous freshwater fish species and invertebrates (Moore, 1991). Plants and animals will accumulate Cr to levels much higher than the ambient water, but levels in biota are usually much lower than levels in sediment (Callahan et al., 1979).

The LSJRB sediment Cr concentrations at one site in Rice Creek (RICE02) were higher than the saltwater PEL SQG of 160 mg/kg, while two additional Rice Creek sites (RICE021, RICE03) had Cr concentrations that were higher than the freshwater PEC of 90 mg/kg (Table 3-8). Biota at these three sites are probably affected adversely by these high sediment Cr concentrations. At 50% of the sites Cr levels were elevated above the saltwater TEL SQG while 60% of the sites had Cr levels greater than the freshwater TEC SQG (Table 3-8). Therefore the organisms at 50% to 60% of the LSJRB sites may be affected by these elevated sediment Cr concentrations.

### Vanadium

Vanadium (V) occurs naturally in combination with many different minerals, but elemental V is not found in nature (ATSDR, retrieved 2011). Vanadium will oxidize and, similar to Cr, form a protective layer against further corrosion. Vanadium is used as a steel additive that increases the strength in steel considerably, therefore approximately 80% of the V produced is used in steel alloys (Lenntech, retrieved 2011). Fossil fuel deposits such as crude oil, coal, oil shale and tar sands contain V, which is released during combustion. Wastewater treatment plant and pulp and paper mill effluents contain elevated levels of V that is discharged and increases V levels in the receiving waters (Moore, 1991).

Vanadium is relatively insoluble, consequently, the concentration of V in natural freshwater is relatively low, usually less than 0.020 mg/L (Beusen and Neven, 1987 [96]). A range of V concentrations in freshwater from 0.0005 to 0.220 mg/L was reported by the ATSDR (retrieved 2011). Concentrations of V in the surface waters of the LSJRB ranged from less than 0.001 to 0.169 mg/L (Florida STORET, retrieved 2011).

Sediment V concentrations typically range from 20 to 150 mg/kg, with a lower range of 29 to 48 found in Arabian Gulf waters, and a higher range from 42 to 180 mg/kg found in the highly contaminated Ganges Estuary (Moore, 1991).

The V concentrations were greater than 100 mg/kg at five sites, and all five sites were located in Rice Creek [Figure 3-36]. The mean V concentration was the second lowest of the Group 4 metals, and only slightly higher than the mean Cr concentration, as shown in Table 3-6. All sites had V concentrations that were measured above detection levels.

The V concentrations measured at the five sites with highest levels, exceeded the TJNAF (Retrieved 2011) estimated crustal abundance value of 120 mg/kg, but only four of the five exceeded Moore's (1991) average crustal abundance level of 150 mg/kg (Table 3-2). The V concentrations at over one quarter of the LSJRB sites were greater than the U.S. soil V concentration of 58 mg/kg (Shacklette and Boerngen, 1984). Unlike many other metals, only a slight decrease in sediment V concentrations was measured with increased distance upstream.

Algae, other plants, invertebrates, fishes and many other species contain V in small amounts (Lenntech, retrieved 2011). Some animals such as sea squirts (ascidians) are able to scavenge and sequester V to high levels (Barnes, 1974). Mussels and crabs also concentrate V to levels greater than the surrounding seawater (Lenntech, retrieved 2011). Vanadium is a component of some proteins and enzymes, and in animal studies it has been found to function similarly to insulin by helping to maintain blood glucose levels. Vanadium and its compounds are toxic when present in excess, and can cause inhibition of certain enzymes in animals resulting in neurological effects (Barceloux, 2000[97]). Beusen and Neven (1987) reported that V concentrations ranging from 10 to 65 mg/L were acutely toxic to some benthic invertebrates (e.g. worms, mussels and crabs). They found much broader acutely toxic concentration ranges from 0.08 to 11.2 mg/L for fish, but stated much of the variance was due to the different V compounds, test duration, species, water pH and hardness that contributed to the broad range (Beusen and Neven, 1987).

No TEL/TEC or PEL/PEC SQG are available for V, but over 95% of the LSJRB sediment V concentrations were within the typical range reported by (Moore, 1991). The four sites in the LSJRB with the highest V concentrations not only exceeded the maximum level of this typical range, but they were also higher than the maximum level found in the highly contaminated Ganges Estuary (Moore, 1991).

### Lead

Lead (Pb) is a highly toxic metal found in small amounts in the earth's crust (NIEHS, retrieved 2011). Therefore, most elevated Pb concentrations that are found in the environment are the result of human activities. Metal production, combustion of leaded fuels, leaded pesticide use, and incineration of waste and coal contribute to environmental contamination (Moore, 1991). The addition of Pb in gasoline has caused Pb pollution to become a worldwide issue (Lenntech, retrieved 2011), but the ban of lead in gasoline in the 1970s in the US has decreased its nationwide occurrence.

Surface water Pb concentrations are highly variable, but typically below 0.050 mg/L (Moore, 1991). In the industrial Illinois River, the Pb levels ranged from 0.001 to 0.018 mg/L (Mathis and Cummings, 1973). Concentrations of Pb in freshwater rivers were reported to range between 0.003 and 0.030 mg/L (Lenntech, retrieved 2011). The Pb concentrations in the lower SJR surface water ranged from <0.001 to 0.370 mg/L (Florida STORET, retrieved 2011).

Lead forms a series of complexes with chloride that will tend to induce Pb precipitation and deposition in estuaries. Residues of Pb in the 15 to 50 mg/kg range were found in estuarine sediment with levels greater than 400 mg/kg near waste outfalls (Moore, 1991). The sediment Pb concentrations in three nonindustrial rivers ranged from 13 to 27 mg/kg, but a wider range from 3 to 140 mg/kg was found in Illinois River sediment (Mathis and Cummings, 1973).

Lead, the least abundant of the Group 4 metals in the earth's crust, would be expected to be the least abundant in the LSJRB sediment. The minimum and median Pb concentrations were lower than the other Group 4 metals, but the maximum and mean Pb concentrations were higher than both the Cr and V concentrations (Table 3-6). Lead concentrations greater than 150 mg/kg were found at eight sites and all but one were located in the Cedar River [Figure 3-32]. This other site was found in the Cedar-Ortega estuary (ORT31). Two other tributaries Moncrief Creek and Ribault River also had Pb levels above 100 mg/kg [Figure 3-31]. The highest Pb concentration found in the mainstem of 89.25 mg/kg, was located in Jacksonville outside of the mouth of Goodbys Creek (GDBY01). All sites had measurable Pb concentrations that exceeded the detection levels.

The average U.S. soil Pb concentration, in contrast with the majority of the metals, was higher than Moore's (1991) average crustal abundance level, or the TJNAF (Retrieved 2011) estimated crustal abundance values (Table 3-2). Approximately 74% of the LSJRB sites had Pb concentrations above the average U.S. soil concentrations of 16 mg/kg. In addition, over 76% of the sites had Pb concentrations that were greater than Moore's (1991) average crustal abundance level of 15 mg/kg sites (Table 3-2). The sediment Pb concentrations show the typical metal pattern in the lower SJR with the highest values occurring in the urban Jacksonville area, particularly in the tributaries (Ribault and Cedar Rivers; Moncrief Creek). Lead levels tended to decrease with distance upstream, with some exceptions around urban Green Cove Springs and in the tributaries.

Lead is a potent neurotoxin that can damage nervous connections and cause blood and brain disorders (NIEHS, retrieved 2011). It is particularly dangerous because it can concentrate in individual organisms and bioaccumulate (Callahan et al., 1979). Moore (1991) reported that Pb is more toxic than Cr or Mn to plants. It is also acutely toxic to invertebrates and fishes, although there is considerable variability between species (Moore, 1991).

Sediment in the lower SJR had Pb concentrations at 20 sites that were greater than the freshwater PEC SQG level of 91.3 mg/kg and at 14 sites that exceeded the saltwater PEL of 112 mg/kg (Table 3-8). The Pb levels are probably affecting sediment dwelling organisms adversely at these 14 to 20 sites. About half of the lower SJR sites had sediment Pb concentrations that were higher than the freshwater TEC and over half of the sites had Pb concentrations that were greater than the saltwater TEL levels. Sediment dwelling organisms at about half of the sample sites may be adversely affected by these Pb levels.

## Metals: Group 5

The Group 5 metals, iron and aluminum, are considered major metals because of their abundance (Table 3-2). Aluminum is the most abundant metallic element on the earth's surface, and comprises more than 8% of the earth's crust. Iron is the second most abundant metal and comprises about 5% of the earth's crust (Moore, 1991). Therefore, the Group 5 metals, geologically, would be expected to have the highest concentrations of the trace metals measured in the LSJRB sediment (Table 3-2). Aluminum and iron can be used to normalize the metal contaminant data following Macdonald, (1994), Luoma, (1990[98]), Schropp et al., (1990[99]) and others.

### Iron

Pure metallic iron (Fe) is rarely found because it is very reactive and oxidizes readily. Iron exists mainly in two oxidation states, the bivalent Fe(II) and trivalent Fe(III) forms (Lenntech, retrieved 2011). In most aerobic surface water Fe(III) compounds are the dominate dissolved forms, but in anaerobic conditions Fe(II) is soluble and is the most prevalent (Moore, 1991). Concentrations of Fe in surfaces waters are extremely variable, ranging from very low 0.004 mg/L to concentrations over 50 mg/L (Moore, 1991). Seawater contains approximately 0.001 to 0.003 mg/L of Fe, although as with freshwater these amounts will vary (Lenntech, retrieved 2011). In the lower SJR surface water the Fe concentrations ranged from <0.001 to 11.8 mg/L (Florida STORET, retrieved 2011).

Sediment Fe concentrations found in the Great Lakes ranged from 0.5 to 9.6 mg/kg, in the North Sea the range was from 9,000 to 15,000 and in Bombay Harbor the Fe levels ranged from 62,000 to 76,000 mg/kg (Moore, 1991).

The maximum Fe concentration in the LSJRB sediment was over 80 times the minimum measured concentration, and mean, median and range of Fe values are shown in Table 3-7. Six sites had Fe concentrations that were greater than 35,000 mg/kg, and the two highest concentrations were found in the river (BOLL02; PTLV01). Of the other four sites three were located in the Cedar-Ortega estuary and one was found in the Cedar River [Figures 3-37, 3-38 and 3-39]. The Fe concentrations measured at 27 sites were greater than 30,000 mg/kg, or constituted more than 3% of the sediment. Only one site had undetectable sediment Fe concentration, but five other sites had very low sediment Fe concentrations that were below 1000 mg/kg.

None of the Fe concentrations measured in the LSJRB sediment exceeded Moore's (1991) average Fe crustal abundance level of 5%, or the TJNAF (Retrieved 2011) estimated crustal abundance value of 56,300 mg/kg (Table 3-2). The highest measured Fe concentration comprised just under 4% of the sediment (Table 3-7). Average U.S. soil concentrations for Fe were not available. Sediment Fe concentrations were prevalent throughout the river and tributaries, yet still showed the general pattern of decreasing concentrations with increasing distances upstream.

Iron is an essential trace element required by almost all living organisms (Moore, 1991). The only exceptions are organisms living in iron-poor environments that use different elements such as hemocyanin instead of hemoglobin (NIEHS, retrieved 2011). Iron is an integral part of many proteins and enzymes that catalyze oxidation reactions and participate in transport of soluble gases, but excess amounts can result in toxicity and death. Large amounts of ingested Fe can cause excessive levels in the blood and cells, and iron toxicity occurs. High blood levels of free Fe can damage DNA, proteins and other cellular components. The trivalent Fe(III) is moderately toxic to many aquatic plants and to most invertebrates (Moore, 1991). Concentrations of 0.05 to 0.24 mg/L of soluble Fe were lethal to brown trout (Dalzell, and MacFarlane, 1999[100]) and lethal concentrations to most fish ranged from 0.3 to greater than 10 mg/L (Moore, 1991).

No TEL/TEC or PEL/PEC SQG are available for Fe, but over 65% of the LSJRB sites had sediment Fe concentrations that were greater than the highest levels reported in the North Sea sediment (15,000 mg/kg). None of the LSJRB Fe concentrations were as high as any of the levels found in Bombay Harbor (Moore, 1991). Finally, all but one LSJRB site had Fe concentrations that were higher than the levels reported in the Great Lakes sediment (Moore, 1991).

### Aluminum

Aluminum (Al) naturally occurs in waters in very low concentrations, but because Al is so abundant and produced in huge amounts, relatively high concentrations are found in many lakes and rivers (Lenntech, retrieved 2011). One of the major sources of Al in freshwater is the discharge of alum sludge from municipal water treatment plants (Moore, 1991). Discharges from industries like pulp and paper mills, and Al compounds applied as fertilizer also contribute to increased Al levels (Lenntech, retrieved 2011). Decreasing pH will mobilize Al, so acid rain increases weathering and Al concentrations in runoff and receiving waters (Lenntech, retrieved 2011).

River water generally contains about 0.4 mg/L of Al, but amounts in seawater are much lower, varying between less than 0.0001 and 0.005 mg/L (Lenntech, retrieved 2011). The Al concentrations in two rivers in the United Kingdom ranged from 0.005 to 0.065 mg/L during low flows, and increased from 0.025 to 0.360 mg/L in moderate flows (Moore, 1991). The Al concentrations in the lower SJR varied from less than 0.001 to 5.0 mg/L (Florida STORET, retrieved 2011). Canadian lake sediment Al concentrations were found to range from 31,000 to 49,500 mg/kg, while concentrations in the contaminated Ganges delta averaged 56,500 mg/kg (Moore, 1991).

As expected the Al maximum, mean and median concentrations were the highest for all measured metals in the LSJRB as shown in Table 3-7. The sites with the two highest Al concentrations, 60,850 mg/kg and 60,600 mg/kg, were located in the Cedar River (CED04, CED062) [Figure 3-38 and 3-39]. The overall Al concentrations ranged from just over 6% at these two sites, to under 0.1% (Table 3-7). The maximum Al concentration was over 90 times the minimum measured concentration (Table 3-7). Eighteen sites were found with Al concentrations over 50,000 mg/kg, and all were located in tributaries or in the river around Jacksonville area. Thirteen of the 18 sites were found in urban tributaries, which included the Cedar-Ortega estuary, Trout, Cedar, Ribault and Ortega rivers. The five river sites were found near the Naval Air Station in Jacksonville (PTLV01, BOLL04, PIRC01, HOSP02, and GBY01) [Figure 3-37]. The Al concentrations in over 85% of the samples were greater than 10,000 mg/kg.

Despite these seemingly high Al concentrations, no LSJRB sites exceeded Moore's (1991) average Al crustal abundance level of 8%, or the TJNAF (Retrieved 2011) estimated crustal abundance value of 82,300 mg/kg (Table 3-2). The high Al concentrations were greater in the downstream areas of the river and although pervasive in the tributaries and river, the concentrations generally decreased in the upstream areas.

Although Al is found in essentially all plant and animal species no biological function has been attributed to it, and, more importantly, Al accumulation in tissues and organs result in their dysfunction and toxicity (Verstraeten et al., 2008[101]).

Aqueous concentrations of Al increase in acidified lakes and the number of fish and amphibians declines in these lakes (Lenntech, retrieved 2011). These high Al concentrations not only cause effects upon fish, but also upon birds and other animals that consume contaminated fish and insects (Lenntech, retrieved 2011).

Most of the lower SJR Al concentrations were within or below the levels found in Canadian Lakes reported by Moore (1991). Only three of the lower SJR sites had Al concentrations that were higher than the average Al level found in the contaminated Ganges delta (Moore, 1991). Unfortunately, No TEL/TEC or PEL/PEC SQG are available for Al.

## SECTION 3: Organic compounds

The LSJRB sediment was analyzed for 118 non-polar organic contaminants, but many of the analytical results for these organic contaminants are not displayed individually. Instead, similar individual organic chemical variables or classes were combined and then the sum of all variable concentrations was expressed as a total value (e.g. total polynuclear aromatic hydrocarbons, total chlordanes). For example, the concentrations of the seven individual chlordane isomers and metabolites were summed and the resulting value was called the total chlordane concentration. These total contaminant concentrations were then evaluated, graphed and illustrated at the corresponding sites. Complete inventories of the individual organic contaminant variables that were summed for each class total are listed in Tables 3-9, 3-11, 3-13, 3-15 and 3-17.

The non-polar organic contaminant classes analyzed in the sediment of the LSJRB included the polynuclear aromatic hydrocarbons (PAH), phthalate esters, polychlorinated biphenyls (PCBs), chlorinated pesticides (i.e. DDT, DDD, DDE, chlordane, endosulfans, hexachlorocyclohexanes [HCHs]) and selected types of chlorinated phenolic compounds (chlorinated phenols, anisoles, guaiacols, and catechols). The majority of these organic compounds do not naturally occur in the environment, except for the PAH (Callahan et al., 1973).

The total concentrations of the organic contaminants were compared to available SQG. Sediment quality guidelines have not been developed for the majority of the non-polar organic chemicals, but were available for total PAH, total PCB, and nine pesticides (Table 3-8). These comparisons, analogous to the metal comparisons, provide a useful estimation of the potential harm of the sediment organic contaminant concentrations to aquatic organisms.

Many pesticides are individual organic chemicals not mixtures and therefore were not combined in classes. Instead, these pesticides were evaluated and discussed individually in this Atlas. They were not illustrated on the maps because they were not detected in the sediment, or if detected, were only detected at a few sites at very low concentrations.

The 18 organic contaminant variables are illustrated graphically in this Atlas. These organic contaminant variables were measured and reported in micrograms per kilogram (µg/kg) of sediment in dry weight. As with the metals, each organic contaminant variable with a similar concentration range was grouped together and then individually illustrated on the same maps. The contaminant variables included in each group are listed as follows:

1. **Organic Group 1** includes Total PAH, High Molecular Weight PAH, Low Molecular Weight PAH, and Total Phthalates;
2. **Organic Group 2** includes Sum of PCB and Total PCB;
3. **Organic Group 3** includes Total Chlordane, and Total DDT;
4. **Organic Group 4** includes DDD, DDE and DDT; Total Endosulfans and Total HCH;
5. **Organic Group 5** includes Chlorinated Catechols and Chlorinated Phenols;
6. **Organic Group 6** includes Chlorinated Guaiacols and Chlorinated Anisoles;
7. **Organic Group 7** includes Total Chlorophenolics;
8. **Organic Group 8** includes Aldrin, Dieldrin, Chlorpyrifos, Endrin, Heptachlor, Heptachlor Epoxide, Hexachlorobenzene, Kepone, Lindane, Methoxychlor, Mirex, and Toxaphene.

## Organics: Group 1

The Organic Group 1 contaminants include the total-PAH, which is the sum of the concentrations of 24 individual PAH. The High Molecular Weight (HMW-PAH) class is the sum of the largest 12 of the 24 individual PAH compounds, and the Low Molecular Weight (LMW-PAH) class is the sum of the smallest 12 individual PAH (Table 3-9). All six individual phthalate ester compounds measured in the assessments were used in the summation for the total-Phthalate class (Table 3-9).

### Total-PAH, HMW-PAH, LMW-PAH

The PAH are the only naturally occurring organic chemical contaminants assessed in the LSJRB sediment. The PAH are among the most ubiquitous organic chemicals examined in this Atlas, and trace amounts can be found globally in terrestrial, marine and freshwater environments (Callahan et al., 1979). Naturally occurring PAH are constituents of coal, petroleum, and are also created during forest fires or when any organic material is burned (Grimmer, 1983[102]). PAH concentrations therefore are dramatically increased by human activities.

As previously mentioned, PAH can be grouped into two classes, LMW-PAH and HMW-PAH, according to the number of aromatic hydrocarbon rings that comprise each compound. Naphthalene is the lowest molecular weight PAH, and is composed of two fused rings. The LMW-PAH are typically associated with coal and unrefined, crude petroleum, and therefore are said to be petrogenic (Durell, Fredriksson and Higman, 2004). The HMW-PAH compounds, associated with fires and the combustion of fossil fuels and other organic matter, are described as pyrogenic (Durell, Fredriksson and Higman, 2004). Some substances can contain both LMW-PAH and HMW-PAH. For example, since coal tars and creosote are derived from the high temperature partial-burning or carbonization of coal and petroleum, then they contain abundant PAH of both pyrogenic and petrogenic origin (Durell, Fredriksson, and Higman, 2004). Creosote has been extensively used as a wood preservative, especially for docks and dock pilings and is found in the LSJRB sediment.

Sediment total-PAH concentrations vary extensively and typically increase dramatically near large urban areas. Brown and Neff (1993[103]) reported that background levels in subsurface continental slope sediments offshore of New England ranged from 10 to 20 µg/kg, while sediment off the Palos Verdes Shelf, California, influenced by wastewater discharges, contained from 1,400 to 7,300 µg/kg. The levels of total-PAH in Elizabeth River, Virginia sediment near creosote plants, ranged from 1,000 to 326,000 µg/kg, and in Boston Harbor, Massachusetts sediment PAH concentrations ranged from 1,000 to 718,000 µg/kg (Brown and Neff, 1993). In Panama City, Florida, harbor sediment total-PAH levels ranged from 90 to 1020 µg/kg, but a reference sediment had a level of 11 µg/kg (Mayhew et al, 1993[104]). In addition, Mayhew et al., (1993) found that HMW-PAH levels ranged from 71 to 933 µg/kg while the LMW-PAH levels ranged from 19 to165 µg/kg in the Panama City harbor sediments. They reported that reference sediment levels for HMW-PAH were 6 µg/kg and for LMW-PAH were 5 µg/kg.

The total-PAH levels in the SJR sediment included some of the highest concentrations of all the organic classes. The total-PAH concentrations ranged from 10 to 29,769 µg/kg, with average and median values of 3,588 and 2,265 µg/kg, respectively (Table 3-10). Five sites had total-PAH concentrations above 15,000 µg/kg, and four were located in the Cedar River and the fifth was found in the Cedar-Ortega estuary [Figures 3-44 and 3-45]. The river site with the highest total-PAH value of 13,841 µg/kg was found near St. Vincent's Hospital (LSJ01), in Jacksonville [Figure 3-43]. This river site and other lower SJR sites near the urban areas within Jacksonville (e.g. LSJ02, LSJ05, HOSP02, MON104) exhibited some of the highest total-PAH concentrations [Figure 3-43]. Elevated total-PAH concentrations were also detected in Trout River (TROT02), Goodbys Creek (GDBY01), near and within Rice Creek (e.g., sites RICE021, RICE02 and LSJRC06). The lowest total-PAH concentrations, below 40 µg/kg, were found at six sites located upstream of Green Cove Springs.

The HMW-PAH concentrations ranged from 7.48 to 28,616 µg/kg with an average concentration of 3,140 µg/kg, which is only slightly less than the average total-PAH level (Table 3-10). These data confirm that the majority of total-PAH assessed in the LSJRB are the pyrogenic HMW-PAH. Nine of ten sites with the highest HMW-PAH concentrations, all above 10,000 µg/kg, were located in the Cedar River and Cedar-Ortega estuary, and the other site, LSJ01, was located near the confluence of the LSJ river with the Ortega River [Figures 3-43, 3-44 and Figure 3-45]. The HMW-PAH concentrations below 50 µg/kg were found at eight sites that were located upstream of Green Cove Springs.

The LMW-PAH concentrations were much lower than the HMW-PAH levels, and ranged from 3.23 to 3,795 µg/kg with average and median values of 448 and 253 µg/kg, respectively (Table 3-10). In stark contrast to the total and HMW-PAH contaminant patterns, the four sites with the highest LMW-PAH concentrations were located in and near Rice Creek rather than the Ortega or Cedar rivers [Figure 3-48]. In addition, seven of the eight sites with LMW-PAH levels above 1,500 µg/kg were found in Rice Creek. These data indicate the existence of a local source of LMW-PAH contamination in or near Rice Creek. The lowest LMW-PAH concentrations, measured below 10 µg/kg, were found at eight sites, and all were located upstream of Green Cove Springs. Between the two molecular weight classifications of PAH, 86 sites exhibited HMW-PAH levels above 2,000 µg/kg and seven sites had LMW-PAH levels above 2,000 µg/kg.

Toxicity of PAH compounds varies and generally the unsubstituted LMW-PAH exhibit significant acute toxicity and other adverse effects that are not carcinogenic. The HMW-PAH are demonstrably carcinogenic, mutagenic, or teratogenic to a wide variety of organisms (Grimmer, 1983). Fish and aquatic crustaceans possess enzymes necessary to rapidly metabolize PAH, but some PAH become carcinogenic or mutagenic or both when activated through metabolism (Kennish, 1992[105]). When exposed to PAH contaminated sediment in the laboratory, spot *(Leiostomus xanthurus)* developed fin erosion, dermal lesions and cataracts while others died (Kennish, 1992). Data from feral fish populations support these findings because fish from heavily contaminated sites had the highest incidences of abnormalities (Weeks and Warinner, 1984[106]). Crustaceans are particularly susceptible to PAH toxicity, and shellfish may sequester PAH to a point at which they cannot be safely consumed by humans.

Miller et al. (1982[107]) examined PAH uptake by pink shrimp *(Penaeus duorarum)* and found that the shrimp concentrated chrysene, a HMW PAH, to levels of 9 ug/kg (fresh weight) in the abdomen and 48 ug/kg (fresh weight) in the cephalothorax when exposed to 1.0 ug/L chrysene for 28 days. Even though they were transferred to unpolluted seawater for 28 more days, the shrimp still contained PAH levels deemed to be potentially unsafe for human consumption. Bivalve mollusks cannot properly metabolize and excrete PAH compounds because of inefficient or missing mixed function oxidase (MFO) systems and therefore tend to accumulate high levels in their tissues (Lawrence and Weber, 1984[108]; Sirota and Uthe, 1981[109]; Jackim and Lake, 1978[110]).

The two sites with the highest total-PAH concentrations were CED09 and CED01D, and both had concentrations that exceeded the saltwater PEL of 16,770 µg/kg (Table 3-8). The total-PAH concentration at the CED09 site was also greater than the freshwater PEC of 22,800 µg/kg (Table 3-8). Nineteen sites had HMW-PAH concentrations that were greater than the saltwater PEL of 6,676 mg/kg. Nine of these were located in the Cedar River, three were found in the Cedar-Ortega estuary, three in other tributaries (TROT02, MON104, GDBY01) and one was located in the mainstem of the river (LSJ01). The highest LMW-PAH concentrations discovered at eight sites exceeded the saltwater PEL of 1,442 mg/kg. Seven of the eight sites were located in or near Rice Creek and the other was found in the river. These data indicate that contaminants are present in high enough concentrations so that adverse effects to biota are probably occurring in at least two sites due to the total-PAH, 19 sites due to HMW-PAH, and eight sites due to LMW-PAH.

In addition, the total-PAH concentrations exceeded the freshwater TEC and saltwater TEL SQG at 108 and 109 sites respectively, indicating that total-PAH concentrations may be adversely affecting biota at over 62% of the sampled sites. Only saltwater TEL SQG exist for HMW-PAH and LMW-PAH, and no freshwater TECs are available (Table 3-8). The HMW-PAH concentrations were greater than the saltwater TEL level of 655 µg/kg at 143 sites, and the LMW-PAH concentrations exceeded the saltwater TEL level of 312 µg/kg at 72 sites. These data indicate that HMW-PAH contaminants may be adversely affecting biota at over 81% of the sampled sites, and that LMW-PAH contaminants may be adversely affecting biota at over 41% of the sampled sites.

The PAH concentrations varied widely throughout the LSJRB with widespread contamination in the tributaries and around the urban areas of Jacksonville, Green Cove Springs and Palatka. The sites with high total-PAH also tended to have abundant HMW-PAH. The Cedar River and the Cedar-Ortega estuary had the highest total-PAH and HMW-PAH contamination. The elevated LMW-PAH contamination was mainly found in and around Rice Creek.

### Total Phthalates

The total phthalate esters (total-PHTH*)*, like the PAH, are found throughout the environment and in most organisms (Callahan et al., 1979). They are some of the most widely used industrial chemicals and are major components of most plastics. Phthalate esters are widely used in paints, cosmetics, pesticides and rocket propellants (Macdonald, 1994). High variability in the total-PHTH concentrations can occur among samples due to very small pieces of plastic (Durell, Fredriksson, and Higman, 2004). Two sites BUCK03 and ORG01 had very high concentrations of individual phthalates in only one of the two site replicates, suggesting that plastic fragments could have been responsible. These two outlier values were therefore omitted from this report, but they had previously been reported and the data are available (Durell, Fredriksson, and Higman, 2004).

The total-PHTH concentrations ranged from 12.3 to 2,574 µg/kg, with average and median values of 371 and 188 µg/kg, respectively (Table 3-10). Two of the three sites with total-PHTH concentrations above 2,000 µg/kg were located in the Cedar River (CED04 and CED05) [Figure 3-44]. The third was located in the river in the Jacksonville area (BOL04) [Figure 3-43]. Thirteen sites had total-PHTH concentrations above 1,000 µg/kg. Of the thirteen sites, seven were located in the Cedar River, three in the Cedar-Ortega estuary, two in the lower SJR (BOL04, HSP05), and one was found in Rice Creek (RCJU03) ([Figures 3-43, 3-44 and 3-48].

Sediment quality guidelines have been developed for only one phthalate, and no SQG are available for total-PHTH (Table 3-8). None of the individual bis(2-ethylhexyl) phthalate concentrations exceeded the saltwater PEL value of 2,647 µg/kg, and none of the total-PHTH concentrations exceeded this individual level either. The comparisons of the total-PHTH concentration data to individual phthalate data are typically inappropriate, but in this instance, the comparison was useful, because the total-PHTH concentrations in all samples were less than the individual PEL level.

The total-PHTH concentrations were customarily lower than the PAH concentrations, and showed no clear geographic trend, except for the consistently high concentrations found in the Cedar River and Cedar-Ortega estuary.

## Organics: Group 2

The **Organic Group 2** contaminants include the sum of PCB ($\sum$ of 23 PCB) and the total PCB, which is twice the sum of PCB or 2*($\sum$ of 23 PCB). The sum of the PCB is the sum of 23 of the most prevalent PCB congeners (Table 3-11) that were chosen following the protocol previously described in the Methods Section. These 23 PCB congeners will typically constitute only about one-half of the total PCB concentrations in most environmental samples (Durell et al., 2005). Therefore, the true total-PCB concentrations are approximately two times the sum of these congeners. Although the total-PCB concentrations were not measured in every sample, they were estimated by multiplying the sum of the PCB congener concentrations by two, and then the resulting total-PCB values were graphed for this report.

### Sum of PCBs and Total-PCBs

Polychlorinated biphenyls are created by attaching from one to ten chlorine atoms to a biphenyl molecule. These compounds were once extensively used as dielectric fluids, lubricants, coolants, additives to pesticides, paints, plastics and in a wide variety of other industrial applications (Callahan et al., 1979). The massive production, widespread use and disposal of PCBs lead to their global distribution. Production of PCBs was prohibited in the U.S.A. in 1979, and a subsequent decrease in their use occurred ("PCBs" U.S. EPA, retrieved 2011[111]). PCBs decompose very slowly, so despite the ban and decreased use, PCBs still persist in the environment. Like many chlorinated hydrocarbon chemicals, PCBs have been shown to cause a variety of serious health effects in people, and cancer in animals. They have been classified as probable human carcinogen, and the co-planer PCBs have dioxin-like toxicity ("PCBs" U.S. EPA, retrieved 2011). The PCBs are toxic, persistent and bioaccumulative organic chemical compounds that are significant contaminants of concern ("PCBs" U.S. EPA, retrieved 2011).

The highest concentration of the total-PCBs of 7,854 µg/kg, was found in the Cedar River (CED01) [Figure 3-50]. The second highest concentration of 6,023 µg/kg was located in Rice Creek (RICE021) [Figure 3-54]. The mean, median and range of the sum of the PCB and total-PCB concentrations are shown in Table 3-12. Eight sites had the total-PCB concentrations that were greater than 1000 µg/kg. Six of the eight were located in the Cedar River, and the remaining two sites were located in Rice Creek [Figures 3-50 and Figure 3-54]. Concentrations of the total-PCBs were highest in the northern part of the St. Johns River (e.g. LSJ01, SNAS02), in some urban tributaries (e.g. MON104, RIB105), including Cedar River and near Rice Creek (e.g. RICEC02, RCJU02) as previously discussed [Figures 3-49, 3-50 and 3-54]. No PCBs were detected at two sites. Naturally, the concentrations of the sum of PCB followed the same pattern, since they were one-half the total PCB values.

The SQG are available for the total-PCB concentrations (Table 3-8), but are not available for the sum of the PCB values. For this report, the calculated total-PCB values more accurately predict the potential adverse impact of PCB contaminants on biota because the individual chemicals can act in concert to produce a cumulative toxic effect. Fifteen sites had total-PCB concentrations that exceeded the freshwater PEC level of 676 µg/kg. Nine of the 15 sites were located in the Cedar River, three of the 15 were located in Rice Creek, two were found in the Cedar-Ortega estuary and the other site was located in Moncrief Creek (MON104) [Figures 3-49, 3-50 and 3-54]. Fifty-four sites had total-PCB concentrations greater than the saltwater PEL level of 189 µg/kg. These data indicate that contaminants are in high enough concentrations so that adverse effects to biota are probably occurring in at least 15 to 54 sites due to the total-PCBs. The total-PCB concentrations exceeded the freshwater TEC and saltwater TEL SQG levels at 118 and 145 sites respectively, indicating that total-PCB concentrations may be adversely affecting biota at 67% to 83% of the sampled sites.

PCB contamination occurs throughout the LSJRB, and like the PAH contamination is prominent in tributaries and urban areas. The Cedar River, Rice Creek and the Cedar-Ortega estuary had the highest PCB contamination.

## Organics: Group 3

The **Organic Group 3** contaminants include total chlordane, which is the sum of seven individual chlordane isomers and metabolites, as previously mentioned. The seven individual chlordane isomers that were used in the summation for the total chlordane are listed in Table 3-13. The other Group 3 contaminant is total Dichloro-Diphenyl-Trichloroethane (total-DDT), which is the sum of all isomers of DDT and all isomers of the degradation products DDD and DDE, as listed in Table 3-13.

Many of the chlorinated pesticides that were detected in the LSJRB sediment were introduced more than 50 years ago. For example, DDT was one of the most widely used synthetic pesticides in the late 1950's and early 1960's (Extoxnet, 1994). In 1959 at the peak of its use, over 7.8 billion pounds were applied in the U.S. DDT was banned for nearly all uses in 1972, but concentrations of DDT, and its degradation products, DDE and DDD, are still present in measurable quantities in sediment (Blus, 2003[112]). Similarly, the use of chlordane was restricted, and by 1983 the only permitted use was for structural protection for termites (Extoxnet, 1994). Although the use of chlordane had been eliminated by 1988, concentrations of chlordane and chlordane metabolites continue to negatively influence environmental resources (NOAA, 1990[113]).

### Total Chlordane

Total chlordane is a mixture of chemically similar compounds that includes the *cis* and *trans* chlordane, nonachlor isomers, and heptachlor, among other constituents (Table 3-13). The three most important compounds are *cis*-chlordane, *trans*-nonachlor, and heptachlor (NOAA, 1990). Heptachlor was also manufactured and used separately as a pesticide. The three main metabolites of chlordane are oxychlordane derived from both cis-chlordane and trans-nonachlor, heptachlor epoxide from heptachlor and chlordene epoxide from either chlordane or heptachlor (NOAA, 1990). The toxicity and fate of chlordane is complex due to differences in the parent mixtures, the degradation pathways of the parent compounds and the differences in metabolic pathways of the organisms. Information on the fate can be contradictory, for example the trans-chlordane isomer was found to be more readily degraded while the cis-chlordane isomer was more readily excreted. Some information suggests chlordane is more toxic than heptachlor, but in both cases the metabolites are more toxic than the parent compounds (NOAA, 1990). In addition, these epoxide metabolites can accumulate to relatively high levels in fish tissue. The organochlorine pesticides in general are characterized by their broad-spectrum insecticidal activity, long persistence in the environment, and their tendency to bioaccumulate along food chains (NOAA, 1990).

Total-chlordane concentrations were much lower than the PAH and PCBs, ranging from the maximum value of 100.9 µg/kg to very low non-detectable levels. This range, the average and median total-chlordane concentrations are listed in Table 3-14. Four sites had total-chlordane concentrations greater than 75 µg/kg and three were located in the Cedar-Ortega estuary, while the fourth was found in the Cedar River [Figures 3-56 and 3-57]. Fifteen of 27 sites with total-chlordane concentrations greater than 10 µg/kg were found in the Cedar-Ortega estuary, eleven were located in the Cedar River and the other site was located in the urban Jacksonville tributary called Moncrief Creek (MON104). Total-chlordane concentrations were not detected at 26 sites. Many of these sites were located in the river upstream of Green Cove Springs, a few were located in the Cedar-Ortega estuary and in some other tributaries including Clapboard Creek.

The total-chlordane mixture is toxic, persistent, a priority pollutant, a known carcinogen, and it bioaccumulates (NOAA, 1990). It is more resistant to microbial degradation than DDT and its metabolites, HCH isomers, endrin, aldrin, heptachlor, and methoxychlor (Callahan et al., 1979). Total chlordane concentrations exceeded the freshwater PEC level of 17.6 µg/kg, and the saltwater PEL level of 4.79 µg/kg at 18 and 44 sites, respectively. The total-chlordane contamination therefore is likely to be adversely affecting biota at these sites. In addition, the total-chlordane concentrations were greater than the freshwater TEC of 3.24 µg/kg and saltwater TEL of 2.26 µg/kg at 57 and 75 sites, respectively. These data indicate that the total-chlordane concentrations may be adversely affecting biota at 33 to 43 % of the sites in the LSJRB.

The total-chlordane contamination was greatest in the river in the urban Jacksonville area, especially in urban tributaries and near their confluences (e.g. Cedar-Ortega estuary, Moncrief, Trout, Ribault, Goodbys creeks). Elevated levels of total-chlordane were also found in Rice Creek and in the river downstream of the mouth of Rice Creek.

### Total DDT

DDT is one of the most well known organochlorine pesticides, and first synthesized in 1874, it is one of the oldest (Squibb, 2002[114]). It was used extensively during the Second World War to control insects that transmit diseases like typhus and malaria (Extoxnet, 1994).

The maximum total-DDT concentration was greater than the total-chlordane concentrations, but like the total-chlordane values, the total-DDT levels were much lower than the PAH and PCB concentrations. The maximum total-DDT concentration was 116.37 µg/kg and it was located in the Cedar-Ortega estuary at ORT051 [Figure 3-56]. Two other sites had total-DDT concentrations greater than 50 µg/kg; one was located in the Cedar-Ortega estuary and the other was found in the Cedar River [Figures 3-56 and 3-56]. The average, median and range of total-DDT concentrations are listed in Table 3-14. Eighteen sites had total-DDT concentrations that were greater than 25 µg/kg. Eleven of the 18 sites were located in the Cedar-Ortega estuary, one site, LSJ01 was located outside the mouth of Cedar-Ortega estuary, four were found in the Cedar River, and the other two sites were located in other tributaries called Moncrief Creek and Rice Creek. Total-DDT concentrations were not detected at seven sites, and most of these sites were located in the upstream portion of the river.

DDT is highly toxic to insects, crustaceans, fish and birds (Pesticide Action Network, Pesticide Database, retrieved 2011[115]). DDT produces tremors and a lack of coordination at low doses, and convulsions at higher doses through effects on sodium channels in the nervous system. The tremors and neurotoxic responses produced by DDT exposure results from the repetitive firing of nerve cells; the cells eventually are unable to fire in response to a signal, and the organism dies due to respiratory failure (Squibb, 2002).

The two highest total-DDT concentrations were greater than the saltwater PEL value of 51.7 µg/kg and, as previously mentioned, were located in the Cedar-Ortega estuary (ORT051) and Cedar River (CED01). The biota are probably being adversely affected by the sediment total-DDT concentrations at these two sites. None of the total-DDT concentrations measured in the LSJRB sediment were greater than the freshwater PEC of 572 µg/kg (Table 3-8). The freshwater total-DDT TEC level of 5.28 µg/kg and saltwater total-DDT TEL level of 3.89 µg/kg where exceeded by 113 and 126 sites, respectively. These data indicated that biota may be adversely affected by the total-DDT concentrations at 64% to 72% of the sites in the LSJRB.

The total-DDT contamination was more widespread than total chlordane, and like total-chlordane, the highest concentrations were located in the urban tributaries, especially Cedar-Ortega estuary, and in the St. Johns River near their confluences. Many sites that had elevated total-DDT levels also had elevated total-chlordane concentrations (e.g. MON104). However, the total-DDT concentrations were higher than total-chlordane concentrations at nearly all LSJ sites. Rice Creek and the river downstream of the confluence also had some of the highest total-DDT concentrations.

## Organics: Group 4

The **Organic Group 4** contaminants include dichlorodiphenyltrichloroethane (DDT) which is the sum of the 2,4-DDT + 4,4-DDT isomers; dichlorodiphenyldichloroethane (DDD) which is the sum of the 2,4-DDD + 4,4-DDD isomers; and dichlorodiphenyldichloroethylene (DDE) which is the sum of the 2,4-DDE + 4,4-DDE isomers (Table 3-15). In addition, the Organic Group 4 contaminants include total endosulfan and total hexachlorocyclohexane (t-HCH) also known as benzene hexachloride or BHC. The total-endosulfan discussed in this sediment Atlas and presented in the maps is the sum of endosulfan I, endosulfan II and endosulfan sulfate (Table 3-15). The t-HCH, discussed and displayed in this Atlas, is the sum of the α-HCH, β-HCH, δ-HCH and γ-HCH isomers (Table 3-15).

Although DDT has been banned for use in the U.S., as previously mentioned, endosulfan and the gamma-HCH isomer lindane are still being used as insecticides on tobacco, fruits, vegetables, for wood preservation and in small-scale pest control, and therefore continue to be introduced into the environment. In addition, very small amounts of lindane are still used in treatments against head lice and scabies mites (ATSDR, retrieved 2011).

### DDT, DDE, DDD

The average DDT concentration of 2.253 µg/kg and median concentration of 1.279 µg/kg, as expected, were much lower than the average and median total-DDT concentrations (Tables 3-16, 3-14). The range of DDT concentrations is listed in Table 3-16. Concentrations of DDT were greater than 10 µg/kg at three sites, and the highest concentration of 16.35 µg/kg was found in the Cedar-Ortega estuary (ORT33) [Figure 3-62]. The two other sites were located in the St. Johns River, one in the urban Jacksonville area (LSJ01), and the other upstream at LSJRC10 near the confluence with Rice Creek [Figures 3-61 and 3-66]. The DDT concentrations were greater than 5 µg/kg at 24 sites. Thirteen of these 24 sites were located in the Cedar-Ortega estuary, six of the 24 were found in or near Rice Creek, three were situated in the St. Johns River in the urban Jacksonville area, and two were located in urban tributaries. No measurable DDT contamination was detected at 37 sites and no discernible pattern existed for these sites. DDT was distributed in the river and tributaries in urban Jacksonville, and at upstream sites extending all the way to Welaka.

DDT is toxic to a wide range of animals in addition to insects. It is highly toxic to aquatic life, including crayfish, daphnids, shrimp and many species of fish (U.S. EPA. 1980[116]). Although DDT was developed to be toxic at very low concentrations, the toxicity of the individual isomers, and their analogs will have varying toxic effects (Johnson et al., 1992 [117]) and some metabolites are more toxic than their parent compounds. For example, the acute oral LD-50 for rats was 87 mg/kg for 4,4'-DDT; 880 mg/kg for 4,4'-DDE; and 113 mg/kg for 4,4'-DDD (Montgomery, 1993 [118]). There is strong evidence that 4,4'-DDE inhibits calcium ATPase, and also evidence that 2,4'-DDT disrupts the development of the female avian reproductive tract (Lundholm, 1997 [119]). None of the DDT concentrations exceeded the freshwater PEL of 62.9 µg/kg (Table 3-8), but the DDT concentrations were greater than the freshwater TEL value of 4.16 µg/kg at 31 sites. These data indicated that biota may be adversely affected by DDT concentrations at 17% of the sites in the LSJRB. The salt water SQG are not available for the sums of the 2,4-isomer + 4,4- isomer of DDT, DDE or DDD.

The DDE concentrations ranged from non-detectable levels to a high concentration of 93.12 µg/kg. This maximum DDE concentration was over five times greater than the maximum DDT concentration of 16.35 µg/kg, indicating that it is a more significant contaminant that DDT. The average and median DDE concentrations also exceeded the average and median DDT concentrations (Table 3-16). Three of the four sites with the highest DDE concentrations, all above 20 µg/kg, were located in the Cedar-Ortega estuary and the other site was situated in the Cedar River [Figure 3-62]. Two of the four additional sites with DDE concentrations above 15 mg/kg were also found in the Cedar-Ortega estuary, one in the Cedar River, and the other site (MON104) was located in Moncrief Creek [Figures 3-61and 3-62]. DDE contamination was not detected at 14 sites and most of these sites were located upstream of urban Jacksonville (e.g. Moccasin Slough, Dunns Creek) or in tributaries including Clapboard and Rice creeks.

Two sites, one in the Cedar-Ortega estuary (ORT051) and one in the Cedar River (CED01), exceeded the freshwater PEL of 31.3 µg/kg for DDE (Table 3-8). The sediment DDE concentrations at these two sites are high enough that adverse effects to sediment-dwelling organisms are likely to be occurring. In addition, sediment-dwelling organisms may be affected at over 50% of the sites in the LSJRB, because DDE concentrations were greater than the freshwater TEL value of 3.16 µg/kg at 89 sites.

The maximum, average and median DDD concentrations were higher than the DDT, but lower than the DDE values (Table 3-16). Two sites had DDD concentrations above 30 µg/kg, and both were located in the Cedar River (CED01 and CED062) [Figures 3-62 and 3-63]. Seven sites had DDD concentrations above 20 µg/kg. Three of the seven sites were located in the Cedar-Ortega estuary, two in the Cedar River as previously mentioned, and the other two sites were located in Rice and Moncrief creeks [Figure 3-61, 3-62 and 3-66]. DDD contamination was not detected at 25 sites. The pattern of sites with no detectable DDD contamination was similar to the DDE pattern, since most sites with undetected DDD concentrations were located in upstream regions and in some tributaries.

The two sites with the highest DDD concentrations exceeded the freshwater PEL of 28 µg/kg (Table 3-8). The DDD concentrations are probably adversely affecting the biota at these two sites [Figure 3-62 and 3-63]. Fifty-four sites, or over 30% of the sites, had DDD concentrations that were greater than the freshwater TEL of 4.88 µg/kg (Table 3-8). Sediment-dwelling organisms may be adversely affected by the DDD concentrations at these sites.

Analysis of the relative concentrations of DDT with its degradation products revealed that the DDE contamination was more widespread than the DDT or DDD contamination. The DDE concentrations were higher than DDT concentrations at over 73%, and higher than DDD concentrations at over 56% of the LSJRB sites. In addition, the DDD concentrations exceeded the DDT concentrations at 113 or 70 % of the LSJRB sites.

The DDT concentrations were higher than the DDE concentrations at 45 sites. Of these 45 sites, 19 were located in or near Rice Creek, seven were situated in Cedar-Ortega estuary, two in tributaries and 17 were distributed throughout the river from Jacksonville upstream to Welaka. The DDT concentrations were higher than DDD concentrations at 49 sites. Of these 49 sites, 24 were distributed throughout the river from Jacksonville upstream to Welaka, 13 were located in or near Rice Creek, eight were situated in Cedar-Ortega estuary and four were found in other tributaries. These DDT concentrations that are higher than either degradation product suggest more recent inputs of DDT and/or slower DDT degradation.

### Total Endosulfan

Technical endosulfan is a mixture of two isomers, the alpha-isomer or endosulfan I, and the beta-isomer or endosulfan II. Endosulfan sulfate is the breakdown or degradation product of endosulfan, and is more persistent than the parent compound (Pesticide Action Network, Pesticide Database, retrieved 2011). The total-endosulfan discussed in this sediment Atlas and presented in the maps is the sum of endosulfan I, endosulfan II and endosulfan sulfate concentrations (Table 3-15) as previously described.

Endosulfan is a derivative of hexachlorocyclopentadiene and is chemically similar to aldrin, chlordane and heptachlor (US EPA, 2002[120]). It is a broad spectrum contact insecticide and acaricide (e.g. lethal to ticks and mites), that is also used in wood preservation. Endosulfan has been banned in over 60 countries due to its acute toxicity, potential for bioaccumulation and role as an endocrine disruptor (US EPA, 2002). The U.S. EPA is taking action to end all uses of endosulfan in the United States by 2016.

The maximum total endosulfan concentration of 28.99 µg/kg was found in Cedar River (CED01) and this was the only site that had a total endosulfan concentration greater than 20 µg/kg [Figure 3-62]. The six highest total endosulfan concentrations were all greater than 10 µg/kg. Three of these six sites were located in the Palatka area near Rice Creek, two were found in the Cedar River, and one was located in Moncrief Creek [Figure 3-61, 3-62 and 3-66]. Fourteen sites had total endosulfan concentrations that were greater than 5 µg/kg. Five of the 14 sites were located in Cedar River, three were situated in the Cedar-Ortega estuary, one was found in the river in the Jacksonville area, one was also located upstream near Dunns Creek and, as previously mentioned, three were found in the Palatka area and one in Moncrief Creek. Total endosulfan concentrations were not detected at almost one-third of the LSJRB sites, and these sites extended from the urban Jacksonville area upstream to the Welaka area.

The maximum total endosulfan concentration of 28.99 µg/kg was greater than the maximum DDT concentration, but lower than the maximum DDD or DDE concentrations (Table 3-16). Although the total endosulfan range of concentrations was greater than the DDT range, the mean and median values were lower (Table 3-16). In addition, the DDT concentrations were greater than total-endosulfan at over 60% of the sites. The total endosulfan mean and median values were also lower than DDD and DDE mean and median values (Table 3-16). These total endosulfan concentrations exceeded the DDD, DDE and DDT at 28, 29 and 54 sites, respectively. However, both DDD and DDE contaminant concentrations were greater than the total-endosulfan concentrations at over 82% of the sites.

Endosulfan is highly toxic to many fish species and aquatic invertebrates, and the alpha-isomer, endosulfan I is considered to be more toxic than the beta-isomer (endosulfan II). Bioaccumulation may be significant, and in a mussel species (Mytilus edulis) the compound accumulated to 600 times the ambient water concentration (Extoxnet, 1994). No TEL/TEC or PEL/PEC SQG are available for total endosulfan.

### Total Hexachlorocyclohexane

The t-HCH found in the SJRWMD sediment is from technical hexachlorocyclohexane, which is a mixture of a number of stereoisomers, principally alpha-HCH (α-HCH), beta-HCH (β-HCH), delta-HCH (δ-HCH) and gamma-HCH (γ-HCH), as previously mentioned (Table 3-15). The pesticide lindane is 99% γ-HCH isomer but it also contains the other isomers (Britannica, retrieved 2011[121]). Therefore the t-HCH discussed and displayed in this Atlas is the sum of the α-HCH, β-HCH, δ-HCH and γ-HCH isomers (Table 3-15).

The toxin t-HCH is manufactured as a fungicide. It appears to be a very persistent compound in the aquatic environment and has a high affinity for lipophilic material (Laseter et al., 1976[122]). Bottom sediment retains t-HCH longer than organisms, and sediment exposed to t-HCH solution in the laboratory setting concentrated it rapidly (concentration factor of 40X in 1 day). In one study, after four days of desorption into clean water, the sediment retained concentrations almost as high (concentrations factor of 32X) as those measured initially (Laseter et al., 1976).

The t-HCH range, mean and median values were the lowest of the Group 4 contaminants (Table 3-16). Only three sites had t-HCH concentrations that were greater than 5 µg/kg, including the maximum value of 9.81 µg/kg. These three sites were located in and near Rice Creek (RICE02, LSJRC06) and in the Cedar-Ortega estuary [Figures 3-66 and 3-63]. Of the 20 sites with t-HCH concentrations above 2 µg/kg, eight were located in the Cedar-Ortega estuary, six were found in and near Rice Creek, two were situated in Cedar River, and four were located at widely divergent sites in the river. The t-HCH concentrations were not detected at 51 sites or over 29 % of the LSJRB sampling sites. Similar to the total-endosulfan distribution, the sites where t-HCH contamination was not detected extended from the urban Jacksonville area upstream to the Welaka area. The t-HCH concentrations were lower than the total-endosulfan concentrations at over 60% of the sites, but did exceed the total-endosulfan concentrations at 57 sites.

Among the t-HCH isomers, β-HCH bioaccumulates the most in the food chain (ATSDR, retrieved 2011). Callahan et al. (1979) found that organisms such as algae, plankton, snails, insects and fish bioaccumulate t-HCH, and tissue concentrations increased as the treatment concentrations increased. Murty (1986) demonstrated that rainbow trout t-HCH body burdens increased in direct relation to the t-HCH content of their food. Callahan et al. (1979) also found that higher food web organisms (e.g. snails, and fish) consistently contained 1.5 to 10 times more t-HCH than lower food web organisms. No TEL/TEC or PEL/PEC SQG are available for t-HCH.

## Organics: Group 5, 6 and 7

The **Organic Group 5, 6 and 7** contaminants are the chlorophenolic compounds and include the chlorinated phenols (Cl-Phenols), chlorinated catechols (Cl-Catechols), chlorinated guaiacols (Cl-Guaiacols), chlorinated anisoles (Cl-Anisoles) and total chlorophenolics (Chlorophenolics). These chlorophenolic chemicals have many industrial applications and have been used in the production of antiseptics, insecticides, herbicides and wood preservatives. They can be created as byproducts of industrial operations, such as during pulp and paper mill bleaching processes, incineration of chlorine-containing wastes, chlorine disinfection of municipal water and wastewater (Sonnenberg and Higman, 2001).

Polychlorinated phenols, catechols, guaiacols and anisoles, are some of the toxic substances found in bleached pulp mill effluents (Sodergren, 1992[123]). Scandinavian investigations in the early 1980's found detrimental effects of bleached Kraft pulp mill effluent on fish, including fin erosion, skeletal deformation, and internal metabolic, immunological and reproductive changes; these effects have also been found in North American fishes (Sodergren 1992). Because the District contains approximately half of the pulp mills in the state of Florida, the sediment of the lower SJR was assessed for many of these chlorinated phenols, catechols, guaiacols and anisoles (Durell, Fredriksson and Higman. 2004).

## Organics: Group 5

The **Organic Group 5** contaminants include the chlorinated phenol class (Cl-Phenols) and chlorinated catechol (Cl-Catechols). The Cl-Phenols are the sum of nine chlorinated phenols and the Cl-Catechols are the sum of six chlorinated catechols, as listed in Table 3-17. In some samples, specific Cl-phenol and Cl-catechol contaminants could not be separated or identified because they co-eluted. To clarify this analytical problem, a brief explanation of co-elution follows.

Co-elution occurs when two or more individual chemical compounds emerge from a sample mixture chromatograph at the same time and cannot be separately identified. Since the individual compounds cannot be separated they are reported as one concentration. This concentration measurement could represent a 50%/50% mixture or some other percentage mixture of the co-eluted chemicals (e.g. [10% / 90%]; [70% / 30%]). It is impossible to determine the percent mixture due to the complex chemistry of the co-eluted chemicals. For this Atlas, the concentration of each co-elute was designated as the full measured value (e.g. 100%), which would be the maximum value. These maximum values were used in the summation and mapping of Cl-phenol and Cl-catechol concentrations for each site where co-elution occurred.

### Phenols

The Cl-phenols were the most frequently detected chlorophenolic compound in the LSJRB sediment samples. The average, median and range of values for the Cl-Phenol concentrations are shown in Table 3-18.

Three sites had Cl-Phenol concentrations that exceeded 10,000 µg/kg. The maximum Cl-Phenol concentration of 14,780 µg/kg was located in Goodbys Creek (GDBY01), and the other sites were located near Green Cove Springs (GRNC04), and in Doctors Lake (DRLK01 - Figures 3-67 and 3-70). The nine sites with Cl-Phenol concentrations over 5,000 but under 10,000 µg/kg were clustered near the urban areas of Green Cove Springs and Jacksonville, and included a site in Rice Creek. Concentrations of Cl-Phenols greater than 2,000 µg/kg were found at 42 sites extending over the river from Jacksonville upstream to Welaka. Over 92% of the LSJRB sediment samples had measurable concentrations of Cl-Phenols and only 10 sites had non-detectable levels.

Bioaccumulation of Cl-phenols has been shown and concentration factors increase as the attached chlorine groups increase. The highly chlorinated pentachlorophenol and its degradation products were accumulated by snails, clams and fish, while bluegill sunfish were killed with lethal doses of 32 ug/L (Callahan et al., 1979). No PEL/PEC or TEL/TEC SQG are available for Cl-Phenols.

### Catechols

The maximum Cl-Catechol concentration of 21,476 µg/kg was located at LSJRC05 just outside the mouth of Rice Creek (Figure 3-72). The range, median and average values for Cl-Catechol concentrations are shown in Table 3-18.

Three sites had Cl-Catechol concentrations that were greater than 10,000 µg/kg, and included the previously mentioned site (LSJRC05), the second site (CED04) was located in the Cedar River, while the third (DUN01) was located near the mouth of Dunns Creek (Figures 3-68, 3-71 and 3-72). Six of 15 sites with Cl-Catechol concentrations above 5,000 but below 10,000 µg/kg were found in the Cedar-Ortega estuary, four were located near Green Cove Springs, two were near Julington Creek, and one each near Rice Creek, in Doctors Lake and in the mainstem near Welaka. The Cl-Catechol concentrations were greater than 2,000 µg/kg at 29 sites. Cl-Catechol concentrations were not detected at 32% of the sample sites, and these 46 sites were also divided over the whole river from Jacksonville upstream to Welaka. No PEL/PEC or TEL/TEC SQG are available for Cl-Catechols.

## Organics: Group 6

The **Organic Group 6** contaminants include the chlorinated guaiacols (Cl-Guaiacols) and chlorinated anisoles (Cl-Anisoles). The Cl-Guaiacols are the sum of five chlorinated guaiacols and the Cl-Anisoles are the sum of three chlorinated anisoles, as shown in Table 3-17.

### Guaiacols

The Cl-Guaiacol class had the lowest maximum concentration and the smallest variance of all the chlorophenolic chemicals (Table 3-18). Unlike the Cl-Phenol, Cl-Catechol and Cl-Anisole classes, none of the Cl-Guaiacol concentrations were greater than 10,000 µg/kg. The maximum Cl-Guaiacol concentration of 7,264 µg/kg was found at LSJ23 near Bayard Point (Figure 3-76). This site and two other sites had the highest Cl-Guaiacol concentrations, and all three were greater than 6,000 µg/kg. Seven of 23 sites with Cl-Guaiacol concentrations above 2,000 µg/kg were located in or near Rice Creek, and most of the other sites were found in the river and tributaries in the Jacksonville area. Over 37% of the sites sampled in the LSJRB had non-detectable Cl-Guaiacol concentrations, and like the Cl-Catechols, these sites extended from the Jacksonville area to Welaka.

Polychlorinated guaiacols are toxic and persist in the environment. The 3,4,5-trichloroguaiacol has been found in sediment up to 150 km from the nearest bleached pulp mill outfall (Jonsson et al., 1992[124]). No PEL/PEC or TEL/TEC SQG are available for Cl-Guaiacols.

### Anisoles

The Cl-Anisole class had the highest maximum concentration of all the individual chlorophenolic chemicals, along with the largest variance but with the lowest average value (Table 3-18). The maximum Cl-Anisole concentration of 31,486 µg/kg was located in Rice Creek (RICE02) (Figure 3-78). One other sites also had Cl-Anisole concentrations greater than 10,000 µg/kg but less than this maximum value and was found in Palmo Cove (PALM01) near Green Cove Springs (Figure 3-76). Two sites, had Cl-Anisole concentrations above 5,000 but less than 10,000 µg/kg. These two sites were found near Green Cove Springs (GRNC04) and upstream in Rice Creek (RICE021). Nine sites had Cl-Anisole concentrations above 1,000 and below 5,000 µg/kg, and as with the other classes, these sites were clustered near the urban areas of Green Cove Springs and Jacksonville, and near Rice Creek. Cl-Anisoles were detected at a greater frequency in and near Rice Creek than at any other location. Cl-Anisoles were found at fewer sites throughout the river than Cl-Guaiacols, Cl-Phenols and Cl-Catechols. Cl-Anisole concentrations were not detected at over 63% of the sample sites. No PEL/PEC or TEL/TEC SQG are available for Cl-Anisoles.

## Organics: Group 7

The **Organic Group 7** contaminant is the total chlorophenolics (Chlorophenolic). The Chlorophenolic contaminants are the summation of all the Cl-phenols, Cl-catechols, Cl-guaiacol, and Cl-anisoles as listed in Table 3-17.

### Chlorophenolics

Since the Chlorophenolic contaminants are the summation of all the Cl-phenols, Cl-catechols, Cl-guaiacol, and Cl-anisoles, then as expected this group had the highest maximum, average, and median concentrations (Table 3-18). The site with the maximum chlorophenolic concentrations was found in Rice Creek at site RICE02 (Figure 3-84). Chlorophenolic concentrations were greater than 10,000 µg/kg at 17 sites, and these sites were positioned in or near Rice Creek, and near the municipal areas of Jacksonville, Green Cove Springs and Welaka. Chlorophenolic concentrations above 5,000 µg/kg were found at 47 sites. Approximately 60% of the sites sampled had Chlorophenolic concentrations that exceeded 2,000 µg/kg, and showed the widespread contamination found in the LSJRB sediment.

The detection of Chlorophenolic contamination varied across the lower SJR study area, with over 80% of the sites having concentrations above 500 µg/kg, thus making it difficult to distinguish a clear geographical pattern. The elevated concentrations that were detected in the northern municipal areas and the Rice Creek sites did not reveal any consistent contaminant distribution pattern, and the individual chlorophenolic compounds detected at each site varied among sites (Sonnenberg and Higman, 2001). Only eight sites had non-detectable concentrations of Chlorophenolics. No PEL/PEC or TEL/TEC SQG are available for total Chlorophenolics.

## Organics: Group 8

The **Organic Group 8** contaminants include the individual pesticide compounds aldrin, dieldrin, endrin, chlorpyrifos, heptachlor, heptachlor epoxide, hexachlorobenzene, chlordecone, lindane, methoxychlor, mirex and toxaphene. Eleven of these twelve Group 8 pesticides are organochlorine insecticides. The other pesticide (chlorpyrifos) is classified as an organophosphate pesticide, but it also contains chlorine. All of these pesticides were analyzed and found to be in relatively low concentrations when compared with the major pesticide classes such as chlordane and DDT. Therefore, these Group 8 pesticides were evaluated, but were not graphed or illustrated in this Atlas.

### Pesticides

Aldrin and dieldrin are organochlorine insecticides that do not occur naturally in the environment. Aldrin and dieldrin are closely related with similar chemical structures, and aldrin breaks down to form dieldrin (MedicineNet.com, 2011 retrieved[125]). Aldrin is not toxic to insects until it is oxidized in the insect to form dieldrin, which is the active compound. Aldrin and dieldrin were originally developed in the 1940s as an alternative to DDT, and they proved to be highly effective insecticides. They were very widely used during the 1950s to early 1970s on crops like corn and cotton (ATSDR, retrieved 2011). In 1987, EPA banned all uses of aldrin and dieldrin because of the potential human health concerns and environment damage (U.S. EPA. - Integrated risk information system [IRIS], retrieved 2011[126]).

Aldrin was the least frequently detected Group 8 contaminant, and was only found in 12% of the LSJRB sediment samples. The maximum aldrin concentration was approximately 19 times higher than the average value of 0.09 ug/kg (Table 3-19). Eight sites had aldrin concentrations that exceeded 1.0 ug/kg, including the site with the maximum concentration of 1.75 ug/kg (CED062). These sites were found in the Cedar-Ortega estuary, the Cedar River and in the lower SJR in Jacksonville (LSJ01).

Aldrin and dieldrin demonstrate very high acute toxicity to aquatic organisms such as fishes, crustaceans, and amphibians. Animal studies have linked these chemicals to liver damage, central nervous system effects, and suppression of the immune system (ATSDR, retrieved 2011). No TEL/TEC or PEL/PEC SQG are available for aldrin.

Dieldrin is a priority pollutant, persistent, bioaccumulates, and is resistant to biotransformation. Dieldrin is more resistant to microbial degradation than DDT and its metabolites, HCH isomers, endrin, aldrin, heptachlor and methoxychlor (Callahan et al., 1979).

Dieldrin was the most prevalent of the Group 8 contaminants and was detected in over 70% of the sites. Although widespread, dieldrin was found in low concentrations in the majority of samples, with an average of 0.81 ug/kg, a median of 0.40 ug/kg and a maximum value of 8.06 ug/kg (Table 3-19). The highest dieldrin concentrations, all greater than 5 ug/kg, were found at four sites. Two of the four sites were located in the Cedar River (CED01D; CED02), one was found in the Cedar-Ortega estuary (ORT33), and the fourth site was located in Rice Creek (RICE02).

Dieldrin concentrations were compared to the Florida SQG, and about 3% of the samples (6 sites) had concentrations that were greater than the saltwater PEL of 4.3 ug/kg. The sediment dwelling biota at these six sites are probably being negatively affected by dieldrin contamination. No sites had concentrations that exceeded the fresh water PEC of 61.8 ug/kg (Table 3-8). Dieldrin concentrations in over 35% of the samples were greater than the saltwater TEL of 0.715 ug/kg. The measured concentrations in 21 sites exceeded the fresh water TEC of 1.90 ug/kg. These comparisons indicate that dieldrin may be negatively affecting biota in 12% to 35% of the sediment sites.

Pure endrin is a stereoisomer of dieldrin. Endrin, when manufactured is not purified, so it is a complex mixture of long-lived chlorinated organic compounds, and impurities include endrin aldehyde, alpha-keto endrin, dieldrin, isodrin, aldrin, and others (Callahan et al., 1979). Microbial degradation of endrin in soil forms several ketones and aldehydes,. Photolysis of endrin produces alpha-keto endrin, endrin aldehyde and other compounds (Montgomery, 1993). Endrin has been banned in many countries and has not been produced or sold for general use in the United States since 1986 (ATSDR, retrieved 2011).

Endrin concentrations showed the largest range between the maximum and average concentrations of all Group 8 contaminants. The maximum concentration of 5.04 was over 40 times greater than the average endrin concentration of 0.12 ug/kg (Table 3-19). Endrin was measured in 15% of the sediment samples. The site with the highest concentration was located in the Cedar-Ortega estuary (ORT33), and no other site had endrin levels above 3.0 ug/kg. This site and four other sites had endrin levels greater than 1.0 ug/kg, and all were located in the Cedar River and Cedar-Ortega estuary. No sites had endrin concentrations that exceeded the fresh water PEC of 207 ug/kg (Table 3-8). Only two sites (ORT33; CED02) had endrin concentrations above the fresh water TEC of 2.22 ug/kg (Table 3-8). No salt water TEL/PEL SQG are available for endrin.

Chlorpyrifos, or dursban, is the only broad-spectrum organophosphate insecticide in Group 8. Chlorpyrifos is registered for agricultural use in the U.S., where it is "one of the most widely used organophosphate insecticides," according to Dow AgroSciences (Dow AgroSciences, retrieved 2011[127]).

Chlorpyrifos had a concentration range from non-detection to the highest value of 21.7 ug/kg. Although the concentration range was greater than for dieldrin, only about one-third (35%) of the sediment samples had detectable levels. The maximum chlorpyrifos concentration was over 33 times higher than the average value of 0.65 ug/kg (Table 3-19). Three of the four sites with the highest chlorpyrifos concentrations that were greater than 5 ug/kg were found in the Cedar-Ortega estuary (ORT25, LFW01, ORT33), and the fourth site was located in the Cedar River (CED062). Chlorpyrifos was not detected in over 60% of the sediment samples, and no Florida TEL/TEC or PEL/PEC SQG are available for chlorpyrifos.

Heptachlor is a synthetic organochlorine chemical that was used extensively in the past for killing insects in homes, buildings and on food crops. Currently, its use is limited to fire ant control (ATSDR, retrieved 2011). Heptachlor is also both a degradation product and a component of the pesticide chlordane (NOAA, 1990). Heptachlor will rapidly degrade in the environment to form heptachlor epoxide. Heptachlor epoxide was not manufactured and was not used as an insecticide, but is more likely to be found in the environment than heptachlor (U.S. EPA, IRIS retrieved 2011). Heptachlor is oxidized, after ingestion, by many plants, bacteria and animals to heptachlor epoxide. There are no natural sources of heptachlor or heptachlor epoxide.

The average heptachlor concentration was the lowest, and the maximum concentration was the second lowest of the Group 8 contaminants (Table 3-19). Only 16% of the samples had measurable heptachlor levels. Three of the five sites with the highest heptachlor concentrations, greater than 0.5 ug/kg, were found in the Cedar-Ortega estuary (ORT33, LFW01, ORT31), the fourth was situated in the Cedar River (CED02), and the other site was located in Trout River (TRT01). Elevated heptachlor levels, above 0.20 ug/kg, were also found near Rice Creek. Heptachlor was not detected in over 84% of the sediment samples, and no TEL/TEC or PEL/PEC SQG are available for heptachlor.

Heptachlor epoxide contamination was more widespread and concentrations were typically higher than for heptachlor. Over 19% of the sediment samples had measurable heptachlor epoxide levels with an average value of 0.45 ug/kg (Table 3-19). In contrast with the other pesticides, the three sites with the highest heptachlor epoxide concentrations above 3.0 mg/kg were found in the Rice Creek area (LSJRC06, LSJRC10, LSJRC11). Many sites in the Cedar-Ortega estuary had elevated heptachlor epoxide levels (ORT33, ORT01), but concentrations were lower than the Rice Creek area sites. Eleven sites had heptachlor epoxide levels that were greater than 2.0 ug/kg, and all but the three previously mentioned sites were located either in the Cedar-Ortega estuary or in the Cedar River (CED02). Heptachlor epoxide was not detected in over 80% of the sediment samples. No sites had heptachlor epoxide concentrations that exceeded the fresh water PEC of 16.0 ug/kg (Table 3-8). Nine sites had heptachlor epoxide concentrations that were greater than the fresh water TEC of 2.47 ug/kg, indicating that heptachlor epoxide contamination might be harming biota at these sites. No salt water TEL/PEL SQG are available for heptachlor epoxide concentrations.

Hexachlorobenzene, or perchlorobenzene, was developed in 1945 as a fungicide for seed treatment. It is an animal carcinogen, and slightly toxic to fish species (Extoxnet, 1994). Hexachlorobenzene was banned from use in the United States in 1966. Although hexachlorobenzene does not occur naturally in the environment, it is formed as a by-product while making other chemicals, in the waste streams of chlor-alkali and wood-preserving plants, and when burning municipal waste (ATSDR, retrieved 2011).

Hexachlorobenzene was the third most abundant Group 8 contaminant occurring in 37% of the sediment samples and with an average concentration of 0.79 ug/kg. The maximum hexachlorobenzene concentration of 19.81 ug/kg was greater than most other Group 8 pesticides, except for chlorpyrifos and kepone (Table 3-19). Eight sites had the highest hexachlorobenzene concentrations that were greater than 5.0 ug/kg. Two of the eight sites were located in the Cedar River (CED02, CED07), two in the Cedar-Ortega estuary (ORT23, ORT35), and the other four were located in Rice, Julington, Goodbys and Trout creeks. No TEL/TEC or PEL/PEC SQG are available for hexachlorobenzene.

Chlordecone also known as kepone is a synthetic chlorinated insecticide. Chlordecone is also a degradation product and a ketone analog of the pesticide mirex (NIEHS, retrieved 2011). Chlordecone was first introduced in 1958 and was used as an insecticide until 1978. It is no longer manufactured or used in the United States (ATSDR, retrieved 2011). Chlordecone had the largest variance of the Group 8 pesticides with a maximum concentration of 321.26 ug/kg. This maximum value was over 28 times greater than the average kepone value of 11.23 ug/kg (Table 3-19). Chlordecone occurred much less frequently than many of the other Group 8 pesticides. Only 17% of the sediment samples had measurable levels of chlordecone. Three of the six sites with the highest chlordecone concentrations were located in and near Rice Creek (RICE03, RCJU05, LSJRC081). The other three sites with chlordecone concentrations above 50 ug/kg were found in Goodbys and Julington creeks (GDBR01, JULC01) and in Palmo Cove (PALM01). No TEL/TEC or PEL/PEC SQG are available for chlordecone.

Lindane is the γ-HCH isomer, and is very toxic to fish and aquatic invertebrate species (Extoxnet, 1994). Lindane is the second most abundant Group 8 contaminant after dieldrin, occurring in over 60% of the sediment sites. The maximum and average lindane concentrations of 9.81 and 0.79 ug/kg, respectively, were low compared to some of the other Group 8 contaminants (Table 3-19). The highest lindane concentrations were measured at six sites, and all had levels that were greater than 3 ug/kg. Three of these six sites were located in or near Rice Creek (RICE02, LSJRC06, LSJRC10), one each was found in the Cedar River (CED062) and the Cedar-Ortega estuary and one was located in the mainstem downstream of Palatka (LSJ30). The two sites with the highest lindane concentrations of 9.81 and 5.25 ug/kg exceeded the fresh water PEC of 4.99 ug/kg (Table 3-8), and both were located in or near Rice Creek (RICE02; LSJRC06). The fresh water PEC exceedances indicate that lindane contamination is high enough so that adverse effects to biota are probably occurring in at least two sites. Fourteen sites, that included the two previously mentioned sites, were found to have lindane levels that were greater than the fresh water TEC of 2.37 ug/kg (Table 3-8). This fresh water TEC was much higher than the saltwater PEL of 0.99 ug/kg (Table 3-8). Over 29% of the sites had lindane levels that were above the saltwater PEL of 0.99 ug/kg, and over 51% had lindane levels that exceeded the salt water TEL of 0.32 ug/kg. Lindane contamination may be adversely affecting biota in over 51% of the sampled sites.

Methoxychlor is used as an insecticide that to some degree is a replacement for DDT. Methoxychlor is chemically analogous to DDT but is more potent, does not persist as long and does not bioaccumulate in animals, as does DDT (Encyclopedia Britannica, Inc., retrieved 2011[128]). Methoxychlor, when applied to agricultural crops, forests, and farm animals eventually settles to the ground where it becomes bound to the soil. Methoxychlor is highly toxic to fish and aquatic invertebrates (Extoxnet, 1994).

Methoxychlor was one of the least frequently detected Group 8 contaminants, and was only found in 14% of the samples. The maximum methoxychlor concentration of 15.32 ug/kg was over 33 times higher than the average value of 0.46 ug/kg (Table 3-19). The highest methoxychlor levels were found at three sites, and all these sites had concentrations that were above 5.0 ug/kg. Two of the three sites were located in Rice Creek (RCJU03, RCJU05) and the other was found in the Cedar River (CED09). Methoxychlor was not detected in 86% of the samples, and no TEL/TEC or PEL/PEC SQG are available for methoxychlor.

Mirex is an organochlorine insecticide that was used to control fire ants, and as a flame retardant from 1959 to 1972. Mirex degrades to the chemically similar insecticide chlordecone or kepone. Mirex and chlordecone have not been manufactured or used in the United States since 1978 (ATSDR, retrieved 2011). The mirex maximum concentration of 1.24 ug/kg was the lowest maximum value of the Group 8 contaminants (Table 3-19). Despite the low maximum concentration, mirex contamination was more prevalent than many of the Group 8 contaminants, and was detected in over 23% of the sites. The average mirex concentration of 0.089 ug/kg was the second lowest average concentration of the Group 8 contaminants. The maximum mirex concentration was approximately 14 times greater than this average value (Table 3-19). Two sites (LSJ05, LSJ03) had mirex concentrations above 1.0 ug/kg and both were located in the river in the Jacksonville area. No TEL/TEC or PEL/PEC SQG are available for mirex.

Toxaphene is a complex mixture of approximately 200 chlorinated organic compounds used as an insecticide and is very toxic (Extoxnet, 1994). Although all LSJRB sediment samples were analyzed for toxaphene, it was the only Group 8 pesticide that was not detected. The high detection limits and complexity of chemical mixture most likely contributed to this lack of detection.

## Summary

This Atlas illustrates the results of contaminant assessments made between 1996 and 2003. These preliminary screening-level results revealed highly variable contaminant concentrations in this 162 km (101 mile) segment of the St. Johns River. In addition the natural composition of the riverbed sediment varied widely.

The grain-size composition of the river sediment ranged from sandbars of coarse sand to fine-grained deposits of silts and clays. The sandbars in the river channel had the highest sand concentrations, while tributary sites had the highest clay concentrations. The sites with the lowest silt and clay concentrations were associated with very sandy sediment. The highest silt concentrations were found downstream, in the Jacksonville area, in both river and tributary sites.

The grain size composition did not correlate with the TOC values in the river sediment, which was unexpected. Generally, the TOC concentrations increased with increasing distance upstream, and the highest values were located in and near Rice Creek. The lowest TOC concentrations were typically associated with very sandy sediment.

Metals exist naturally in the environment and most occur in trace quantities. The naturally occurring metal concentrations vary in sediment due to geologic and environmental origins. In the LSJRB, 13 of the 20 metals analyzed were ubiquitous in the sediment. The 13 metals found in all samples at all sites included aluminum, antimony, arsenic, chromium, cobalt, copper, lead, lithium, manganese, mercury, tin, vanadium and zinc. Two other metals, nickel and iron, were found at all except one site each. The remaining five metals, beryllium, cadmium, selenium, silver and thallium, were also prevalent, but were not detected in a few areas of the LSJRB.

The measured sediment concentrations for five metals, arsenic, cadmium, mercury, selenium and silver, exceeded their respective crustal abundance levels at more than 80% of the sites. Five other metals, antimony, lead, lithium, tin and zinc, had sediment concentrations above crustal abundance levels at over 50% of the sites. The sediment concentrations were below natural crustal abundance levels for aluminum, cobalt, iron, manganese and nickel.

Sediment contaminant concentrations were compared to the SQG to estimate potential detrimental influences on riverbed sediment dwelling or benthic organisms and communities. The SQG are available for 9 of the 20 metals and included arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. All nine metal contaminants are probably having adverse affects on biota in some areas of the river, with lead, zinc and mercury contamination being the most widespread. These three metals, lead, zinc and mercury, are probably adversely affecting biota in 8, 11 and 30% of the sites, respectively. Contamination from all nine metals exceeded the threshold SQG (TEL/TEC) at many more sites, and therefore may be having adverse affects on benthic organisms in at least 30 to over 90% of the riverbed sites.

In general, sediment concentrations for many of the 20 metals assessed in the LSJRB tended to decrease from the highest concentrations in the northern region and the Jacksonville area to lower concentrations upstream, in the central and southern regions. Eleven metals, aluminum, antimony, beryllium, cadmium, cobalt, iron, lead, lithium, silver, tin and zinc, followed this general spatial trend of decreasing concentrations with increasing distance upstream. Two other metals, nickel and vanadium, showed only a slight decrease in sediment concentrations with increased distance upstream. Sediment selenium concentrations showed a very different spatial pattern in relation to most other metals, as Se concentrations generally increased with distance upstream. A mixed spatial pattern of sediment copper concentrations existed with high concentrations in both the northern and southern regions. Five other metals, arsenic, chromium, manganese, mercury and thallium, did not show a distinct spatial distribution pattern in the river sediment.

Unlike the metals, the majority of organic compounds found in the LSJRB do not occur naturally. The PAH are the only naturally occurring class and are among the most ubiquitous organic chemicals measured in the LSJRB sediment. The PAH concentrations varied widely throughout the LSJRB with much higher levels occurring in the tributaries and around the urban areas of Jacksonville, Green Cove Springs and Palatka. The PAH concentrations are high enough so that adverse effects to benthic communities are probably occurring in at least two sites due to the total-PAH, 19 sites due to HMW-PAH, and eight sites due to LMW-PAH. In addition, the TEL/TEC exceedances indicated that the HMW-PAH contaminants may possibly be adversely affecting biota at over 81%, and the LMW-PAH contaminants at over 41% of the sampled sites.

The total phthalate esters, like the PAH, are found throughout the environment and in most organisms. The total-phthalate concentrations were customarily lower than the PAH concentrations, and showed no clear geographic trend, except for the consistently high concentrations found in the Cedar–Ortega estuary and the Cedar River. It is unlikely total-phthalate sediment concentrations are adversely affecting biota in the LSJRB.

PCB contamination occurs throughout the LSJRB, and like the PAH contamination is prominent in tributaries and urban areas. The Cedar River and the Cedar-Ortega estuary had the highest PCB contamination. Total-PCB contamination is high enough so that adverse effects to benthic communities are probably occurring in at least 15% to 28% of the sites and may be adversely affecting biota at 67% to 83% of the sampled sites.

Many of the chlorinated pesticides that were detected in the LSJRB sediment were introduced more than 50 years ago, demonstrating their long persistence in the environment. The total-DDT and total chlordane contamination was widespread and greatest in the river in the urban Jacksonville area, especially in urban tributaries and near their confluences. Many sites that had elevated total-DDT levels also had elevated total-chlordane concentrations. The total-DDT concentrations were higher than total-chlordane concentrations at nearly all LSJ sites, but were much lower than the PAH and PCB concentrations. The highest total-DDT and total-chlordane concentrations were located in the urban tributaries, especially in the Cedar River, Cedar-Ortega estuary, and St. Johns River near the confluence with the Cedar-Ortega estuary. The biota are probably being adversely affected by the sediment total-DDT concentrations at two sites, and may be adversely affected at 64% to 72% of the sites in the LSJRB. The total-chlordane contamination is likely to be adversely affecting biota at 10% to 25% of the sampled sites, and may be adversely affecting biota at 32% to 42% of the sites in the LSJRB.

Analysis of the relative concentrations of DDT with its degradation products revealed that the DDE contamination was more widespread than the DDT or DDD contamination. The DDT, DDE and DDD isomer concentrations were much lower than the total-DDT concentrations, but high enough that sediment-dwelling organisms may be affected at 17% of the sites by DDT, 50% of the sites by DDE, and at 30% of the sites by DDD concentrations.

The two remaining pesticide classes, total endosulfans and total HCH, were found in relatively low concentrations. Total endosulfan and t-HCH concentrations were both detected at approximately 70% of the LSJRB sampling sites. No SQG are available for either total-endosulfan or for t-HCH.

Four of the 12 individual pesticide compounds that were assessed in the LSJRB had SQG that could be compared with the measured sediment concentrations. Dieldrin was found in 70% of the samples. The dieldrin sediment concentrations indicated that adverse effects to benthic communities are probable at 3% of these sites, and may be adversely affecting biota in 12% to 35% of the sites. Lindane sediment concentrations were also high enough that they may be adversely affecting biota in 29% to 51% of the sampled sites. Endrin and heptachlor epoxide concentrations could have a negative influence on biota at 1% and 5% of the sampled sites, respectively.

The remaining individual pesticide compounds were infrequently observed in the LSJRB sediment, and toxaphene was not detected at any of the sites. Aldrin, methoxychlor, heptachlor and chlordecone were found in 12%, 14%, 16% and 17% of the sites, respectively. Mirex, chlorpyrifos and hexachlorobenzene contaminant concentrations were more prevalent and detected in 23%, 35% and 37% of the sites. No TEL/TEC or PEL/PEC SQG are available for these eight pesticide compounds.

The chlorophenolic chemicals were widespread in the LSJRB, and over 60% of the sites sampled had concentrations above 2,000 ug/kg. The Cl-Phenol class was the most frequently detected chlorophenolic contaminant class in the LSJRB sediment samples, followed by Cl-Catechol and Cl-Guaiacol. The least frequently detected was the Cl-Anisole contaminant class. Chlorophenolic chemicals are possibly having negative effects on sediment dwelling biota in the LSJRB, but no TEL/TEC or PEL/PEC SQG are available to estimate these detrimental effects.

The areas of the river with elevated metal and organic contaminant concentrations were most often adjacent to urban centers, and the downstream segment of St. Johns River was conspicuously more contaminated. Tributary sediment, and predominantly urban tributaries like the Cedar River and the Cedar-Ortega estuary, consistently had higher contaminant concentrations than the river sediment. The potential metal contaminants of concern, based on data in this Atlas include, but are not limited to, the toxic metals arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, selenium, and zinc. The potential organic contaminants of concern, based on this Atlas information include, but are not limited to, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, chlorinated pesticides (e.g. DDTs, chlordane) and selected classes of chlorinated phenolic compounds. Historic and current discharges from industrial and domestic sources, as well as runoff from the large urbanized areas, appear to be contributing to the contaminant concentrations in the sediment in much of the lower St. Johns River.

Table 2-1. **All Measured Variables (5 Physical; 20 Metal; and 118 Organic)**

| **Variable Type** | **Variable Group #** |
|---|---|
| Physical Characteristics | |
| Grain Size (%sand, %silt, %clay) | Physical Characteristics (Group 1) |
| Total Organic Carbon (TOC) | Physical Characteristics (Group 2) |
| % Moisture | Not illustrated on Maps |
| Total Volatile Solids | Not illustrated on Maps |
| Total Solids | Not illustrated on Maps |
| | |
| Metal Elements | |
| Antimony (Sb) | Metal Concentrations (Group 1) |
| Beryllium (Be) | Metal Concentrations (Group 1) |
| Cadmium (Cd) | Metal Concentrations (Group 1) |
| Mercury (Hg) | Metal Concentrations (Group 1) |
| Silver (Ag) | Metal Concentrations (Group 1) |
| Thallium (Tl) | Metal Concentrations (Group 1) |
| Cobalt (Co) | Metal Concentrations (Group 2) |
| Selenium (Se) | Metal Concentrations (Group 2) |
| Tin (Sn) | Metal Concentrations (Group 2) |
| Arsenic (As) | Metal Concentrations (Group 3) |
| Copper (Cu) | Metal Concentrations (Group 3) |
| Lithium (Li) | Metal Concentrations (Group 3) |
| Nickel (Ni) | Metal Concentrations (Group 3) |
| Chromium (Cr) | Metal Concentrations (Group 4) |
| Lead (Pb) | Metal Concentrations (Group 4) |
| Manganese (Mn) | Metal Concentrations (Group 4) |
| Vanadium (V) | Metal Concentrations (Group 4) |
| Zinc (Zn) | Metal Concentrations (Group 4) |
| Aluminum (Al) | Metal Concentrations (Group 5) |
| Iron (Fe) | Metal Concentrations (Group 5) |

Table 2-1. **All Measured Variables (5 Physical; 20 Metal; and 118 Organic)**

| **Variable Type** | **Variable Group #** |
|---|---|
| Organic Contaminants - Polynuclear Aromatic Hydrocarbons | continued |
| 1-Methylnaphthalene | Organic Concentrations (Group 1) |
| 1-Methylphenanthrene | Organic Concentrations (Group 1) |
| 2-Methylnaphthalene | Organic Concentrations (Group 1) |
| 2,6-Dimethylnaphthalene | Organic Concentrations (Group 1) |
| 2,3,5-Trimethylnaphthalene | Organic Concentrations (Group 1) |
| Acenaphthene | Organic Concentrations (Group 1) |
| Acenaphthylene | Organic Concentrations (Group 1) |
| Anthracene | Organic Concentrations (Group 1) |
| Benzo(a)anthracene | Organic Concentrations (Group 1) |
| Benzo(a)pyrene | Organic Concentrations (Group 1) |
| Benzo(e)pyrene | Organic Concentrations (Group 1) |
| Benzo(b)fluoranthene | Organic Concentrations (Group 1) |
| Benzo(g,h,i)perylene | Organic Concentrations (Group 1) |
| Benzo(k)fluoranthene | Organic Concentrations (Group 1) |
| Biphenyl | Organic Concentrations (Group 1) |
| Chrysene | Organic Concentrations (Group 1) |
| Dibenz(a,h)anthracene | Organic Concentrations (Group 1) |
| Fluoranthene | Organic Concentrations (Group 1) |
| Fluorene | Organic Concentrations (Group 1) |
| Indeno(1,2,3-cd)pyrene | Organic Concentrations (Group 1) |
| Isophorone | Organic Concentrations (Group 1) |
| Naphthalene | Organic Concentrations (Group 1) |
| Perylene | Organic Concentrations (Group 1) |
| Phenanthrene | Organic Concentrations (Group 1) |
| Pyrene | Organic Concentrations (Group 1) |
| 1-Chloronaphthalene | Not illustrated on Maps |
| 2-Chloronaphthalene | Not illustrated on Maps |
| | |
| Organic Contaminants - Phthalates | |
| Butylbenzylphthalate | Organic Concentrations (Group 1) |
| Di-N-butylphthalate | Organic Concentrations (Group 1) |
| Diethylphthalate | Organic Concentrations (Group 1) |
| Dimethylphathalate | Organic Concentrations (Group 1) |
| Bis(2-ethylhexyl)phthalate | Organic Concentrations (Group 1) |
| Di-N-octylphthalate | Organic Concentrations (Group 1) |
| | |
| Organic Contaminants - Polychlorinated Biphenyls | |
| Cl2(8) | Organic Concentrations (Group 2) |
| Cl3(18) | Organic Concentrations (Group 2) |
| Cl3(28) | Organic Concentrations (Group 2) |
| Cl4(52) | Organic Concentrations (Group 2) |
| Cl4(44) | Organic Concentrations (Group 2) |
| Cl4(66) | Organic Concentrations (Group 2) |
| Cl4(77)/Cl5(110) | Organic Concentrations (Group 2) |
| Cl5(101) | Organic Concentrations (Group 2) |
| | |

Table 2-1. **All Measured Variables (5 Physical; 20 Metal; and 118 Organic)**

| **Variable Type** | **Variable Group #** |
|---|---|
| Organic Contaminants - Polychlorinated Biphenyls | continued |
| Cl5(118) | Organic Concentrations (Group 2) |
| Cl6(153) | Organic Concentrations (Group 2) |
| Cl5(105) | Organic Concentrations (Group 2) |
| Cl6(138) | Organic Concentrations (Group 2) |
| Cl5(126)/Cl6(129) | Organic Concentrations (Group 2) |
| Cl7(187) | Organic Concentrations (Group 2) |
| Cl6(128) | Organic Concentrations (Group 2) |
| Cl7(180) | Organic Concentrations (Group 2) |
| Cl6(169) | Organic Concentrations (Group 2) |
| Cl7(170) | Organic Concentrations (Group 2) |
| Cl8(195) | Organic Concentrations (Group 2) |
| Cl9(206) | Organic Concentrations (Group 2) |
| Cl10(209) | Organic Concentrations (Group 2) |
| | |
| Organic Contaminants - Pesticides | |
| Cis (α)-Chlordane | Organic Concentrations (Group 3) |
| Trans (γ)-Chlordane | Organic Concentrations (Group 3) |
| Heptachlor | Organic Concentrations (Group 3) |
| Methoxychlor | Organic Concentrations (Group 3) |
| Oxychlordane | Organic Concentrations (Group 3) |
| Cis-Nonachlor | Organic Concentrations (Group 3) |
| Trans-Nonachlor | Organic Concentrations (Group 3) |
| 4,4'-DDD | Organic Concentrations (Group 4) |
| 2,4'-DDD | Organic Concentrations (Group 4) |
| 4,4'-DDE | Organic Concentrations (Group 4) |
| 2,4'-DDE | Organic Concentrations (Group 4) |
| 4,4'-DDT | Organic Concentrations (Group 4) |
| 2,4'-DDT | Organic Concentrations (Group 4) |
| Endosulfan | Organic Concentrations (Group 4) |
| Endosulfan II | Organic Concentrations (Group 4) |
| Endosulfan sulfate | Organic Concentrations (Group 4) |
| α-HCH | Organic Concentrations (Group 4) |
| β-HCH | Organic Concentrations (Group 4) |
| δ-HCH | Organic Concentrations (Group 4) |
| γ-HCH; (Lindane) | Organic Concentrations (Group 4) |
| Aldrin | Organic Concentrations (Group 8) Not illustrated on Maps |
| Dieldrin | Organic Concentrations (Group 8) Not illustrated on Maps |
| Chlorpyriphos (Dursban) | Organic Concentrations (Group 8) Not illustrated on Maps |
| Endrin | Organic Concentrations (Group 8) Not illustrated on Maps |
| Endrin aldehyde | Organic Concentrations (Group 8) Not illustrated on Maps |
| Endrin ketone | Organic Concentrations (Group 8) Not illustrated on Maps |
| Heptachlor epoxide | Organic Concentrations (Group 8) Not illustrated on Maps |
| Hexachlorobenzene | Organic Concentrations (Group 8) Not illustrated on Maps |
| Chlordecone (Kepone) | Organic Concentrations (Group 8) Not illustrated on Maps |
| Mirex | Organic Concentrations (Group 8) Not illustrated on Maps |
| Toxaphene | Organic Concentrations (Group 8) Not illustrated on Maps |

Table 2-1. **All Measured Variables (5 Physical; 20 Metal; and 118 Organic)**

| **Variable Type** | **Variable Group #** |
|---|---|
| Organic Contaminants - Chlorinated Phenolics | continued |
| 4-Chlorocatechol | Organic Concentrations (Group 5) |
| 3,5-Dichlorocatechol | Organic Concentrations (Group 5) |
| 4,5-Dichlorocatechol | Organic Concentrations (Group 5) |
| 3,4,5-Trichlorocatechol | Organic Concentrations (Group 5) |
| 3,4,6-Trichlorocatechol | Organic Concentrations (Group 5) |
| Tetrachlorocatechol | Organic Concentrations (Group 5) |
| 2-Chlorophenol | Organic Concentrations (Group 5) |
| 2,4-Dichlorophenol | Organic Concentrations (Group 5) |
| 2,6-Dichlorophenol | Organic Concentrations (Group 5) |
| 2,4,5-Trichlorophenol | Organic Concentrations (Group 5) |
| 2,4,6-Trichlorophenol | Organic Concentrations (Group 5) |
| 2,3,4,5-Tetrachlorophenol | Organic Concentrations (Group 5) |
| 2,3,4,6-Tetrachlorophenol | Organic Concentrations (Group 5) |
| Pentachlorophenol | Organic Concentrations (Group 5) |
| 4-Chloro-3-methylphenol | Organic Concentrations (Group 5) |
| 4,5-Dichloroguaiacol | Organic Concentrations (Group 6) |
| 3,4,5-Trichloroguaiacol | Organic Concentrations (Group 6) |
| 3,4,6-Trichloroguaiacol | Organic Concentrations (Group 6) |
| 4,5,6-Trichloroguaiacol | Organic Concentrations (Group 6) |
| Tetrachloroguaiacol | Organic Concentrations (Group 6) |
| 2-Chloroanisole | Organic Concentrations (Group 6) |
| 2,4-Dichloroanisole | Organic Concentrations (Group 6) |
| Pentachloroanisole | Organic Concentrations (Group 6) |
| Total Chlorophenolic | Organic Concentrations (Group 7) |
| | |
| Organic Contaminants - Industrial Chlorinated | |
| 1,2-Dichlorobenzene | Not illustrated on Maps |
| 1,3-Dichlorobenzene | Not illustrated on Maps |
| 1,4-Dichlorobenzene | Not illustrated on Maps |
| 1,2,4-Trichlorobenzene | Not illustrated on Maps |
| 1,2,4,5-Tetrachlorobenzene | Not illustrated on Maps |
| Hexachlorobutadiene | Not illustrated on Map |
| Hexachloroethane | Not illustrated on Maps |
| Hexachlorocyclopentadiene | Not illustrated on Maps |
| | |

Table 2-2. **Total Chlordane Class - Individual Isomers and Metabolites.**

| Total Chlordane is the summation of 7 isomers and metabolites. |
|---|
| Cis ($\alpha$) chlordane |
| Trans ($\gamma$) chlordane |
| Heptachlor |
| Methoxychlor |
| Oxychlordane |
| Cis-nonachlor |
| Trans-nonachlor |

Table 3-1. **Physical Variables - Groups 1 and 2: % Sand, % Silt, % Clay and TOC Statistics.**

| Physical Variables (in percent) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Sand | 98.7 | 50.4 | 48.9 | 15.9 | 182 |
| Silt | 75.9 | 45.2 | 47.6 | 0.9 | 182 |
| Clay | 23.7 | 4.4 | 3.6 | 0.05 | 182 |
| TOC | 39.6 | 12.5 | 11.8 | 0.23 | 182 |

Table 3-1 presents the mean and median concentrations and the concentration ranges of the Group 1 and 2 physical variables found at the sampling locations.

Table 3-2. **Naturally Occurring Average Metal Concentrations and Lower St. Johns River Sediment Maximum, Median and Minimum Metal Concentrations**

| | **Metal** | **Metal** | **Crustal** | **Estimated** | **U.S.** | **LSJR** | **LSJR** |
|---|---|---|---|---|---|---|---|
| | Units are in | **Symbol** | **Abundance** | **Crustal** | **Soil** | **Sediment** | **Sediment** |
| | mg/kg unless noted as % | | | **Abundance** | (Shacklette and | (Median values) | (Range Max - Min) |
| | NA = Not Available | | (Moore, 1991) | (TJNAF, 2011) | Boerngen, 1984) | | |
| 1 | Aluminum | Al | 8% | 82300 | NA | 30,600 | 60,850 - 636.500 |
| 2 | Antimony | Sb | NA | 0.20 | 0.48 | 0.293 | 1.415 - 0.033 |
| 3 | Arsenic | As | 2 to 5 | 1.8 | 5.2 | 4.780 | 24.500 - 0.055 |
| 4 | Beryllium | Be | 2.5 | 2.8 | 0.63 | 0.704 | 3.180 - Below Detection |
| 5 | Cadmium | Cd | 0.20 | 0.15 | NA | 0.587 | 3.830 - Below Detection |
| 6 | Chromium | Cr | 100 | 102 | 37 | 51.700 | 174.500 - 2.470 |
| 7 | Cobalt | Co | 25 | 25 | NA | 3.700 | 7.420 - 0.119 |
| 8 | Copper | Cu | 50 | 60 | 17 | 19.300 | 133.600 - 0.241 |
| 9 | Iron | Fe | 5% | 56300 | NA | 21,400 | 38,900 - Below Detection |
| 10 | Lead | Pb | 15 | 14 | 16 | 31.500 | 384.000 - 0.311 |
| 11 | Lithium | Li | NA | 20 | NA | 23.300 | 54.000 - 0.377 |
| 12 | Manganese | Mn | 950 | 950 | NA | 154.000 | 485.000 - 9.923 |
| 13 | Mercury | Hg | 0.08 | 0.085 | 0.058 | 0.278 | 5.513 - 0.005 |
| 14 | Nickel | Ni | 75 | 84 | 13 | 14.000 | 54.967 - Below Detection |
| 15 | Selenium | Se | 0.10 | 0.05 | 0.26 | 1.740 | 6.930 - Below Detection |
| 16 | Silver | Ag | 0.70 | 0.075 | NA | 0.386 | 5.390 - Below Detection |
| 17 | Thallium | Tl | 0.50 | 0.85 | NA | 0.343 | 0.587 - Below Detection |
| 18 | Tin | Sn | 2.0 | 2.3 | 0.89 | 2.684 | 15.700 - 0.120 |
| 19 | Vanadium | V | 150 | 120 | 58 | 48.400 | 252.000 - 2.920 |
| 20 | Zinc | Zn | 70 | 70 | 48 | 108.000 | 2,050.000 - 2.090 |
| | | | | | | | |

Table 3-3. **Metal Variables - Group 1: Beryllium, Thallium, Cadmium, Silver, Antimony and Mercury Statistics.**

| All values in mg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Beryllium | 3.180 | 0.819 | 0.704 | Below Detection | 175 |
| Thallium | 0.587 | 0.311 | 0.343 | Below Detection | 175 |
| Cadmium | 3.830 | 0.734 | 0.587 | Below Detection | 175 |
| Silver | 5.390 | 0.513 | 0.386 | Below Detection | 175 |
| Antimony | 1.415 | 0.334 | 0.293 | 0.033 | 175 |
| Mercury | 5.513 | 0.419 | 0.278 | 0.005 | 175 |

Table 3-3 presents the mean and median concentrations and the concentration ranges of the Group 1 metals found at the sampling locations.

Table 3-4. **Metal Variables - Group 2: Cobalt, Tin and Selenium Statistics.**

| All values in mg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Cobalt | 7.420 | 3.356 | 3.700 | 0.119 | 175 |
| Tin | 15.700 | 3.084 | 2.684 | 0.120 | 175 |
| Selenium | 6.930 | 1.785 | 1.740 | Below Detection | 175 |

Table 3-4 presents the mean and median concentrations and the concentration ranges of the Group 2 metals found at the sampling locations.

Table 3-5. **Metal Variables - Group 3: Lithium, Copper, Nickel and Arsenic Statistics.**

| All values in mg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Lithium | 54.000 | 22.669 | 23.300 | 0.377 | 175 |
| Copper | 133.600 | 26.651 | 19.300 | 0.241 | 175 |
| Nickel | 54.967 | 13.328 | 14.000 | Below Detection | 175 |
| Arsenic | 24.500 | 5.187 | 4.780 | 0.055 | 175 |

Table 3-5 presents the mean and median concentrations and the concentration ranges of the Group 3 metals found at the sampling locations.

Table 3-6. **Metal Variables - Group 4: Manganese, Zinc, Chromium, Vanadium and Lead Statistics.**

| All values in mg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Manganese | 485.000 | 171.305 | 154.000 | 9.923 | 175 |
| Zinc | 2,050.000 | 157.245 | 108.000 | 2.090 | 175 |
| Chromium | 174.500 | 48.192 | 51.700 | 2.470 | 175 |
| Vanadium | 252.000 | 49.211 | 48.400 | 2.920 | 175 |
| Lead | 384.000 | 50.285 | 31.500 | 0.311 | 175 |

Table 3-6 presents the mean and median concentrations and the concentration ranges of the Group 4 metals found at the sampling locations.

Table 3-7. **Metal Variables - Group 5: Iron and Aluminum Statistics**.

| All values in mg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Iron | 38,900 | 19,425 | 21,400 | Below Detection | 175 |
| Aluminum | 60,850 | 30,090.1 | 30,600 | 636.5 | 175 |

Table 3-7 presents the mean and median concentrations and the concentration ranges of the Group 5 metals found at the sampling locations.

Table 3-8. **Sediment Quality Guidelines for Marine and Freshwater Sediment.**

| Metal and Non-polar organic contaminants | Group | TEL[a] For marine sediment (µg/kg in dry wt) | PEL[b] For marine sediment (µg/kg in dry wt) | TEC[c] For freshwater sediment (µg/kg in dry wt) | PEC[d] For freshwater sediment (µg/kg in dry wt) |
|---|---|---|---|---|---|
| **Metal contaminants** | | | | | |
| | | | | | |
| Antimony | Group 1 | NA | NA | NA | NA |
| Beryllium | Group 1 | NA | NA | NA | NA |
| Cadmium | Group 1 | 0.676 | 4.21 | 0.596 | 3.53 |
| Mercury | Group 1 | 0.13 | 0.696 | 0.174 | 0.486 |
| Silver | Group 1 | 0.733 | 1.77 | NA | NA |
| Thallium | Group 1 | NA | NA | NA | NA |
| | | | | | |
| Cobalt | Group 2 | NA | NA | NA | NA |
| Selenium | Group 2 | NA | NA | NA | NA |
| Tin | Group 2 | NA | NA | NA | NA |
| | | | | | |
| Arsenic | Group 3 | 7.24 | 41.6 | 5.9 | 17 |
| Copper | Group 3 | 18.7 | 108 | 35.7 | 197 |
| Lithium | Group 3 | NA | NA | NA | NA |
| Nickel | Group 3 | 15.9 | 42.8 | 18 | 35.9 |
| | | | | | |
| Chromium | Group 4 | 52.3 | 160 | 37.3 | 90 |
| Lead | Group 4 | 30.2 | 112 | 35 | 91.3 |
| Manganese | Group 4 | NA | NA | NA | NA |
| Vanadium | Group 4 | NA | NA | NA | NA |
| Zinc | Group 4 | 124 | 271 | 123.1 | 315 |
| | | | | | |
| Aluminum | Group 5 | NA | NA | NA | NA |
| Iron | Group 5 | NA | NA | NA | NA |
| | | | | | |

Table 3-8: [a]Threshold Effect Levels (TEL); [b]Probable Effect Levels (PEL); [c]Threshold Effect Concentrations (TEC); [d]Probable Effect Concentrations (PEC).

Table 3-8. **Sediment Quality Guidelines for Marine and Freshwater Sediment.**

| **Metal and Non-polar organic contaminants** | **Group** | **TEL$^a$ For marine sediment (µg/kg in dry wt)** | **PEL$^b$ For marine sediment (µg/kg in dry wt)** | **TEC$^c$ For freshwater sediment (µg/kg in dry wt)** | **PEC$^d$ For freshwater sediment (µg/kg in dry wt)** |
|---|---|---|---|---|---|
| | | | | | |
| **Non-polar organic contaminants** | | | | | |
| | | | | | |
| Total PAH | group 1 | 1,684 | 16,770 | 1,610 | 22,800 |
| Low PAH | group 1 | 312 | 1,442 | NA | NA |
| High PAH | group 1 | 655 | 6,676 | NA | NA |
| Total Phthalates | group 1 | NA | NA | NA | NA |
| Bis(2-ethylhexyl)phthalate | group 1 | 182 | 2,647 | NA | NA |
| | | | | | |
| Total PCBs | group 2 | 21.6 | 189 | 59.8 | 676 |
| | | | | | |
| Total Chlordane | group 3 | 2.26 | 4.79 | 3.24 | 17.6 |
| Total DDT | group 3 | 3.89 | 51.7 | 5.28 | 572 |
| | | | | | |
| 4,4'-DDD | group 4 | 1.22 | 7.81 | NA | NA |
| DDD (sum of: 2,4' + 4,4') | group 4 | NA | NA | 4.88 | 28 |
| 4,4'-DDE | group 4 | 2.07 | 374 | NA | NA |
| DDE (sum of: 2,4' + 4,4') | group 4 | NA | NA | 3.16 | 31.3 |
| 4,4'-DDT | group 4 | 1.19 | 4.77 | NA | NA |
| DDT (sum of: 2,4' + 4,4') | group 4 | NA | NA | 4.16 | 62.9 |
| γ-HCH; (Lindane) | group 4 | 0.32 | 0.99 | 2.37 | 4.99 |
| | | | | | |
| Chlorinated -Catechols | group 5 | NA | NA | NA | NA |
| Chlorinated -Phenols | group 5 | NA | NA | NA | NA |
| | | | | | |
| Chlorinated -Guaiacols | group 6 | NA | NA | NA | NA |
| Chlorinated -Anisoles | group 6 | NA | NA | NA | NA |
| | | | | | |
| Total Chlorophenolics | group 7 | NA | NA | NA | NA |
| | | | | | |
| Dieldrin | group 8 | 0.715 | 4.3 | 1.9 | 61.8 |
| Endrin | group 8 | NA | NA | 2.22 | 207 |
| Heptachlor epoxide | group 8 | NA | NA | 2.47 | 16 |

Table 3-8: [a]Threshold Effect Levels (TEL); [b]Probable Effect Levels (PEL); [c]Threshold Effect Concentrations (TEC); [d]Probable Effect Concentrations (PEC).`

Table 3-9. **Organic Group 1: PAH and Phthalate Compound Classes - Individual Compounds.**

| Total PAH | Total HMW-PAH | Total LMW-PAH | Total Phthalates |
|---|---|---|---|
| | Benzo(a)anthracene | 1 Methylnaphthalene | Dimethylphthalate |
| LMW-PAH | Benzo(a)pyrene | 1-Methylphenanthrene | Diethylphthalate |
| | Benzo(e)pyrene | 2 Methylnaphthalene | Di-N-butylphthalate |
| HMW-PAH | Benzo(b)fluoranthene | 2,6 Dimethylnaphthalene | Butylbenzylphthalate |
| | Benzo(g,h,i)perylene | 2,3,5-Trimethylnaphthalene | Bis(2-ethylhexyl)phthalate |
| | Benzo(k)fluoranthene | Acenaphthene | Di-N-octylphthalate |
| | Chrysene | Acenaphthylene | Dimethylphthalate |
| | Dibenz(a,h)anthracene | Anthracene | |
| | Fluoranthene | Biphenyl | |
| | Indeno(1,2,3-cd)pyrene | Fluorene | |
| | Perylene | Naphthalene | |
| | Pyrene | Phenanthrene | |

Table 3-9 presents the 24 individual PAH compounds that were separated into 12 HMW and 12 LMW classes, and the 6 individual phthalate ester compounds. These individual compounds were summed for the Total PAH, HMW-PAH, LMW-PAH and Total Phthalate classes.

Table 3-10. **Organic Group 1: PAH and Phthalate Compound Class Statistics.**

| All values in µg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Total PAH | 29,769.4 | 3588.8 | 2,265.3 | 10.72 | 175 |
| High PAH (HMW) | 2,8616.9 | 3140.4 | 1952.8 | 7.48 | 175 |
| Low PAH (LMW) | 3,795.4 | 448.4 | 253.7 | 3.23 | 175 |
| Total Phthalate | 2,574.9 | 371.8 | 188.9 | 12.30 | 175 |

Table 3-10 presents the mean and median concentrations and the concentration ranges of Group 1 compounds found at the sampling locations.

Table 3-11. **Organic Group 2: PCB Compound Class and Individual Congeners.**

| Sum of PCBs | | | | | |
|---|---|---|---|---|---|
| $Cl_2$(8) | $Cl_3$(18) | $Cl_3$(28) | $Cl_4$(44) | $Cl_4$(52) | $Cl_4$(66) |
| $Cl_4$(77) | $Cl_5$(101) | $Cl_5$(105) | $Cl_5$(110) | $Cl_5$(118) | $Cl_5$(126) |
| $Cl_6$(128) | $Cl_6$(129) | $Cl_6$(138) | $Cl_6$(153) | $Cl_6$(169) | $Cl_7$(170) |
| $Cl_7$(180) | $Cl_7$(187) | $Cl_8$(195) | $Cl_9$(206) | $Cl_{10}$(209) | |

Table 3-11 presents the 23 individual PCB congeners that were summed for the Sum of PCB class.

Table 3-12. **Organic Variables Group 2: PCB Compound Class Statistics.**

| All values in µg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---|---|---|---|---|
| Total PCB | 7,854.11 | 321.21 | 97.23 | Below Detection | 175 |
| Sum of PCB | 3,927.05 | 160.79 | 49.83 | Below Detection | 175 |

Table 3-12 presents the mean and median concentrations and the concentration ranges of Group 2 compounds found at the sampling locations.

Table 3-13. **Organic Group 3:  Total Chlordane and Total DDT Compound Classes - Individual Isomers and Metabolites.**

| Total Chlordane | Total DDT |
|---|---|
| Cis (*α*) chlordane | DDT  (2,4’-DDT and 4,4’-DDT)* |
| Trans (γ) chlordane | DDE  (2,4’-DDE and 4,4’-DDE)* |
| Heptachlor | DDD  (2,4’-DDD and 4,4’-DDD)* |
| Methoxychlor | |
| Oxychlordane | |
| Cis-nonachlor | |
| Trans-nonachlor | *(also see Table 3-15) |

Table 3-13 presents the seven individual chlordane and six DDT constituents that were summed for the Total Chlordane and Total DDT classes

Table 3-14. **Organic Group 3:  Total Chlordane and Total DDT Compound Class Statistics.**

| All values in µg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples |
|---|---:|---:|---:|---:|---:|
| Total Chlordane | 100.92 | 6.59 | 1.51 | Below Detection | 175 |
| Total DDT | 116.37 | 11.46 | 8.15 | Below Detection | 175 |

Table 3-14 presents the mean and median concentrations and the concentration ranges of the Group 3 compounds found at the sampling locations.

Table 3-15. **Organic Group 4:  DDT, DDD, DDE, Total Endosulfan and Total HCH Compound Classes - Individual Isomers and Metabolites.**

| DDT | DDE | DDD | Total Endosulfan | Total HCH |
|---|---|---|---|---|
| 2,4’-DDT | 2,4’-DDE | 2,4’-DDD | Endosulfan I | α-HCH |
| 4,4’-DDT | 4,4’-DDE | 4,4’-DDD | Endosulfan II | β-HCH |
| | | | Endosulfan sulfate | γ-HCH |
| | | | | δ-HCH |

Table 3-15 presents the individual isomers that were summed for the DDT, DDE, and DDD. Total Endosulfan and Total HCH classes

Table 3-16. **Organic Group 4:  DDT, DDD, DDE, Total Endosulfan and Total HCH Compound Class Statistics.**

| All values in µg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples (N) |
|---|---:|---:|---:|---:|---:|
| **DDT** | 16.35 | 2.253 | 1.279 | Below Detection | 175 |
| **DDD** | 52.23 | 4.556 | 2.792 | Below Detection | 175 |
| **DDE** | 93.12 | 4.653 | 3.198 | Below Detection | 175 |
| **Total Endosulfan** | 28.99 | 1.924 | 0.669 | Below Detection | 175 |
| **Total HCH** | 9.81 | 0.919 | 0.548 | Below Detection | 175 |

Table 3-16 presents the mean and median concentrations and the concentration ranges of Group 4 compounds found at the sampling locations.

Table 3-17. **Organic Groups 5, 6 and 7: Chlorinated Phenol, Cl-Catechol, Cl-Guaiacol, Cl-Anisole and Total Chlorophenolic Compound Classes – Individual Compounds.**

| Chlorophenolic Class | Cl-Phenol Class | Cl-Catechol Class | Cl-Guaiacol Class | Cl-Anisole Class |
|---|---|---|---|---|
| Cl-Phenol | 2-Chlorophenol | 4-Chlorocatechol | 4,5-Dichloroguaiacol | 2-Chloroanisole |
| Cl-Catechol | 2,4-Dichlorophenol | 3,5-Dichlorocatechol | 3,4,5-Trichloroguaiacol | 2,4-Dichloroanisole |
| Cl-Guaiacol | 2,6-Dichlorophenol | 4,5-Dichlorocatechol | 3,4,6-Trichloroguaiacol | Pentachloroanisole |
| Cl-Anisole | 2,4,5-Trichlorophenol | 3,4,5-Trichlorocatechol | 4,5,6-Trichloroguaiacol | |
| | 2,4,6-Trichlorophenol | 3,4,6-Trichlorocatechol | Tetrachloroguaiacol | |
| | 2,3,4,5-Tetrachlorophenol | Tetrachlorocatechol | | |
| | 2,3,4,6-Tetrachlorophenol | | | |
| | 4-Chloro-3-methylphenol | | | |
| | Pentachlorophenol | | | |

Table 3-17 presents individual compounds that were summed for the Cl-Phenol, Cl-Catechol, Cl-Guaiacol, and Cl-Anisole classes. In addition, this table shows the individual classes that were summed for the Chlorophenolic class.

Table 3-18. **Organic Groups 5, 6 and 7: Cl-Phenol, Cl-Catechol, Cl-Guaiacol, Cl-Anisole and Total Chlorophenolic Compound Class Statistics.**

| All values in µg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples (N) |
|---|---|---|---|---|---|
| **Cl-Phenol** | 14,780.0 | 1906.9 | 993.6 | Below Detection | 140 |
| **Cl-Catechol** | 21,476.7 | 1602.7 | 185.8 | Below Detection | 140 |
| **Cl-Guaiacol** | 7264.0 | 923.1 | 266.1 | Below Detection | 140 |
| **Cl-Anisole** | 31,486.1 | 619.7 | 0 | Below Detection | 140 |
| **Total Chlorophenolics** | 39,610.8 | 4754.1 | 2650.2 | Below Detection | 140 |

Table 3-18 presents the mean and median concentrations and the concentration ranges of Group 5, 6 and 7 compounds found at the sampling locations.

Table 3-19. **Organic Group 8. Pesticide Compounds and Statistics**

| All values in µg/kg (dry wt.) | Maximum | Mean | Median | Minimum | No. of Samples (N) |
|---|---|---|---|---|---|
| **Aldrin** | 1.75 | 0.09 | 0 | Below Detection | 175 |
| **Dieldrin** | 8.06 | 0.81 | 0.40 | Below Detection | 175 |
| **Endrin** | 5.04 | 0.12 | 0 | Below Detection | 175 |
| **Chlorpyrifos** | 21.70 | 0.65 | 0 | Below Detection | 160 |
| **Heptachlor** | 1.42 | 0.05 | 0 | Below Detection | 175 |
| **Heptachlor epoxide** | 4.18 | 0.45 | 0 | Below Detection | 175 |
| **Hexachlorobenzene** | 19.81 | 0.79 | 0 | Below Detection | 175 |
| **Kepone** | 321.26 | 11.23 | 0 | Below Detection | 166 |
| **Lindane** | 9.81 | 0.79 | 0.37 | Below Detection | 175 |
| **Methoxychlor** | 15.32 | 0.46 | 0 | Below Detection | 175 |
| **Mirex** | 1.24 | 0.089 | 0 | Below Detection | 175 |

Table 3-19 presents the mean and median concentrations and the concentration ranges of Group 8 pesticide compounds found at the sampling locations.

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# The Lower St. Johns River Basin Sediment Atlas: Riverbed Sediment Characteristics and Contaminant Concentrations

# Appendix A

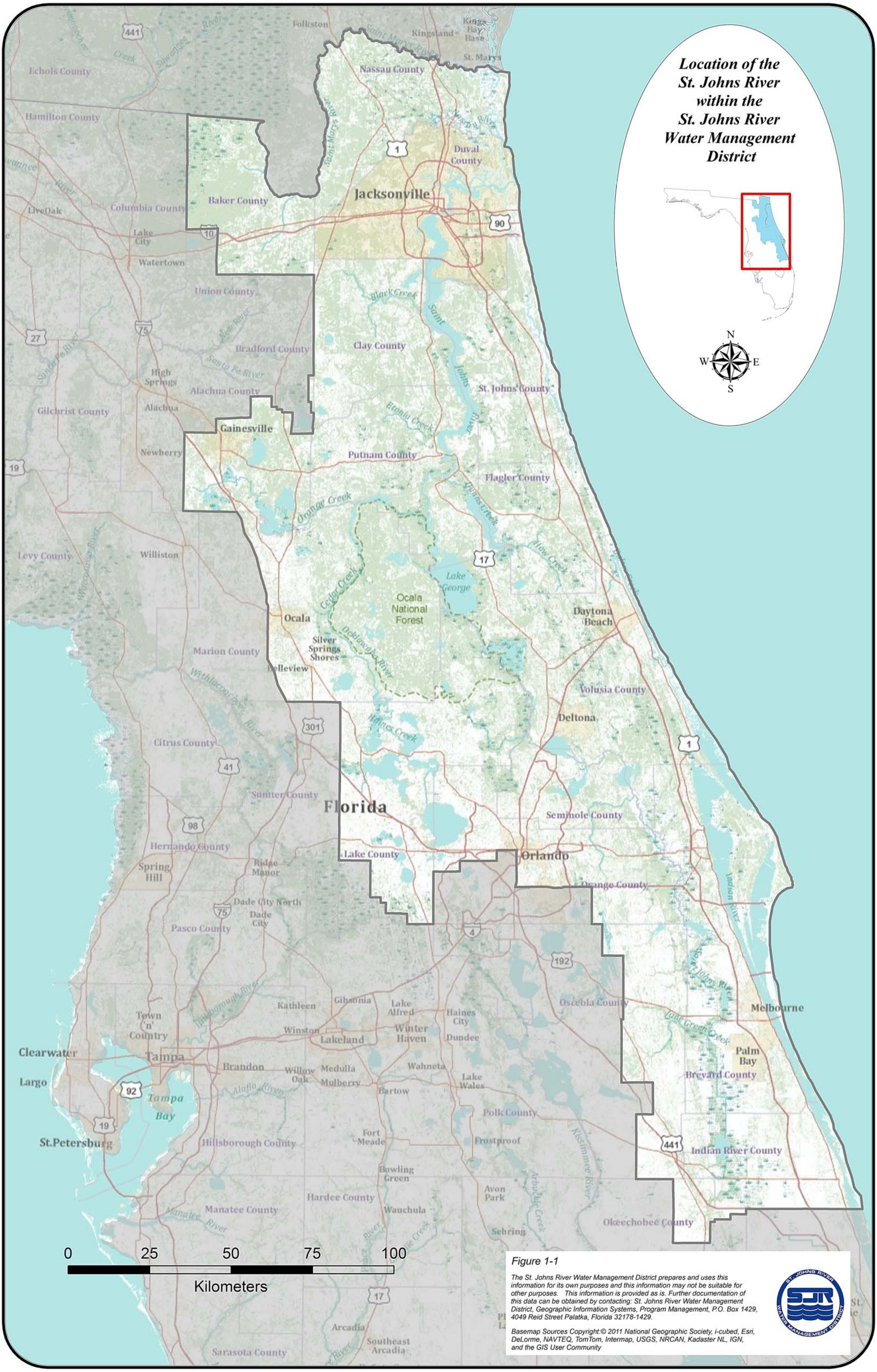


Figure 1-1

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429.

Basemap Sources Copyright:© 2011 National Geographic Society, i-cubed, Esri, DeLorme, NAVTEQ, TomTom, Intermap, USGS, NRCAN, Kadaster NL, IGN, and the GIS User Community

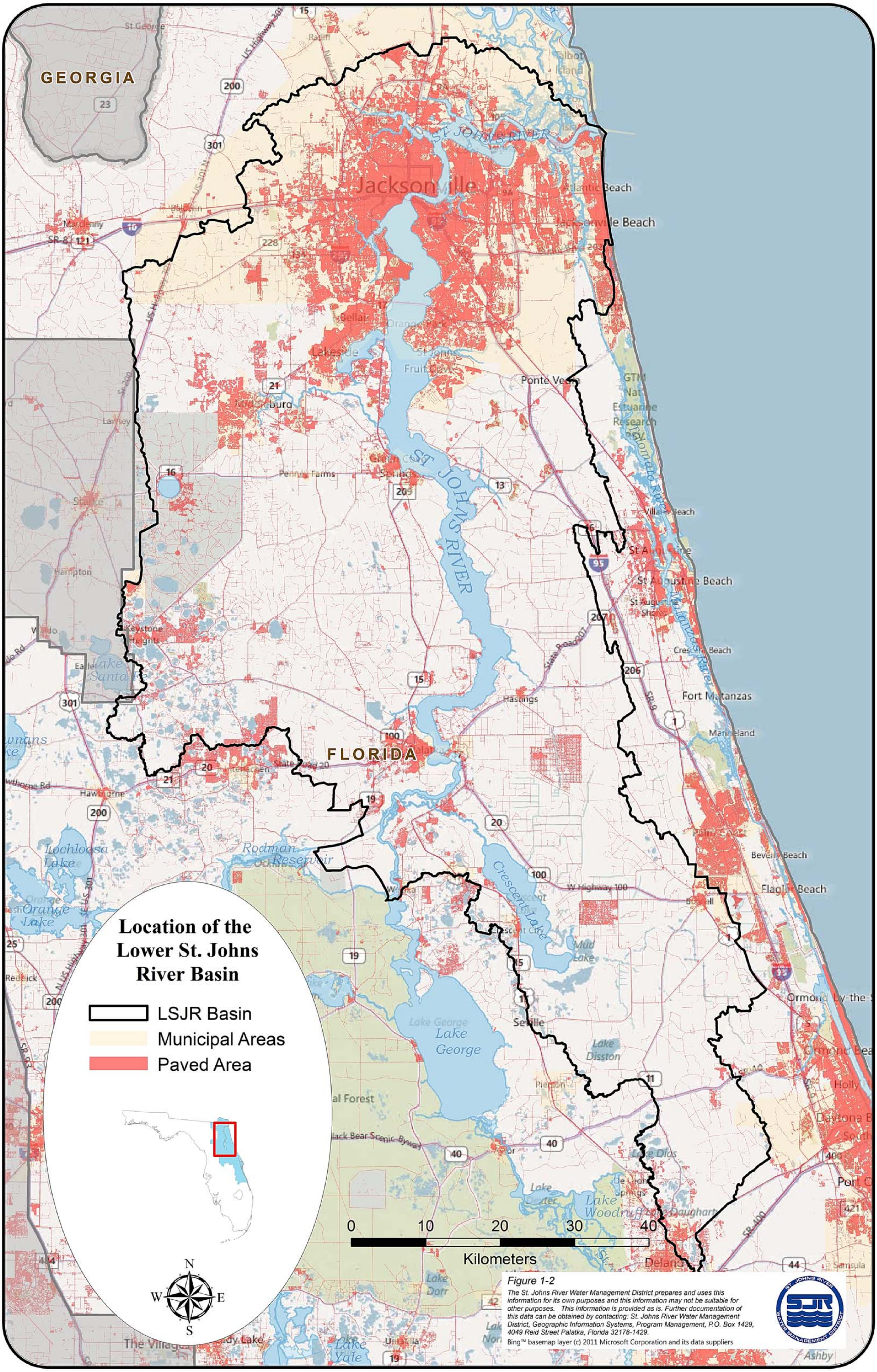
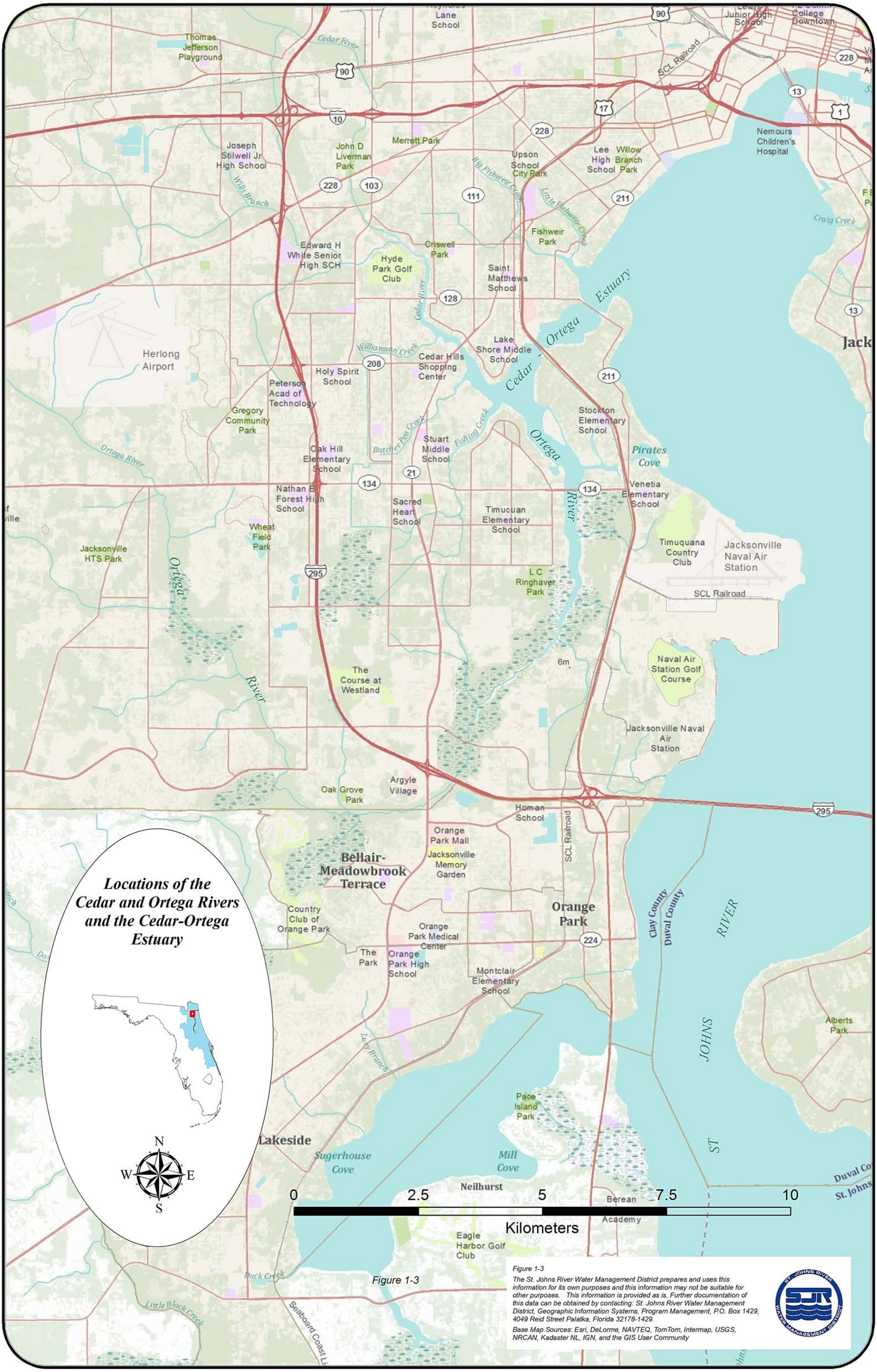


Figure 1-2

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429.

Bing™ basemap layer (c) 2011 Microsoft Corporation and its data suppliers



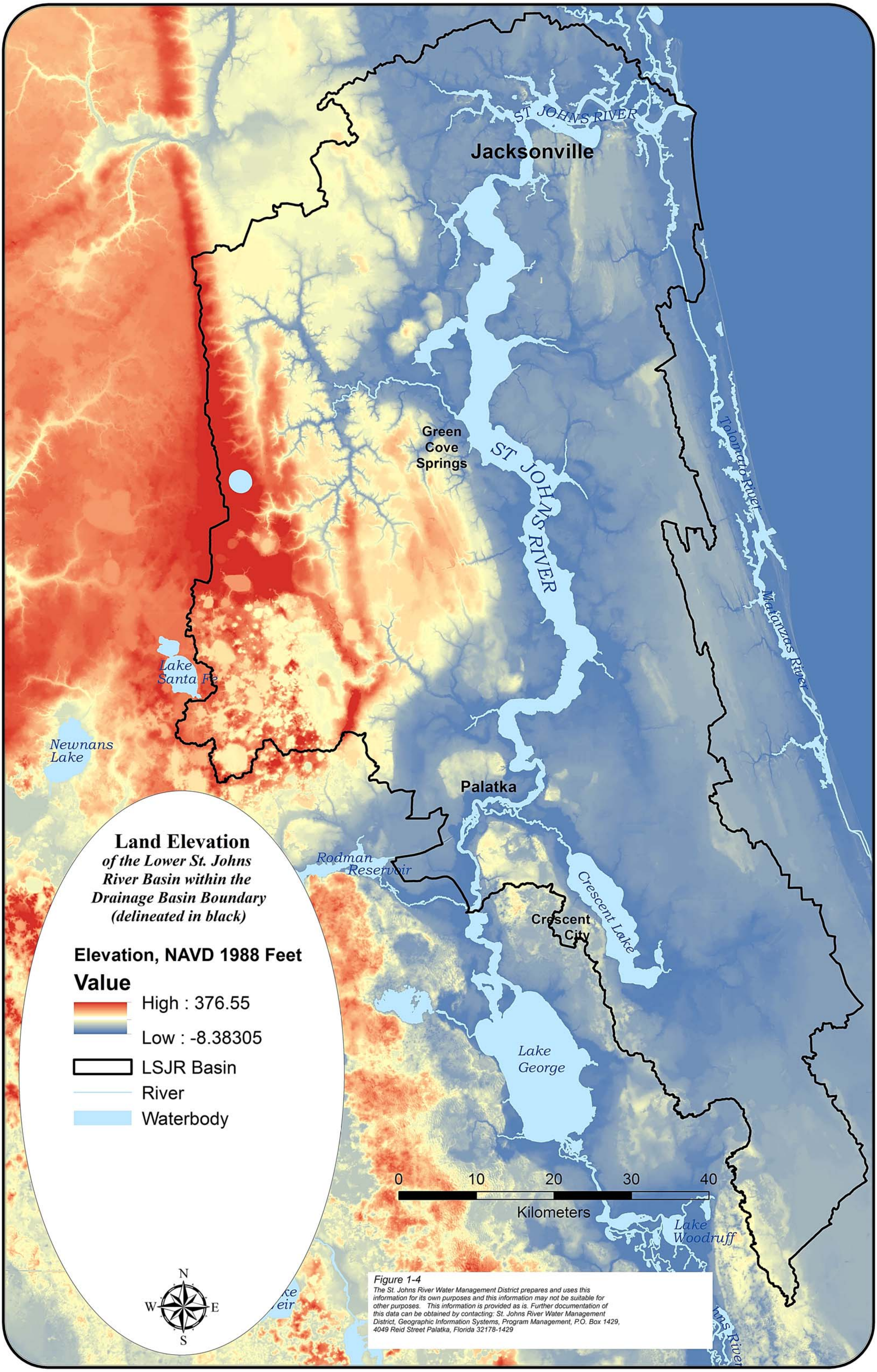
Locations of the Cedar and Ortega Rivers and the Cedar-Ortega Estuary

Figure 1-3

Figure 1-3

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429.

Base Map Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, USGS, NRCAN, Kadaster NL, IGN, and the GIS User Community



Land Elevation
*of the Lower St. Johns River Basin within the Drainage Basin Boundary (delineated in black)*

Elevation, NAVD 1988 Feet

**Value**

High : 376.55

Low : -8.38305

LSJR Basin

River

Waterbody

*Figure 1-4*

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429*

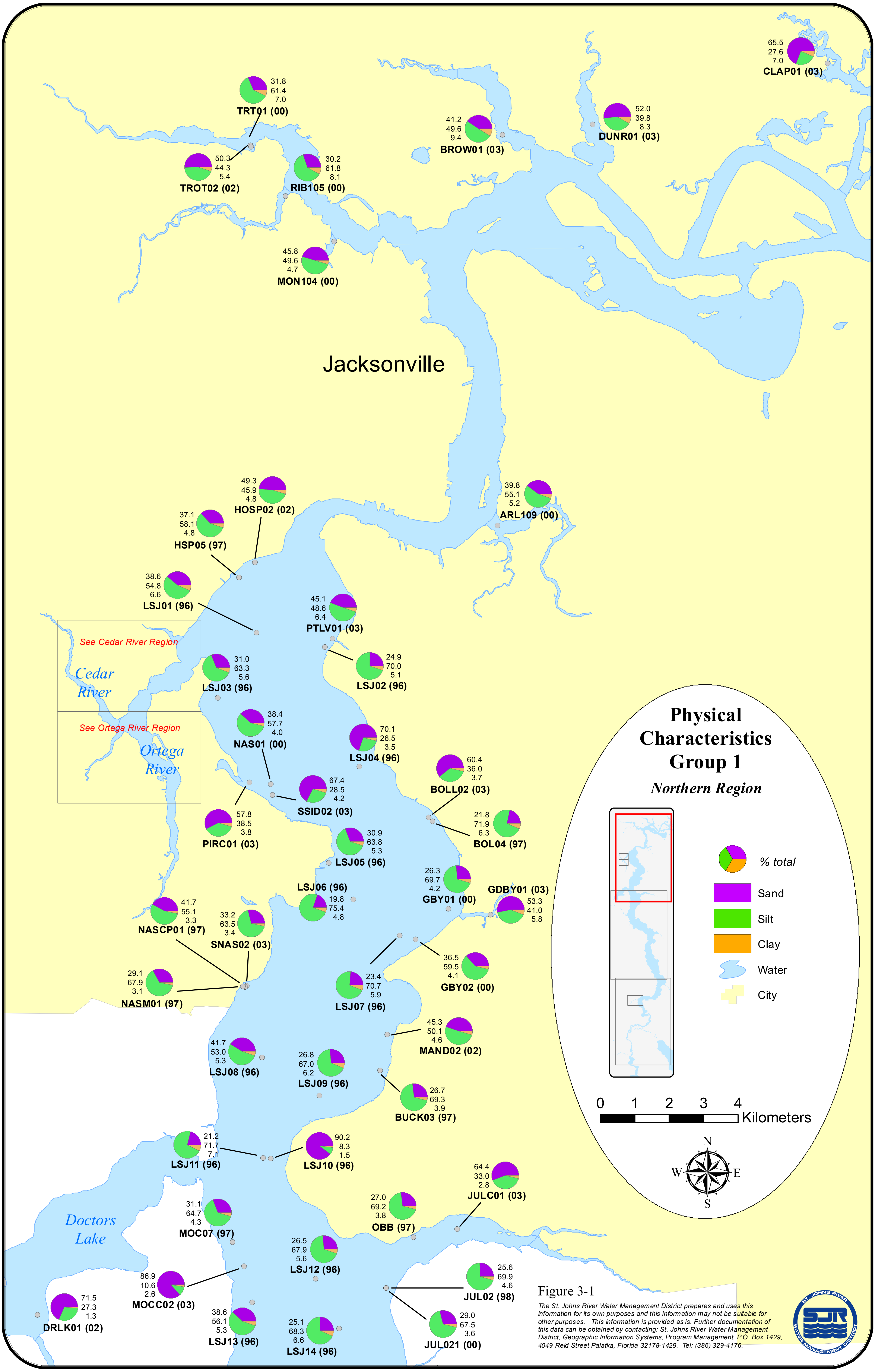
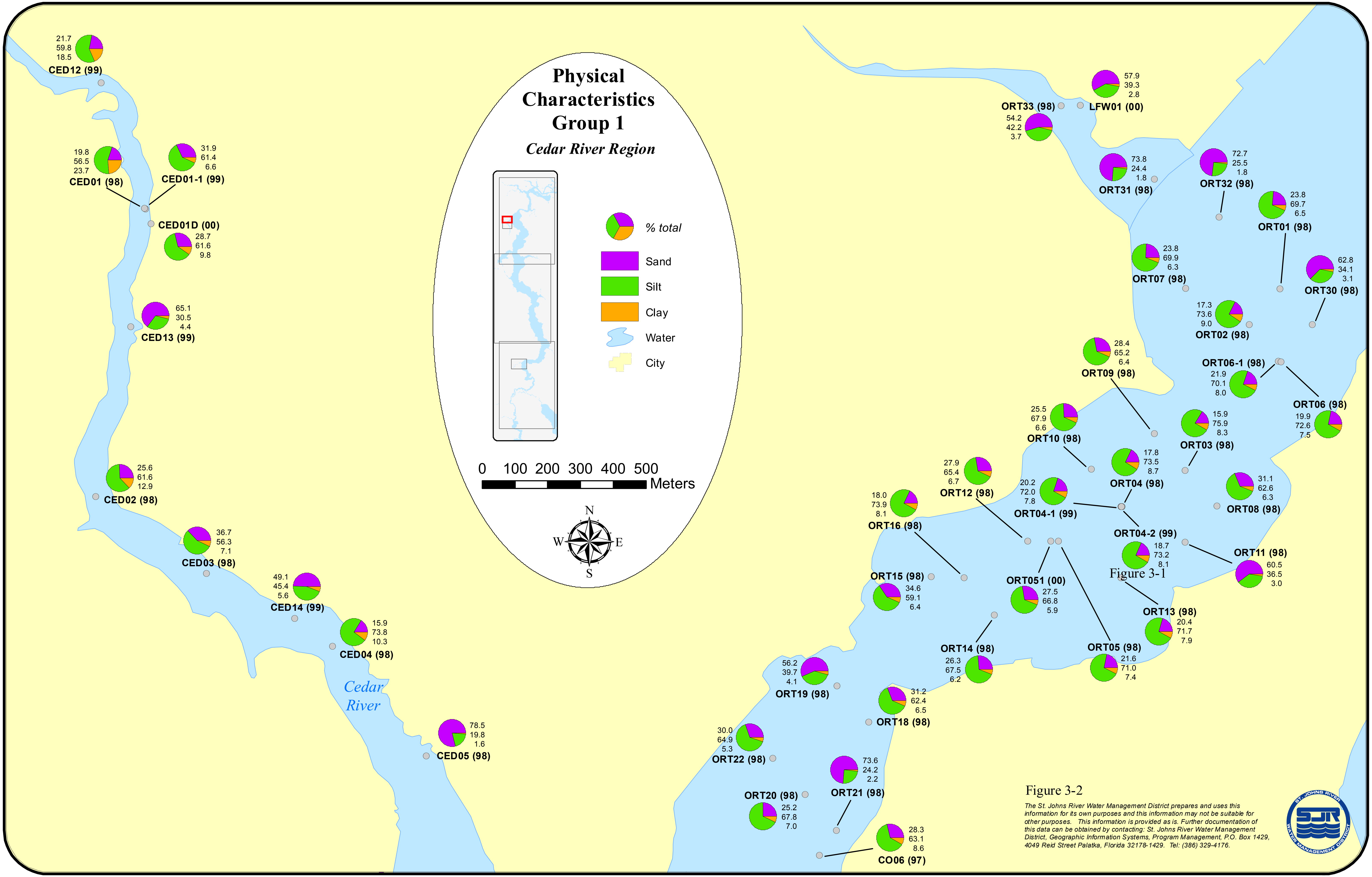


Figure 3-1

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

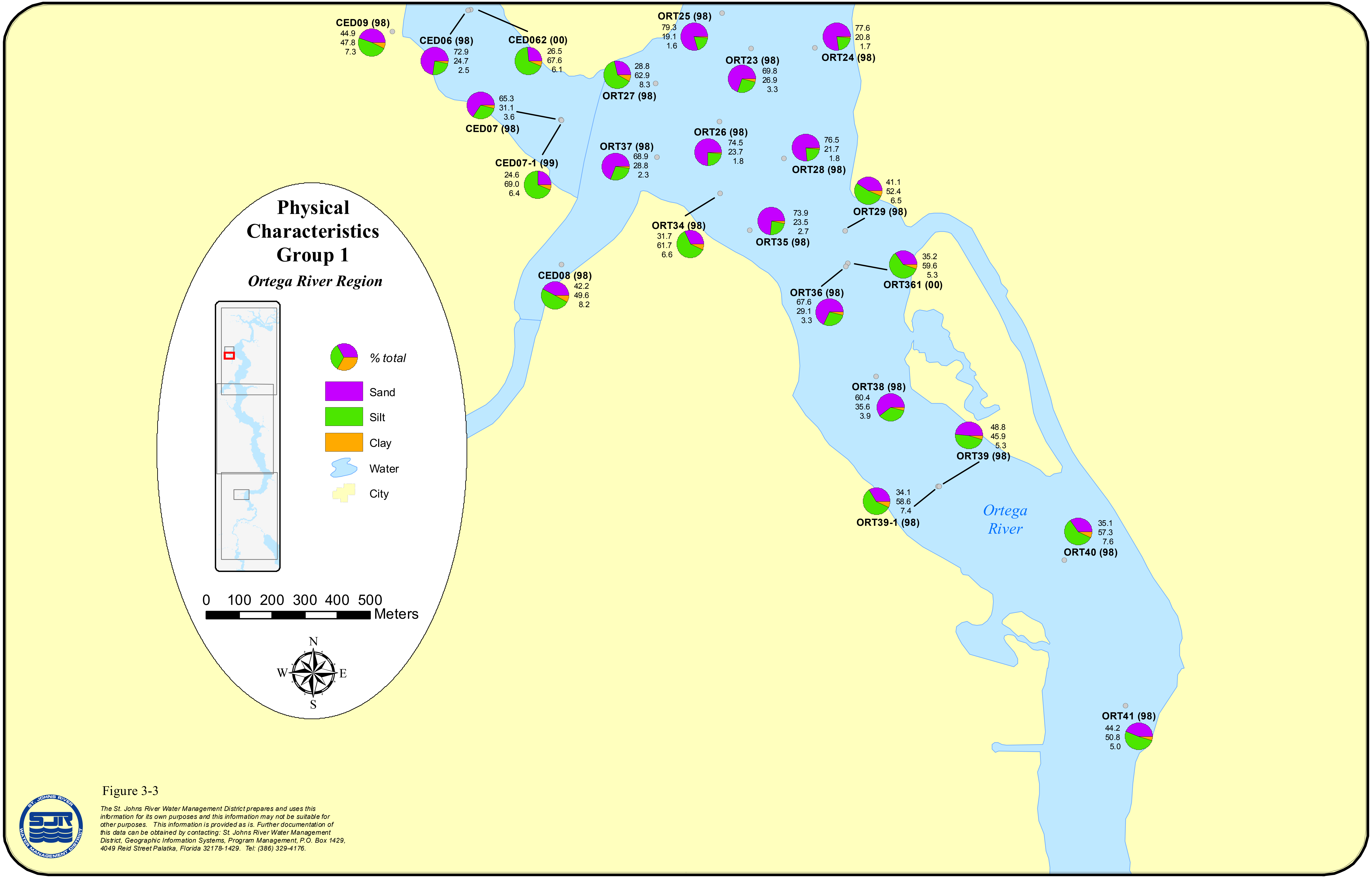


# Physical Characteristics Group 1

*Cedar River Region*

Figure 3-2

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



# Physical Characteristics Group 1

*Ortega River Region*

Figure 3-3

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

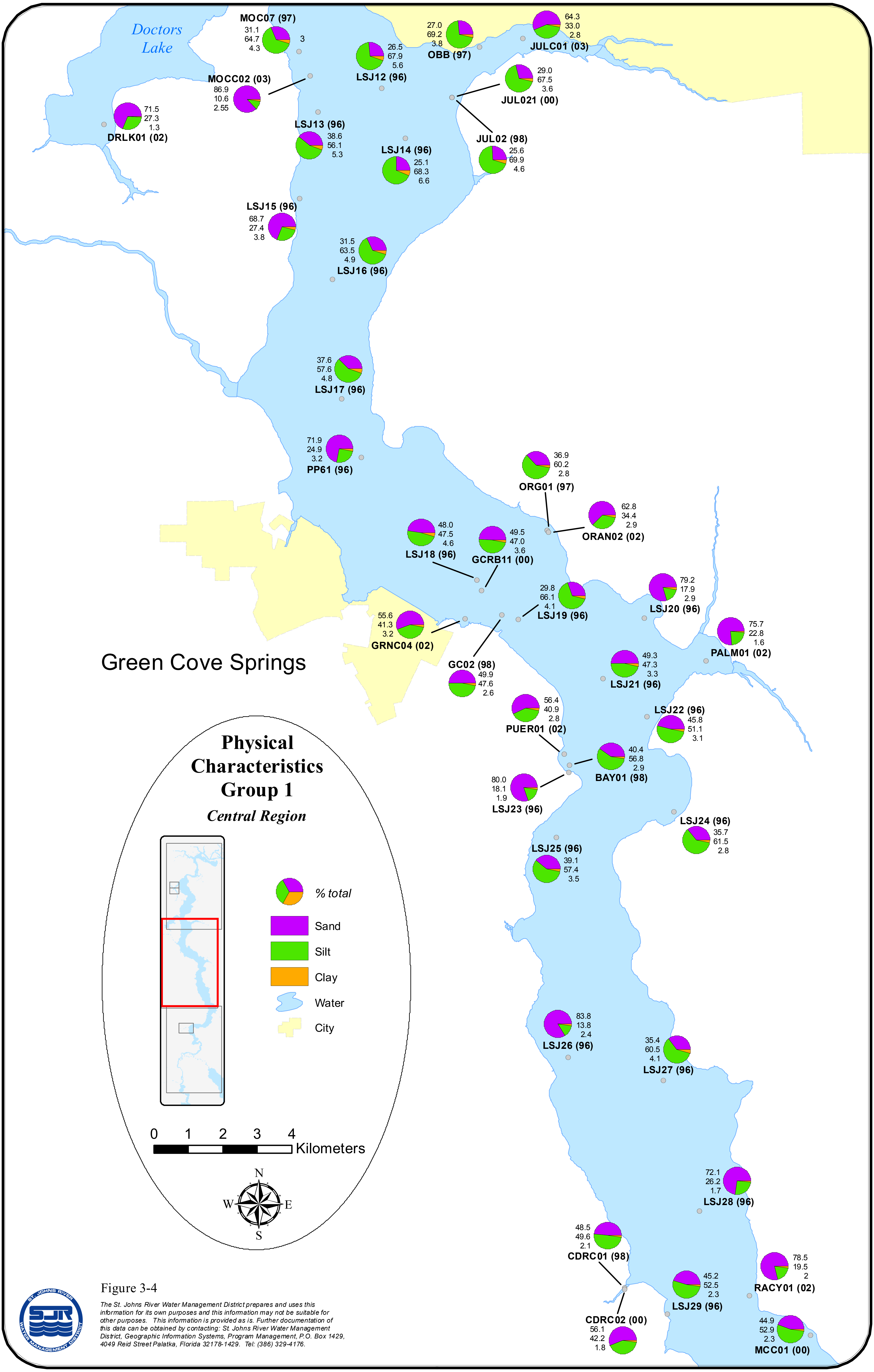


Figure 3-4

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

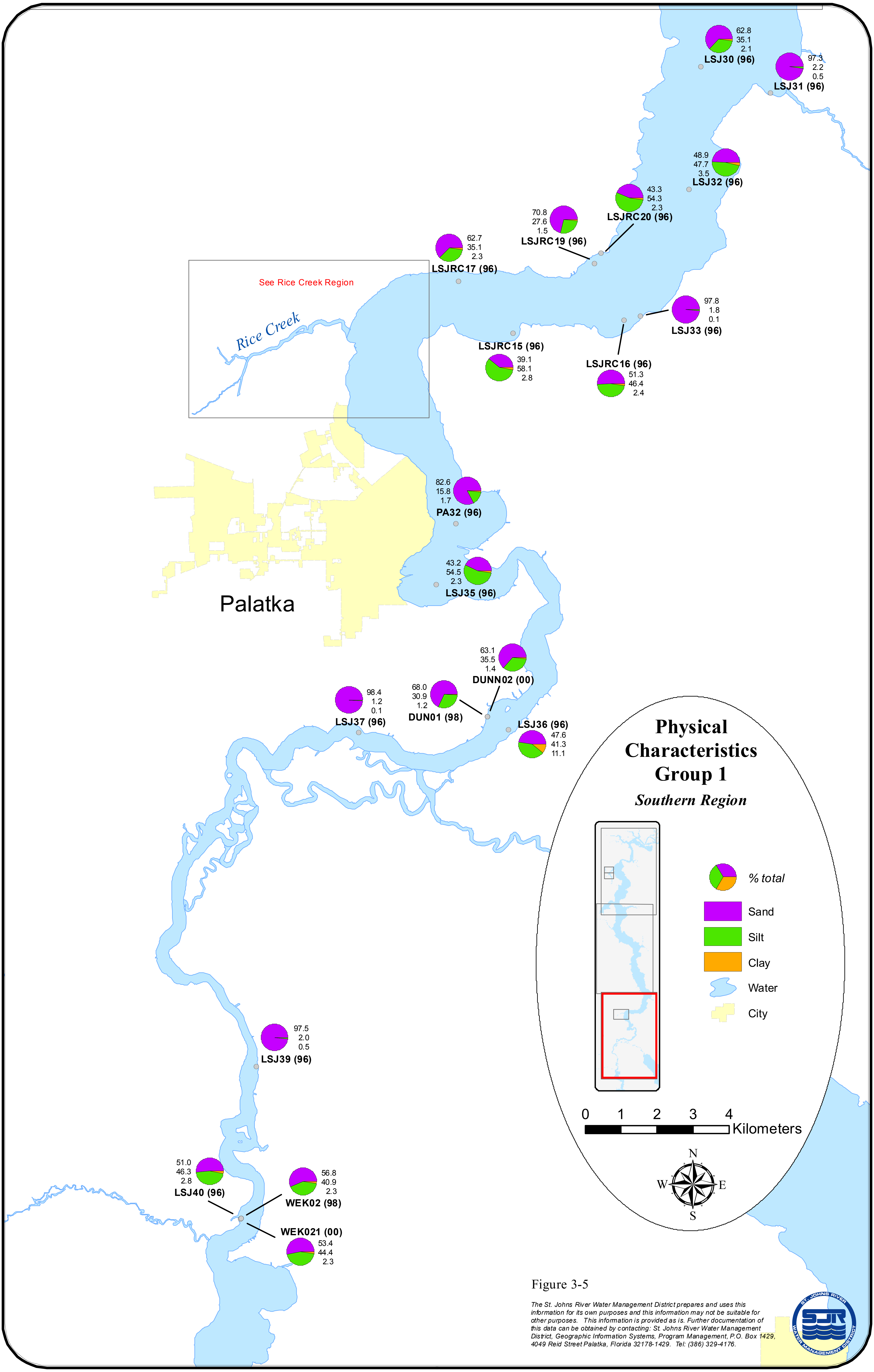


Figure 3-5

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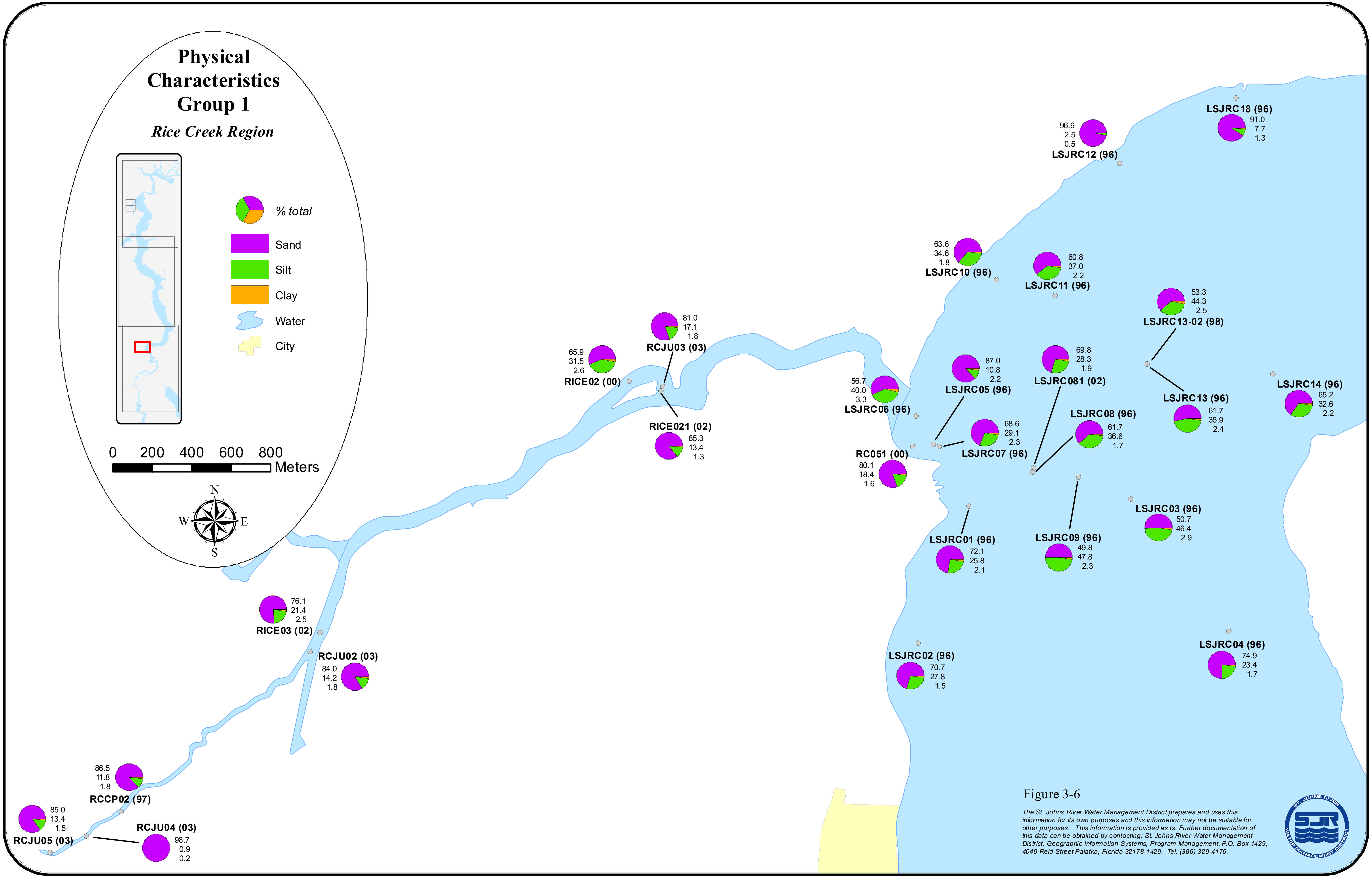

Figure 3-6

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

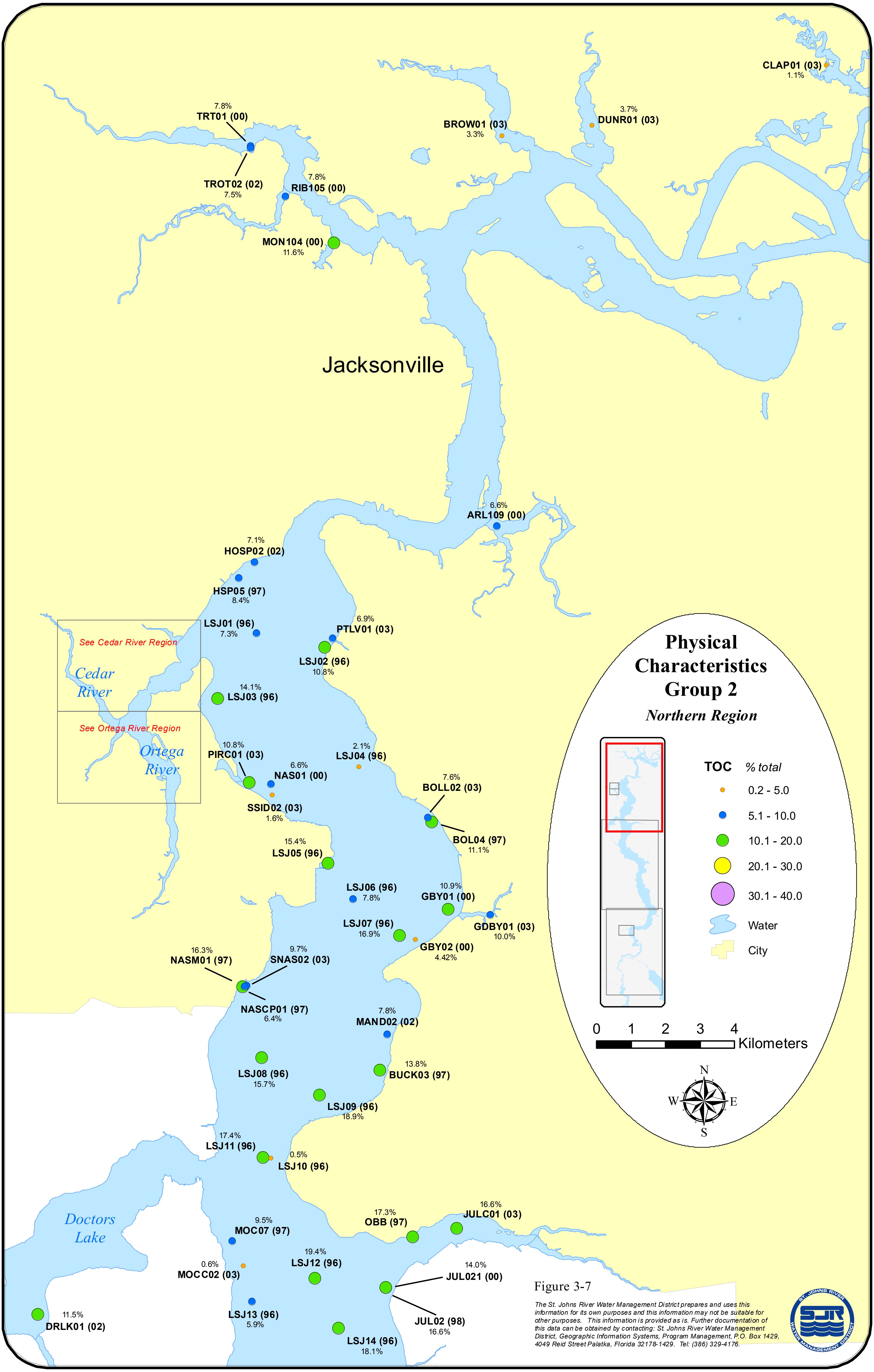

Figure 3-7

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Physical Characteristics Group 2

*Cedar River Region*

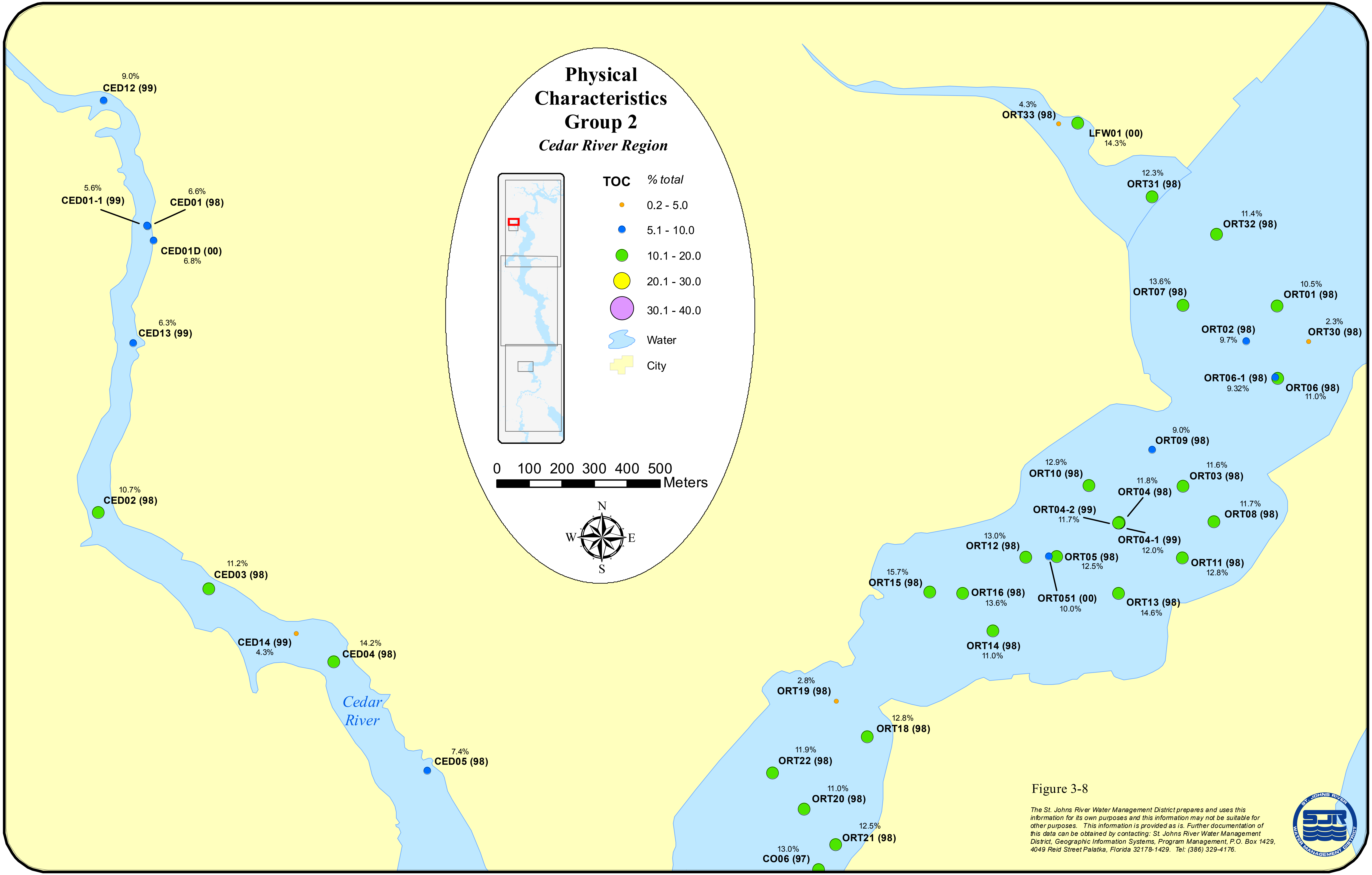

Figure 3-8

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.

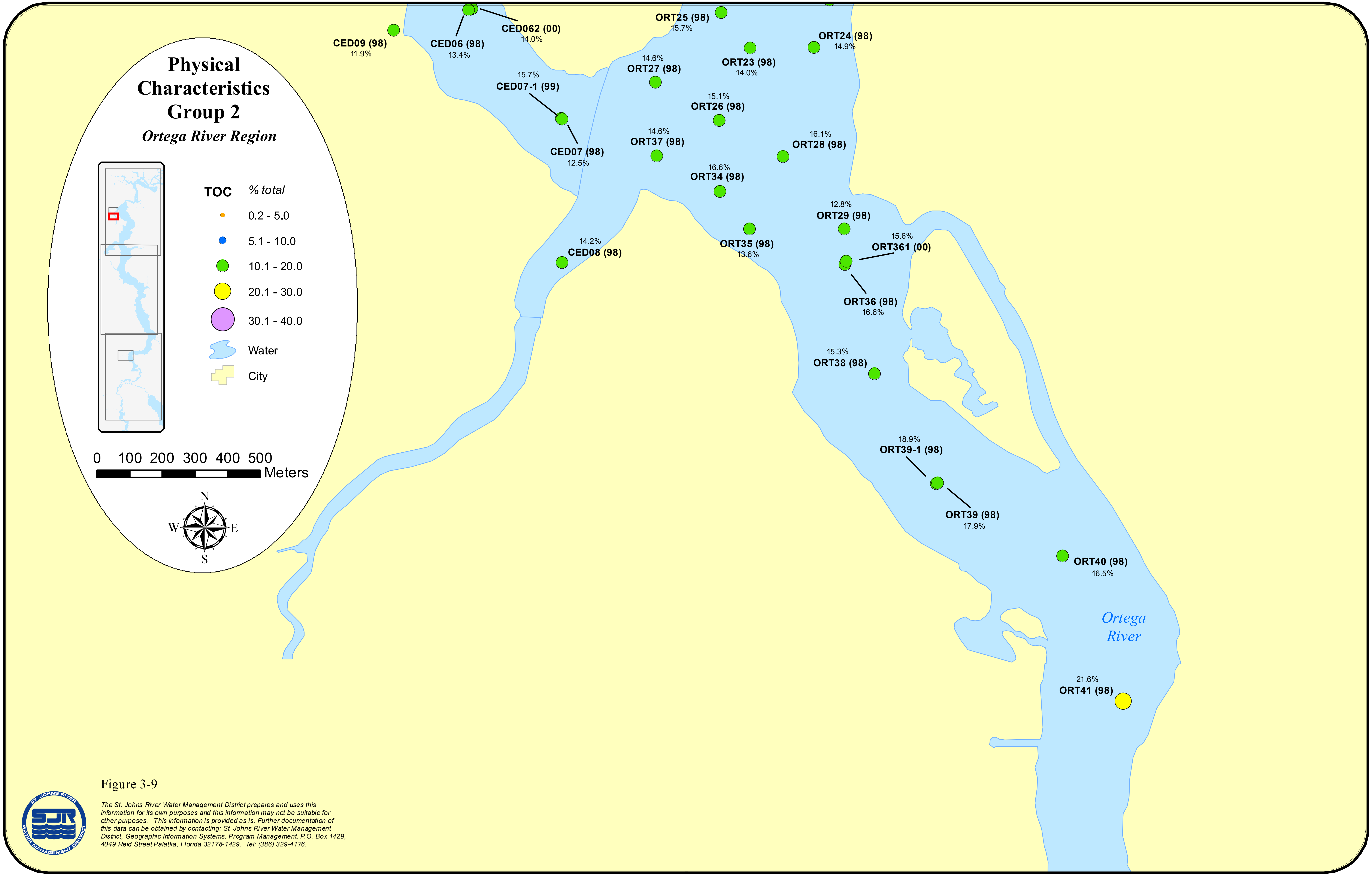

Figure 3-9

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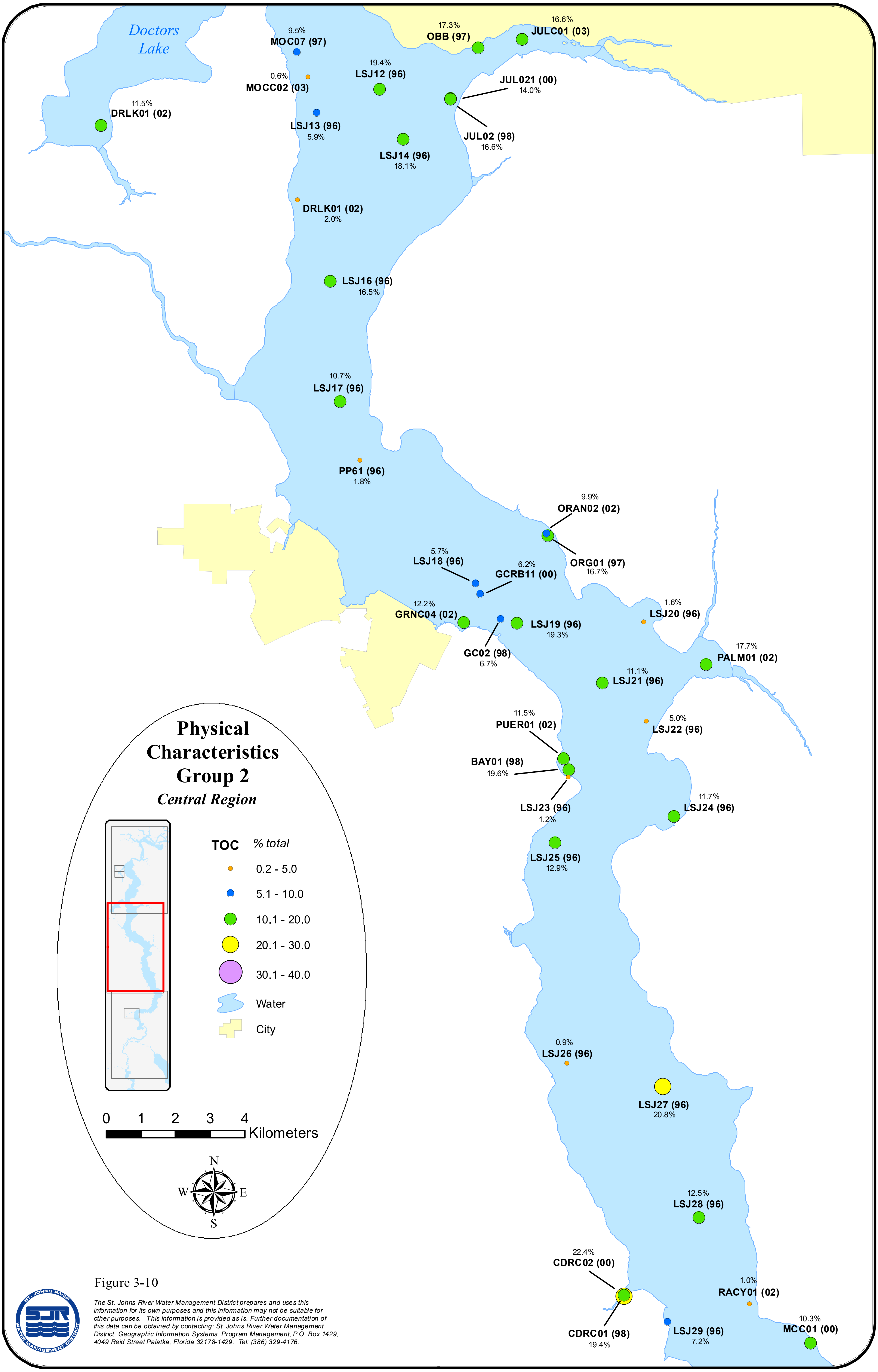


# Physical Characteristics Group 2

*Central Region*

Figure 3-10

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

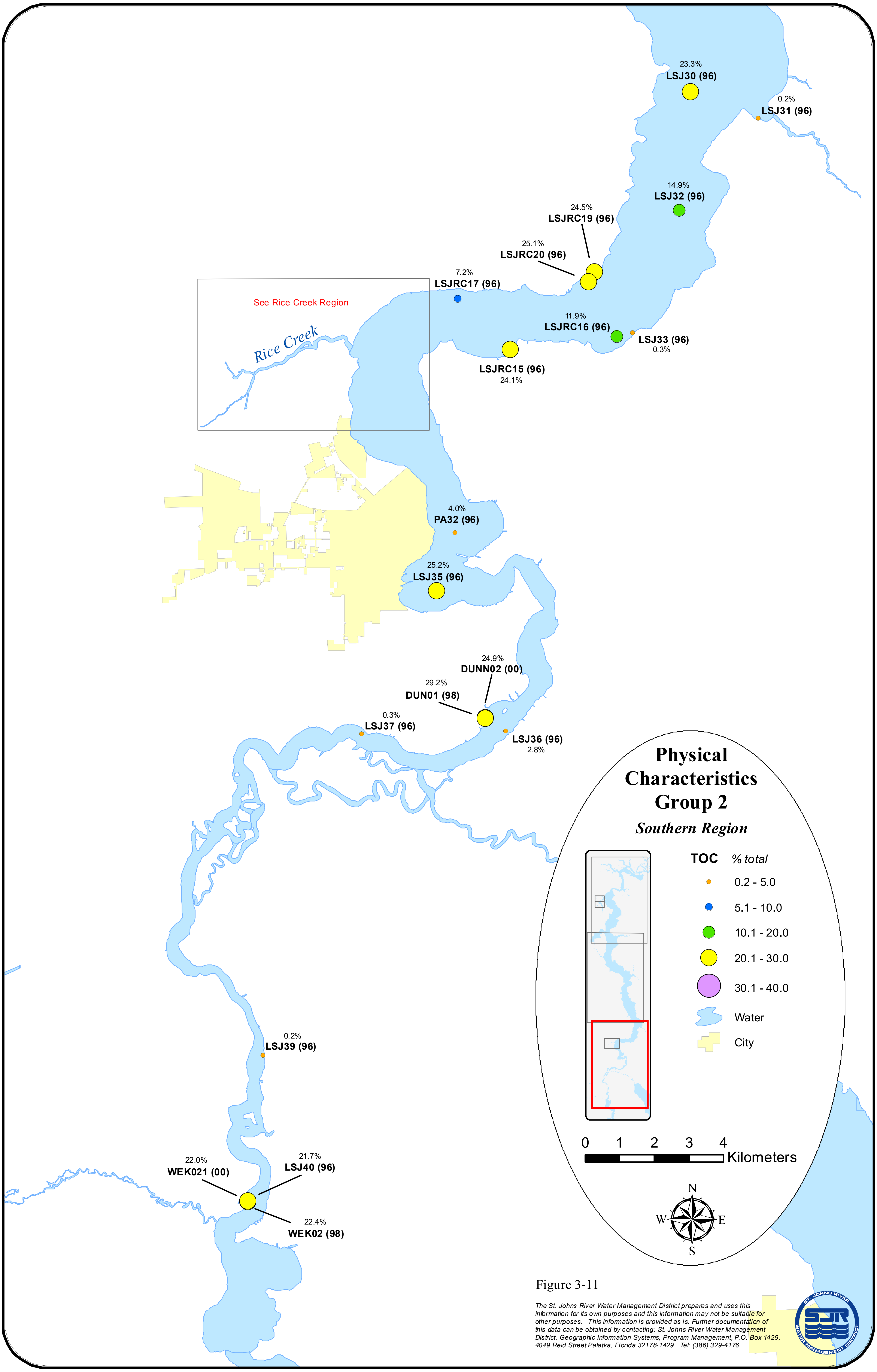


Figure 3-11

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

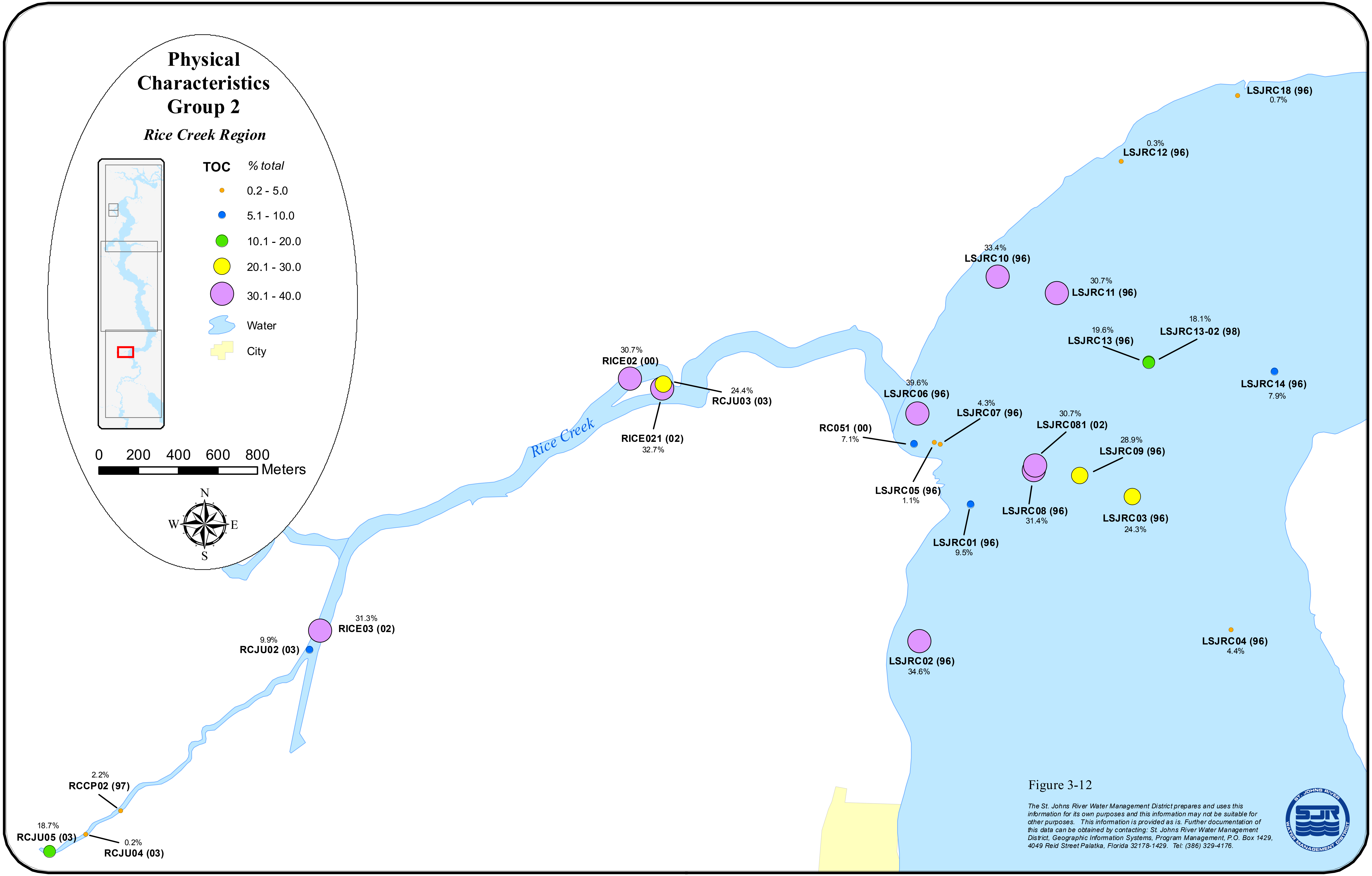


Figure 3-12

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Metal Concentrations (Group 1)

### Northern Region

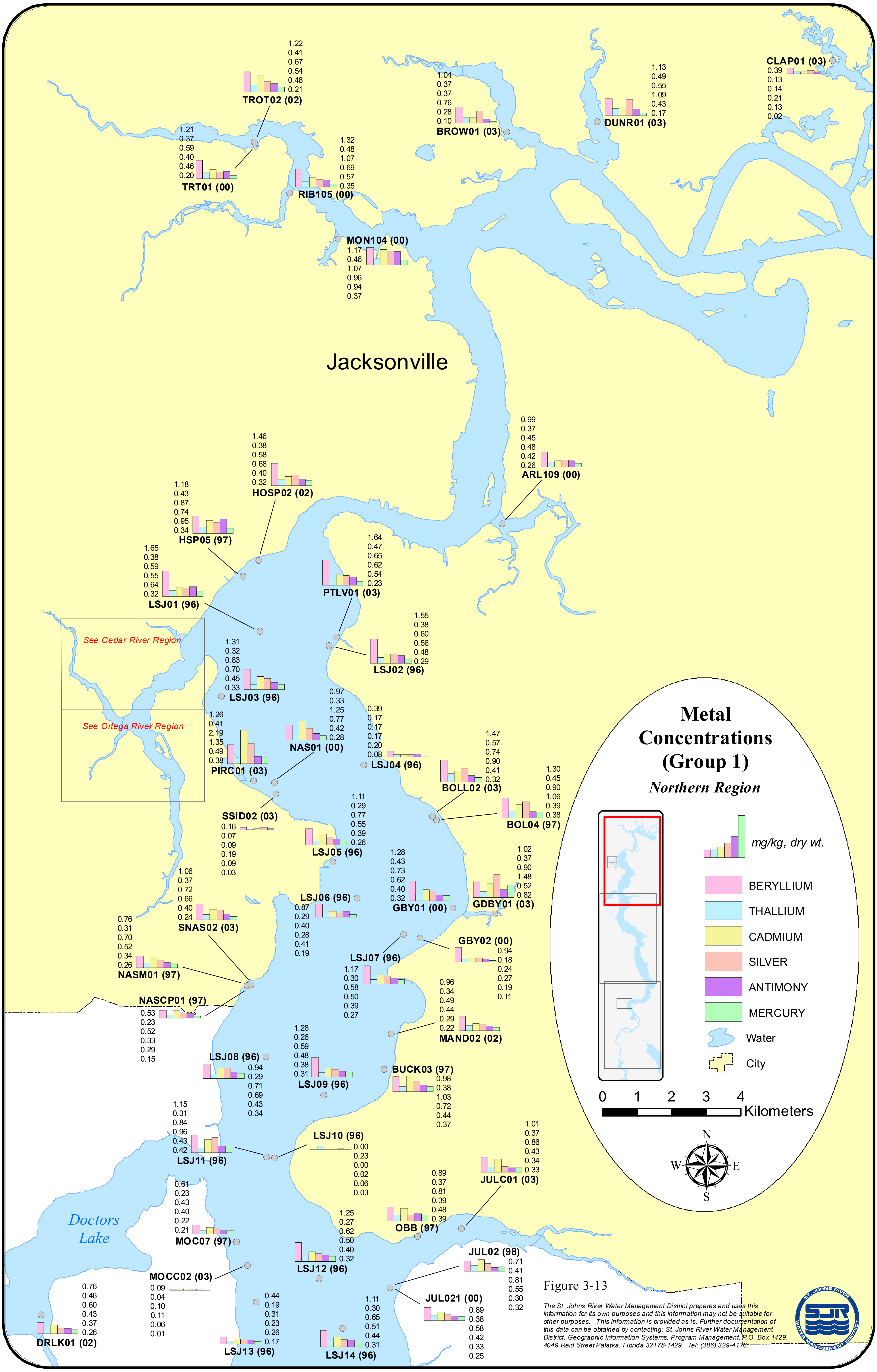
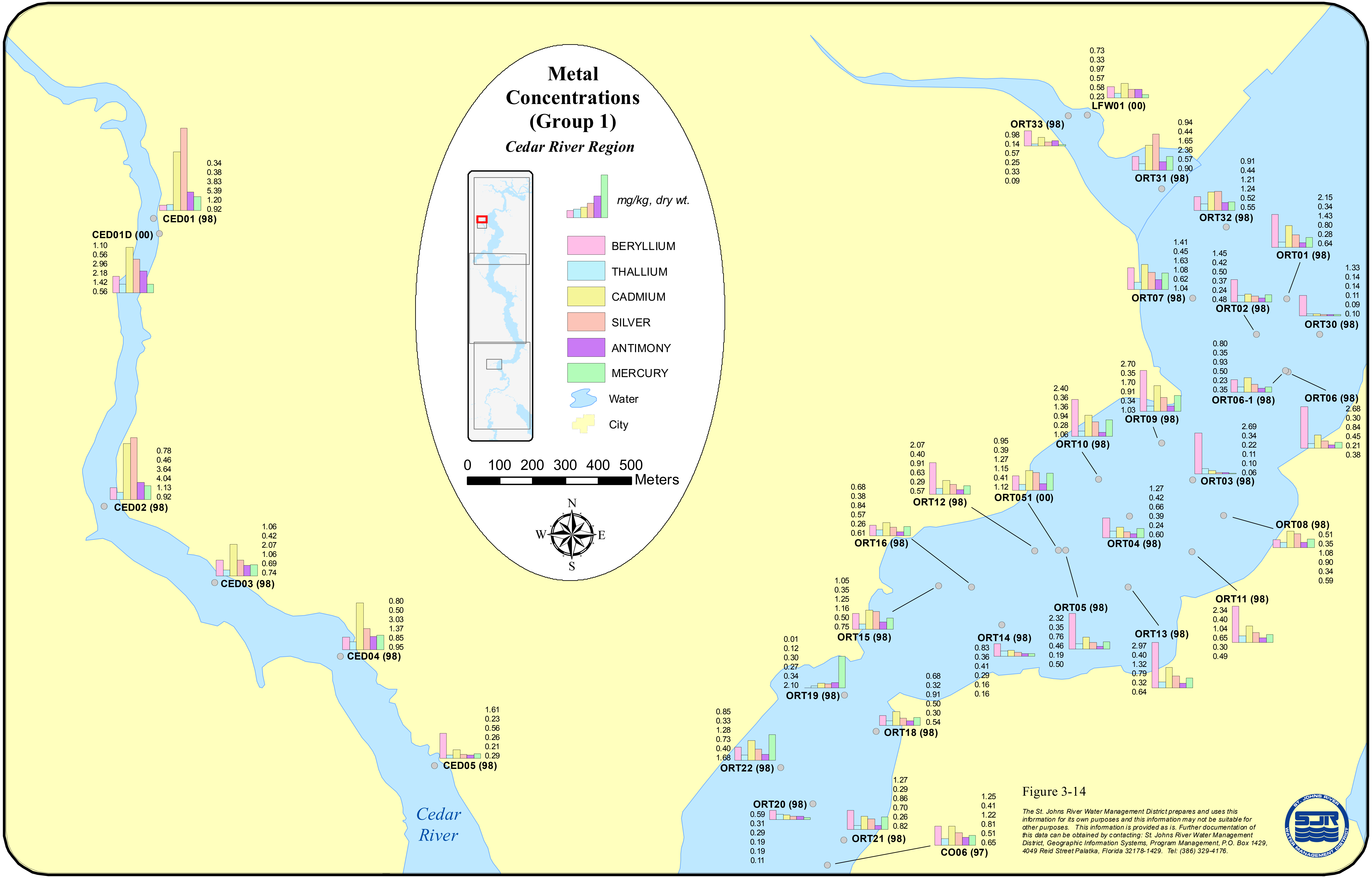


Figure 3-13

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



**Metal Concentrations (Group 1)**

*Cedar River Region*

Figure 3-14

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

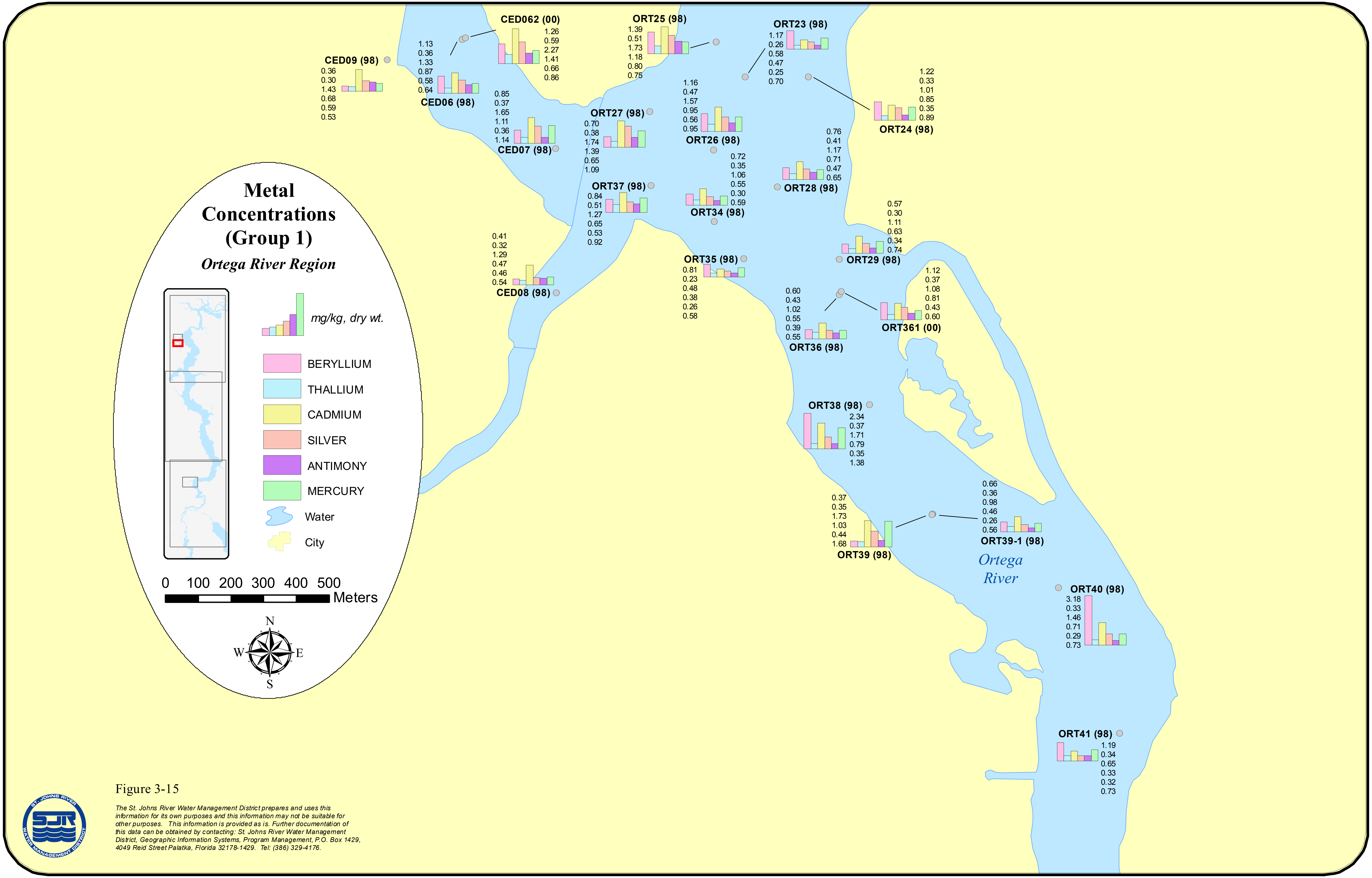


Figure 3-15

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Metal Concentrations (Group 1)

*Central Region*

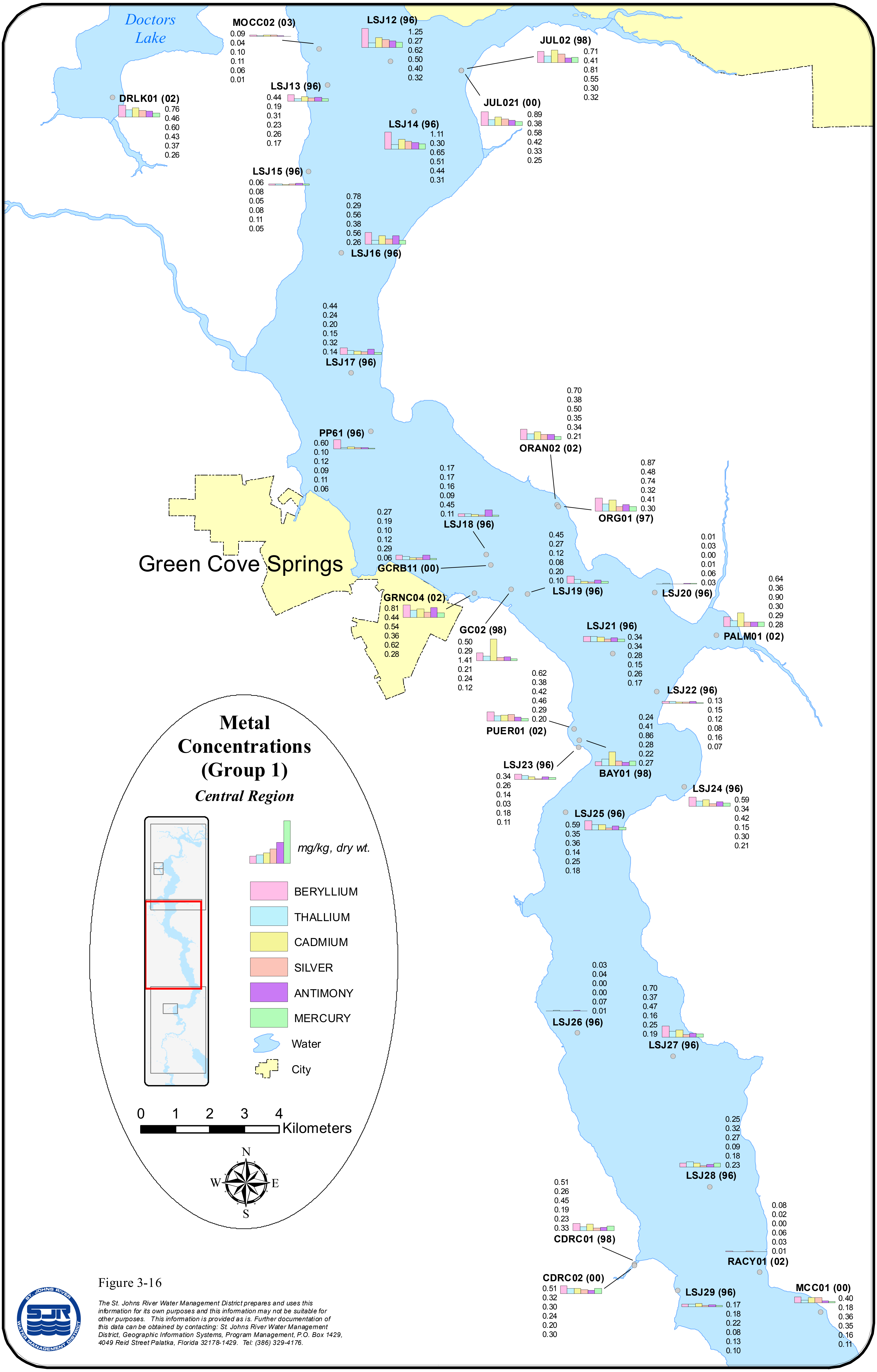
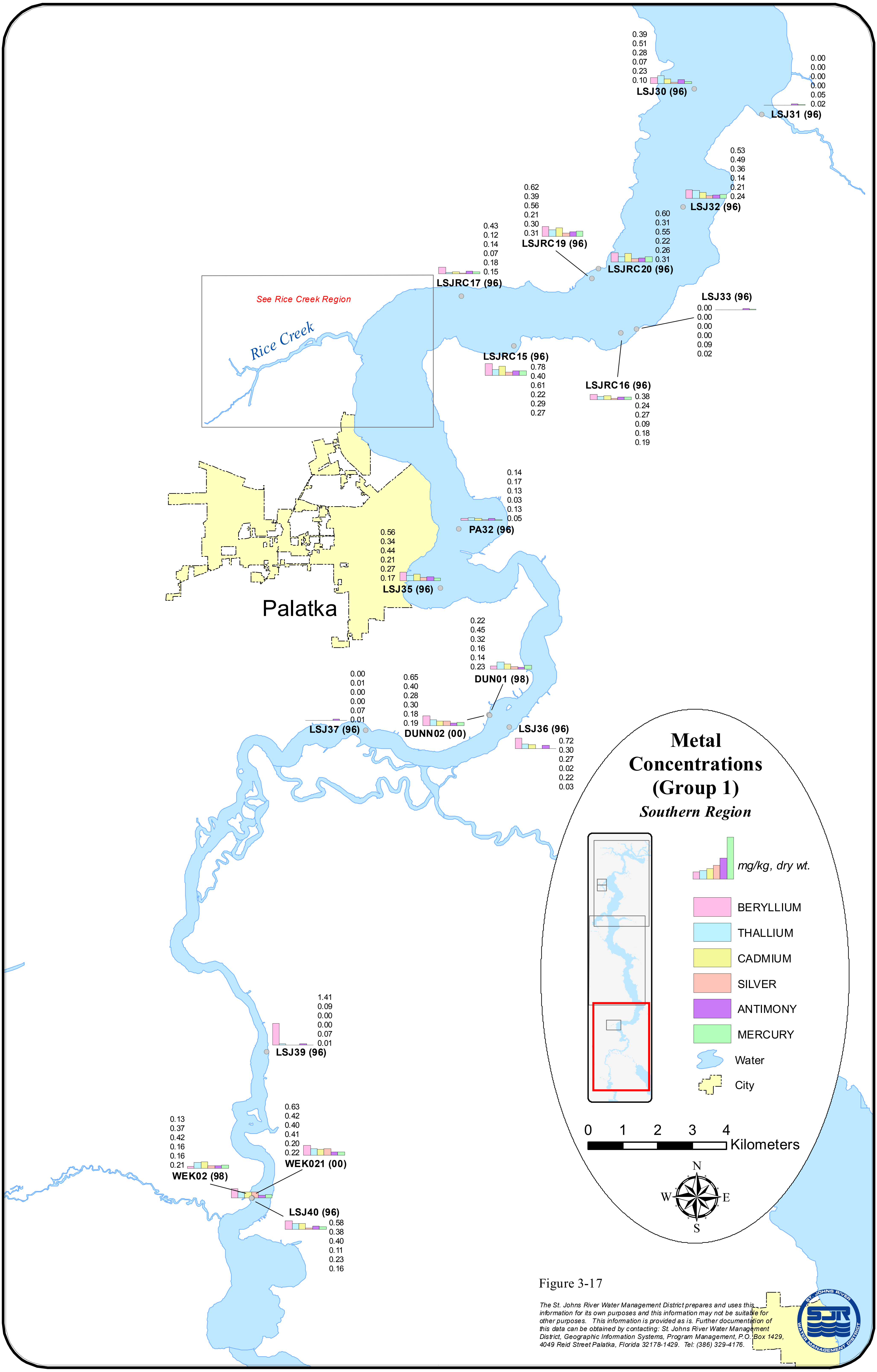


Figure 3-16

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



Metal Concentrations (Group 1)

*Southern Region*

Figure 3-17

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Metal Concentrations (Group 1)

*Rice Creek Region*

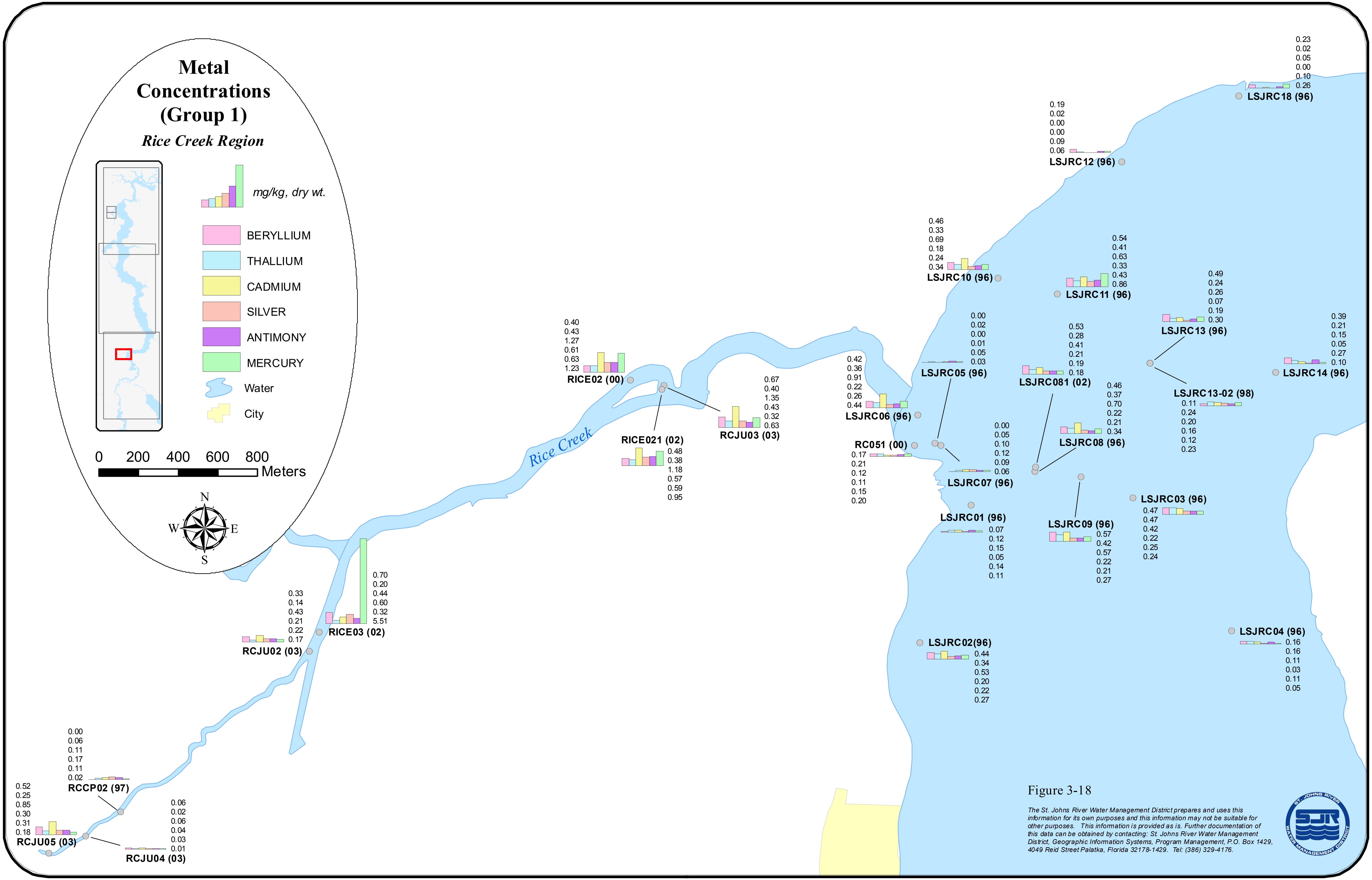
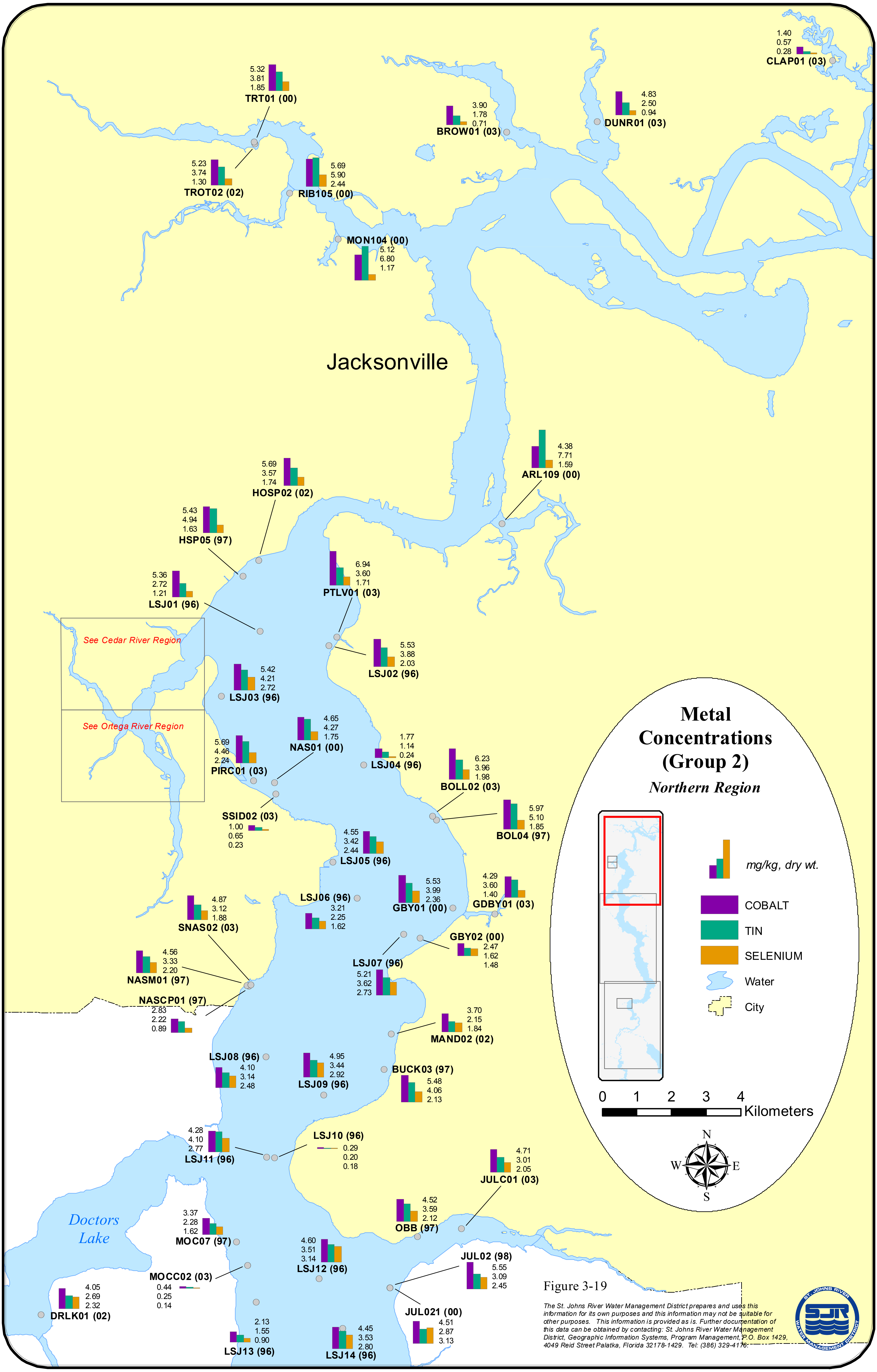


Figure 3-18

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



# Metal Concentrations (Group 2)

## *Northern Region*

Figure 3-19

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.

# Metal Concentrations (Group 2)

*Cedar River Region*

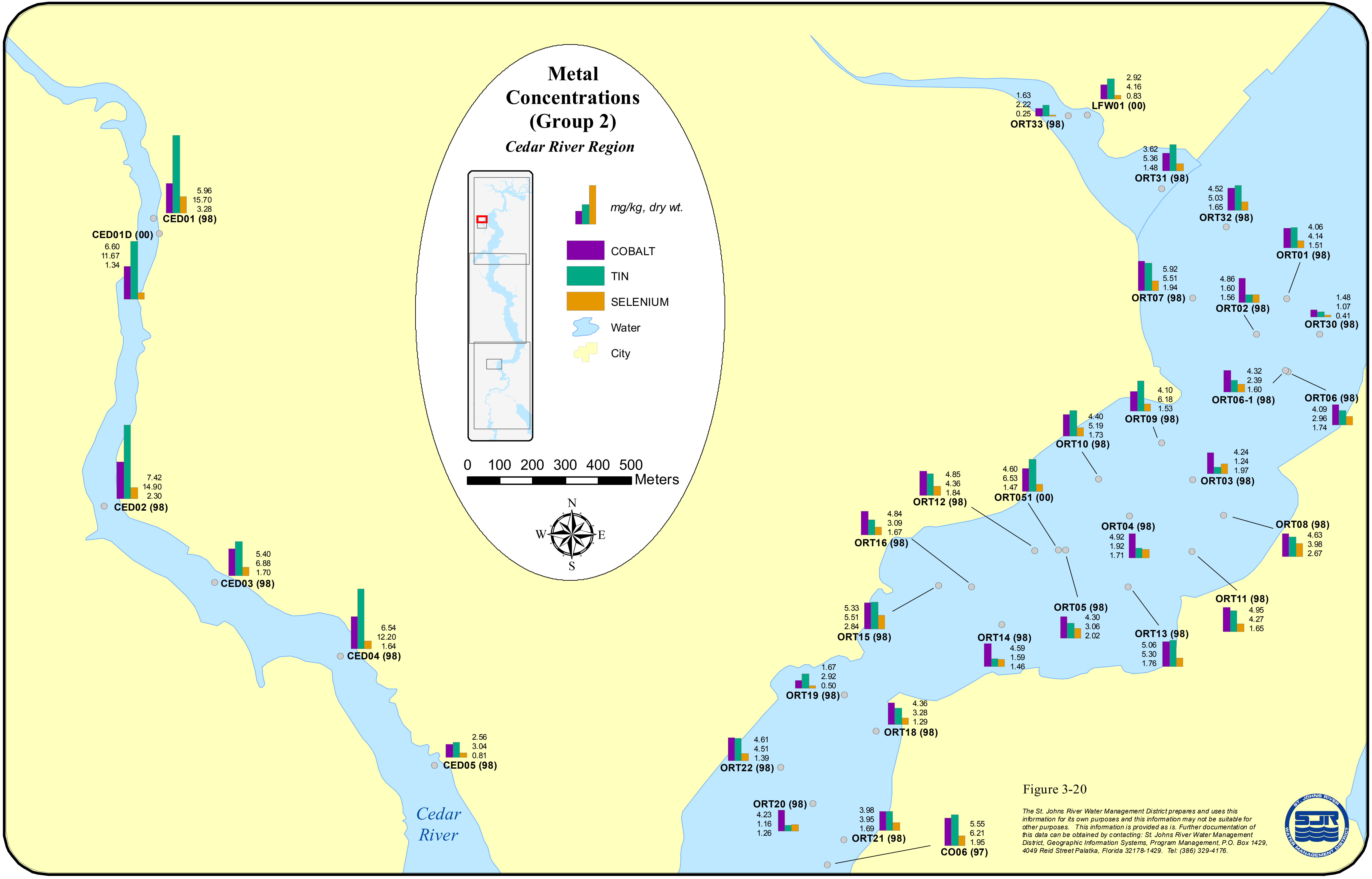
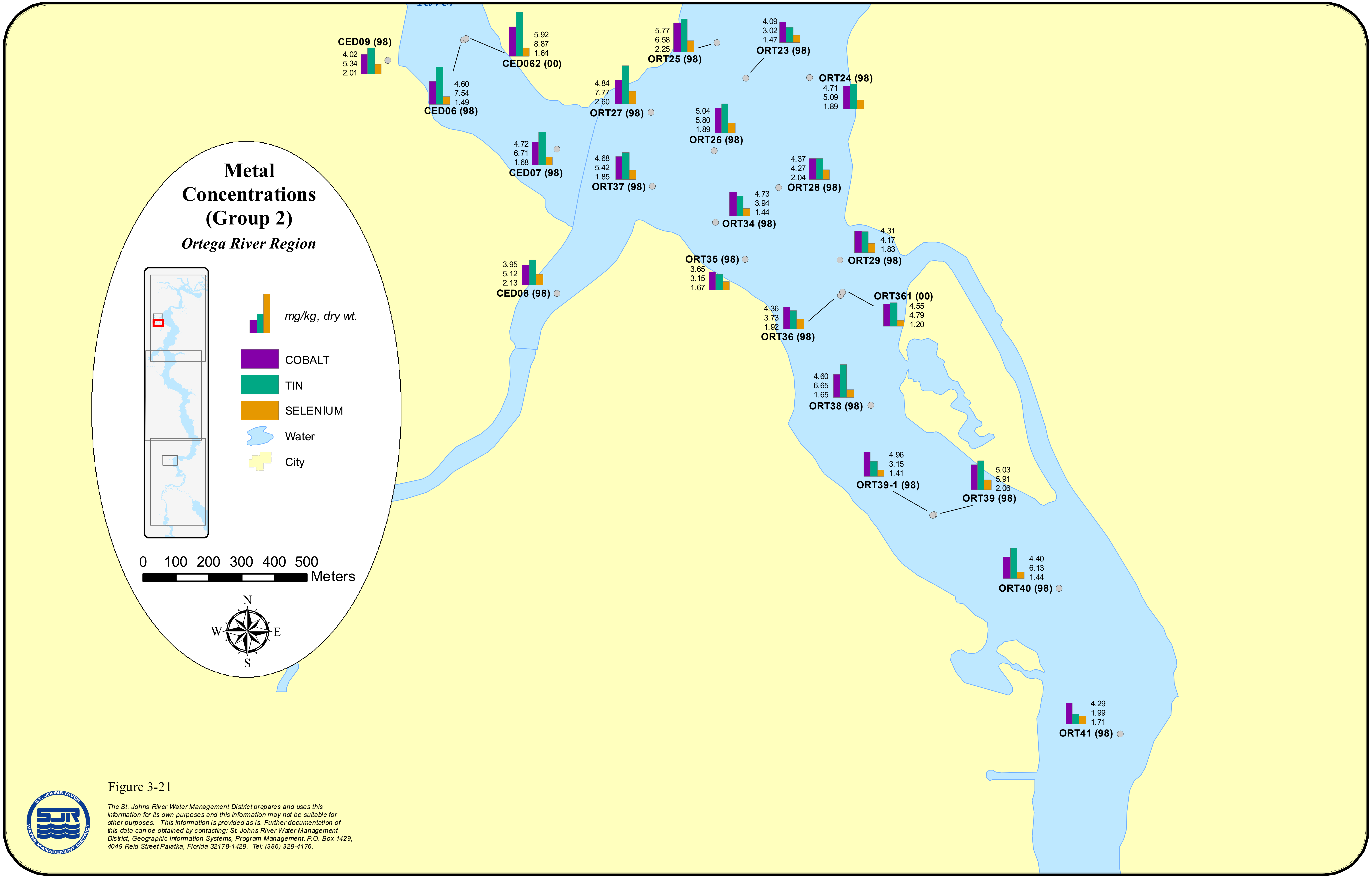


Figure 3-20

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



Metal Concentrations (Group 2)

*Ortega River Region*

Figure 3-21

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

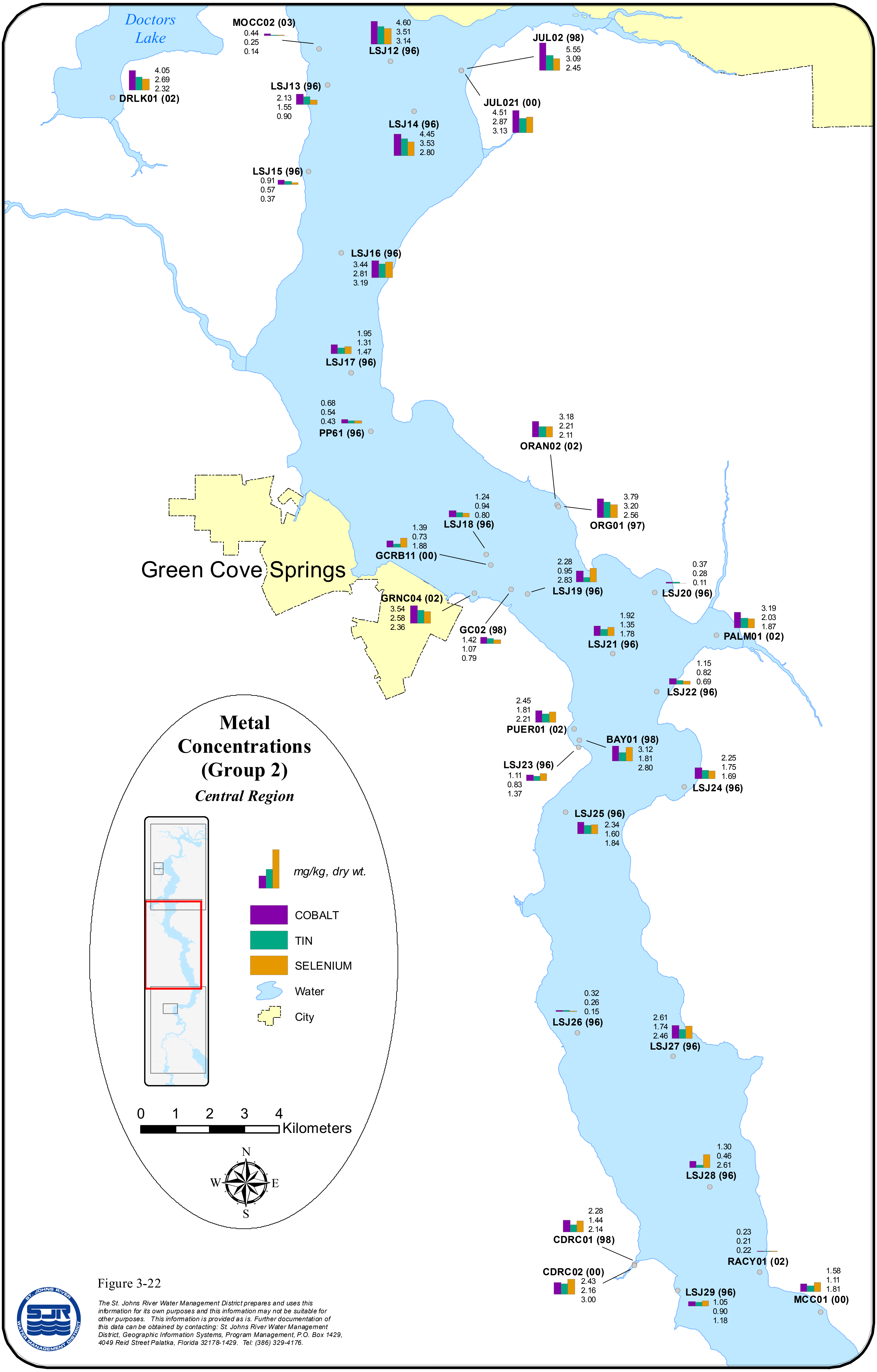


Figure 3-22

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

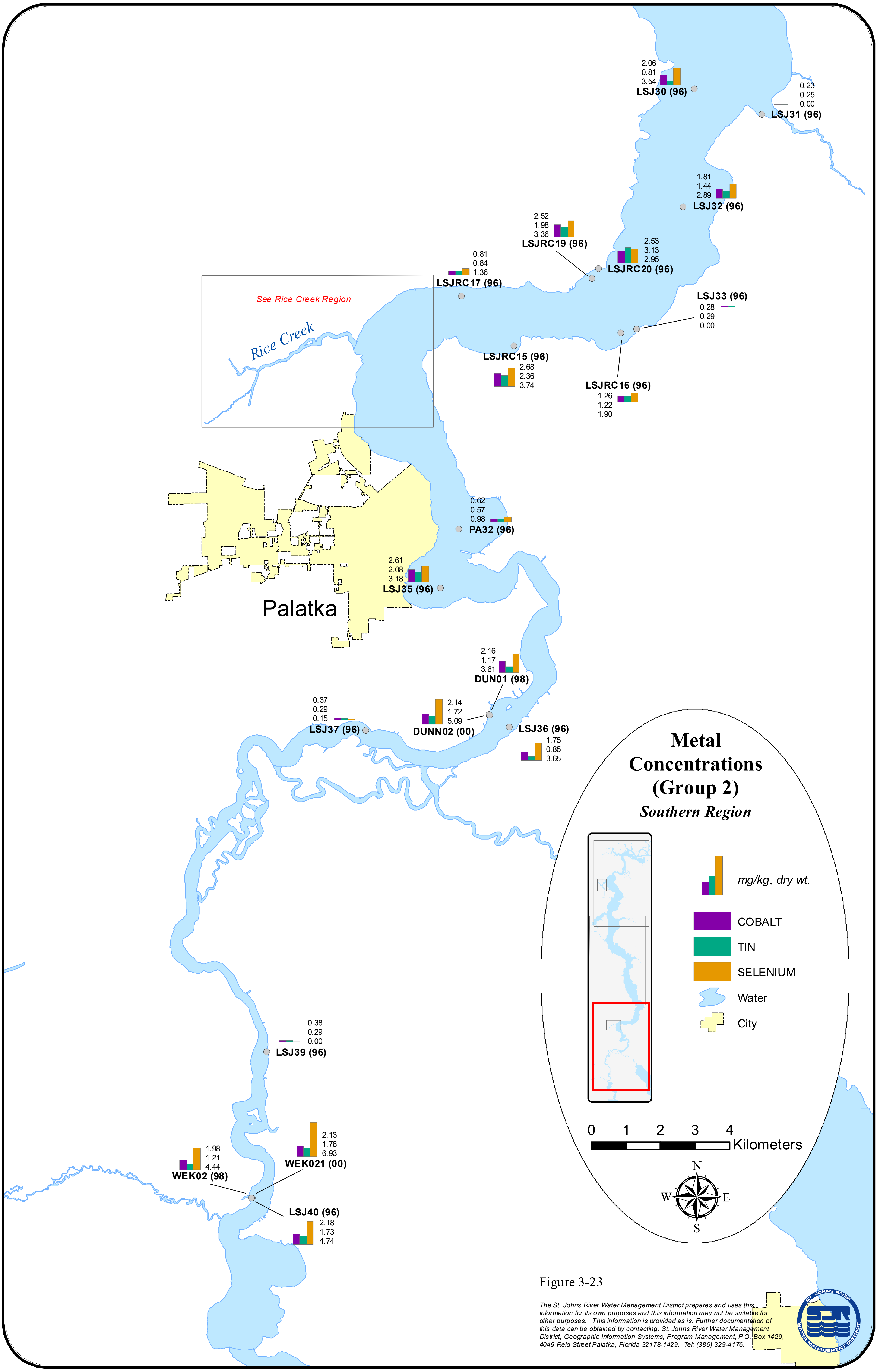


Figure 3-23

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# Metal Concentrations (Group 2)

*Rice Creek Region*

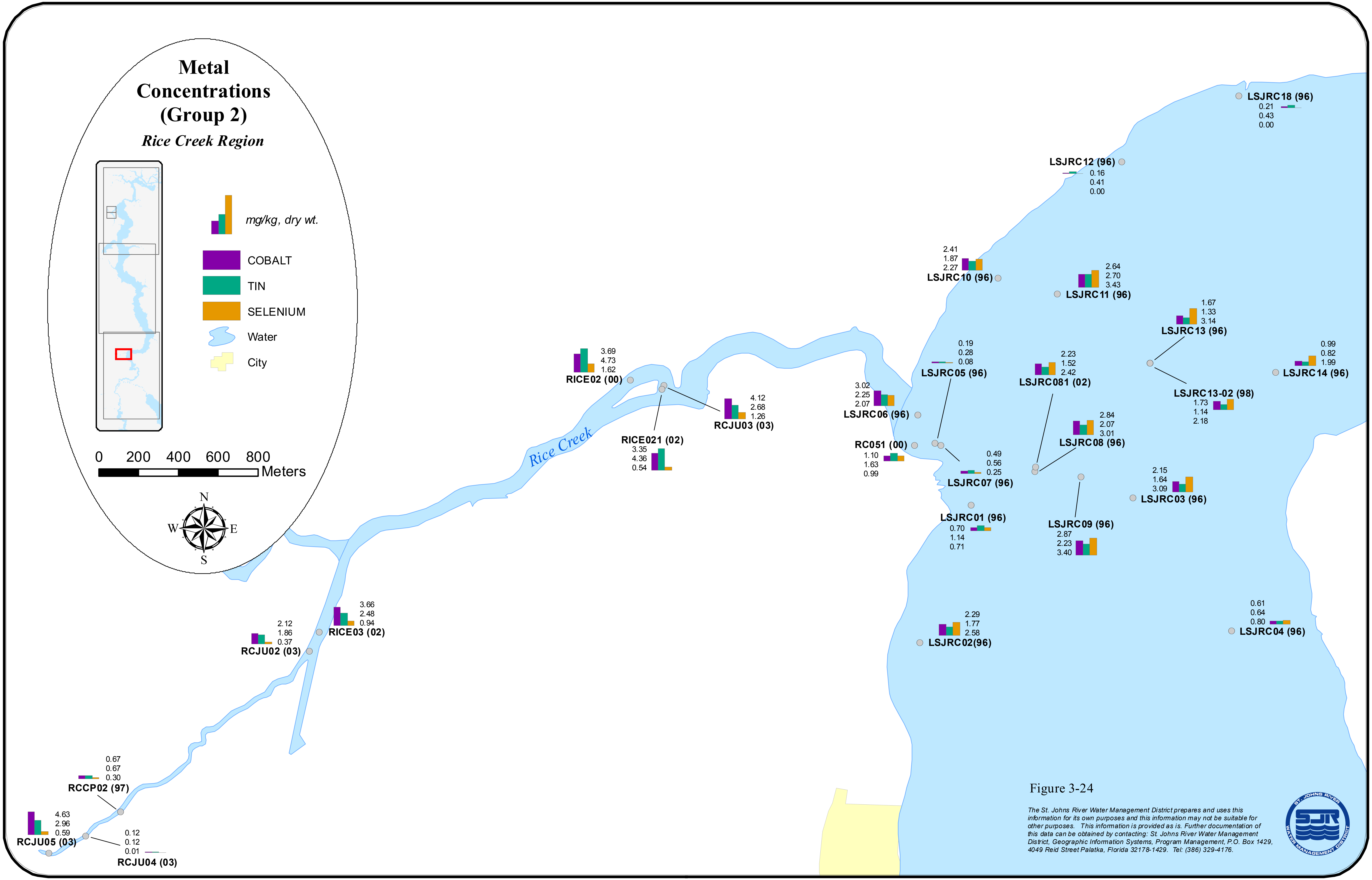
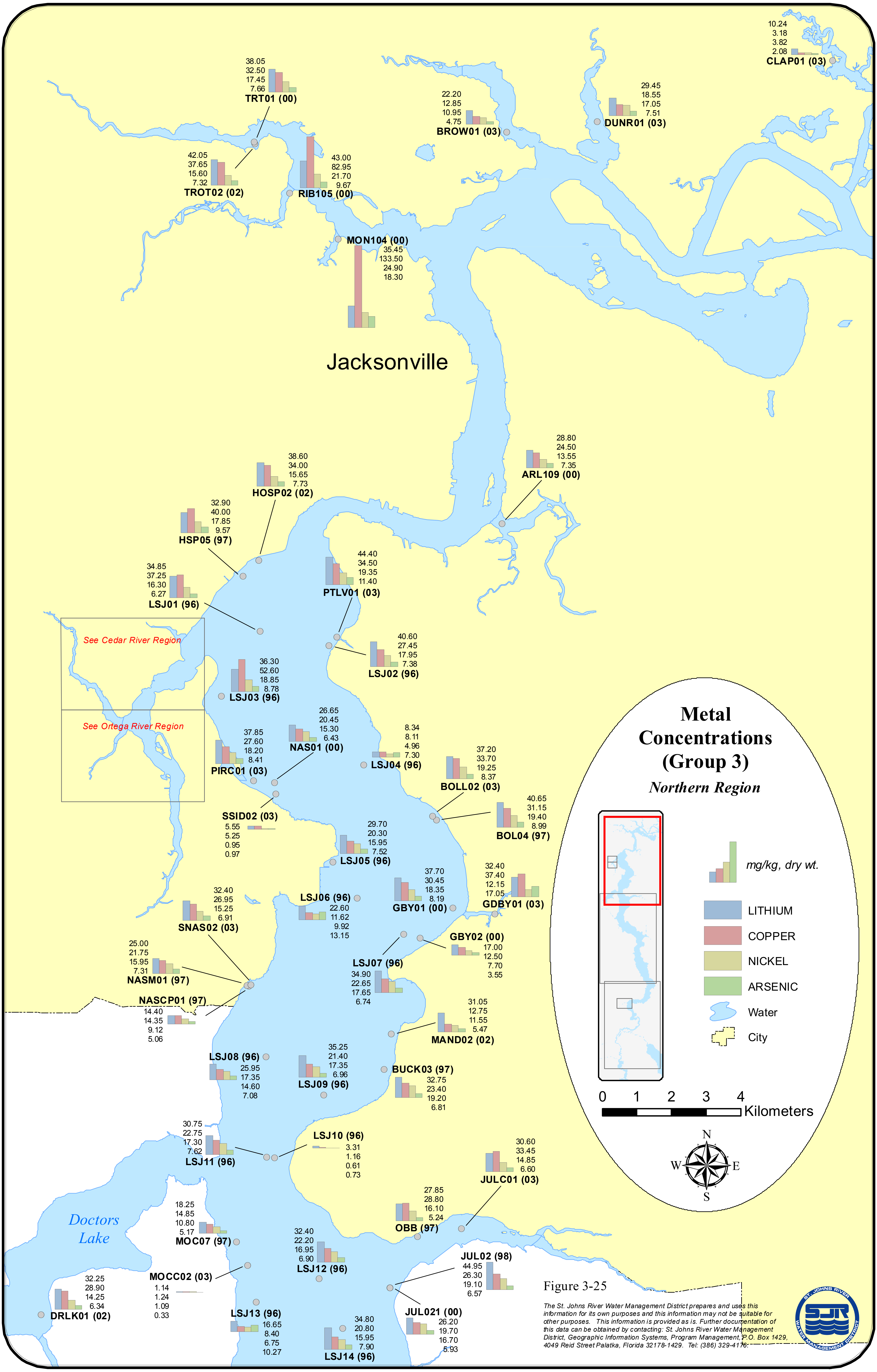


Figure 3-24

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

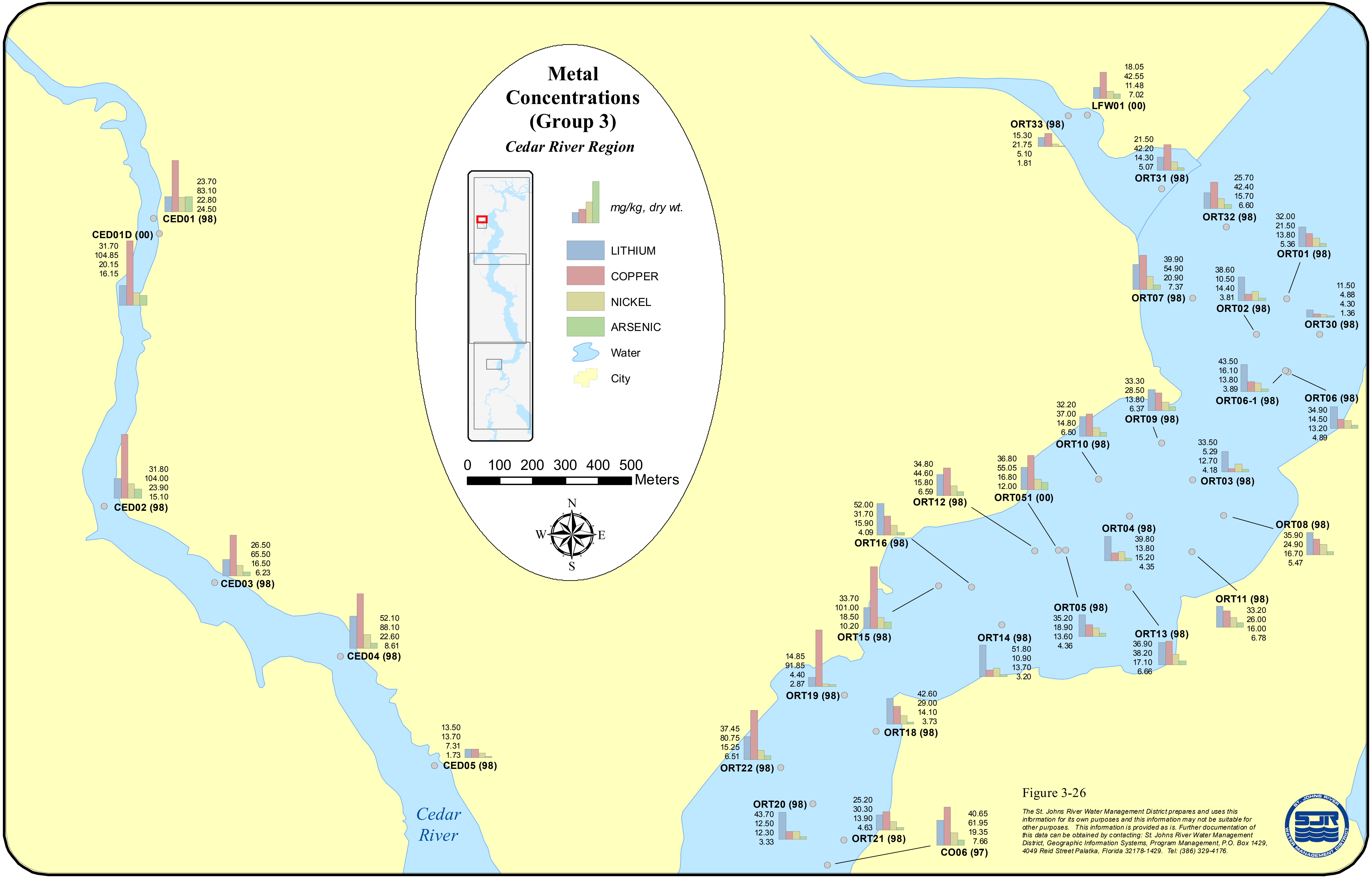


# Metal Concentrations (Group 3)

## *Northern Region*

Figure 3-25

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.



# Metal Concentrations (Group 3)

*Cedar River Region*

Figure 3-26

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

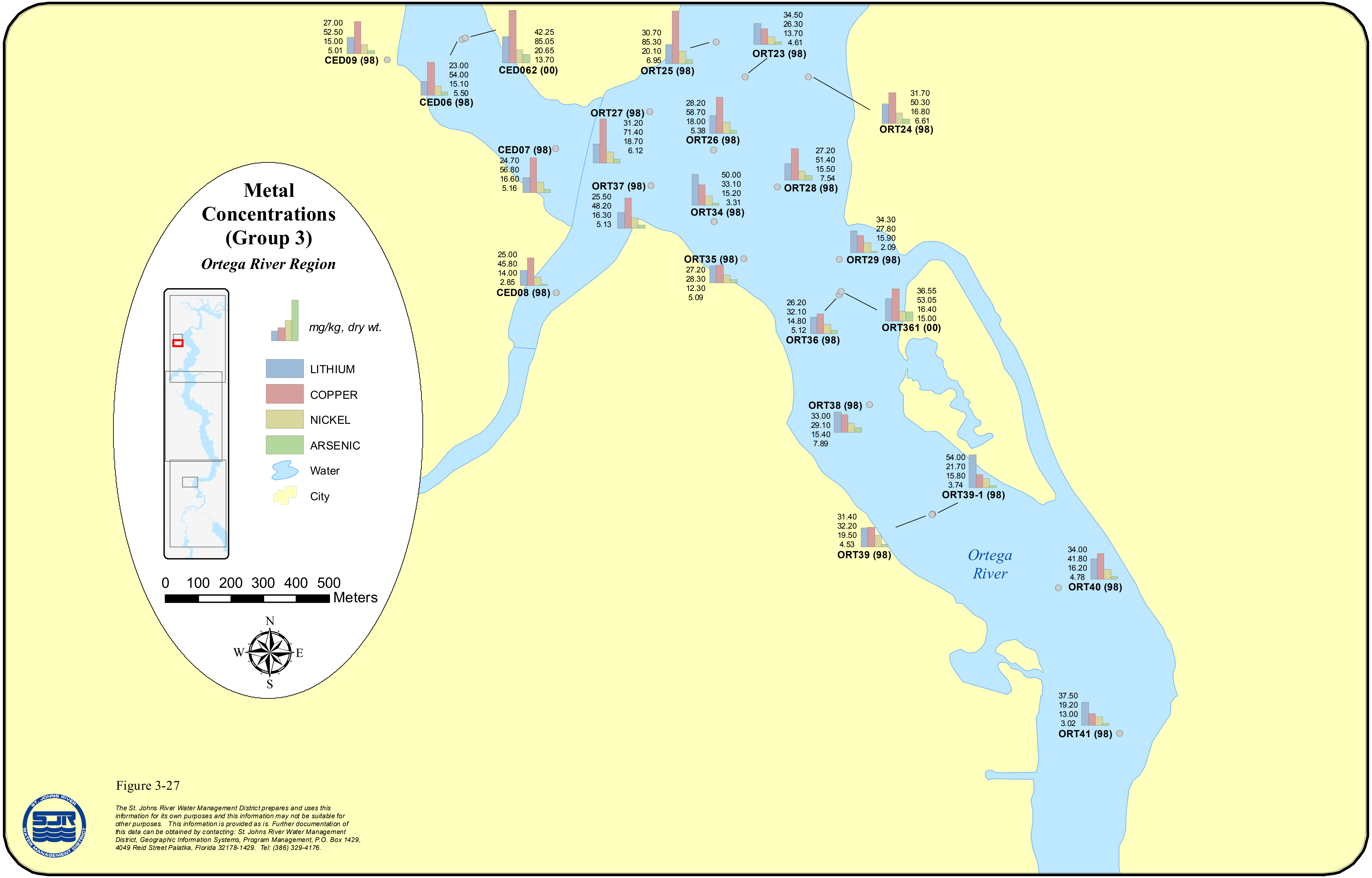


Figure 3-27

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Metal Concentrations (Group 3)

*Central Region*

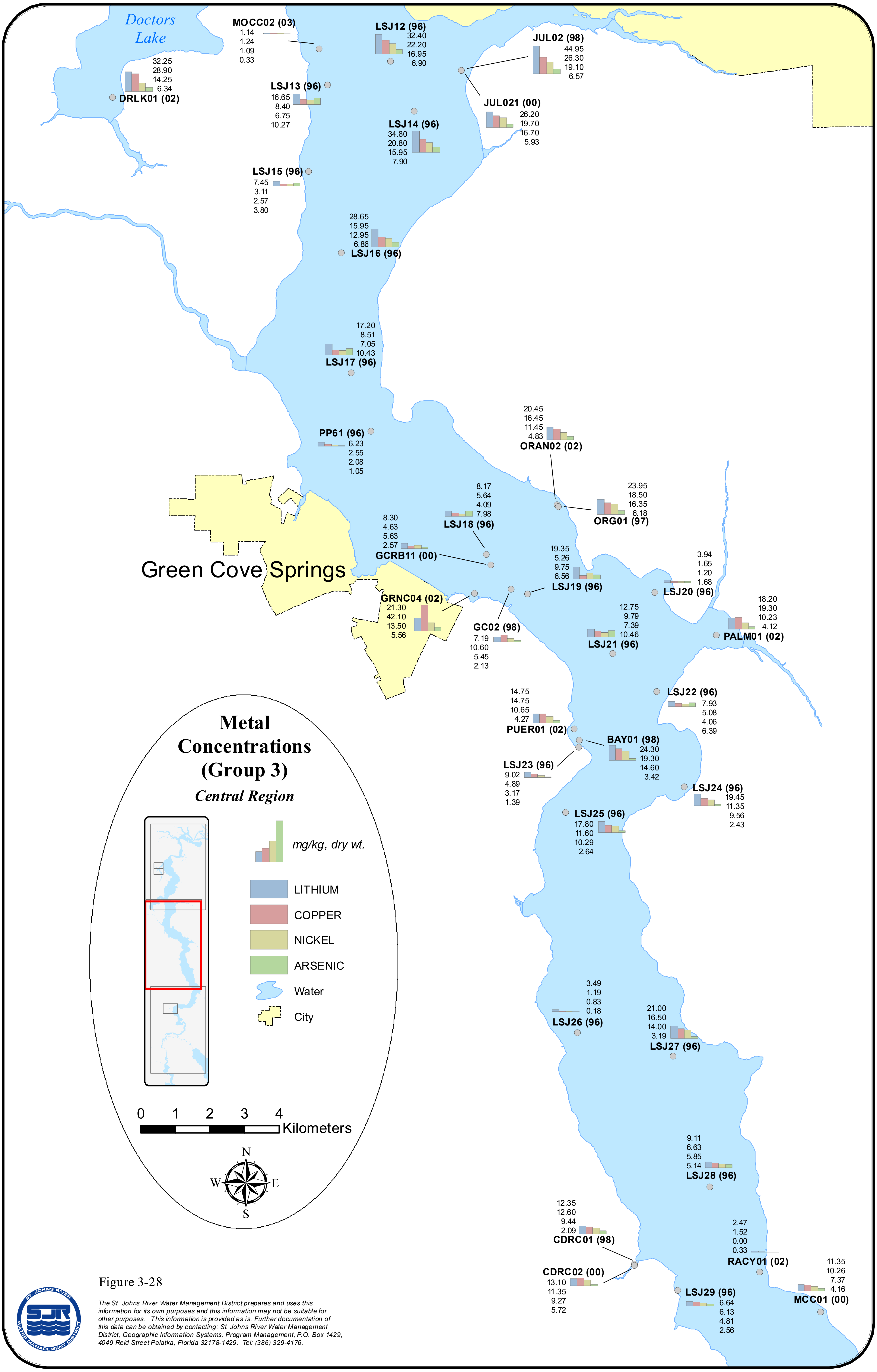
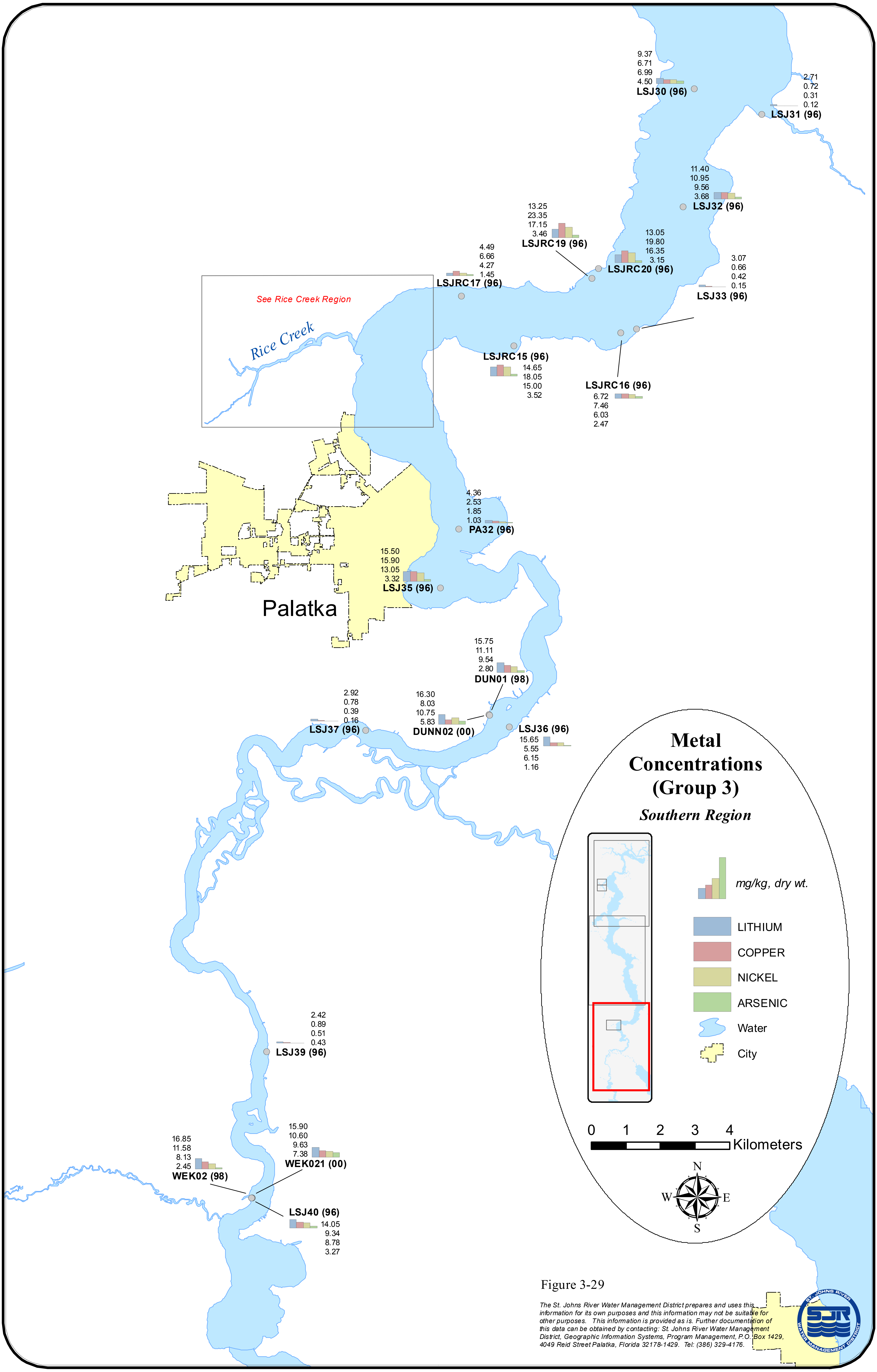


Figure 3-28

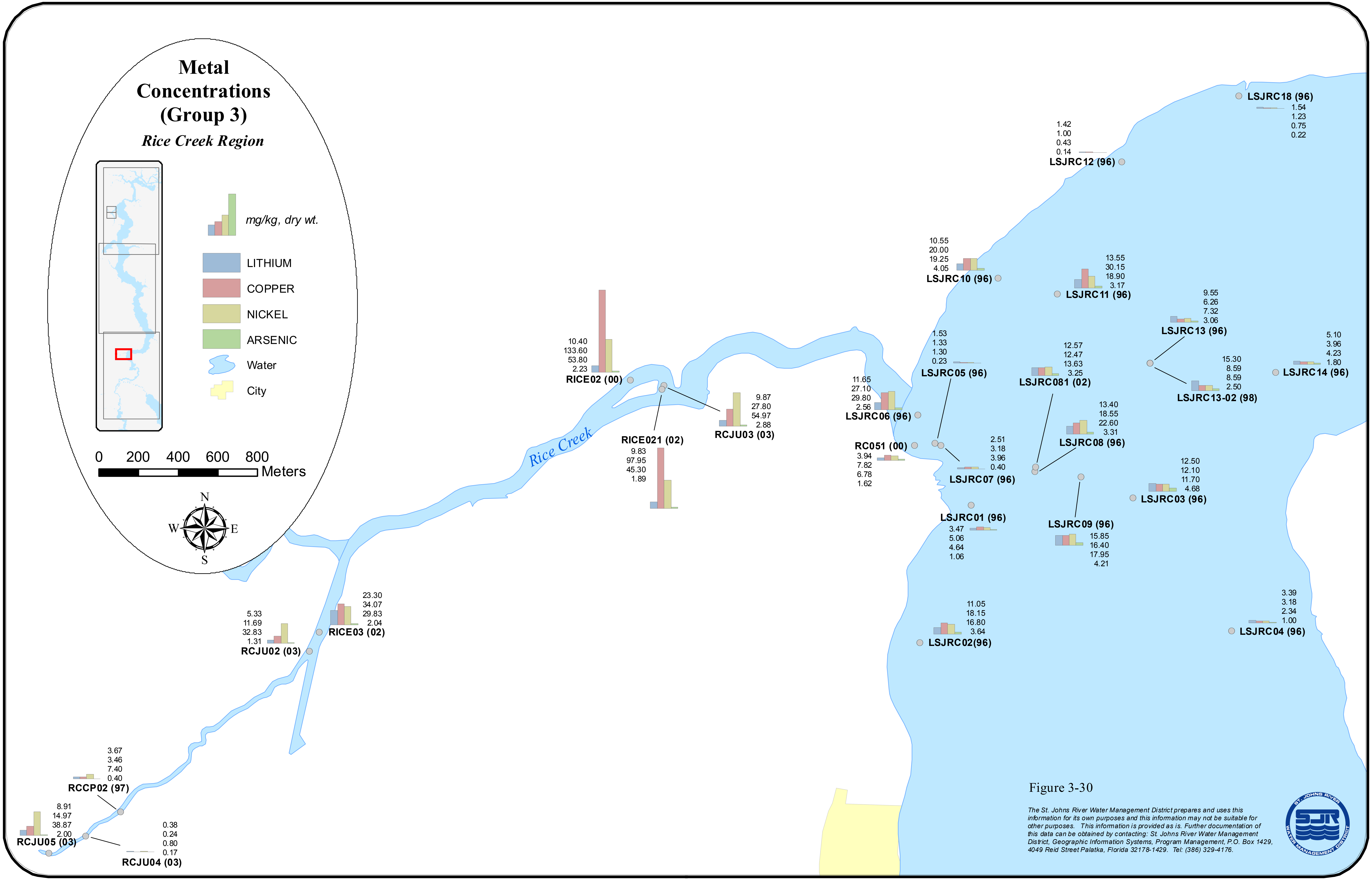
*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*


Metal Concentrations (Group 3)

*Southern Region*

Figure 3-29

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

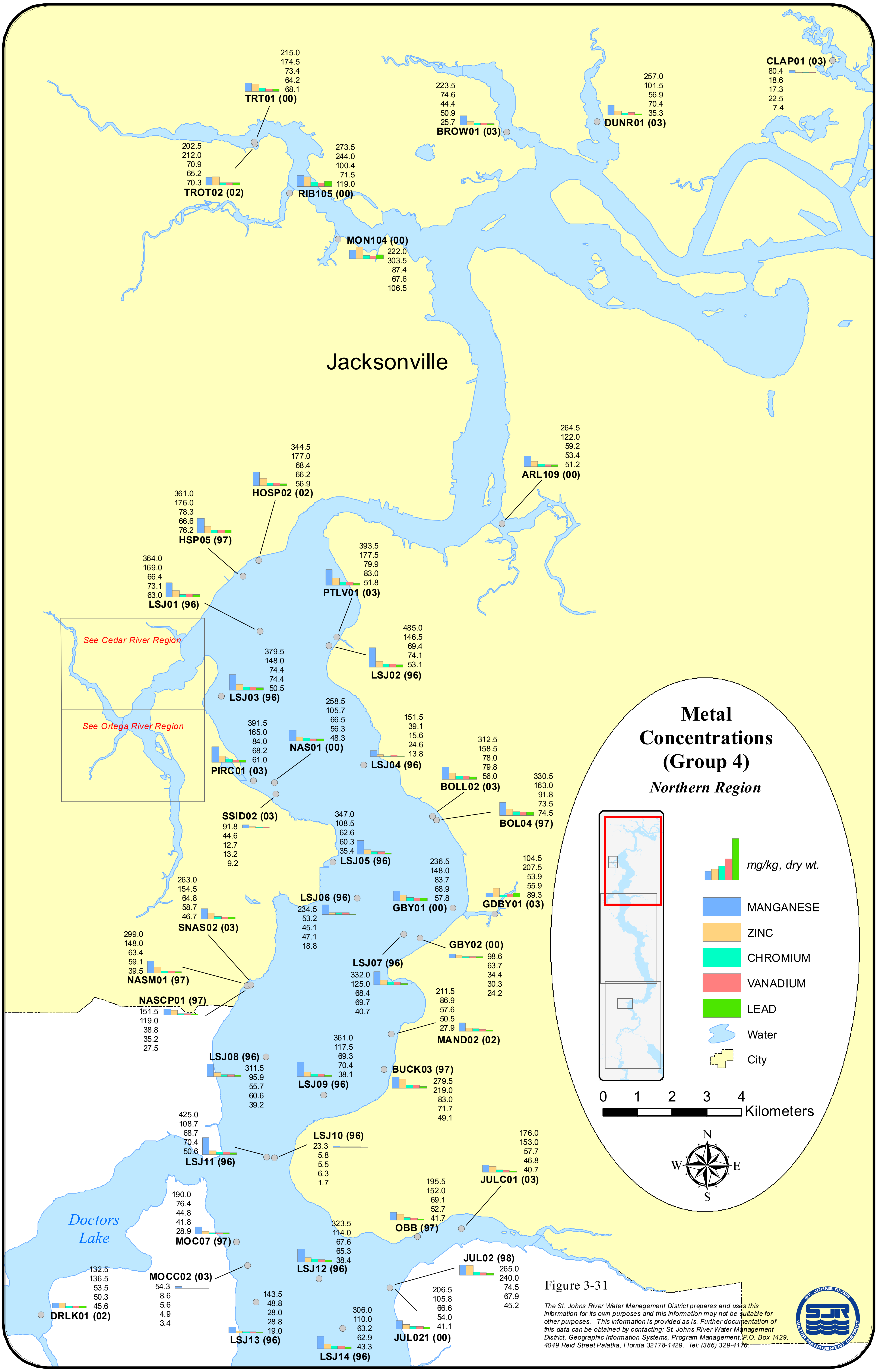


# Metal Concentrations (Group 3)

*Rice Creek Region*

Figure 3-30

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



# Metal Concentrations (Group 4)

*Northern Region*

Figure 3-31

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

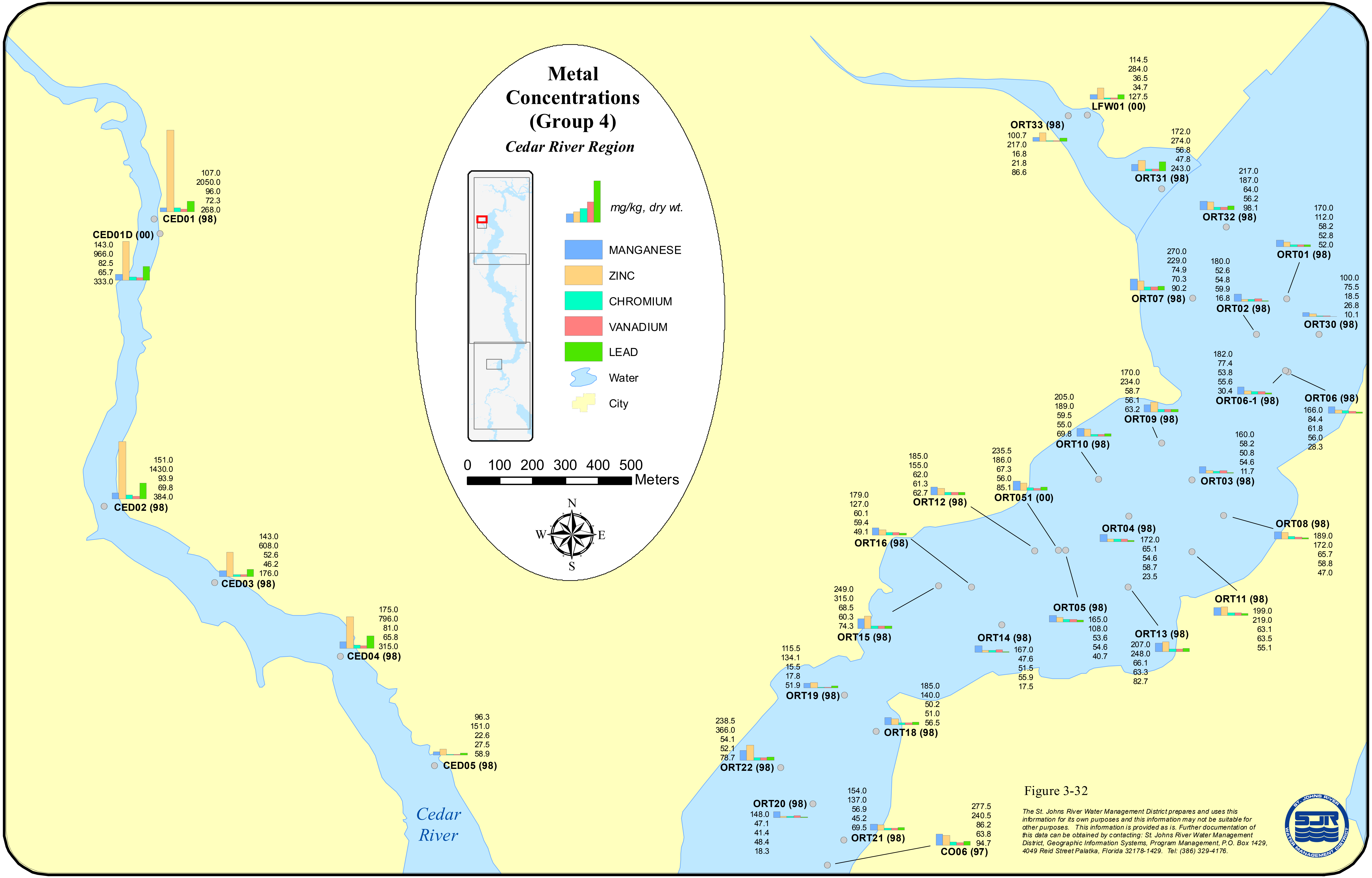


Figure 3-32

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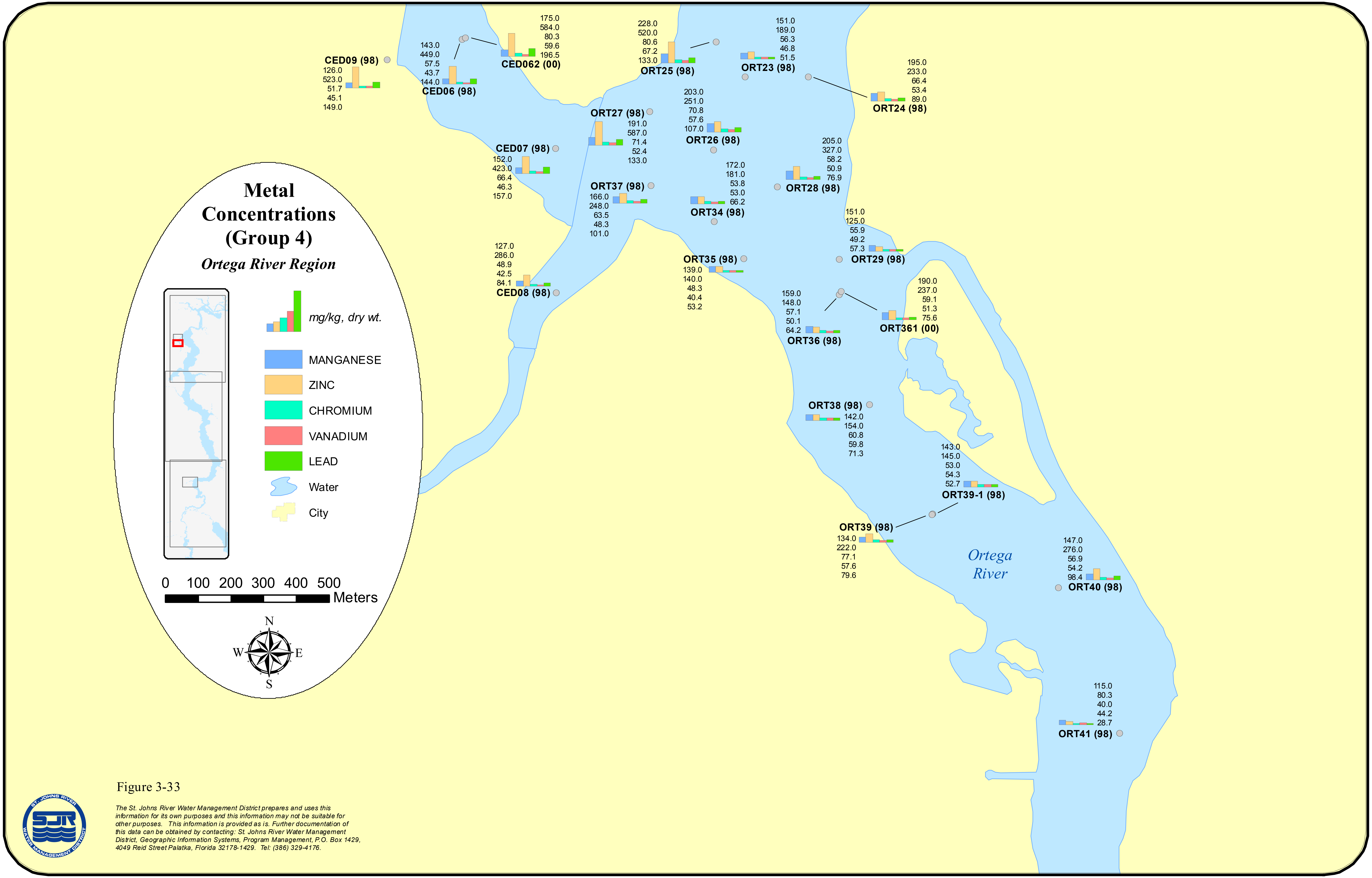

Metal Concentrations (Group 4)

*Ortega River Region*

Figure 3-33

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

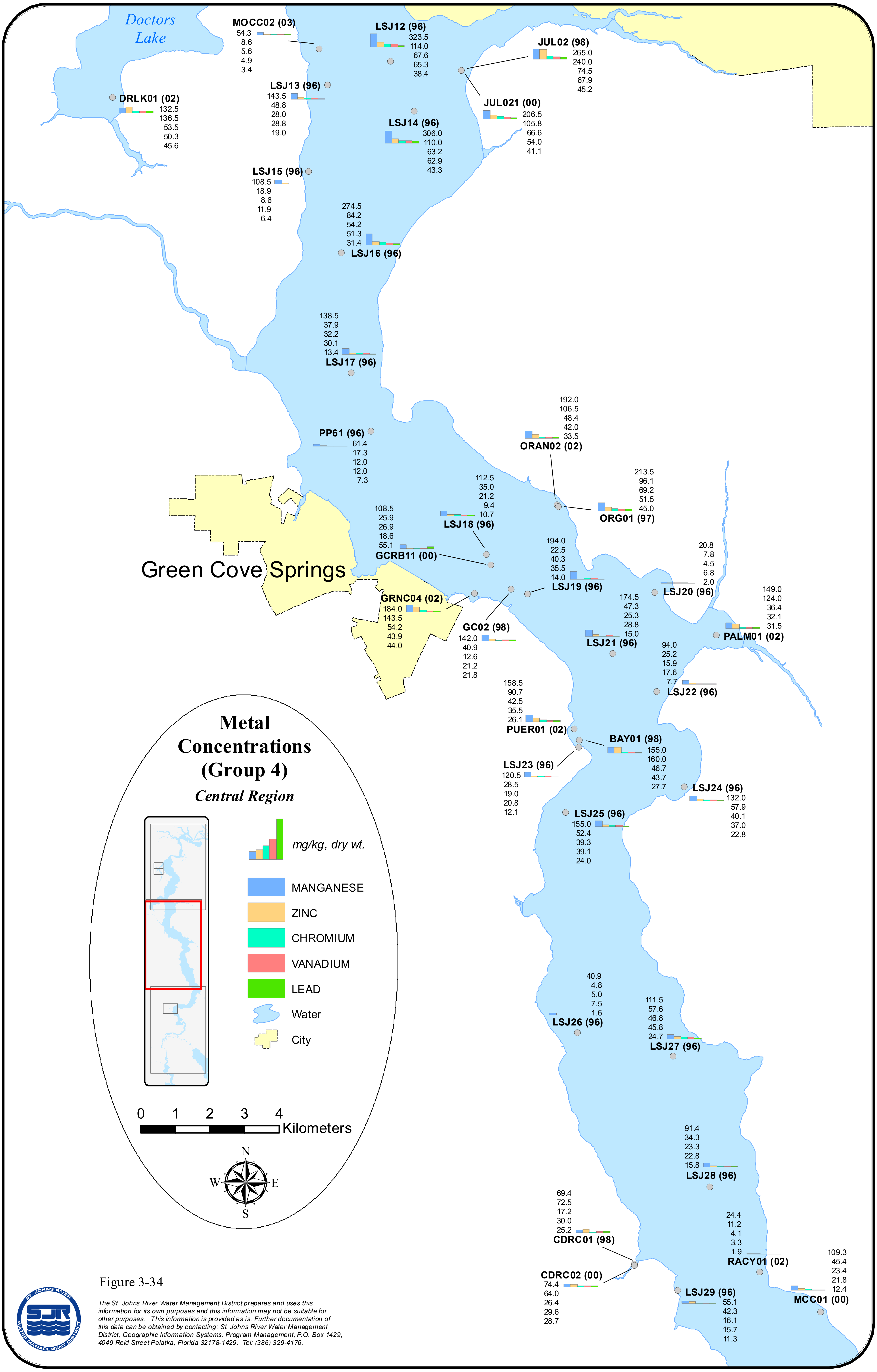

Figure 3-34

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

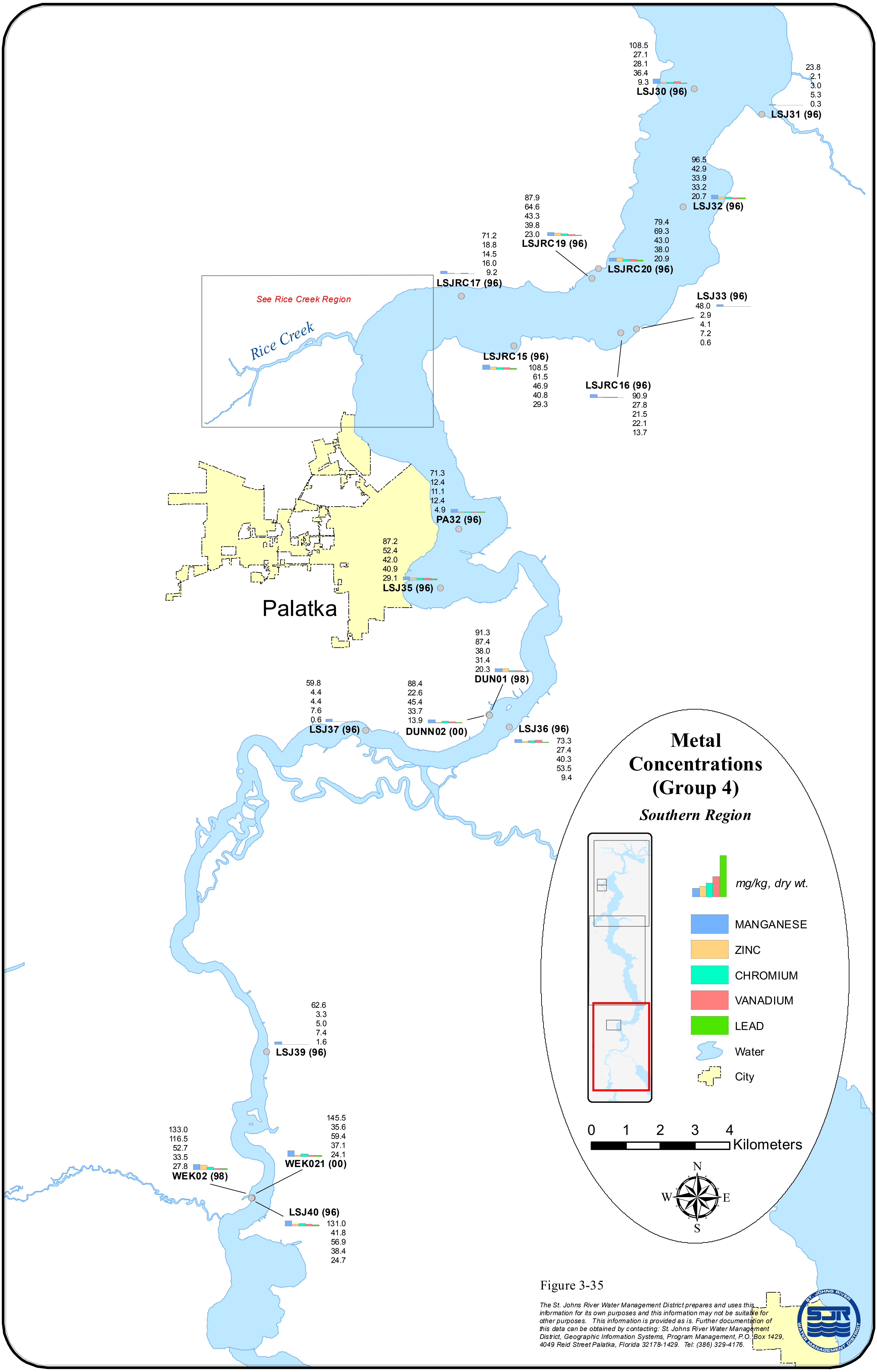

Figure 3-35

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# Metal Concentrations (Group 4)

*Rice Creek Region*

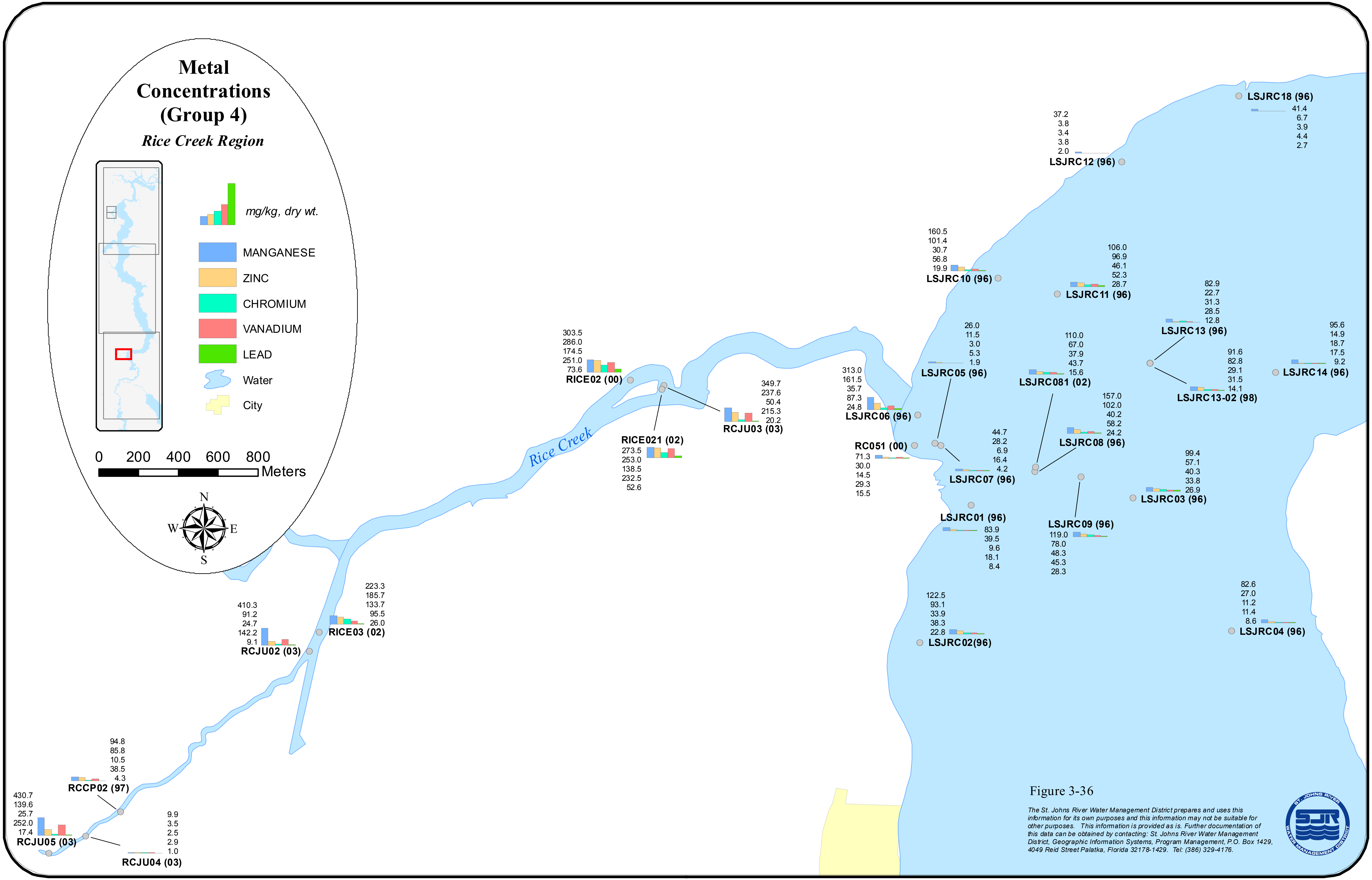

Figure 3-36

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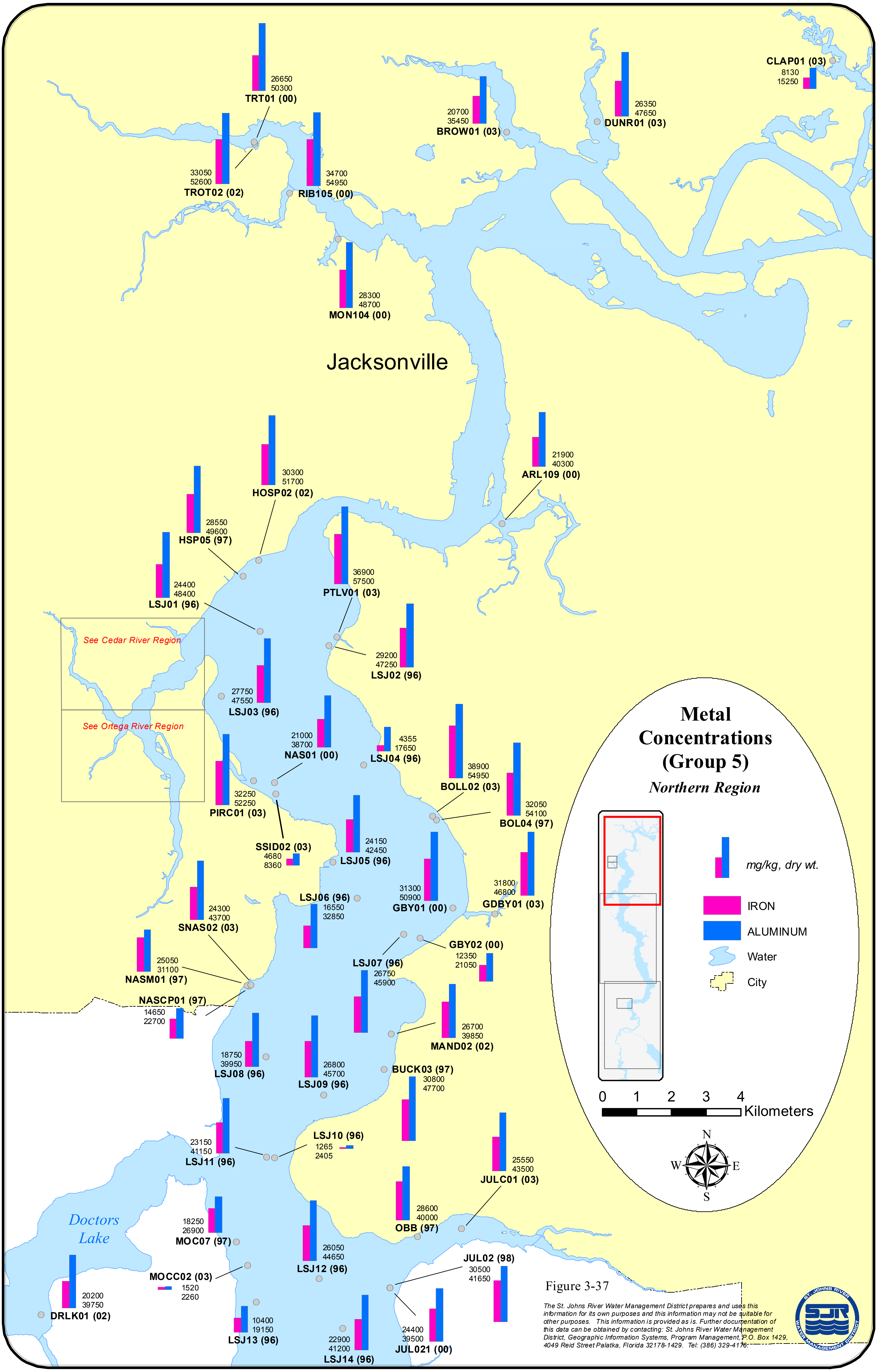
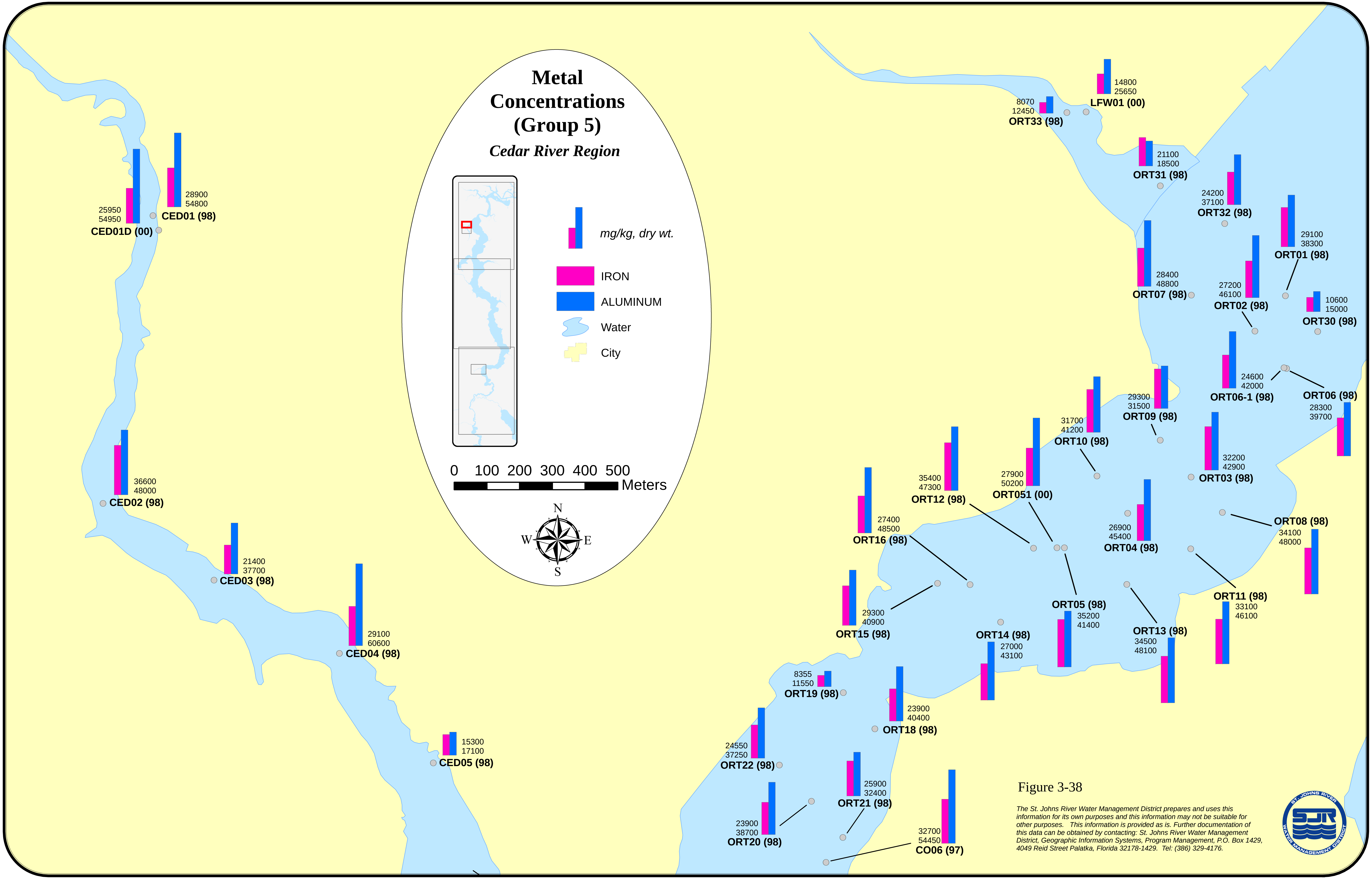


# Metal Concentrations (Group 5)

*Northern Region*

Figure 3-37

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

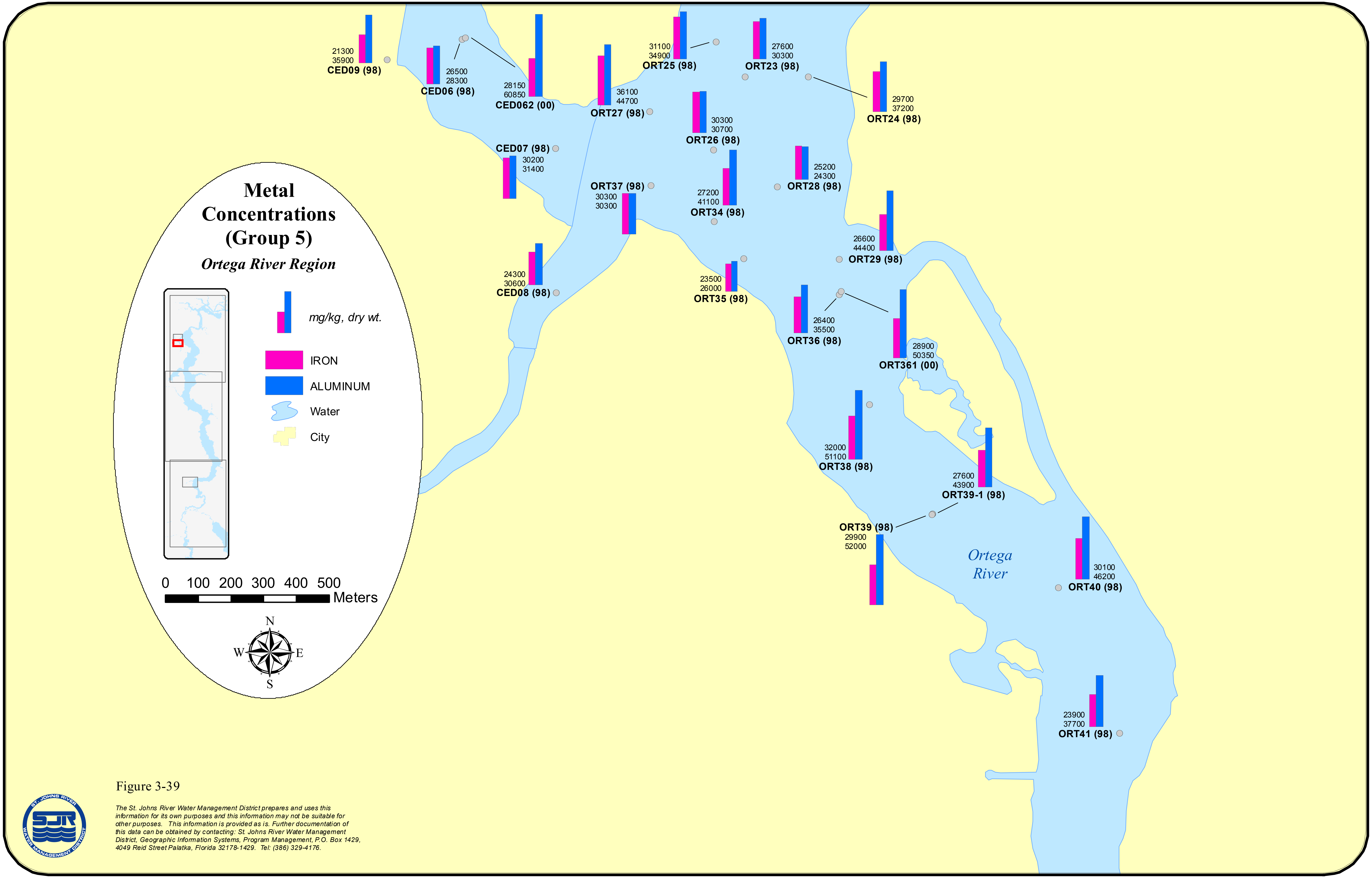


# Metal Concentrations (Group 5)

### *Cedar River Region*

Figure 3-38

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



# Metal Concentrations (Group 5)

*Ortega River Region*

Figure 3-39

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

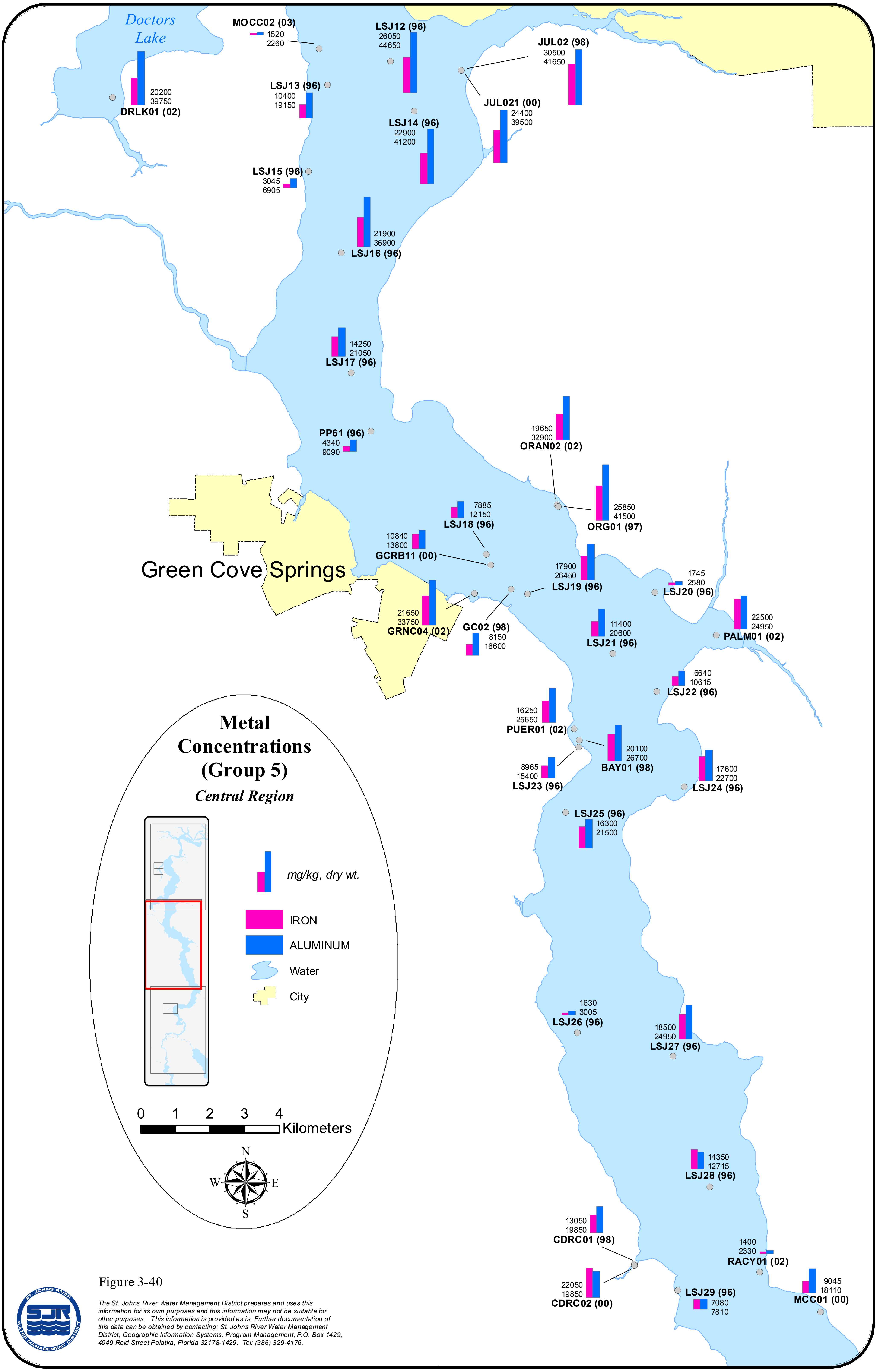


Figure 3-40

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

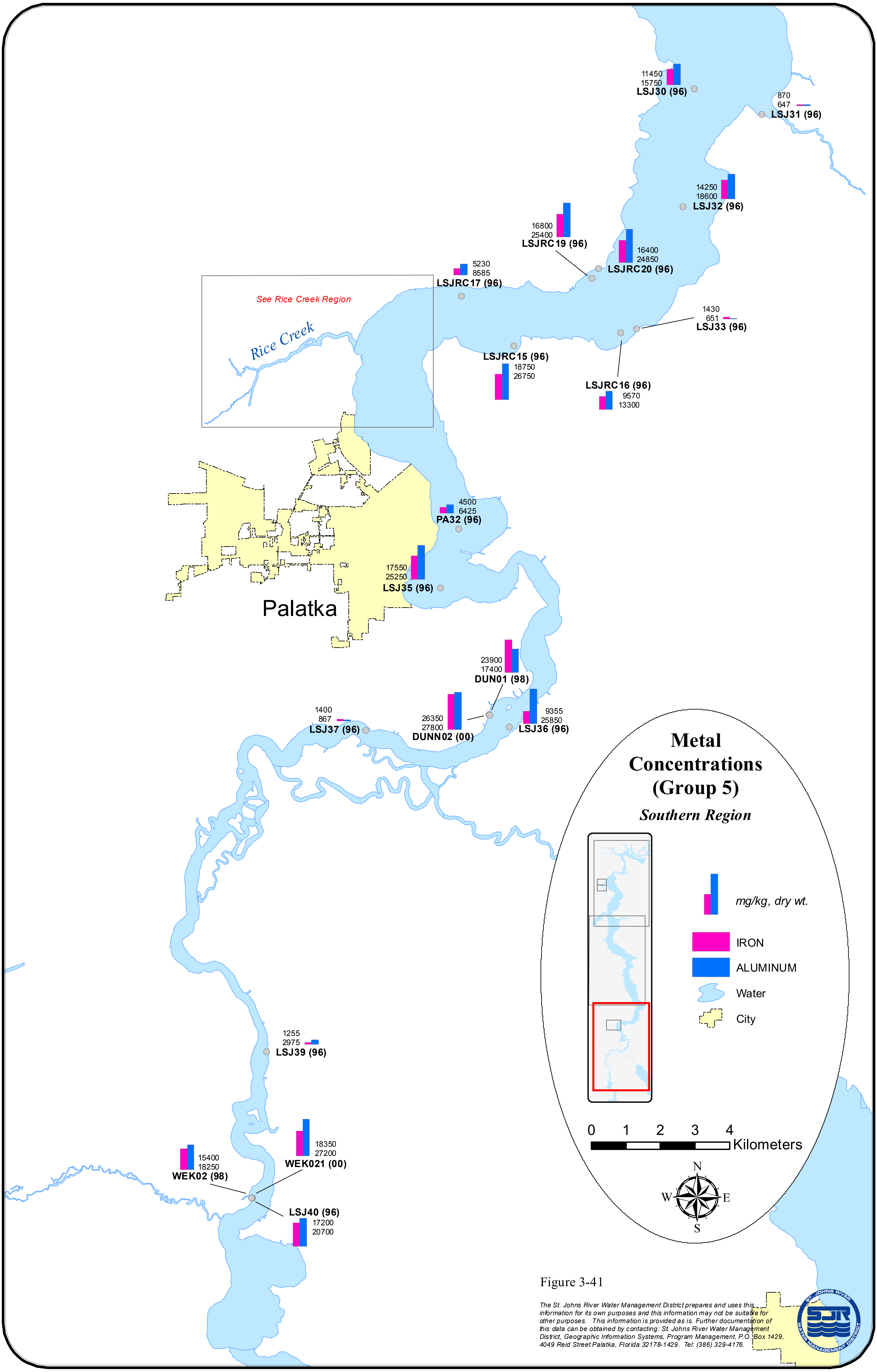
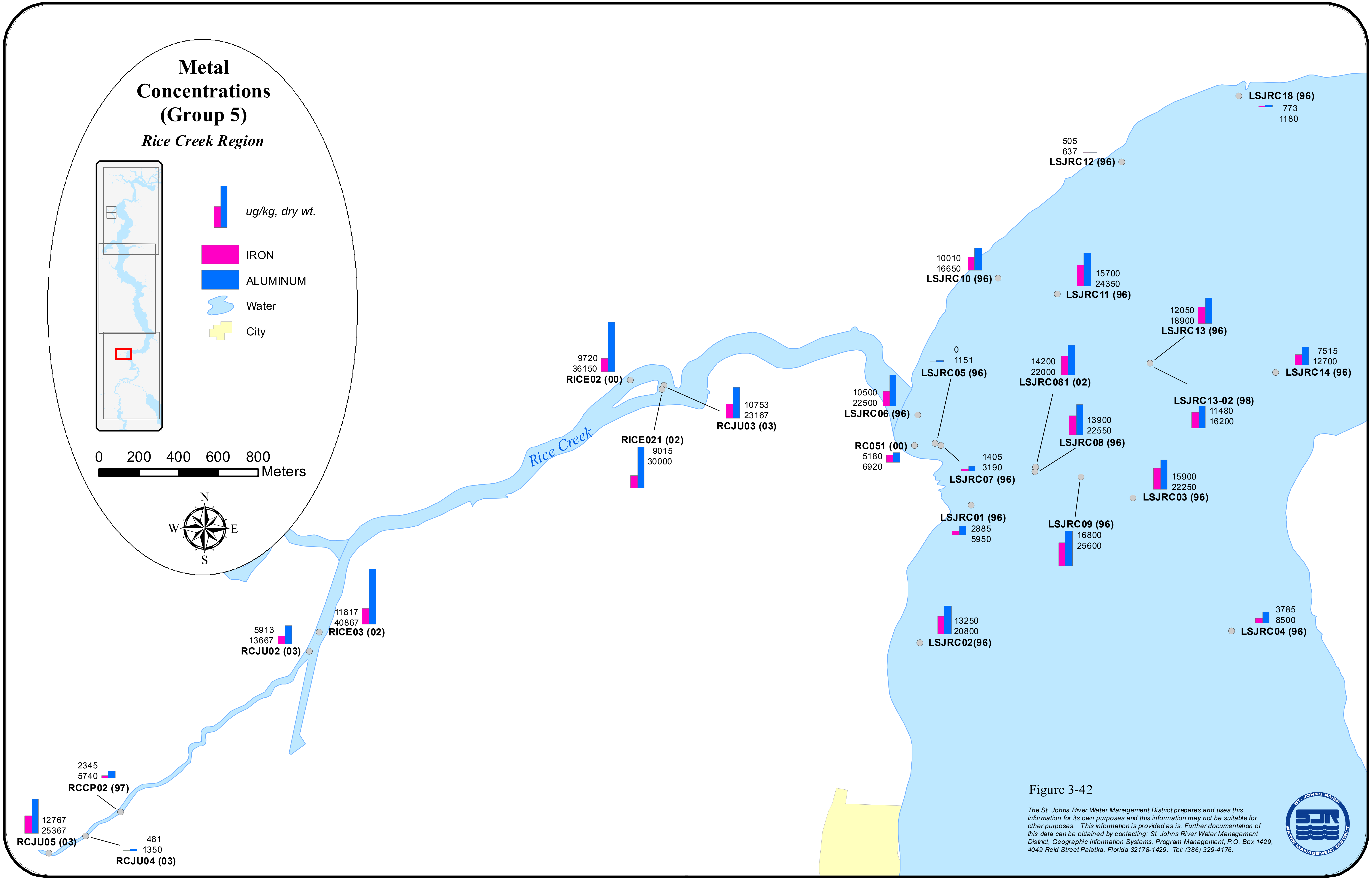


Figure 3-41

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.



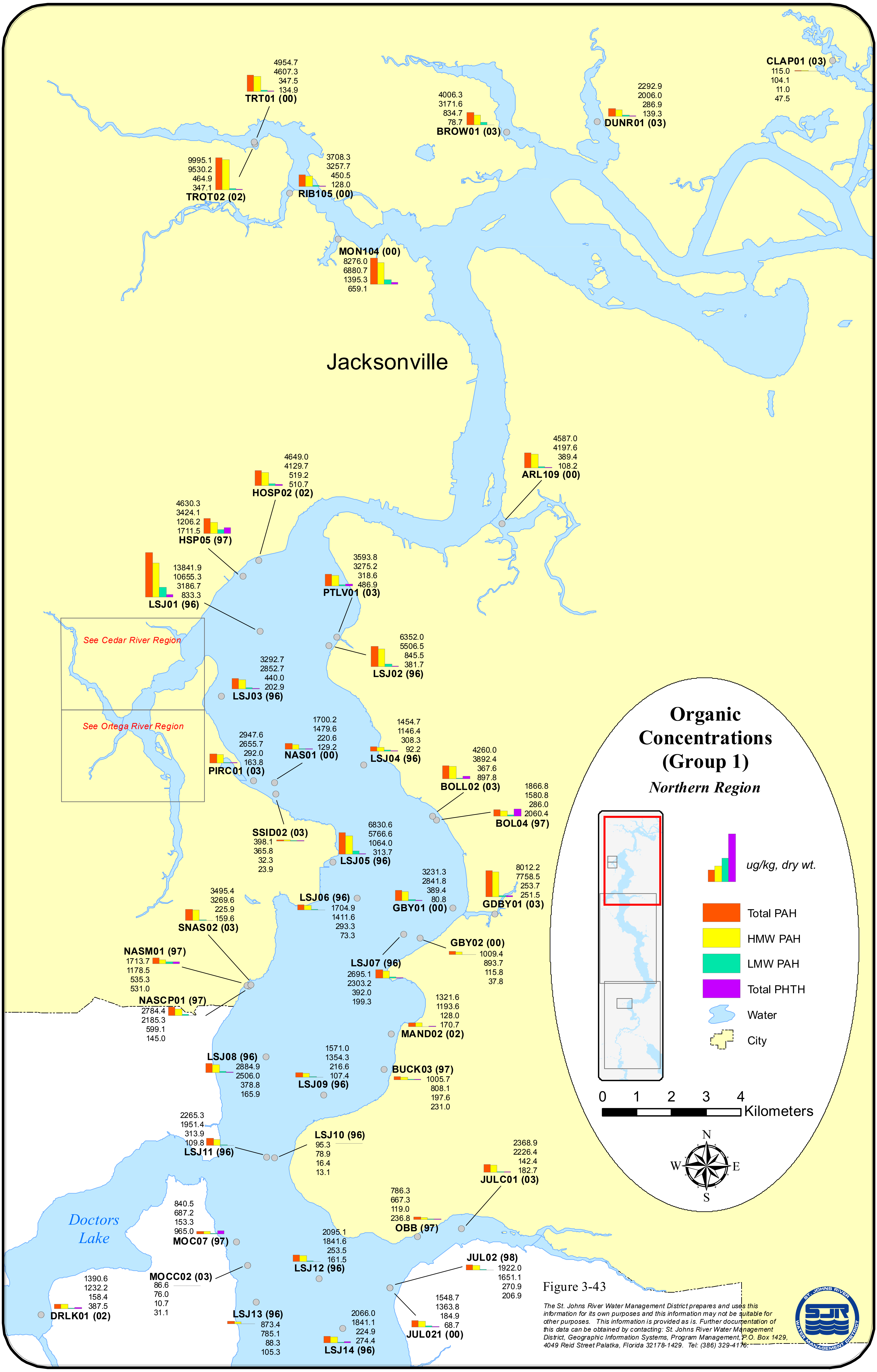


Figure 3-43

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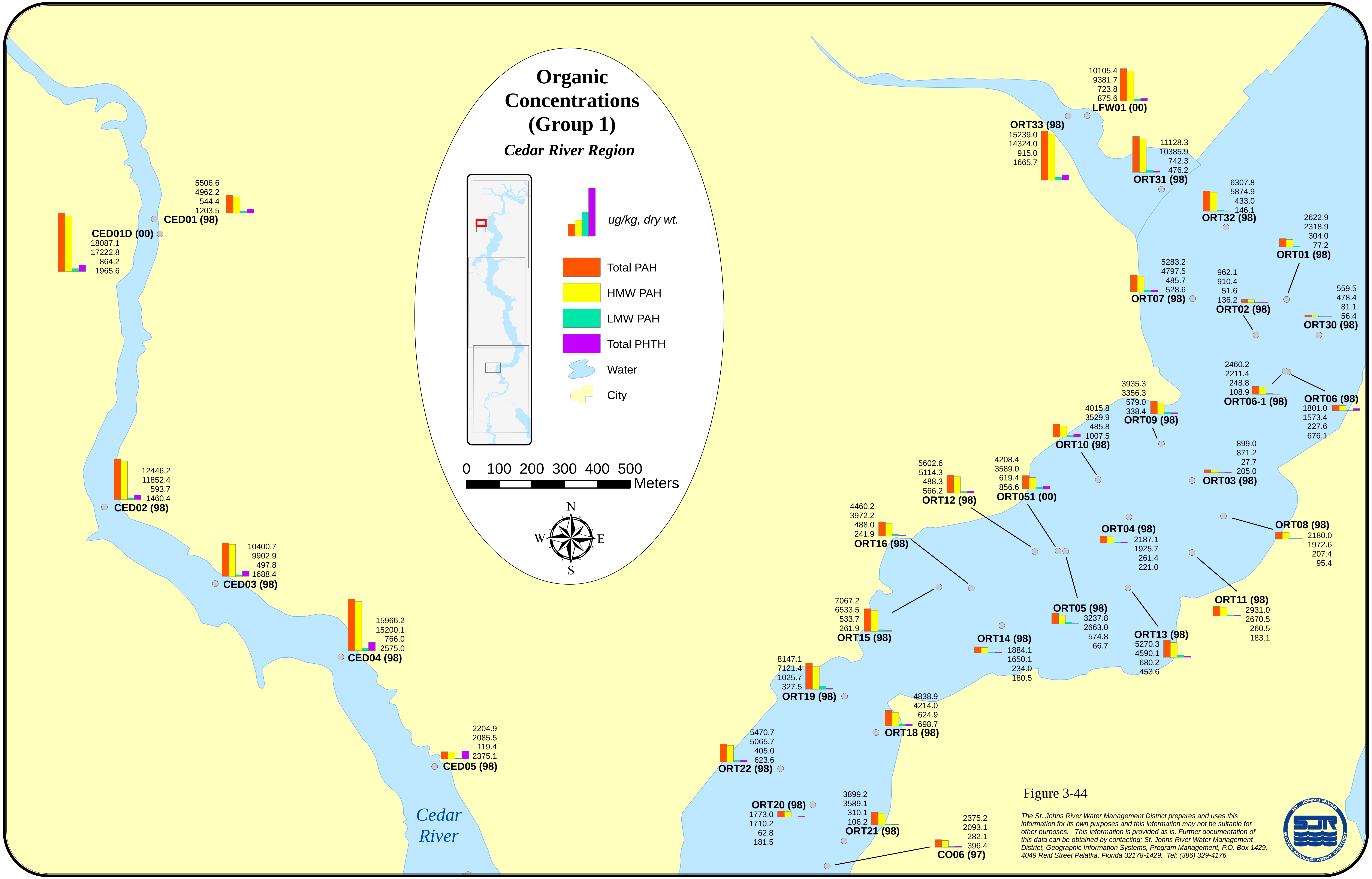

Figure 3-44

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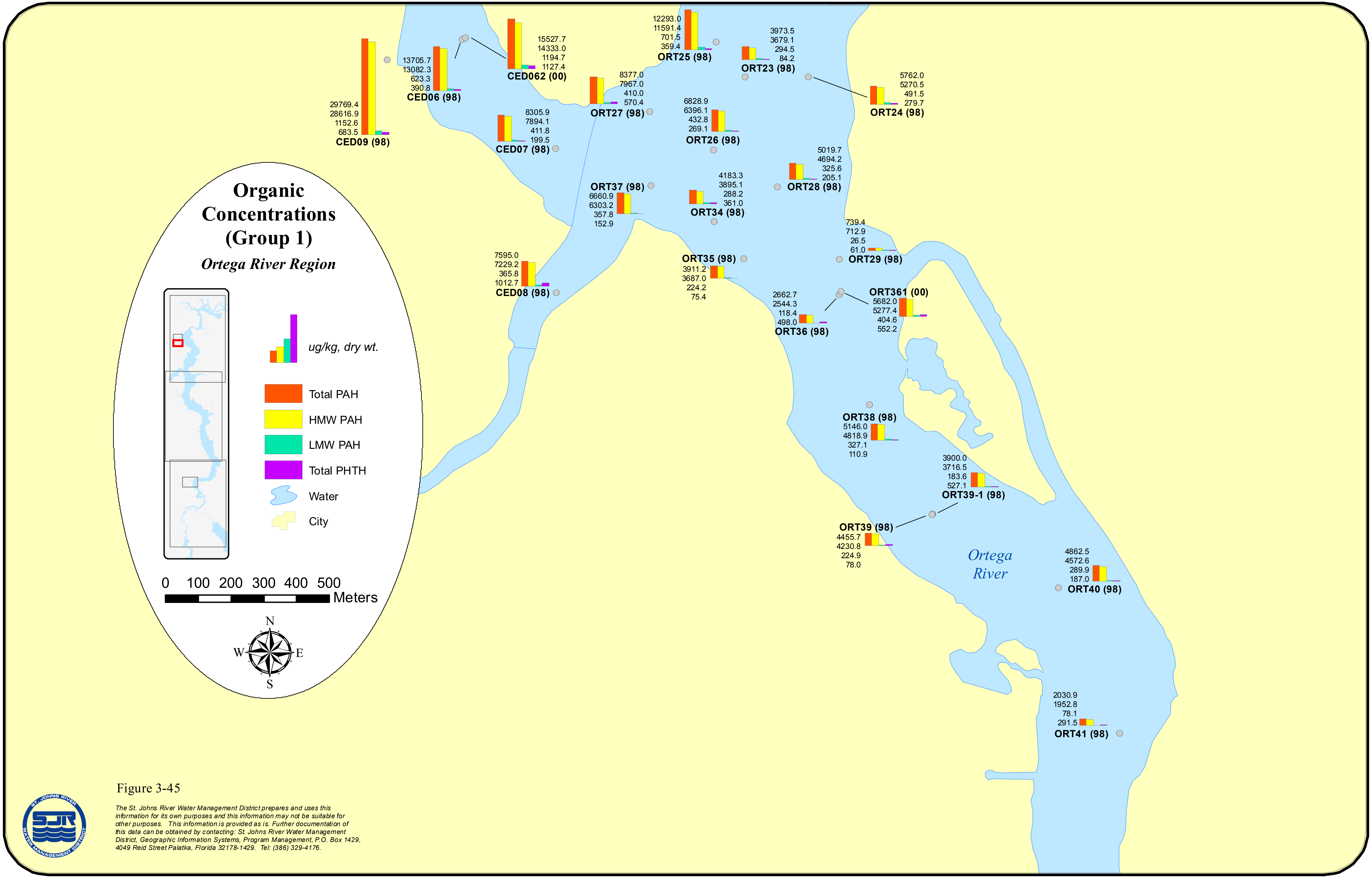


# Organic Concentrations (Group 1)

*Ortega River Region*

Figure 3-45

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

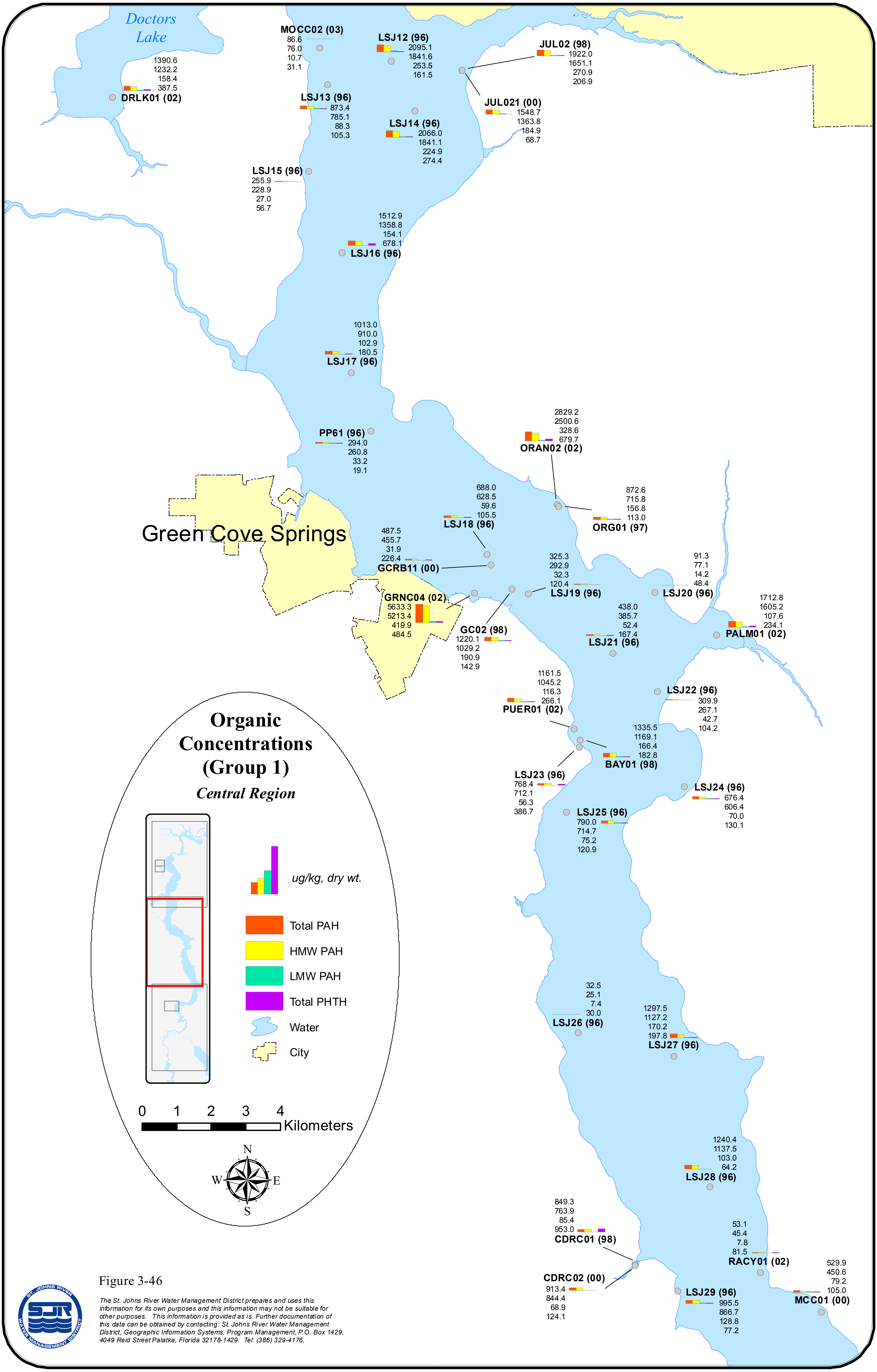


Figure 3-46

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.

# Organic Concentrations (Group 1)

## *Southern Region*

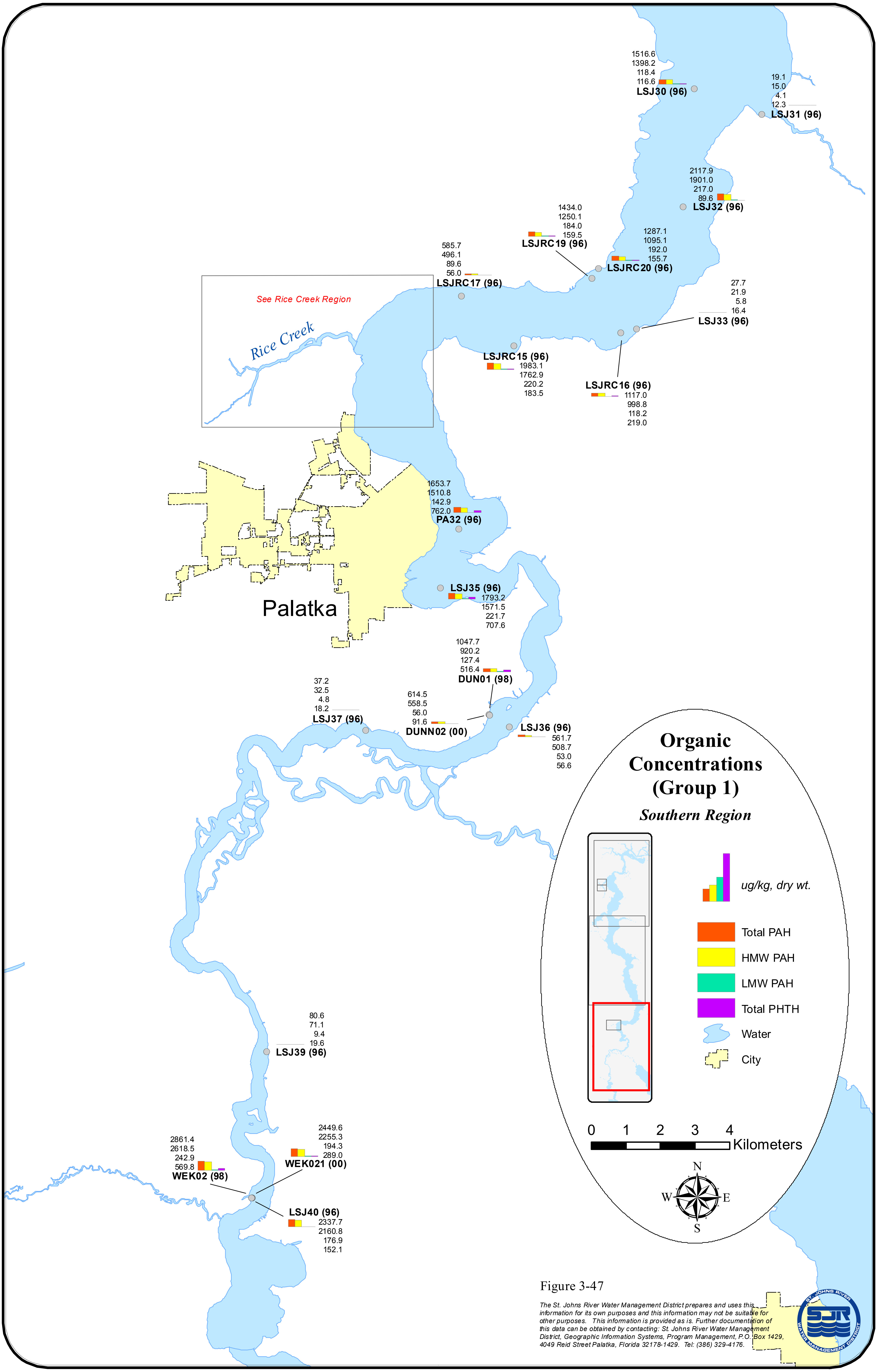


Figure 3-47

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

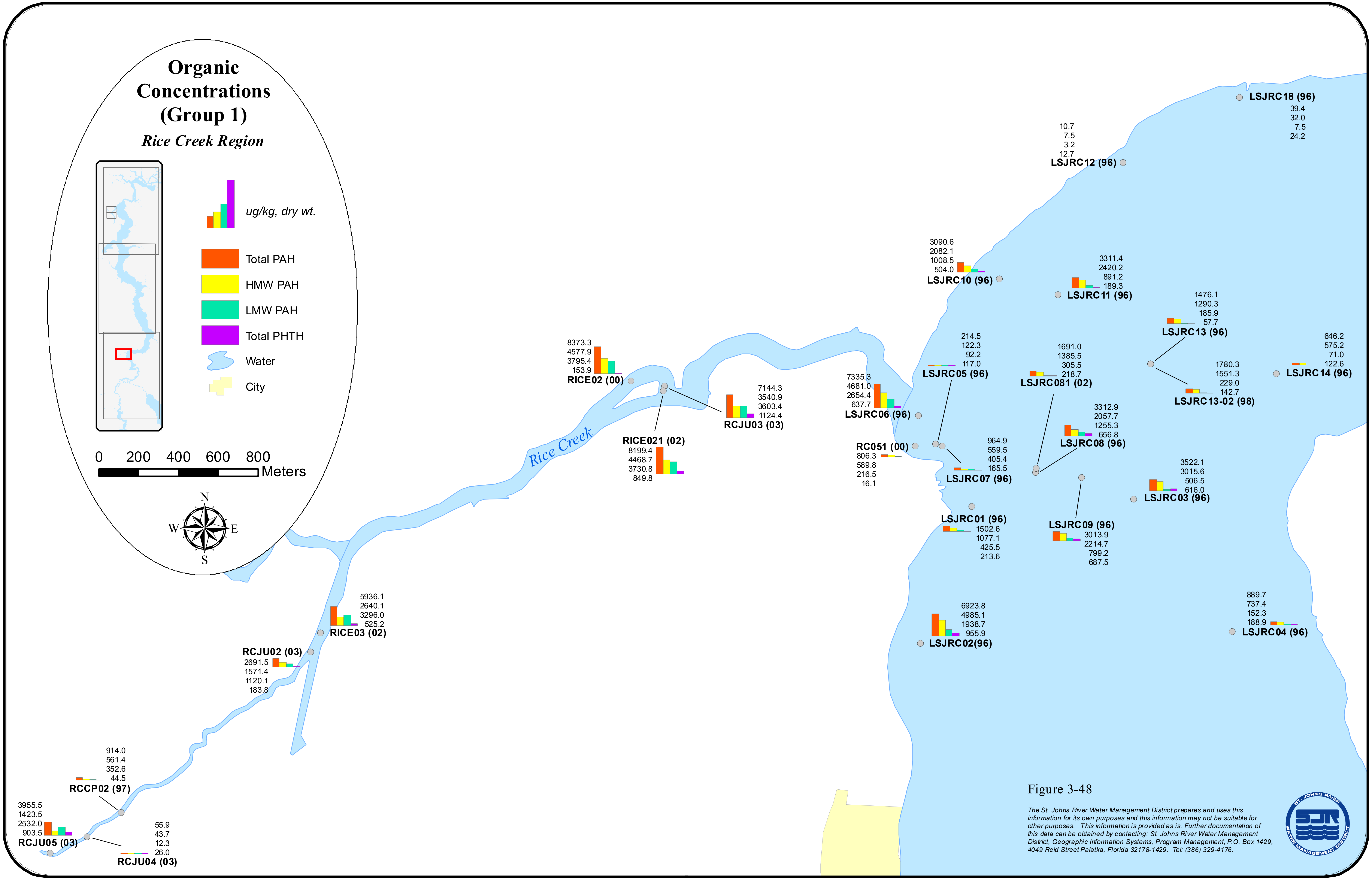


Figure 3-48

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

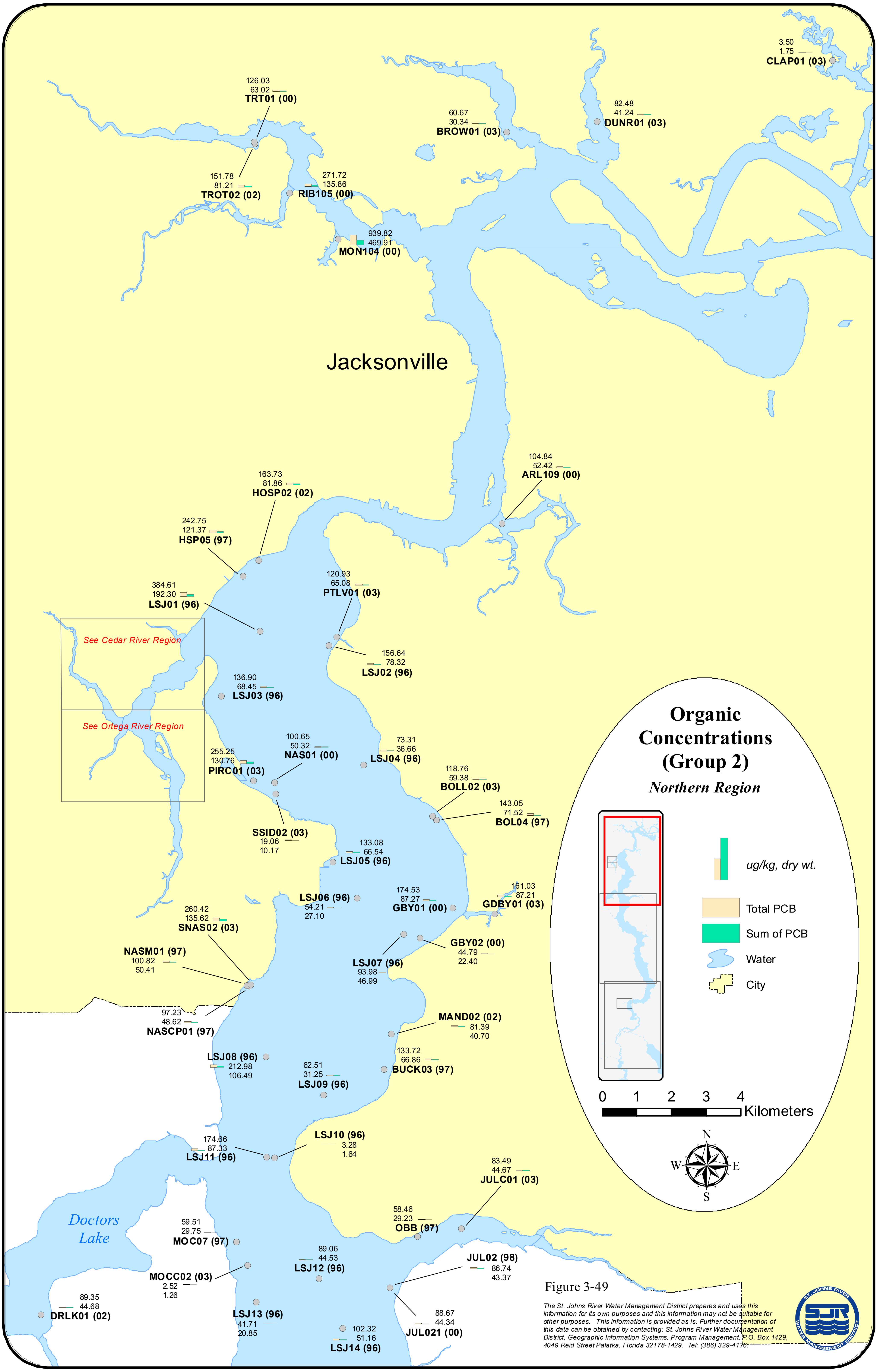


Figure 3-49

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.

# Organic Concentrations (Group 2)

*Cedar River Region*

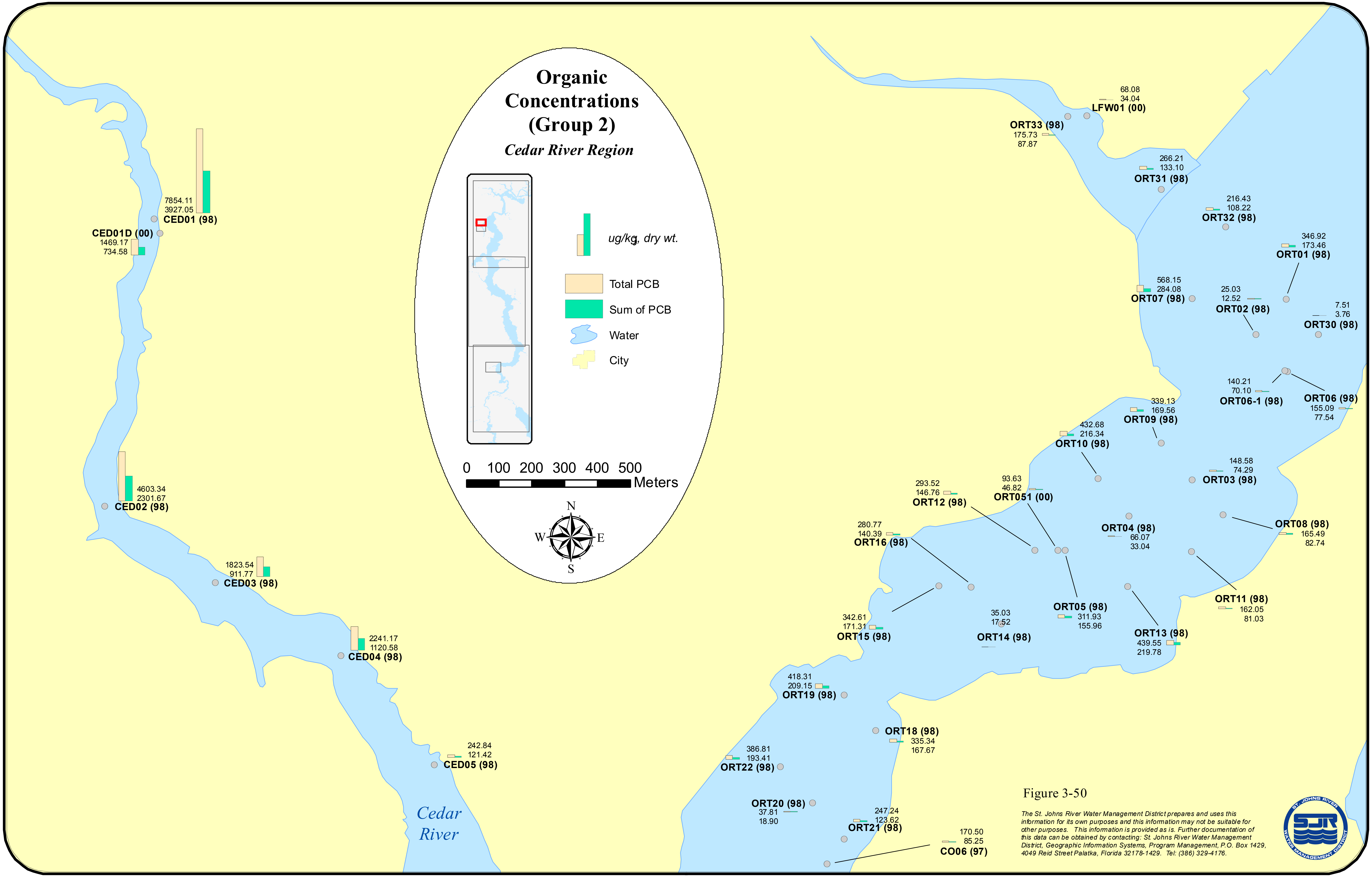
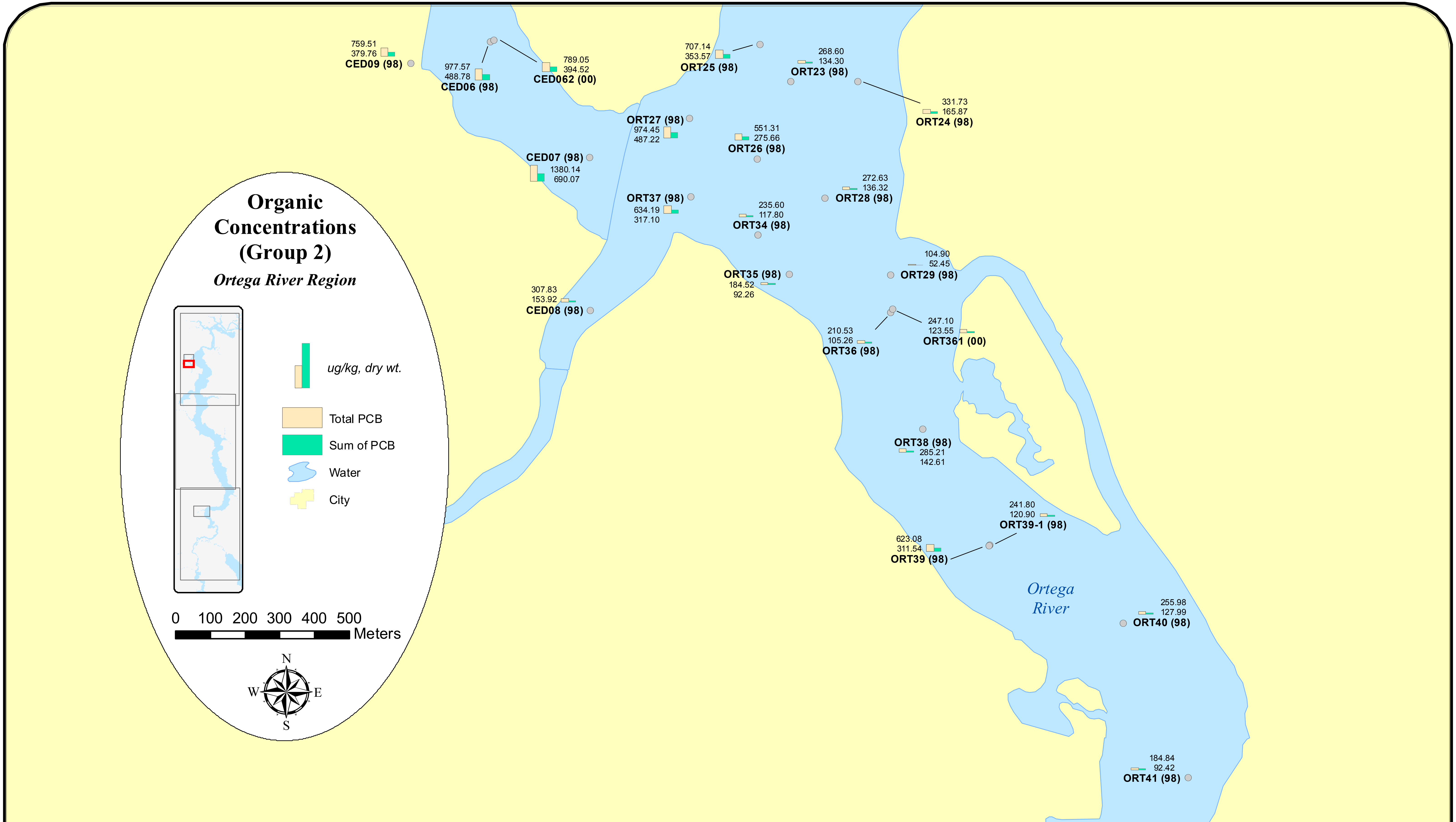


Figure 3-50

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



# Organic Concentrations (Group 2)

*Ortega River Region*

Figure 3-51

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

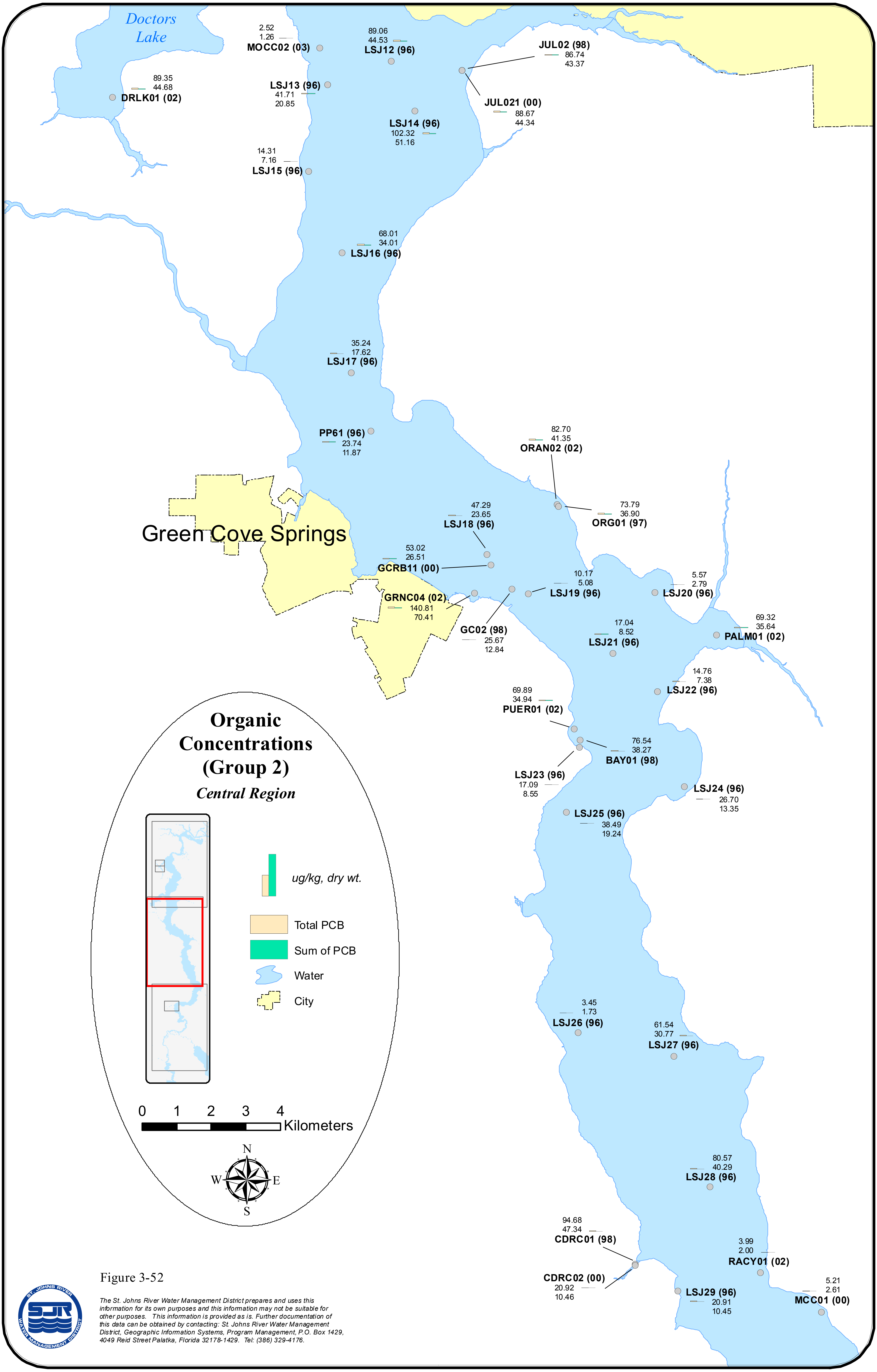
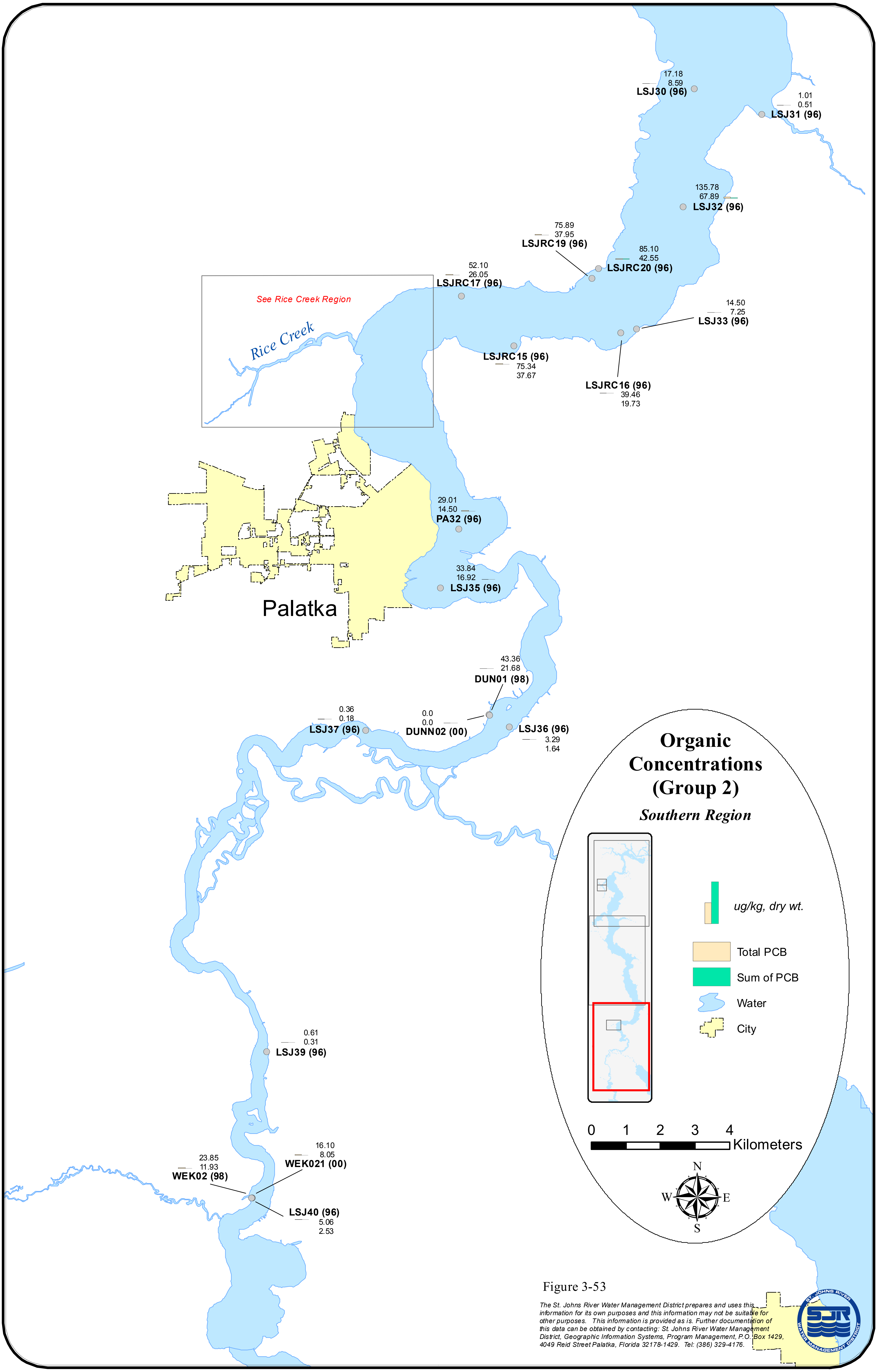


Figure 3-52

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.



# Organic Concentrations (Group 2)

## *Southern Region*

Figure 3-53

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

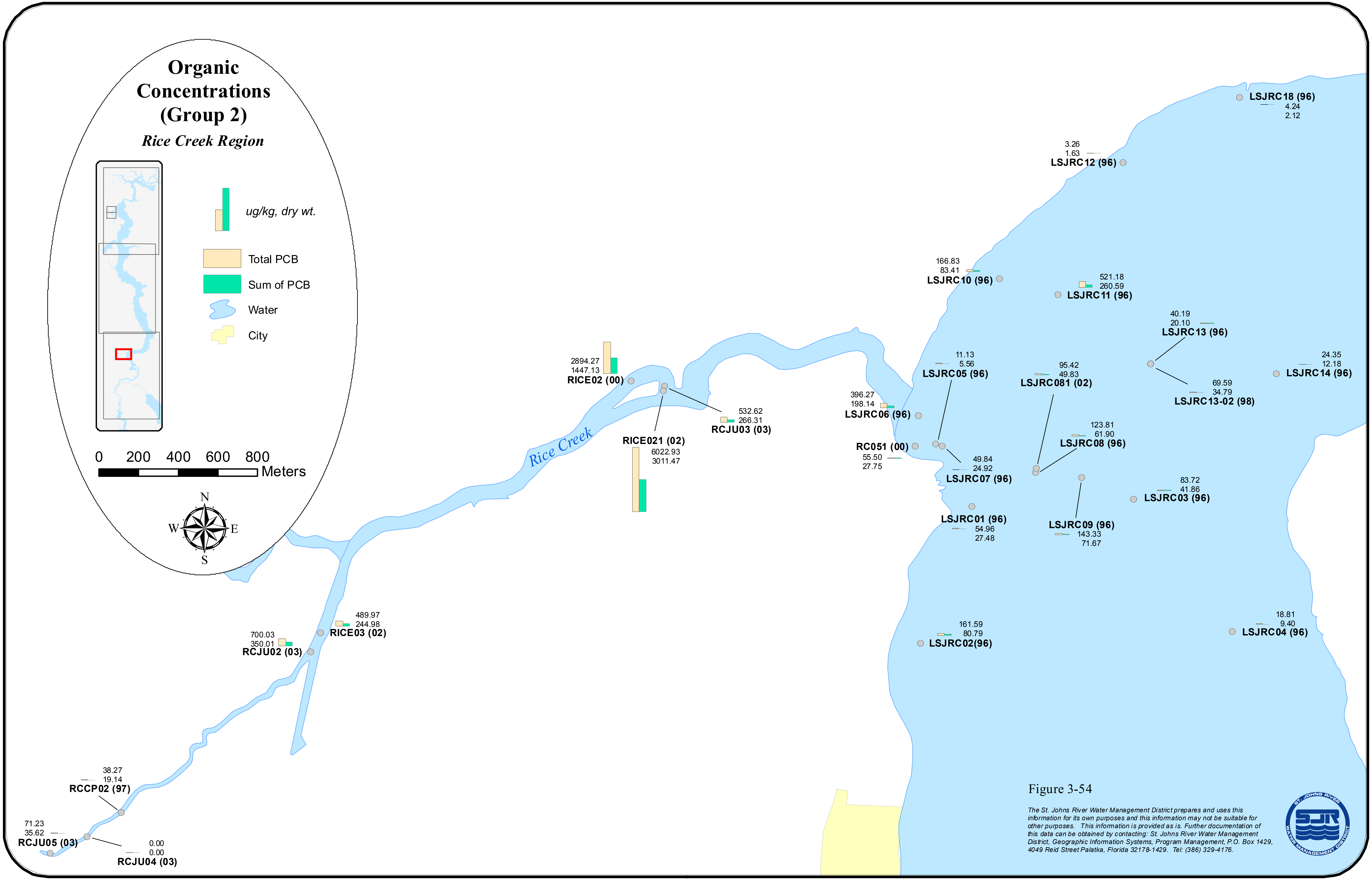


Figure 3-54

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

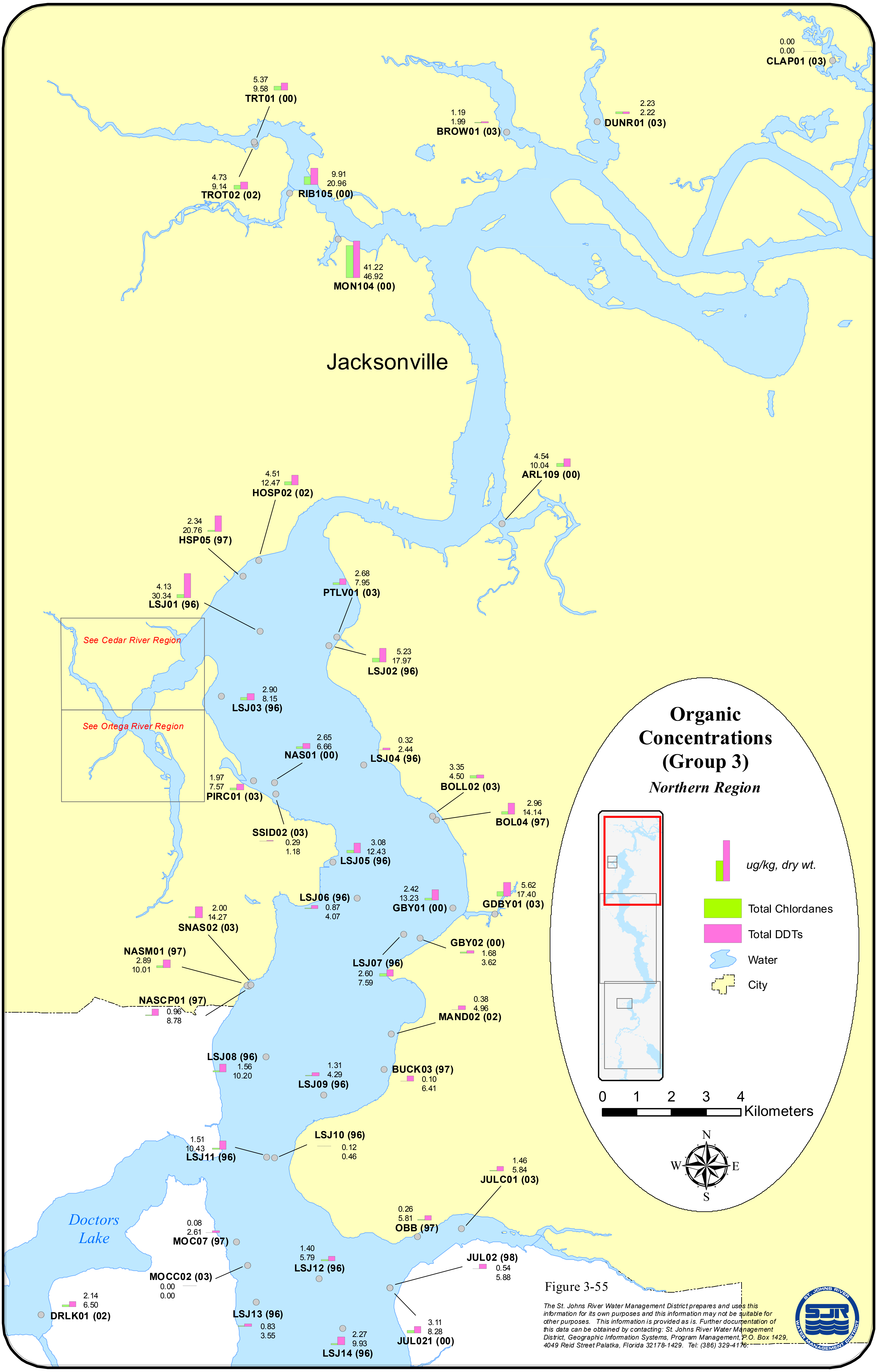


Figure 3-55

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Organic Concentrations (Group 3)

*Cedar River Region*

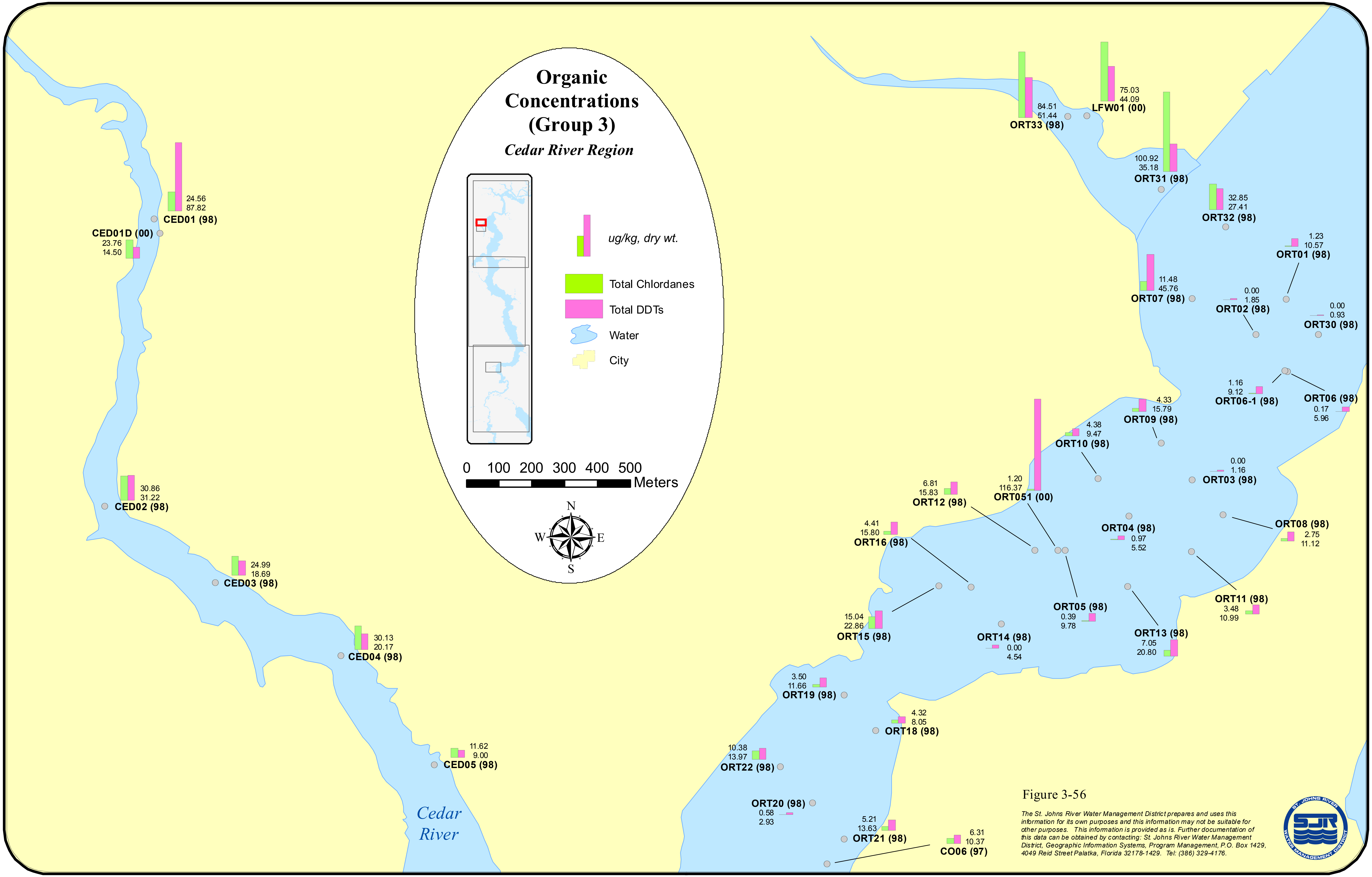


Figure 3-56

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Organic Concentrations (Group 3)

*Ortega River Region*

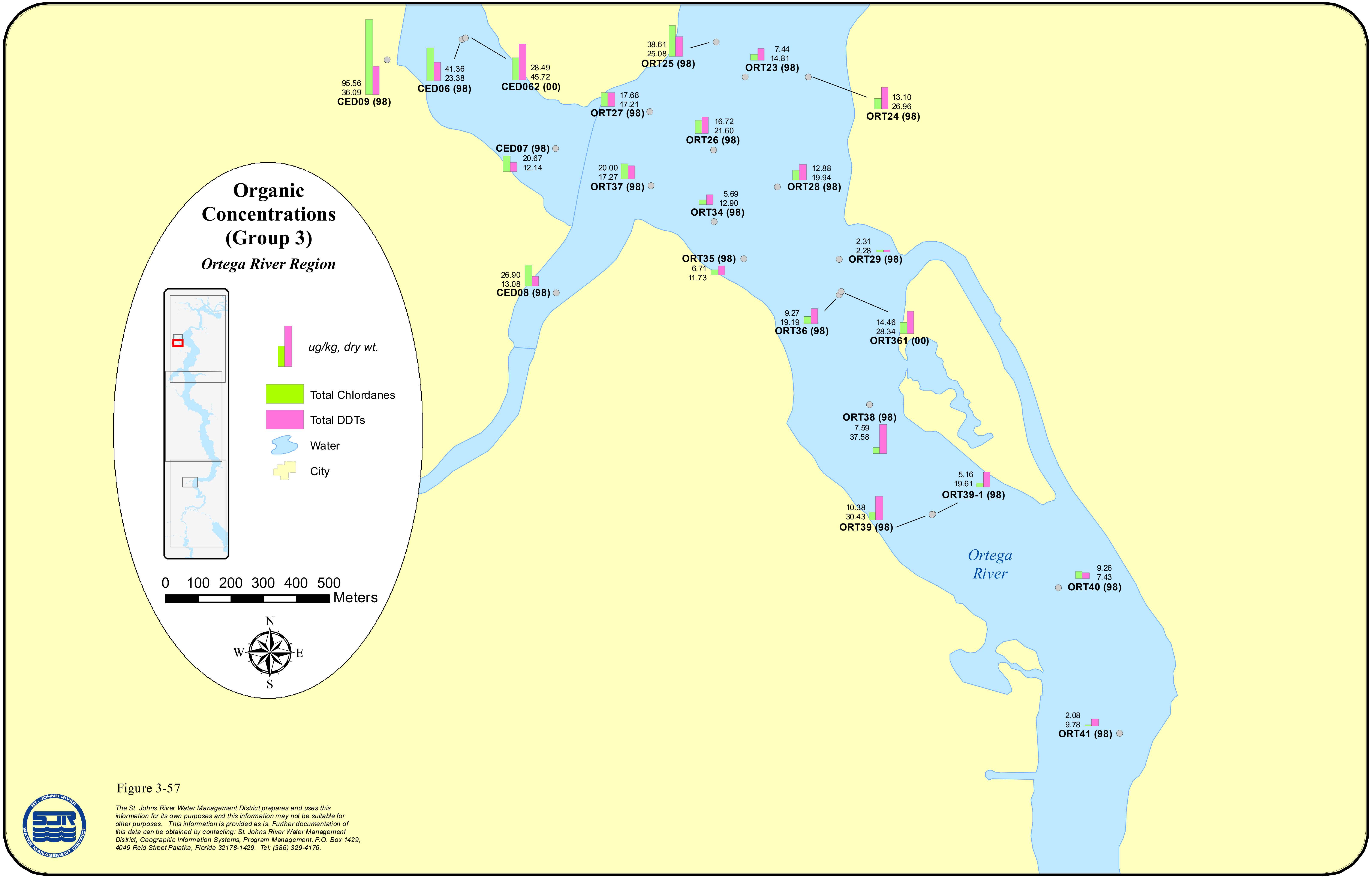
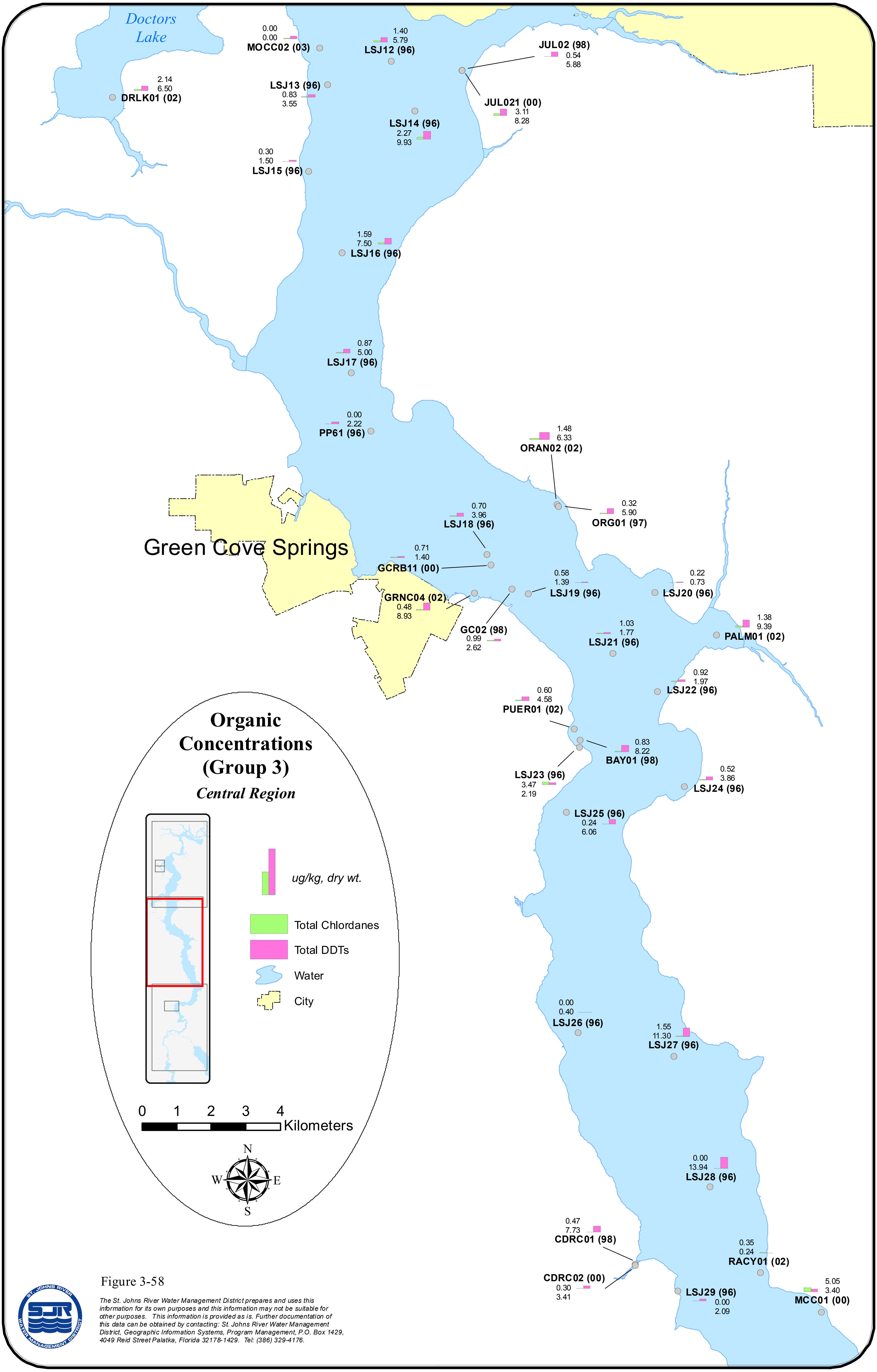


Figure 3-57

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

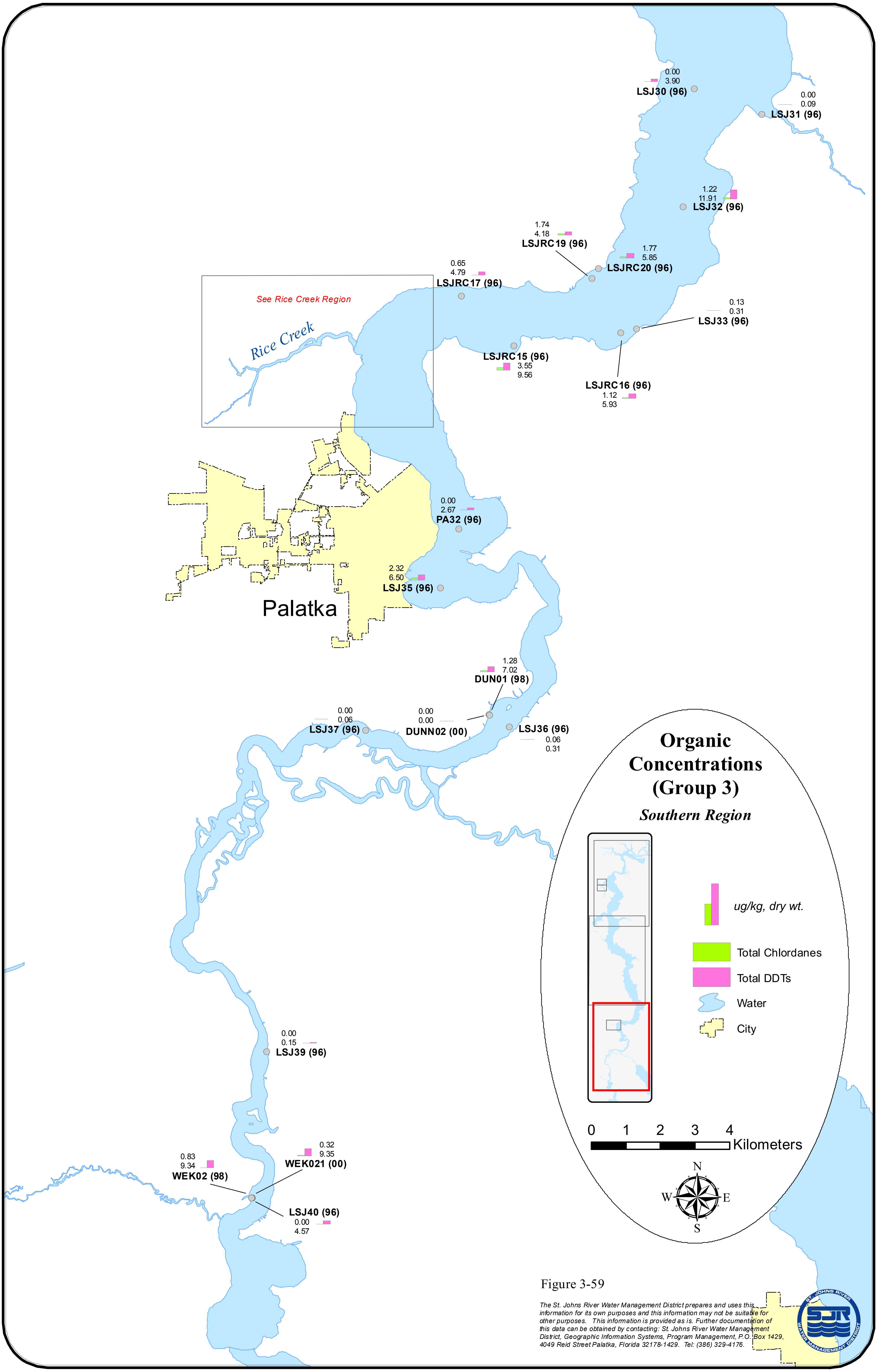


# Organic Concentrations (Group 3)

*Central Region*

Figure 3-58

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



# Organic Concentrations (Group 3)

## *Southern Region*

Figure 3-59

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

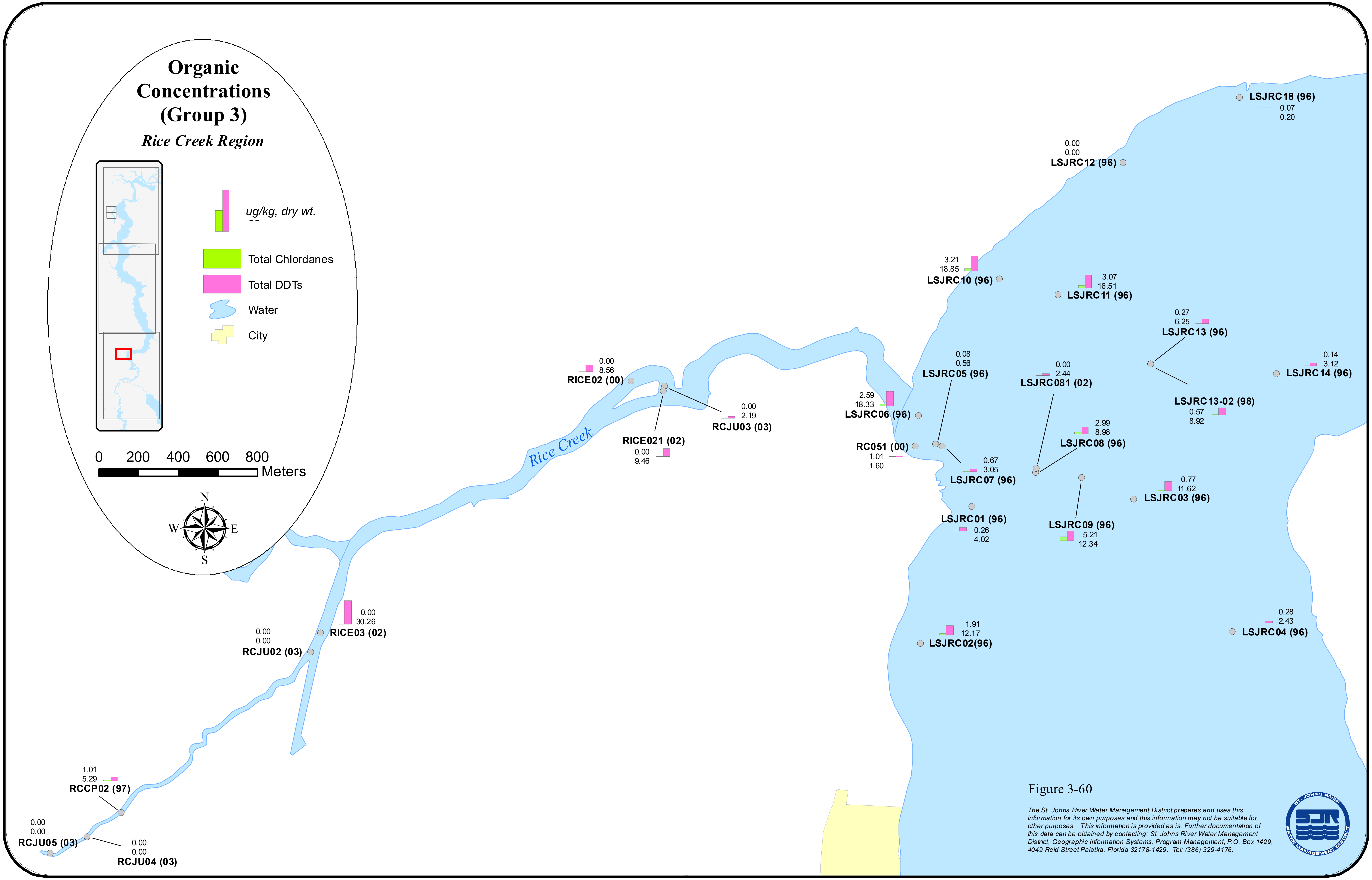


Figure 3-60

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

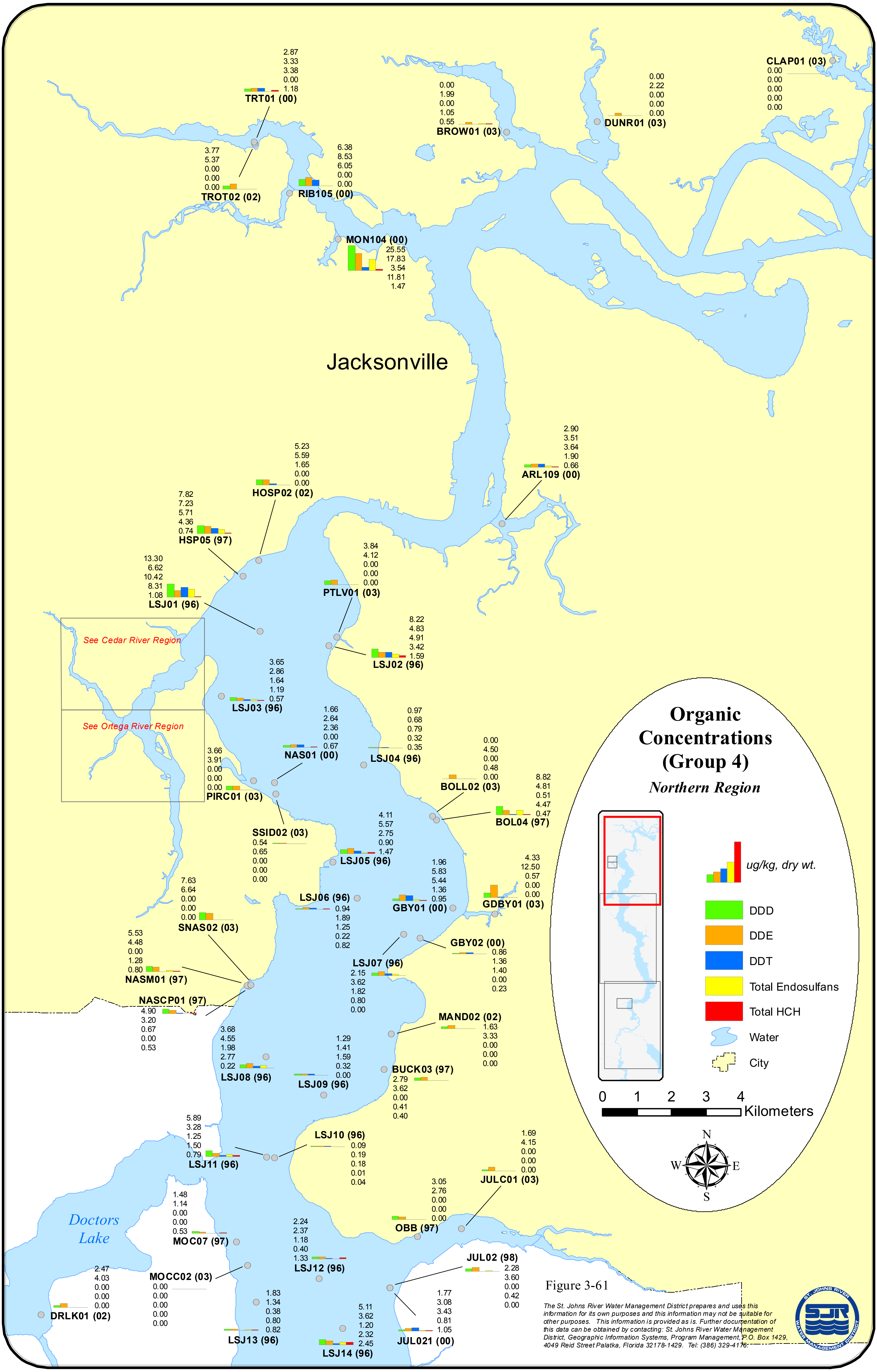
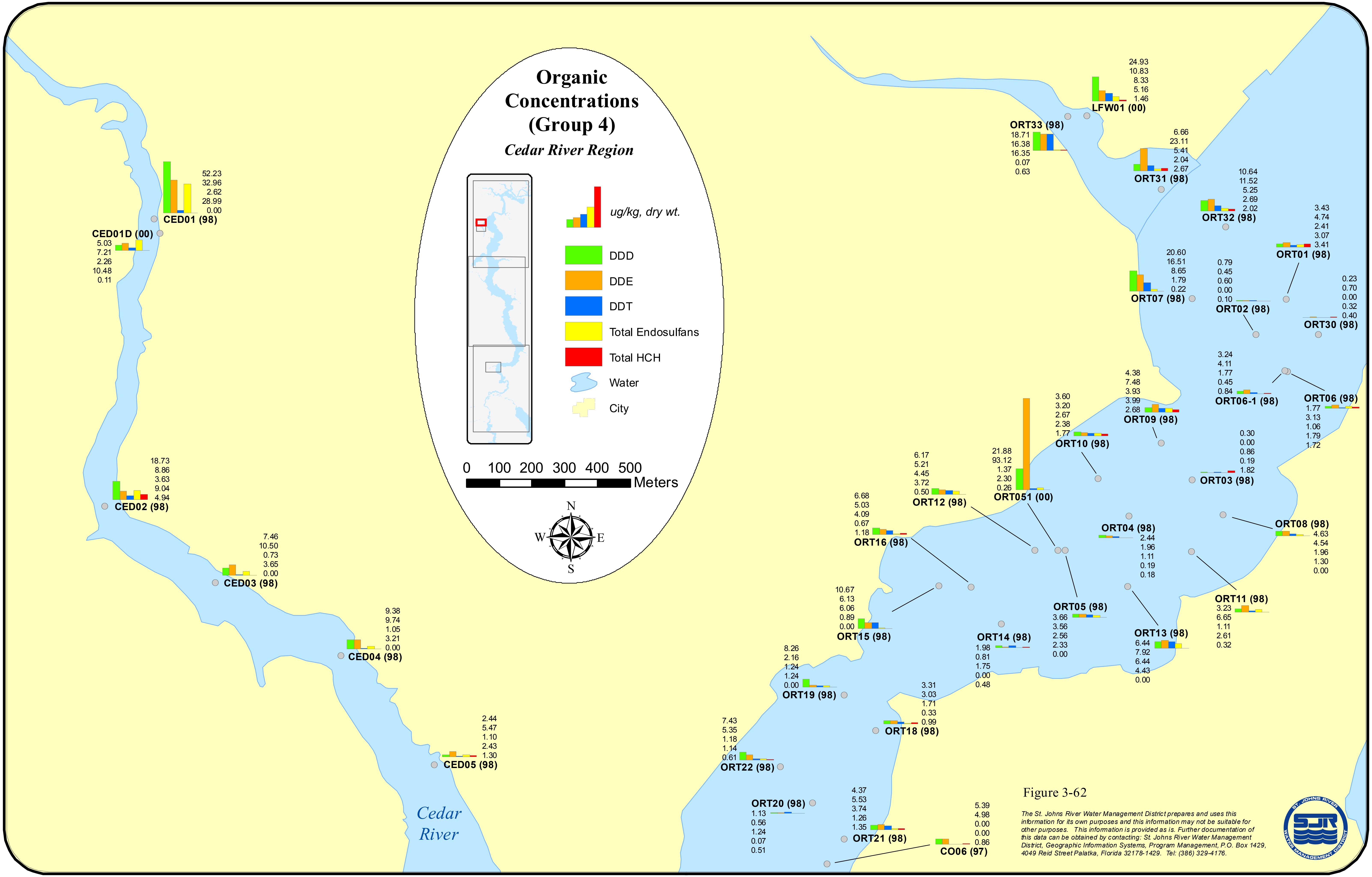


Figure 3-61

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



Organic Concentrations (Group 4)

*Cedar River Region*

Figure 3-62

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Organic Concentrations (Group 4)

### *Ortega River Region*

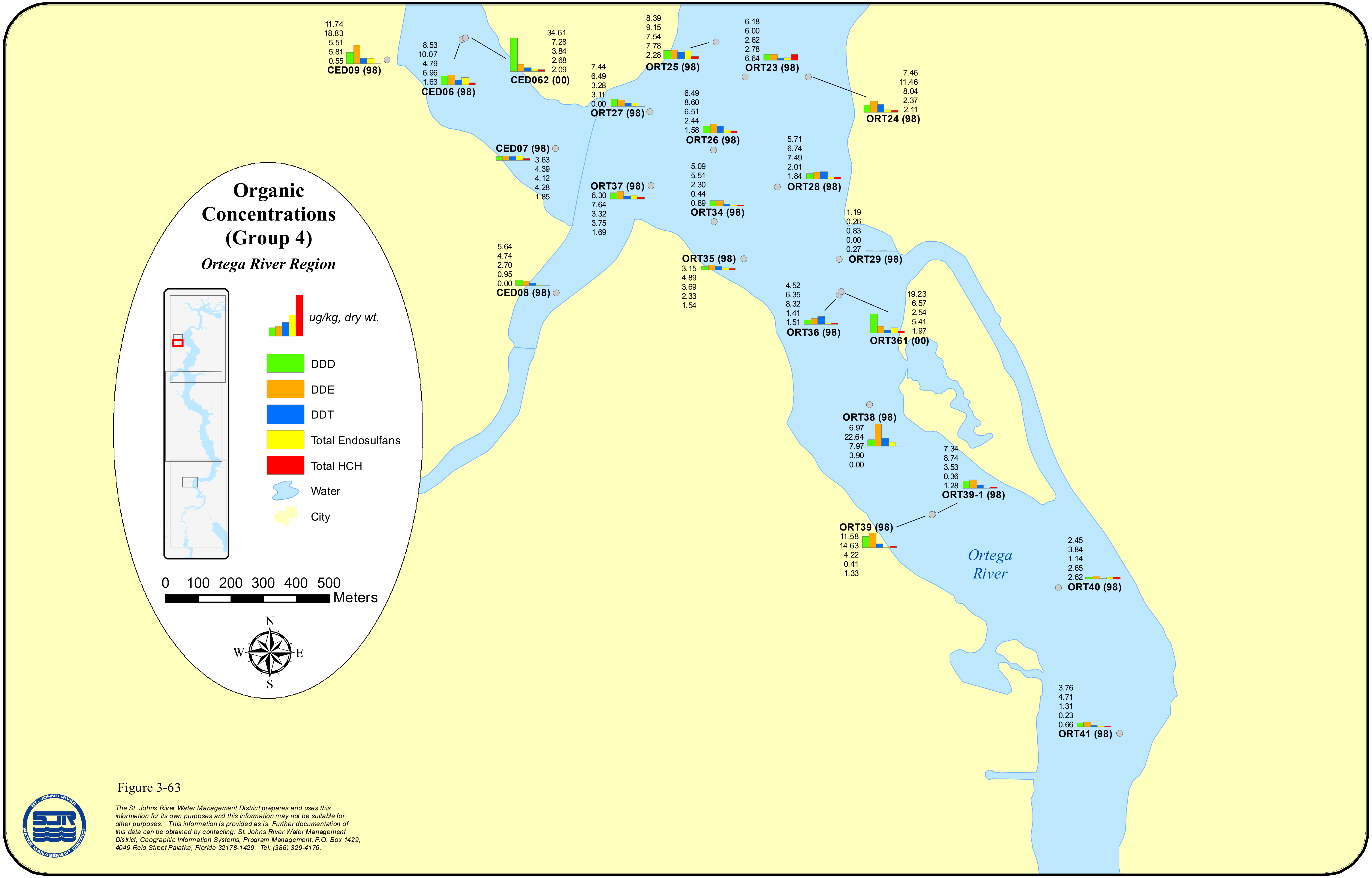


Figure 3-63

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

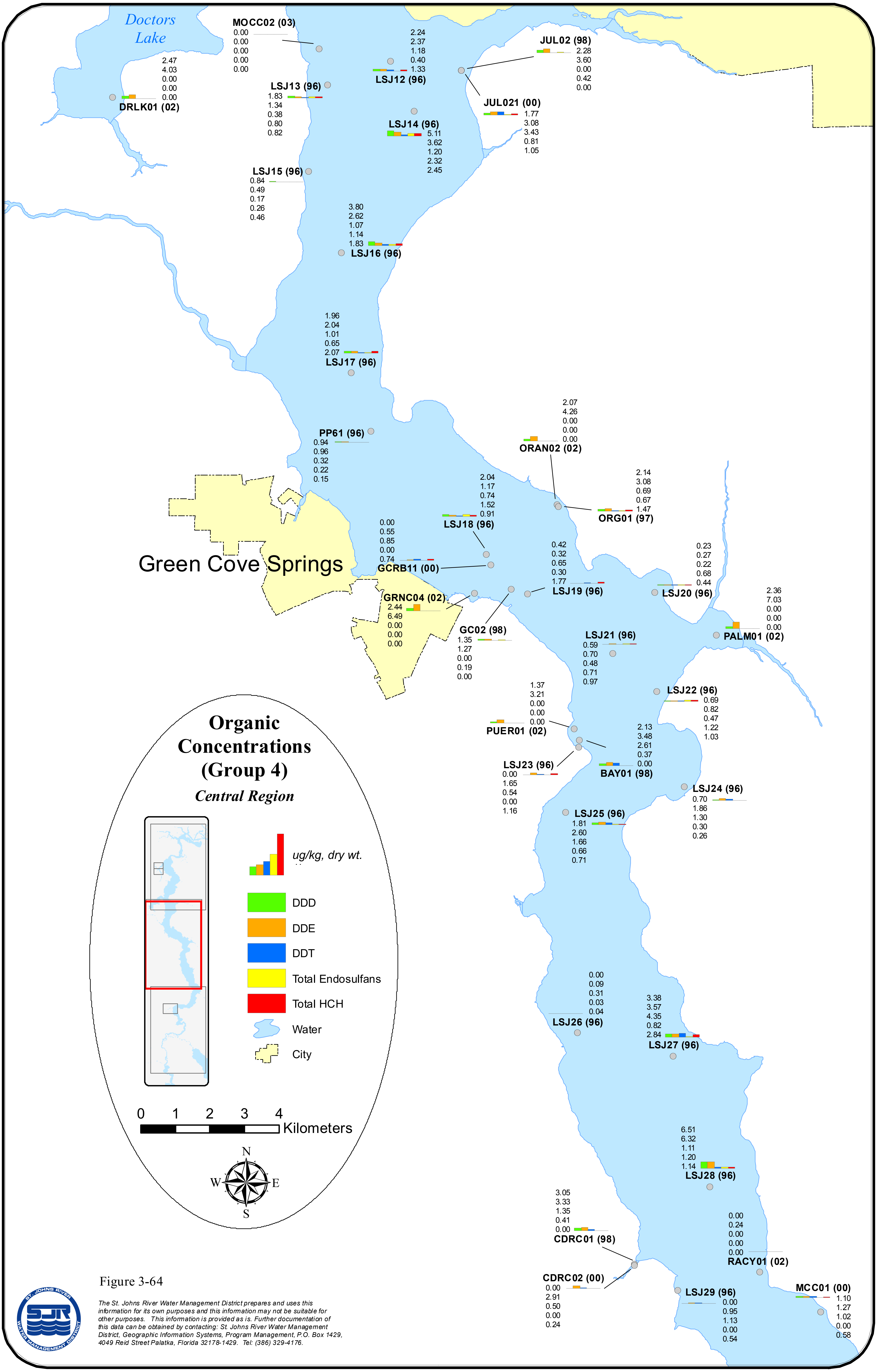


Figure 3-64

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

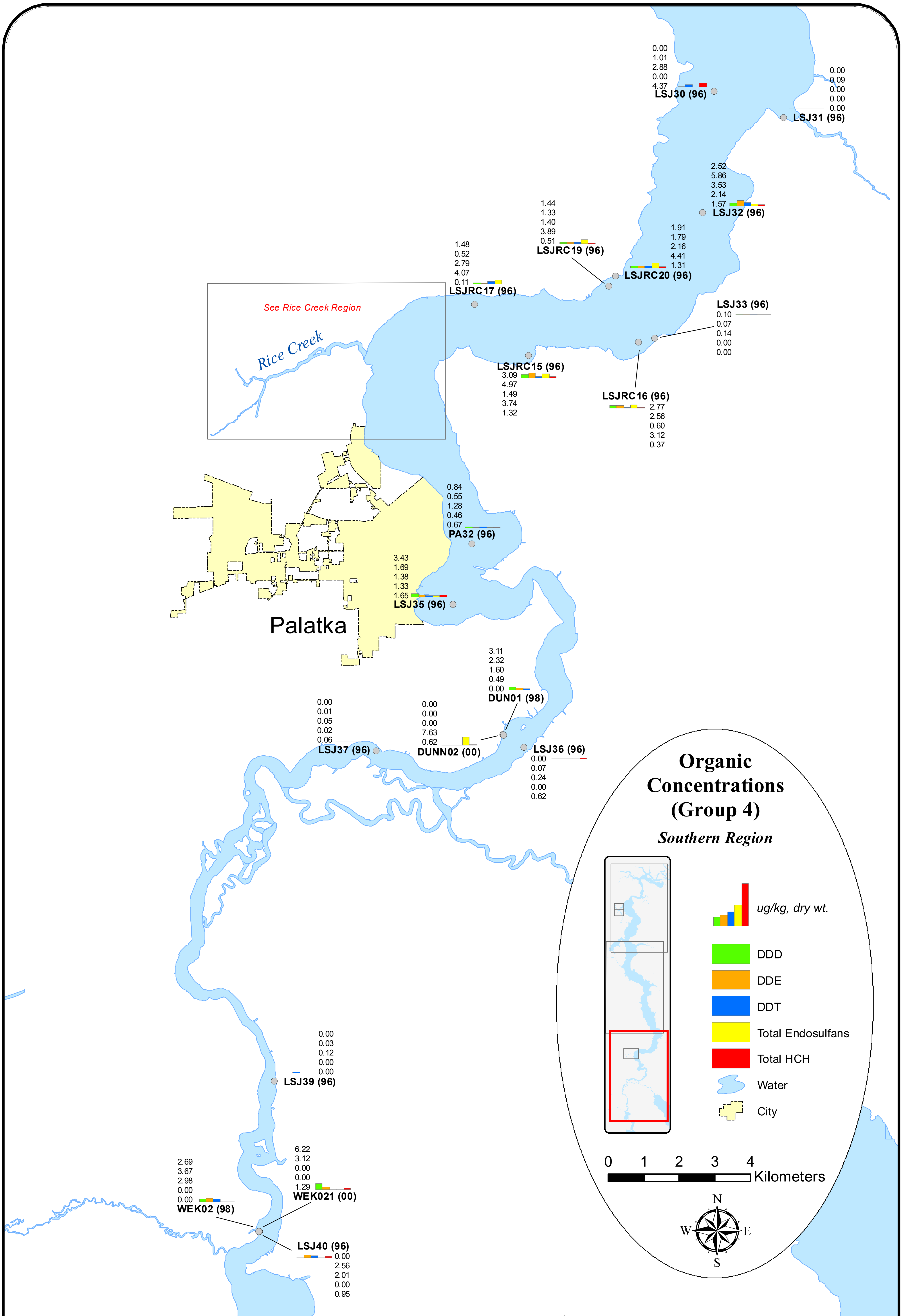


Figure 3-65

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# Organic Concentrations (Group 4)

*Rice Creek Region*

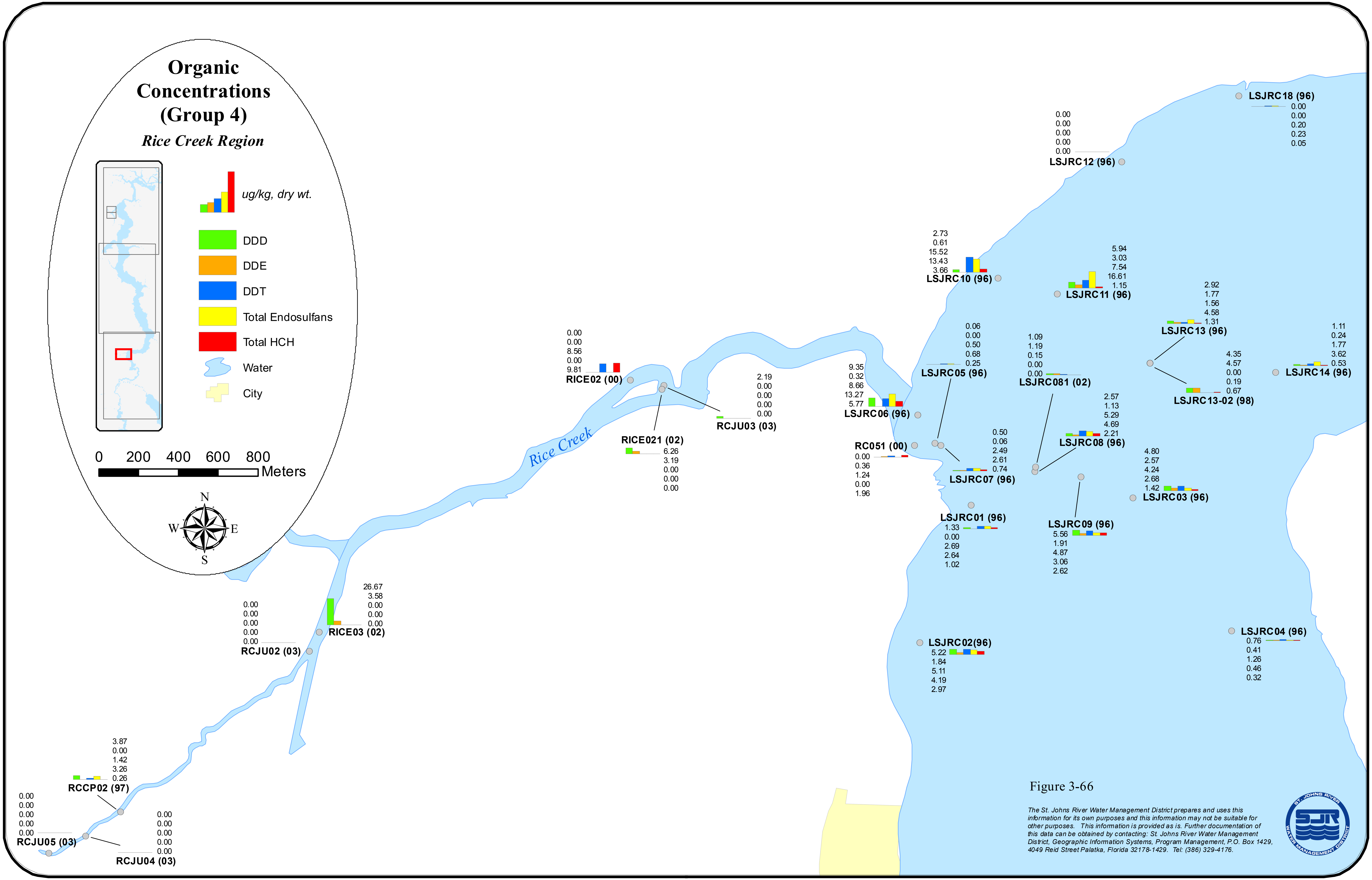

Figure 3-66

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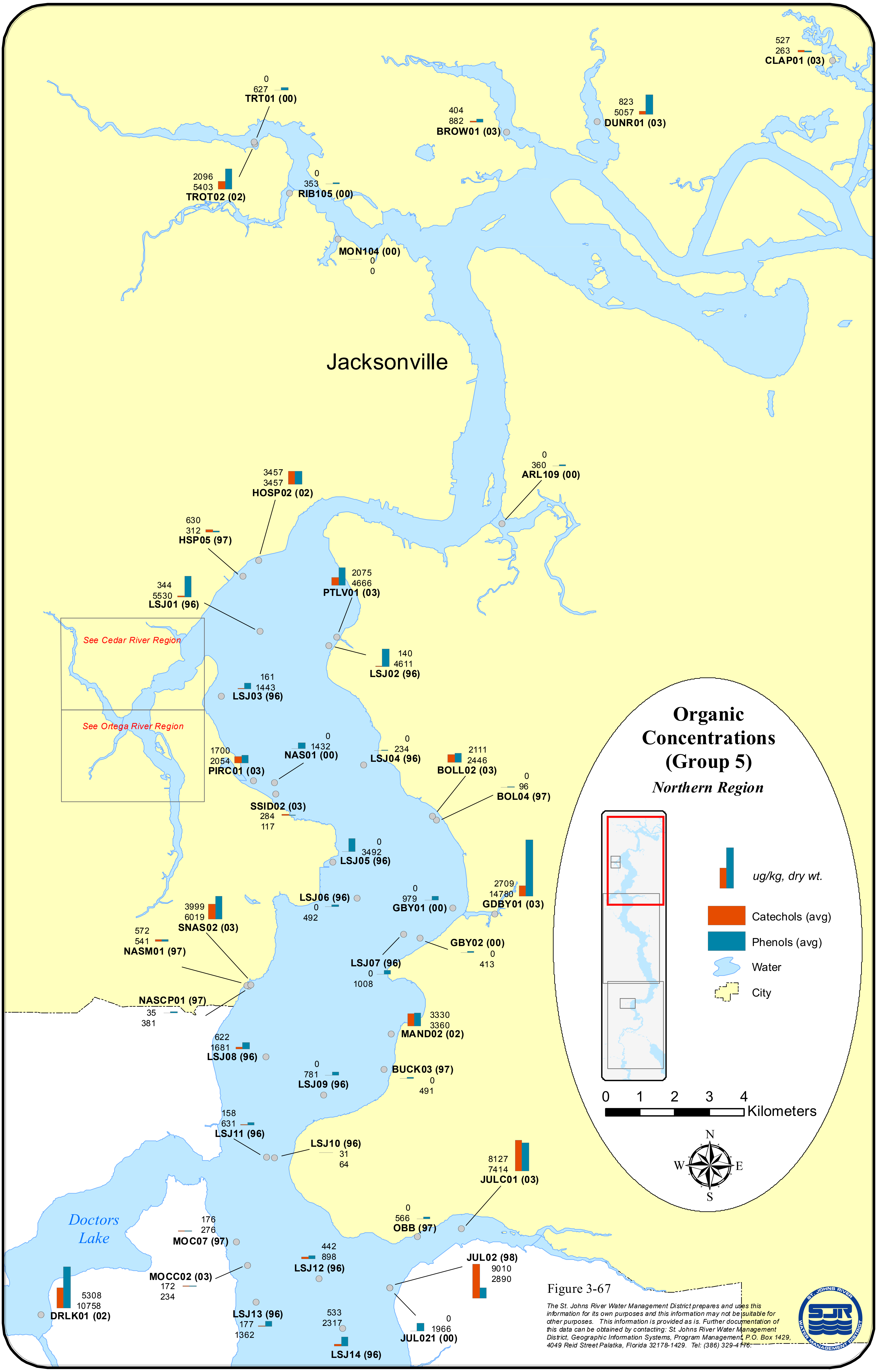

Figure 3-67

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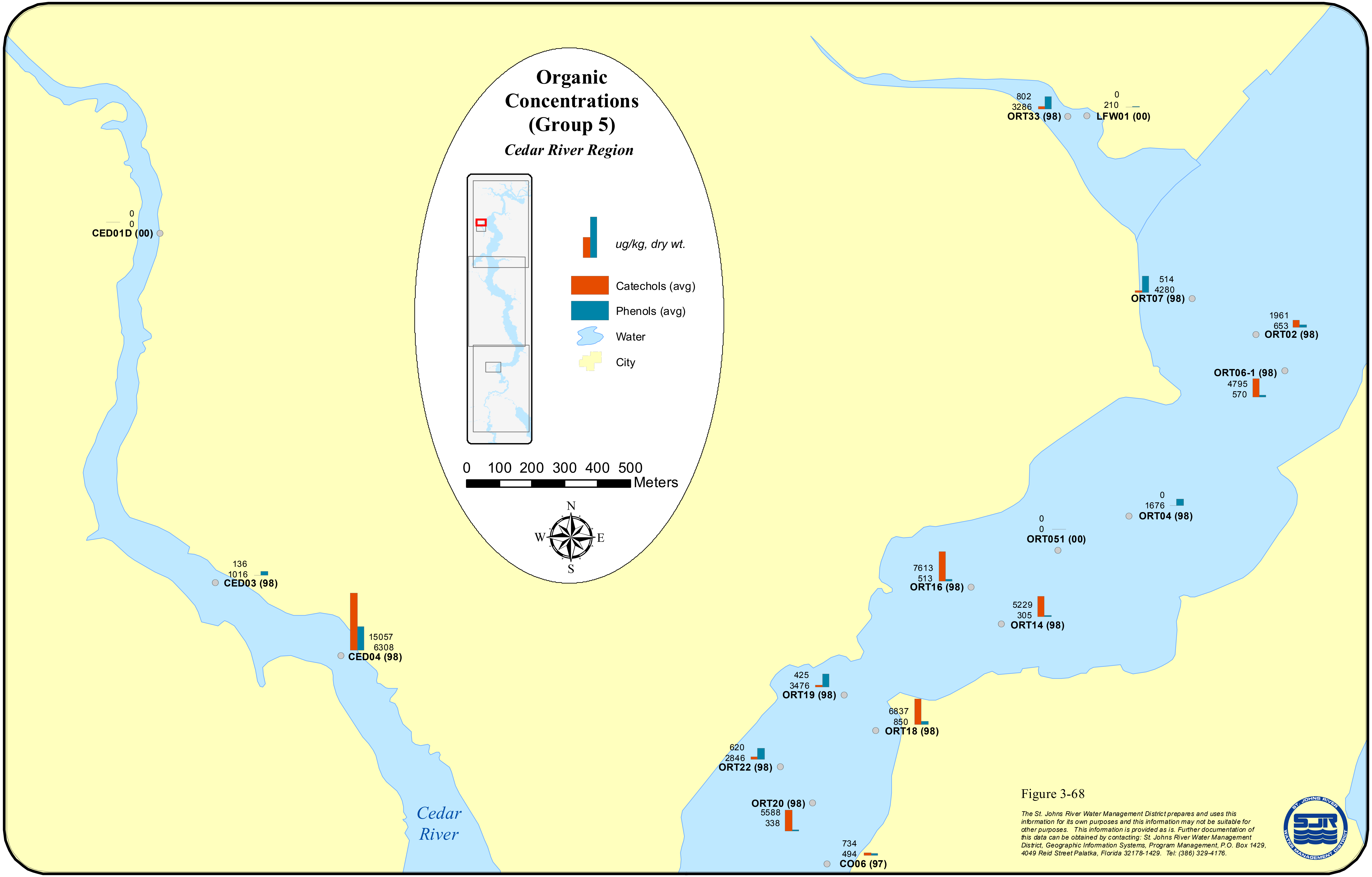

# Organic Concentrations (Group 5)

*Cedar River Region*

Figure 3-68

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Organic Concentrations (Group 5)

*Ortega River Region*

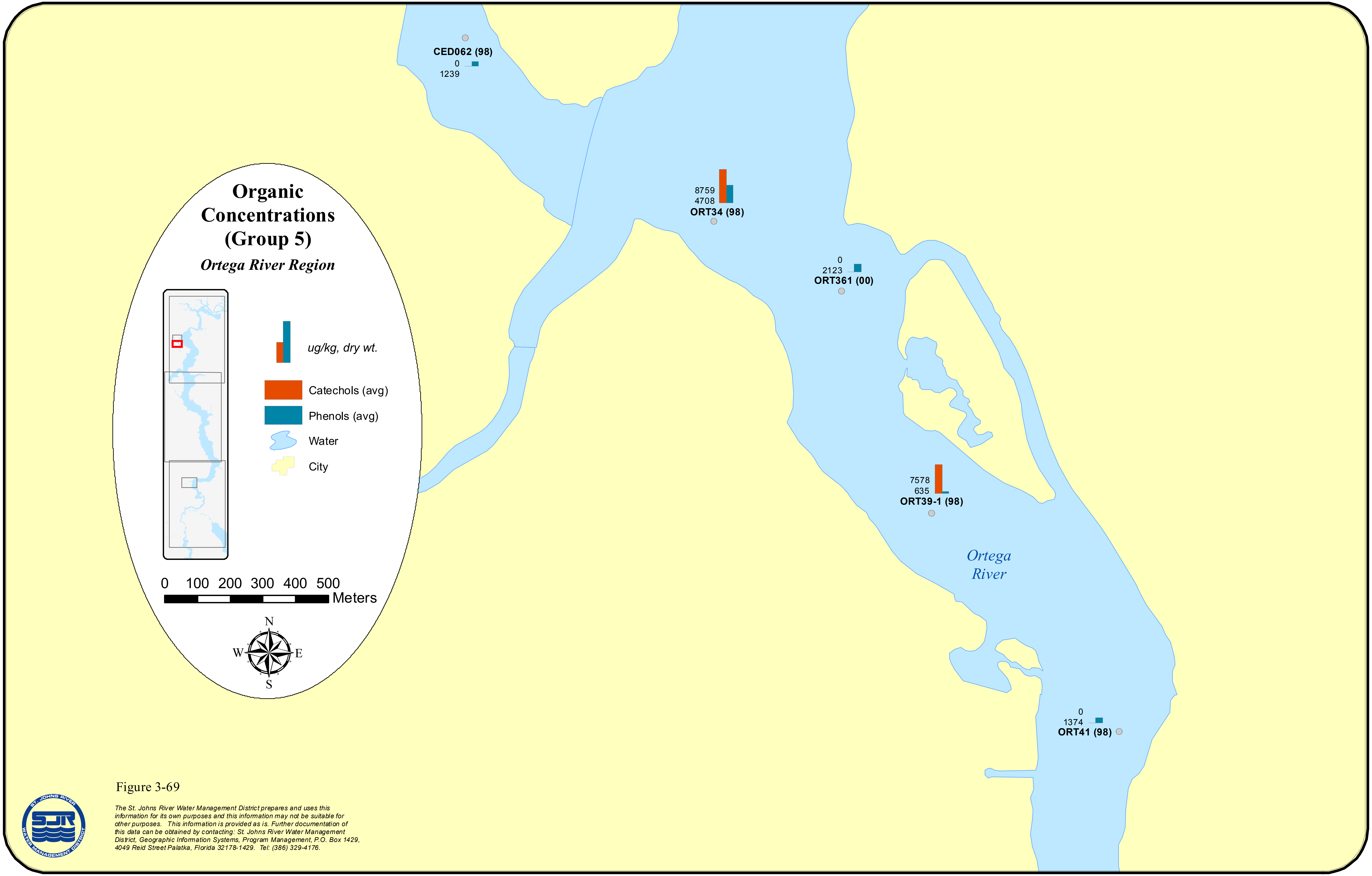

Figure 3-69

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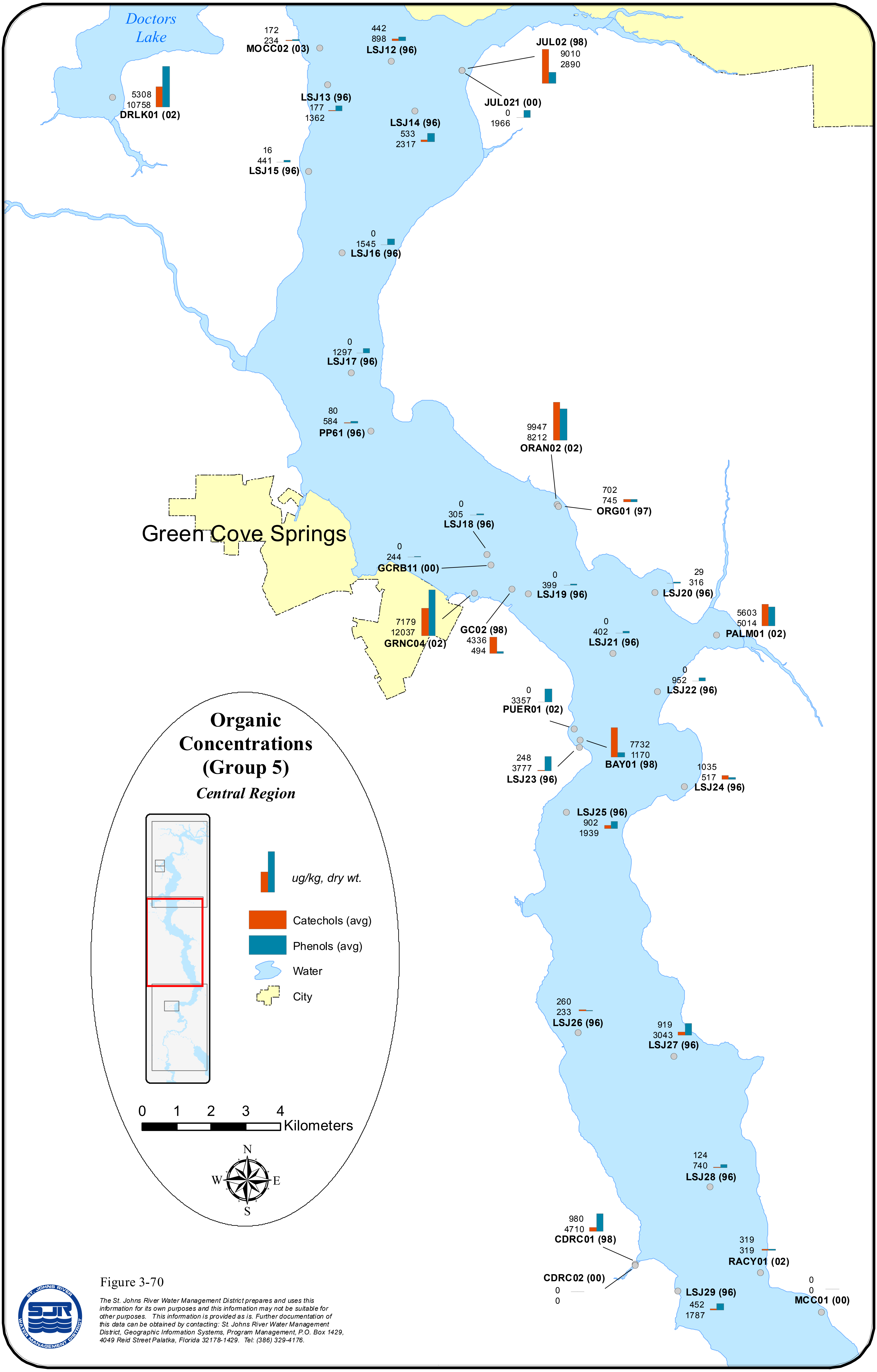
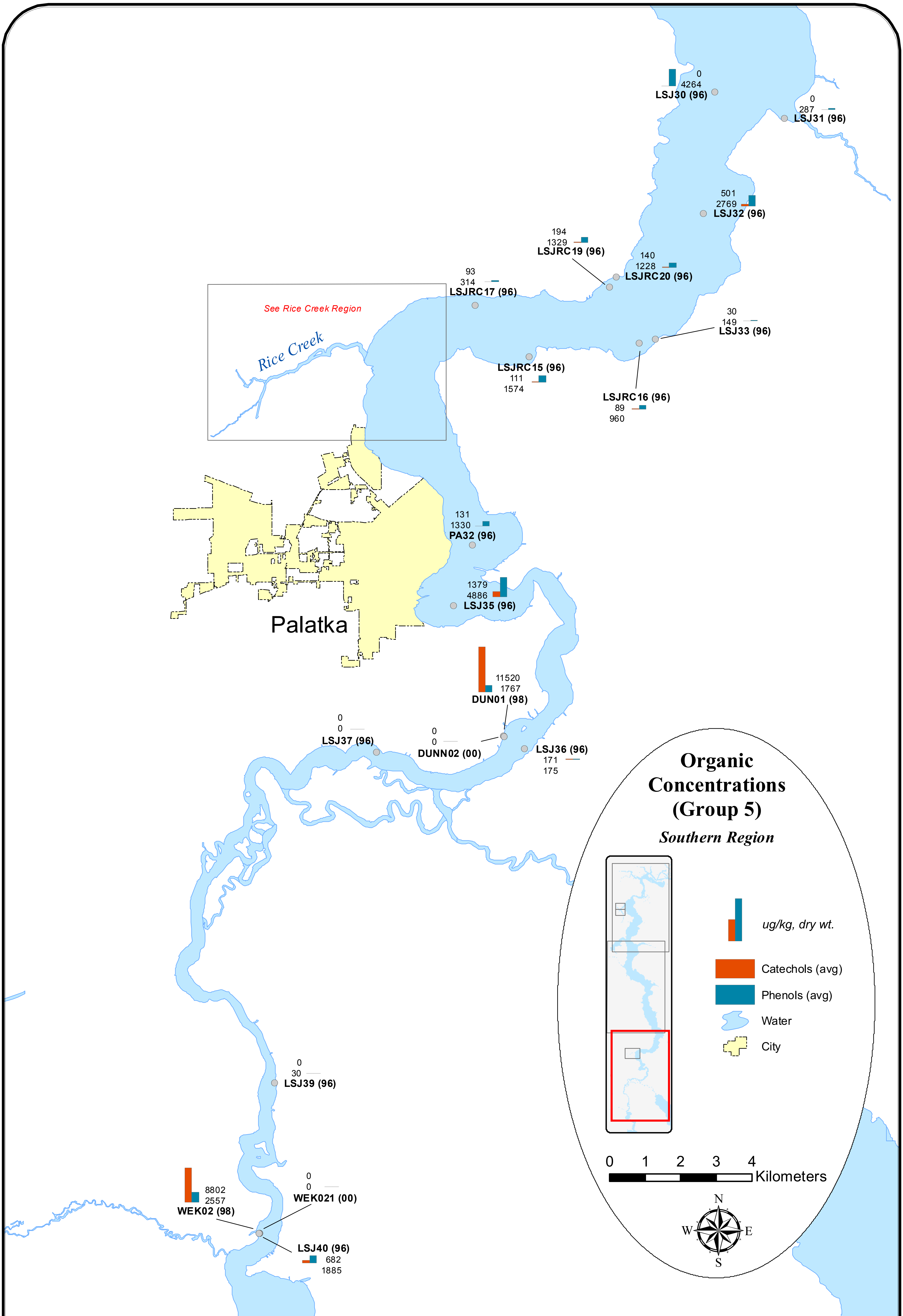


Figure 3-70

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.



# Organic Concentrations (Group 5)

## *Southern Region*

Figure 3-71

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Organic Concentrations (Group 5)

*Rice Creek Region*

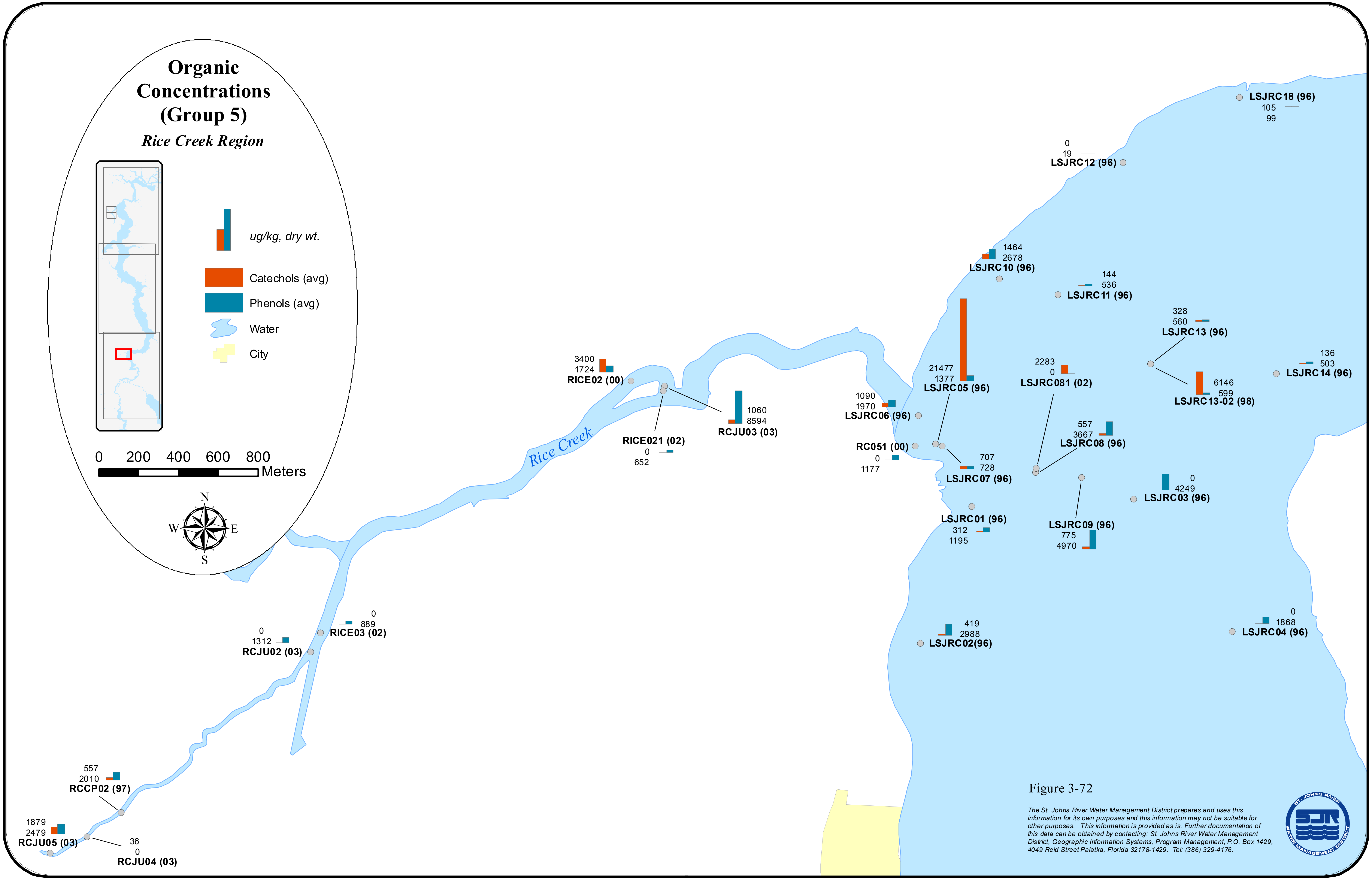


Figure 3-72

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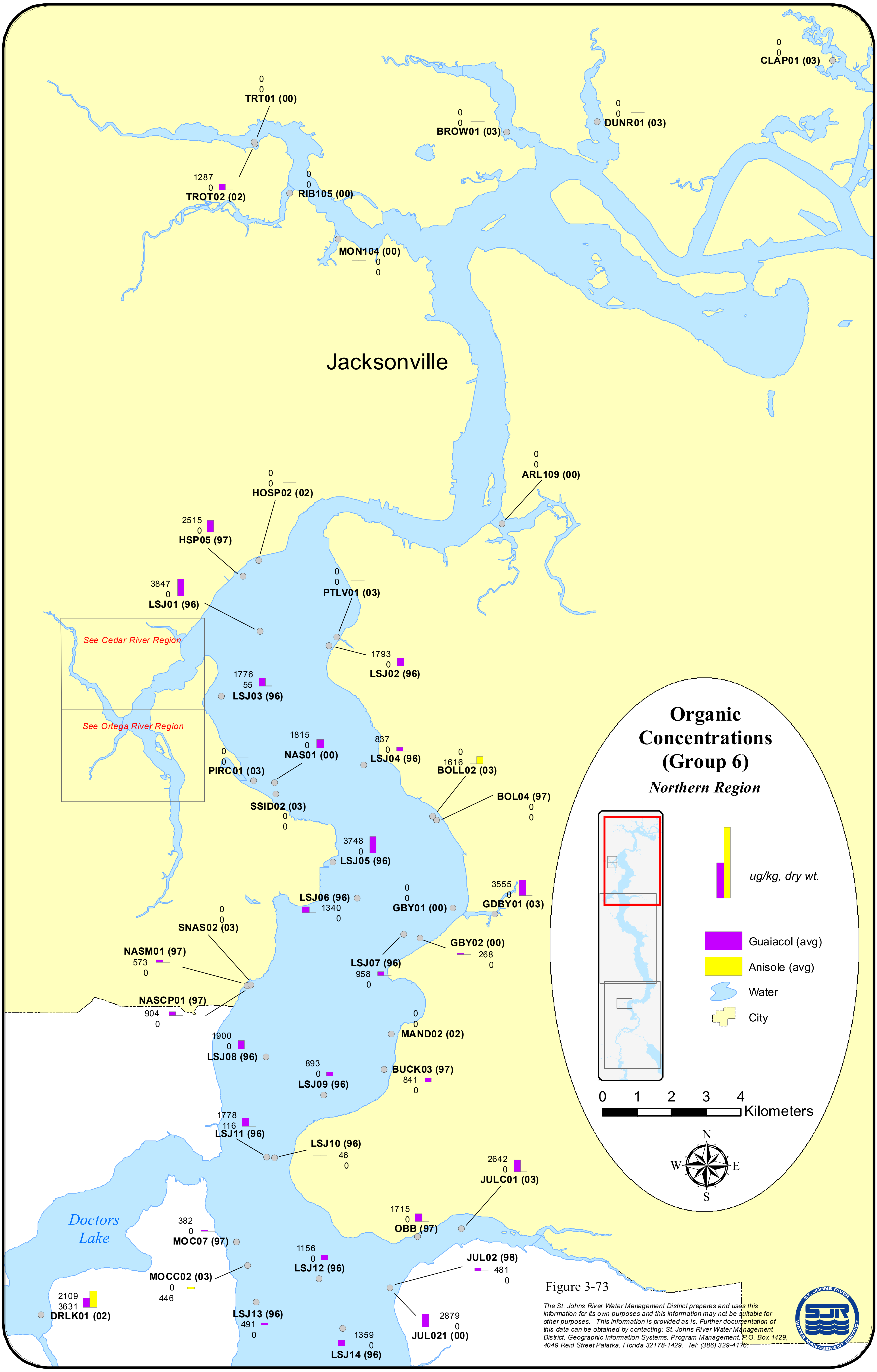
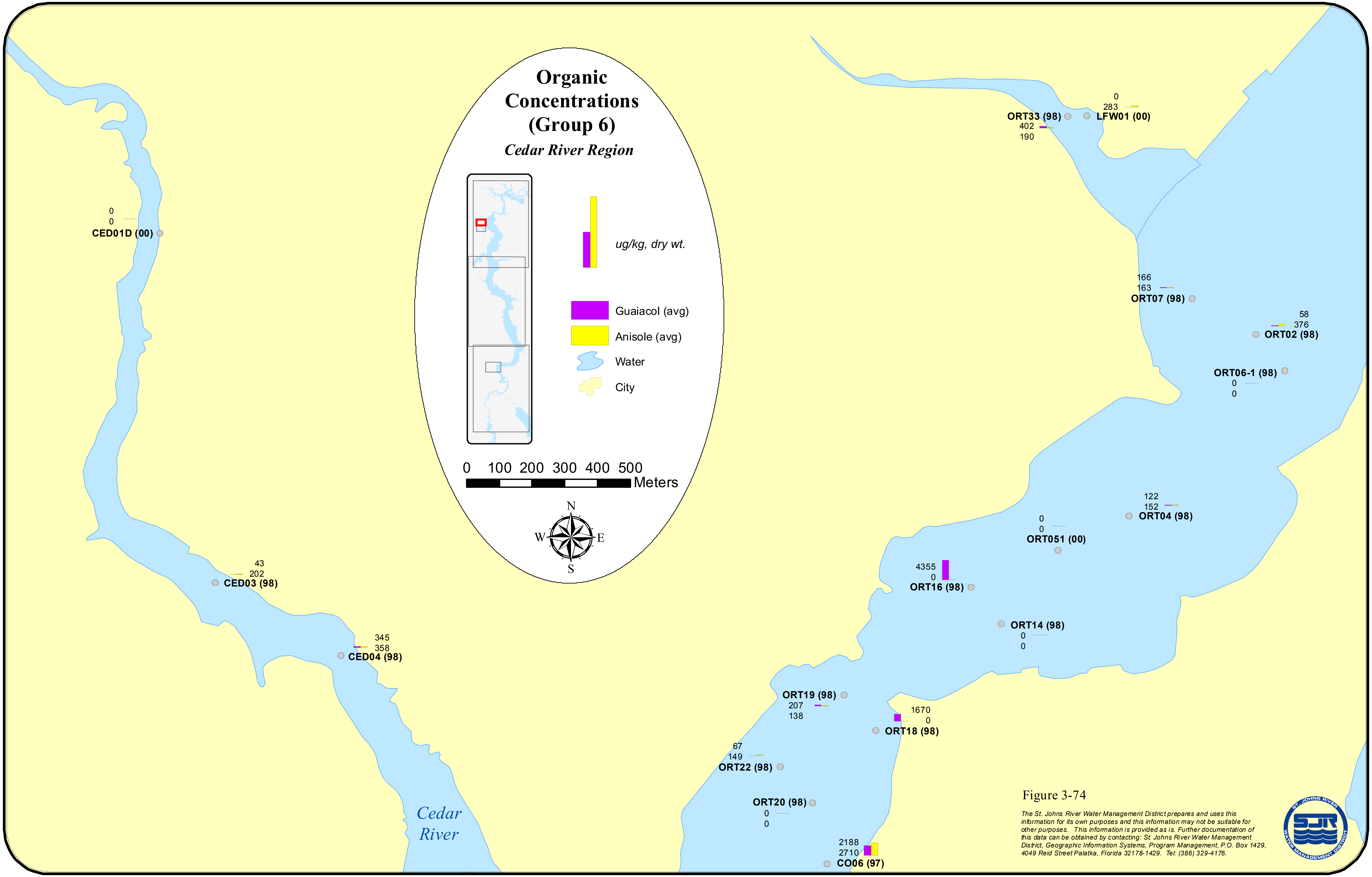


# Organic Concentrations (Group 6)

## *Northern Region*

Figure 3-73

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*



# Organic Concentrations (Group 6)

*Cedar River Region*

Figure 3-74

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Organic Concentrations (Group 6)

*Ortega River Region*

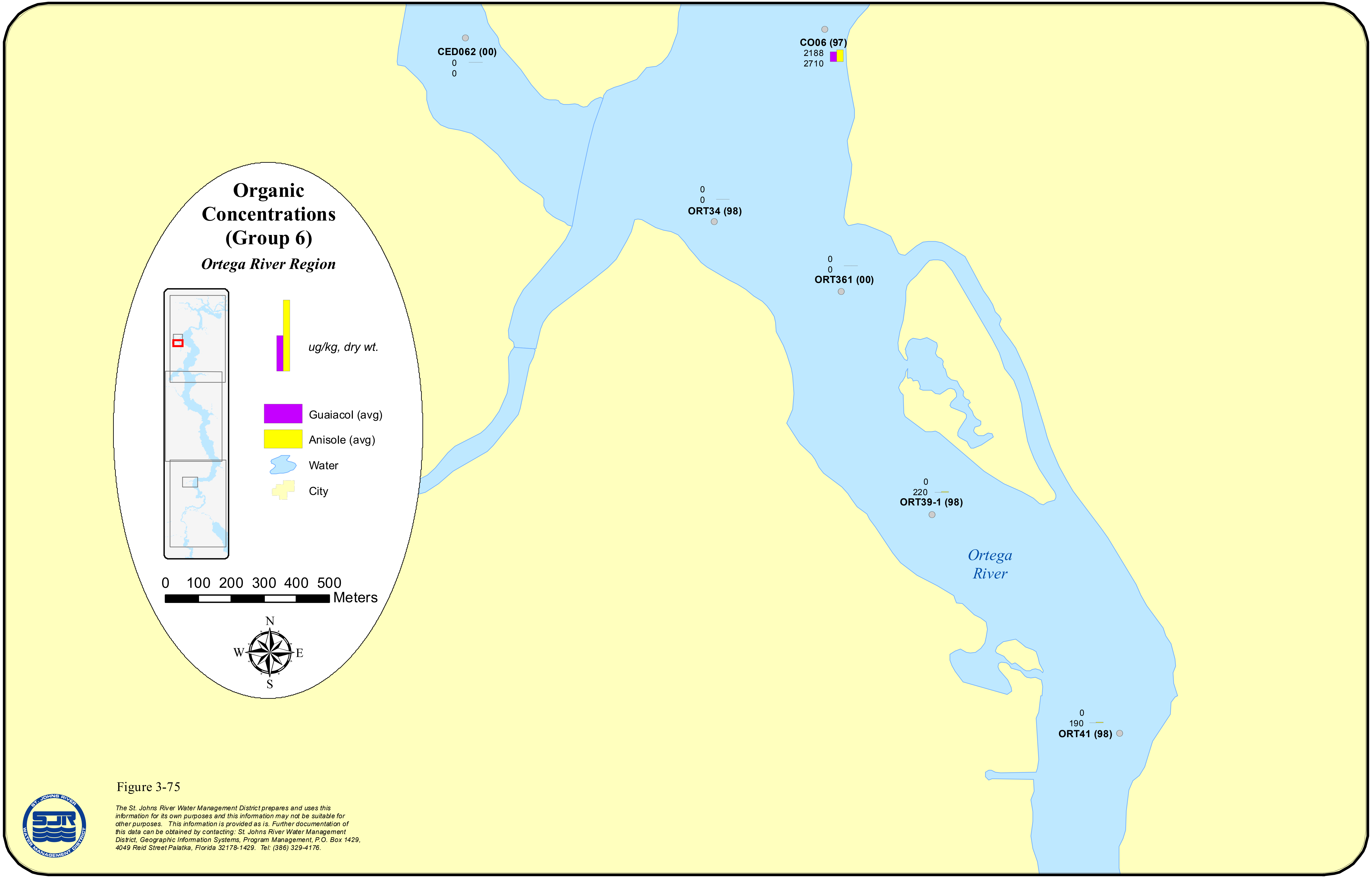


Figure 3-75

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

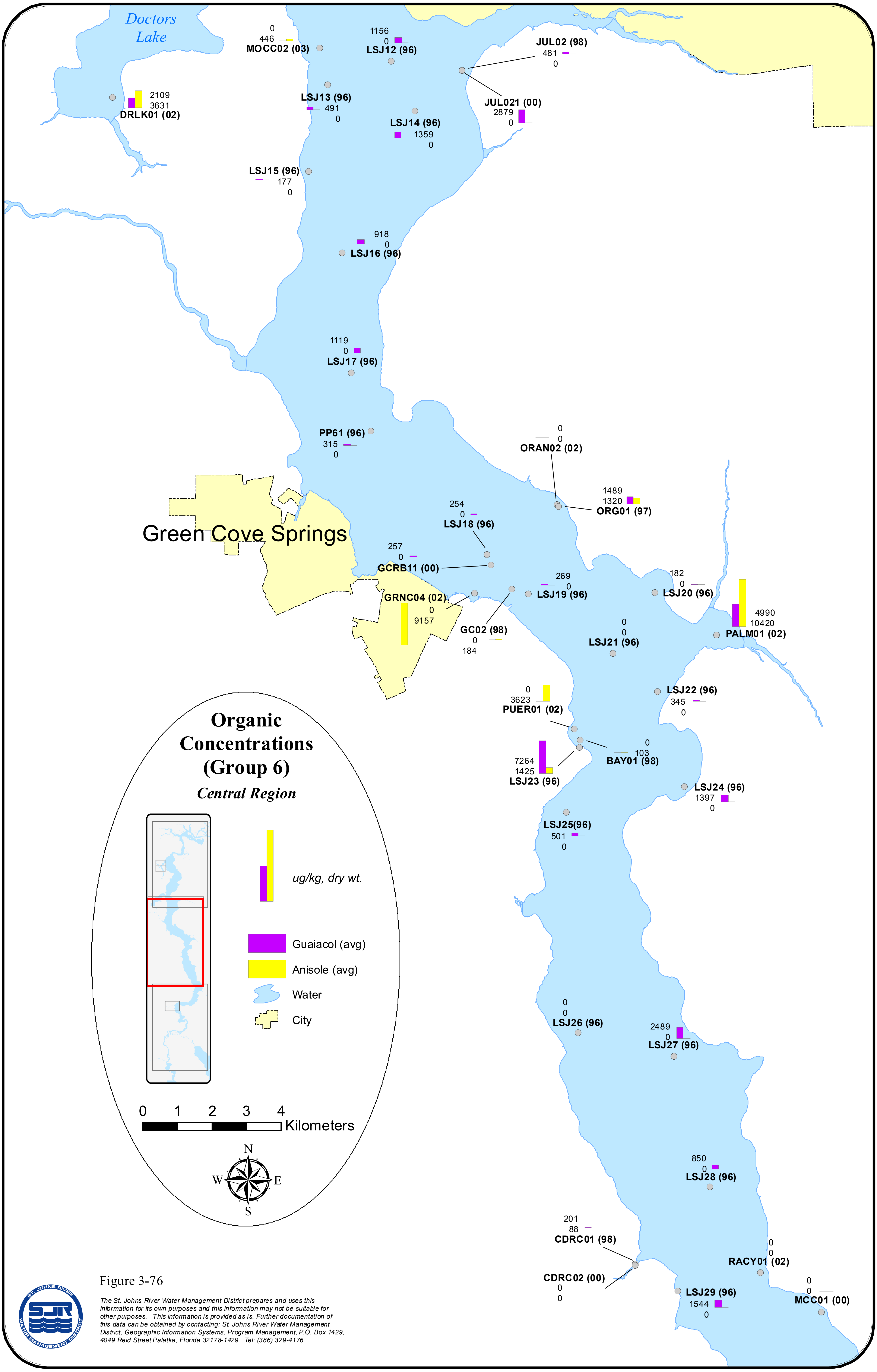


Figure 3-76

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.

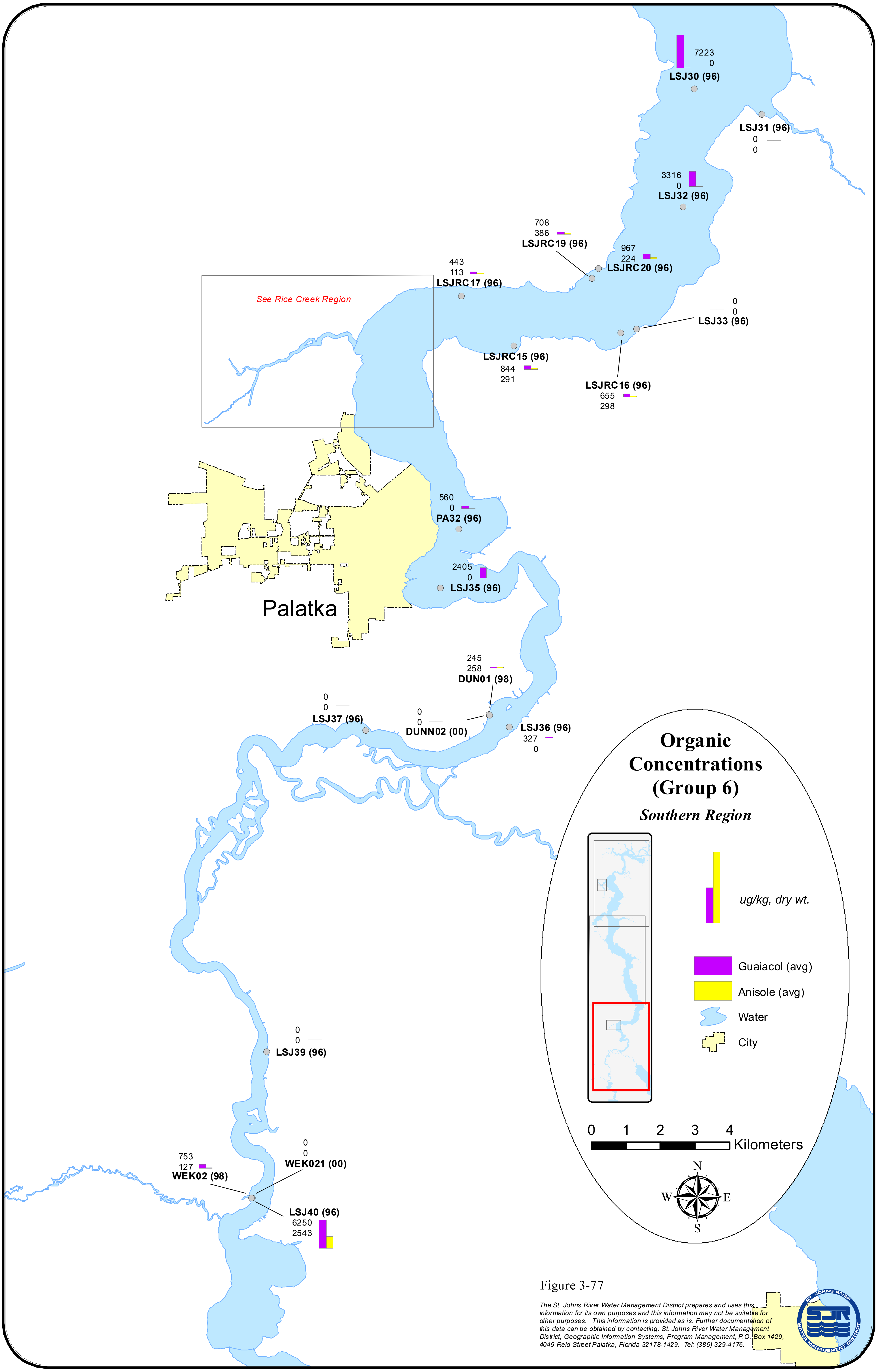


Figure 3-77

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.

# Organic Concentrations (Group 6)

*Rice Creek Region*

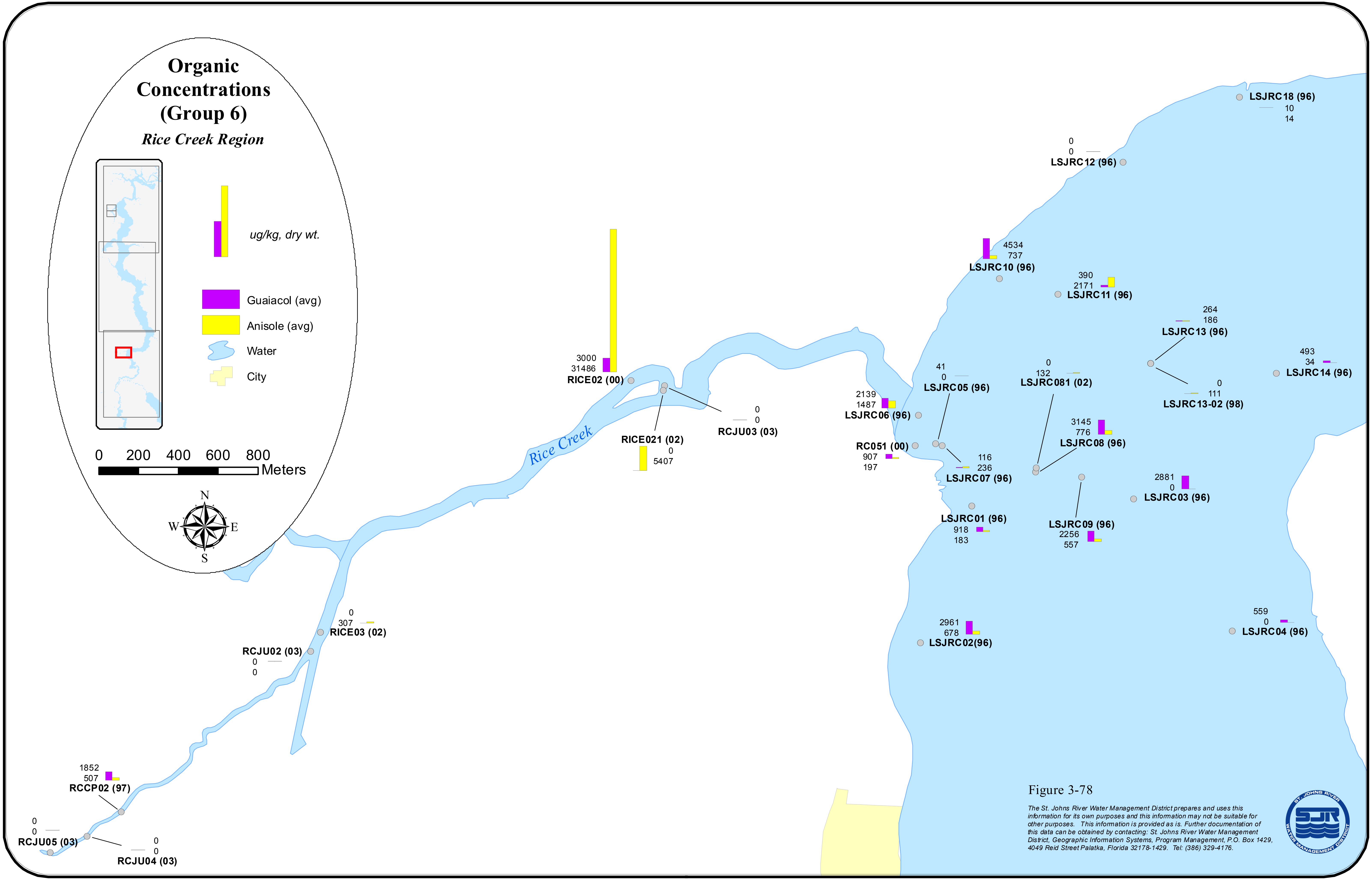


Figure 3-78

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

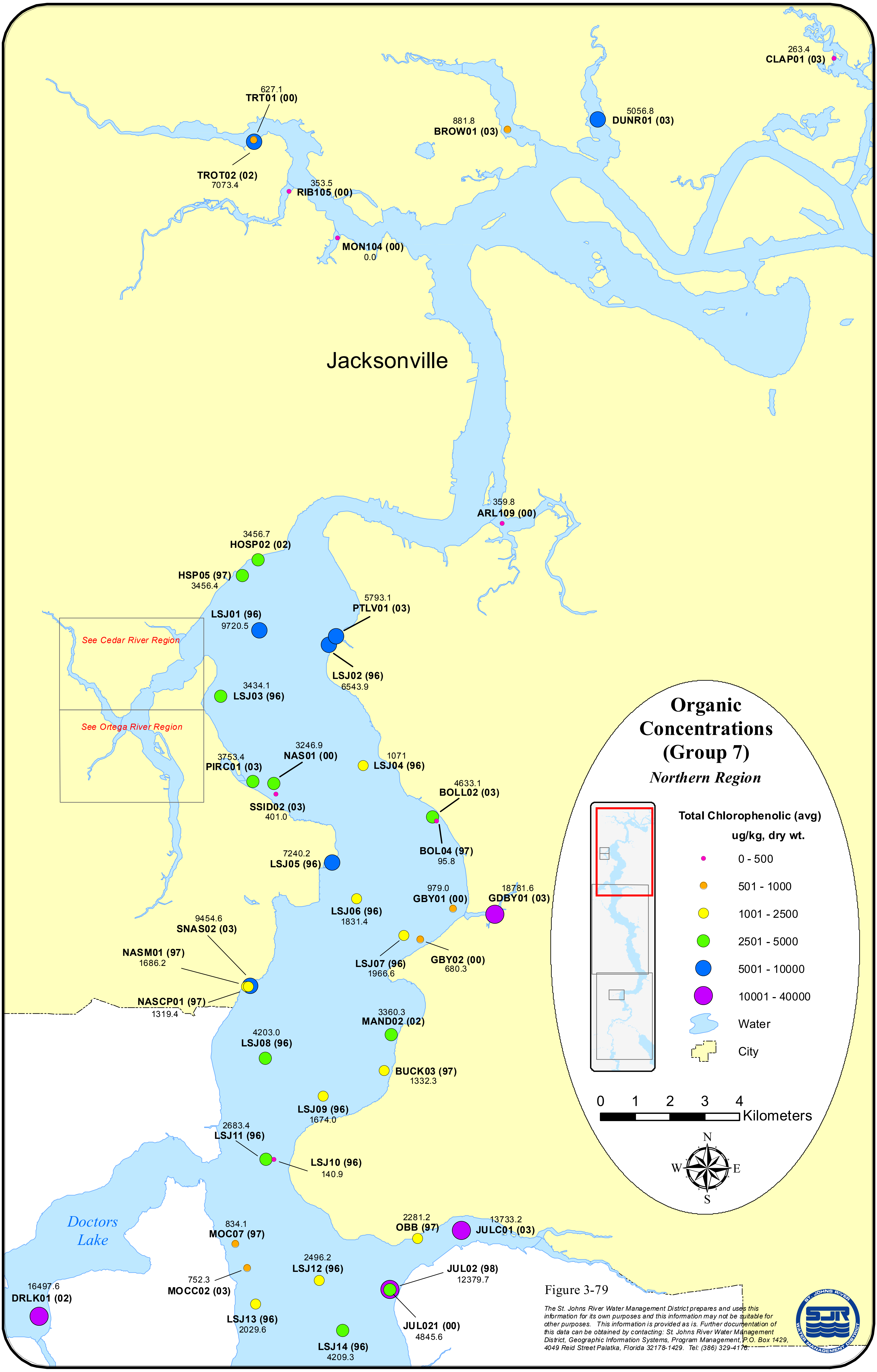


Figure 3-79

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

# Organic Concentrations (Group 7)

*Cedar River Region*

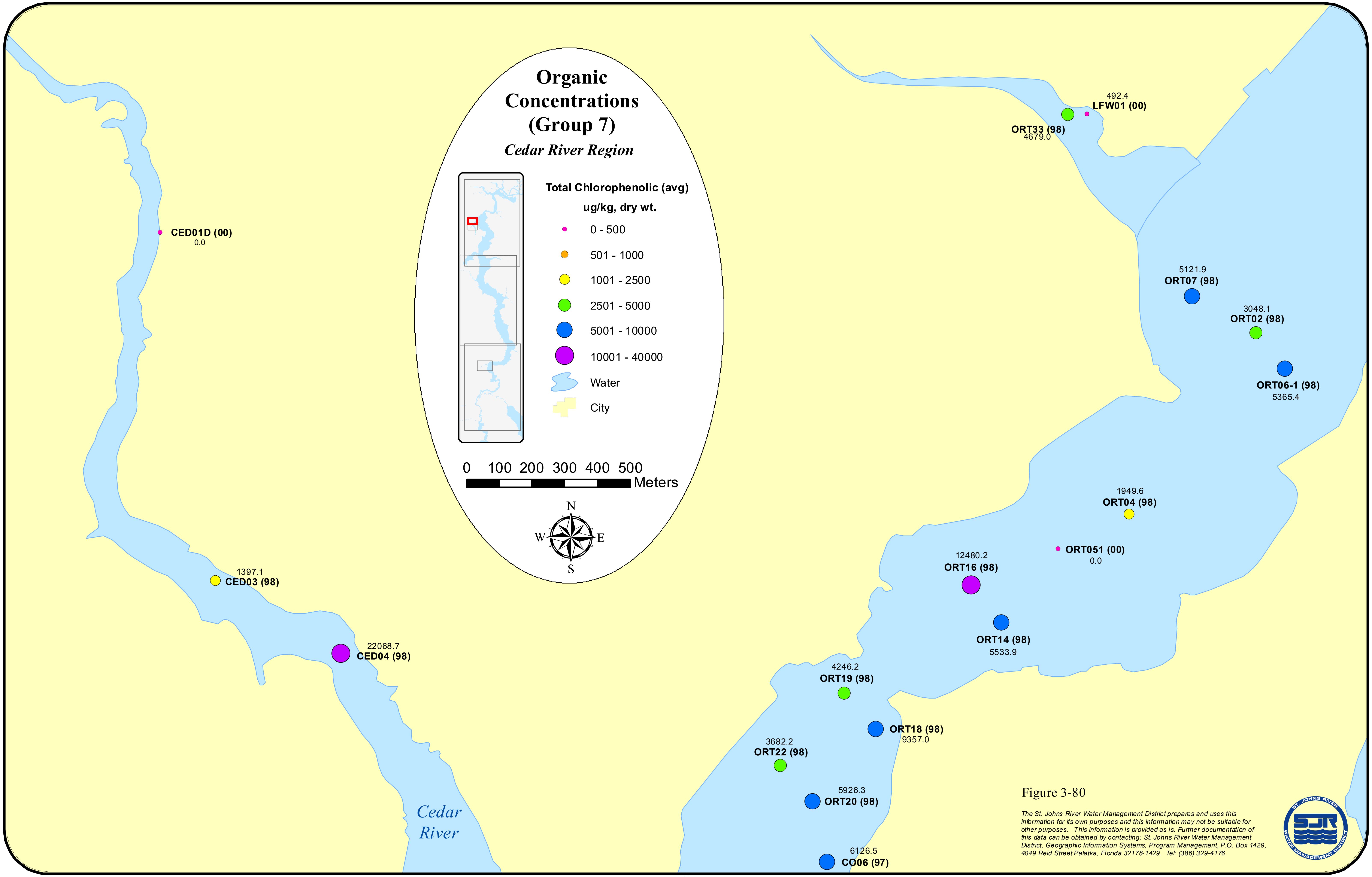


Figure 3-80

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

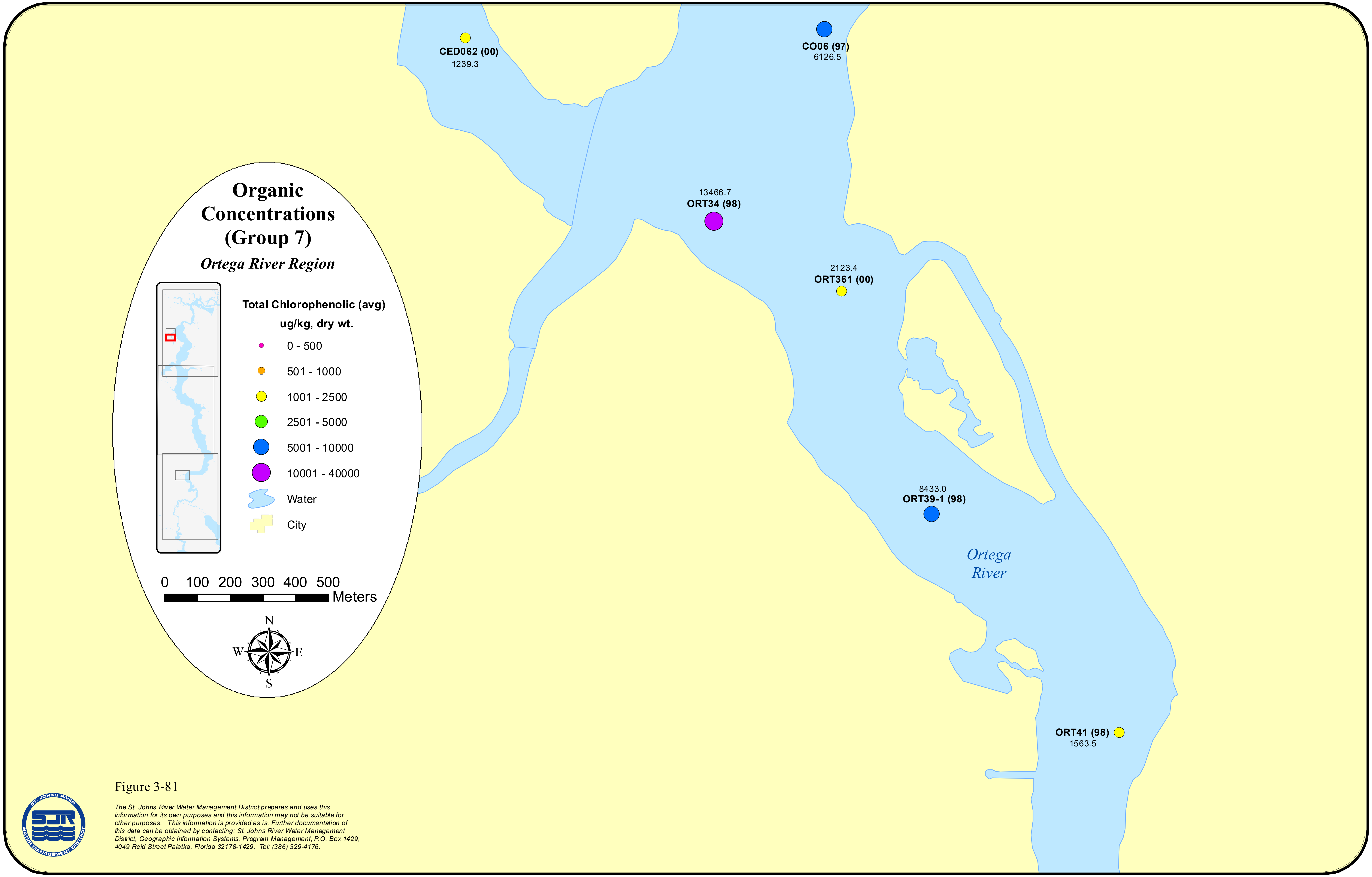


Figure 3-81

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*

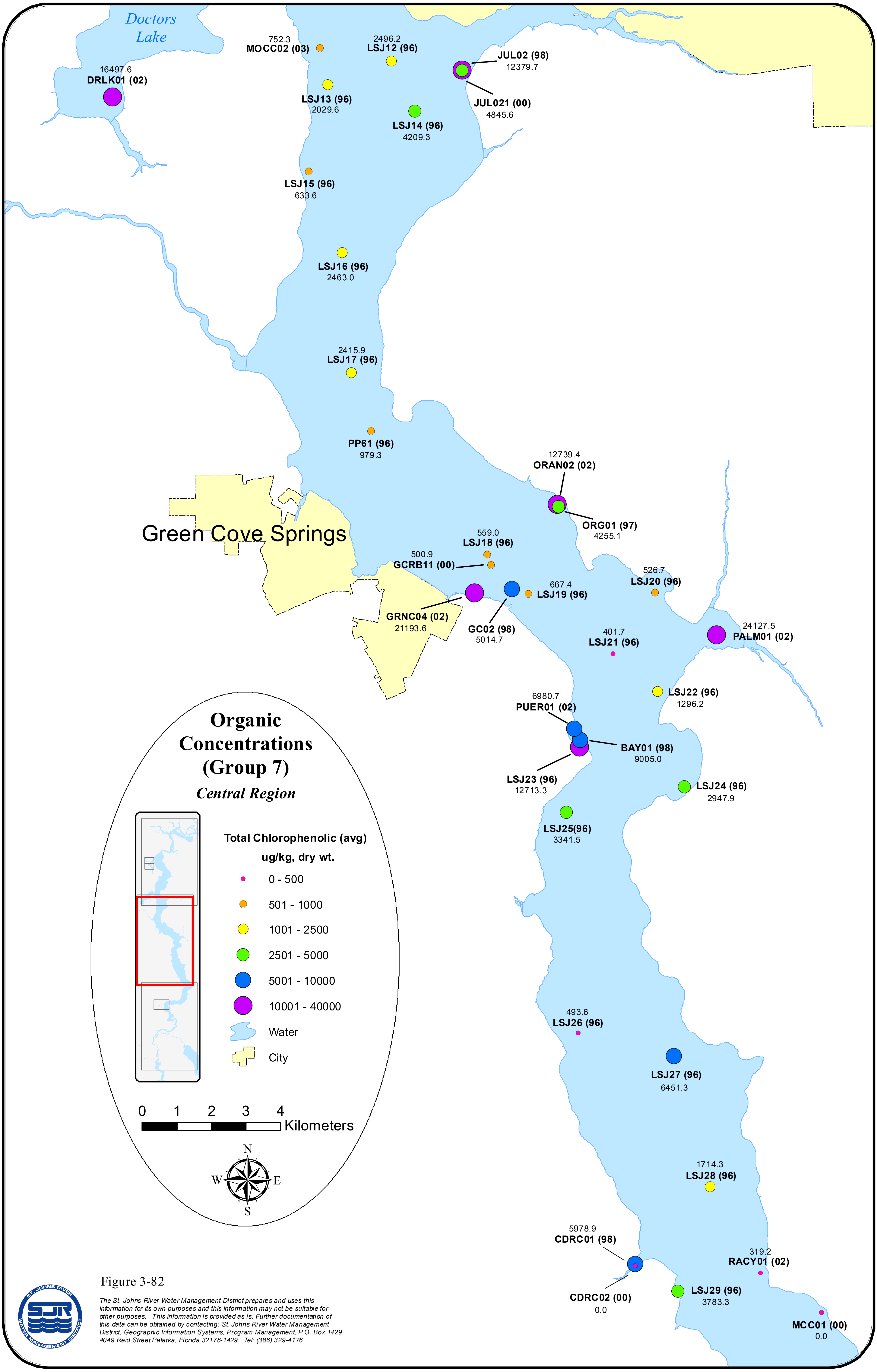


Figure 3-82

The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.

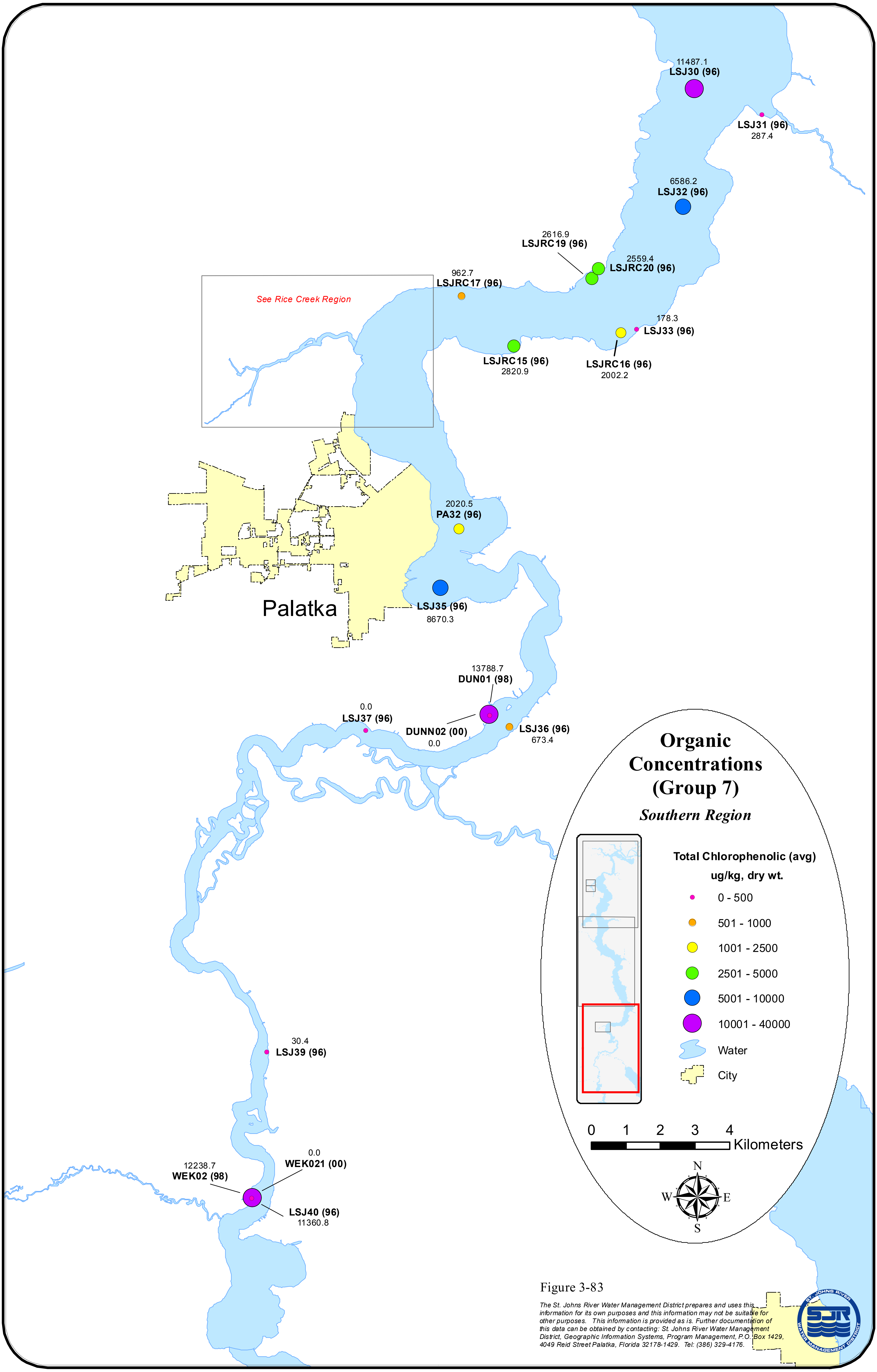


Figure 3-83

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# Organic Concentrations (Group 7)

*Rice Creek Region*

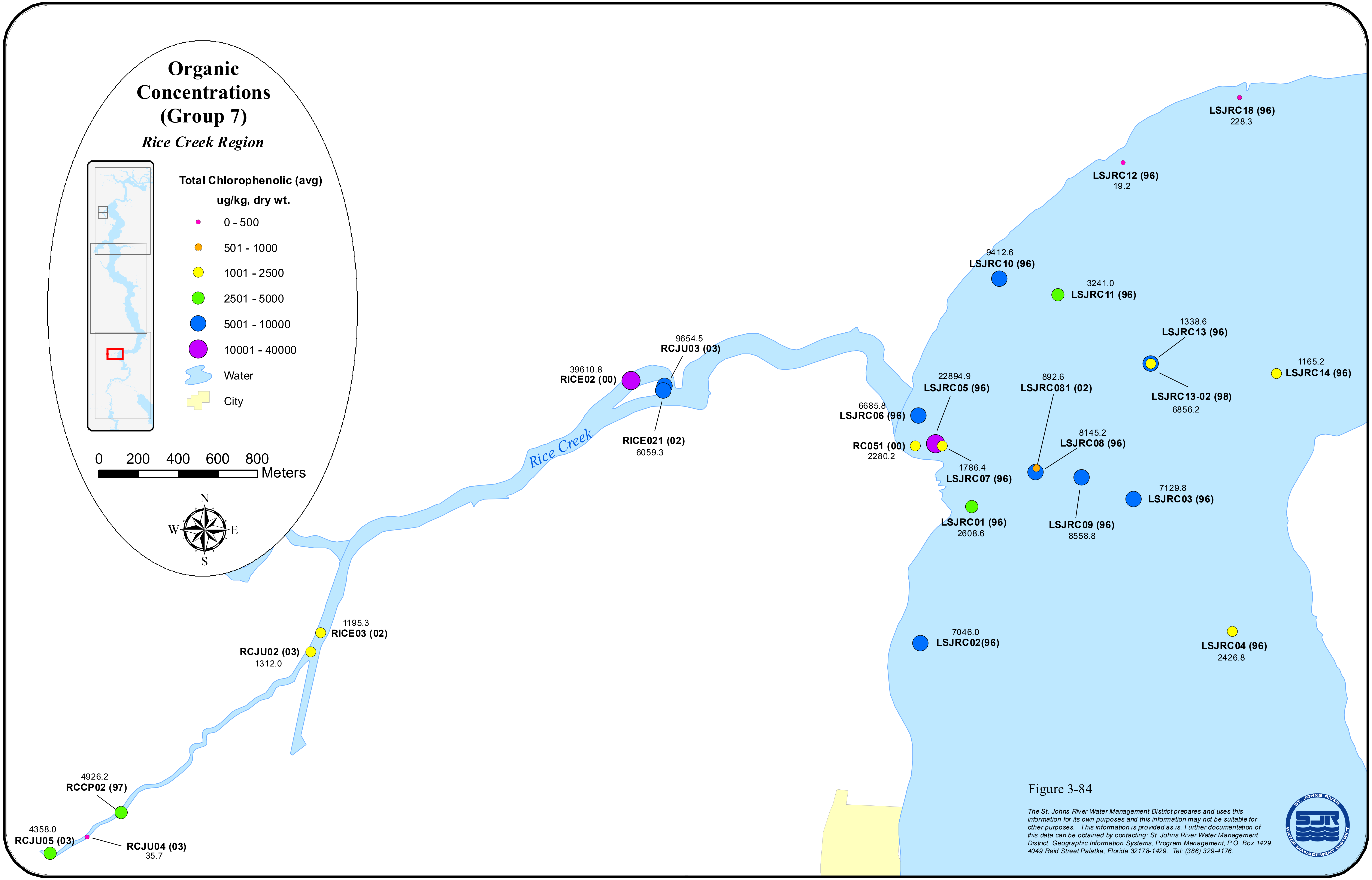

Figure 3-84

*The St. Johns River Water Management District prepares and uses this information for its own purposes and this information may not be suitable for other purposes. This information is provided as is. Further documentation of this data can be obtained by contacting: St. Johns River Water Management District, Geographic Information Systems, Program Management, P.O. Box 1429, 4049 Reid Street Palatka, Florida 32178-1429. Tel: (386) 329-4176.*