Chapter 9. Submerged Aquatic Vegetation

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ACRONYMS, ABBREVIATIONS, AND CONVERSION FACTORS

μS/cm	micro-Siemens per cm
CDOM	Colored dissolved organic matter
DOC	Dissolved organic carbon
EFDC	Environmental Fluid Dynamics Code
GIS	Geographic Information System
K_d	Light Attenuation (m^{-1})
LSJRB	Lower St. Johns River basin
NA	Not applicable
NR	Not ranked
PSU	Practical salinity units
RCI	Relative condition index
SAV	Submerged aquatic vegetation
SLR	Sea level rise
TSS	Total suspended solids

1 ABSTRACT

The objective of this chapter is to describe the Submerged Aquatic Vegetation Working Group's analysis of potential effects on submerged aquatic vegetation in the littoral zone from water withdrawals from the St. Johns River. After reviewing the literature, field and experimental results, and analyses from other ecological working groups, two factors were identified as creating potential impacts in the littoral zone: (1) alterations to stage (water levels) and (2) elevated salinity. Hydrologic model scenarios (see Chapter 6. River Hydrodynamics Results) were ranked according to the magnitude of effect for each of these two factors, and analysis proceeded from greatest to least effect. For stage, the greatest effect was predicted in river segments 7 and 8 (river km 310 to 420) with scenario Full1995NN. For salinity, the greatest effect was predicted in river segments 2 and 3 (river km 40 to 160) with scenario FwOR1995PS. When the littoral zone ecological response models were applied to the hydrologic data outputs, it was determined that negligible effects would be expected within the littoral zone under the top-ranked scenario for each factor. By extension, scenarios with lesser magnitude effects would be expected to have lesser and, therefore, negligible ecological effects. Overall uncertainty for the stage and salinity analyses was considered medium and low, respectively.

2 INTRODUCTION

Both emergent and submerged plants have been included in classical definitions of the littoral zone. As defined in this chapter, however, the littoral zone includes only submerged plants. Submerged aquatic vegetation (SAV) is an important component of the aquatic ecosystem. It anchors sediments and creates substrate for epifauna and epiphyton, provides dissolved oxygen, offers wildlife refuge and food resources, and competes with phytoplankton for nutrients.

Because of the low relief in the St. Johns River basin, floodplain wetlands are very extensive and likely responsive to a different hydrologic regime than SAV. Data indicate that floodplain wetlands may become hydrologically decoupled from river or lake water levels on the falling limb of the hydrograph (see Chapter 10. Wetland Vegetation). This physical separation suggests that the biological connectedness between SAV and floodplain wetlands may be less than in a classical littoral paradigm. Therefore, the Wetland Vegetation Working Group analyzed the emergent portion of the littoral zone (see Chapter 10. Wetland Vegetation), while the Submerged Aquatic Vegetation Working Group (working group) analyzed the effects on SAV.

SAV is present throughout the St. Johns River watershed; and is largely confined to lakes in the upper and middle basins of the river. Within the lower basin, SAV occurs in both lakes and in broad littoral shelves in the main stem of the river (Sagan 2009).

The SAV community contains 12 documented species (Table 2–1, Appendix 9.A). *Vallisneria americana* is the dominant species in the lower and middle basins and is a codominant species in the upper basin, where *Hydrilla verticillata* is more widespread and dominant at times. There is active and sustained suppression of *H. verticillata* through aggressive, repeated application of herbicides, which likely affects the entire SAV community in terms of both composition and coverage.

Table 2–1. Relative abundance of SAV species at four long-term (1996 to 2008) monitoring sites in the lower St. Johns River basin (LSJRB).

Species	**Relative Abundance**
Vallisneria americana	61%
Najas guadalupensis	17%
Ruppia maritima	5%
Hydrilla verticillata	3%
Charophyte sp.	3%
Micranthemum sp.	3%
Potamogeton pusillus	3%
Zannichellia palustris	2%
Eleocharis sp.	1%
Sagittaria subulata	1%
Potamogeton illinoensis	< 1%
Ceratophyllum demersum	< 1%

For SAV analyses, we used *V. americana* as the representative species for the SAV community. *V. americana* is a cosmopolitan species, and its physiology and ecology are well studied (Appendix 9.B). *V. americana* is the dominant species in the estuarine reach of the river (Sagan 2009) (Appendix 9.A). It is an important pioneer species because other endemic species are almost never found when *V. americana* is absent (Sagan 2009). For example, out of nearly 8,000 sample transects performed from 1996 to 2008, other species were present without *V. americana* in only 8% of the samples (D. Dobberfuhl, unpublished data).

Many factors potentially affect SAV in the river (e.g., light attenuation, sediment quality, nutrients, wave action, and salinity). However, we restricted this analysis to only those factors potentially affected by surface water withdrawals (Figure 2–1). The working group identified two major factors. First, we judged that water withdrawals could affect long-term average water levels. Second, we judged that water withdrawals could reduce discharge and affect salinity patterns in the estuarine reach of the river. Both of these hydrologically mediated factors ultimately affect SAV abundance and distribution. Given the importance of SAV as habitat, these changes would ultimately affect other biological functions of aquatic ecosystems.

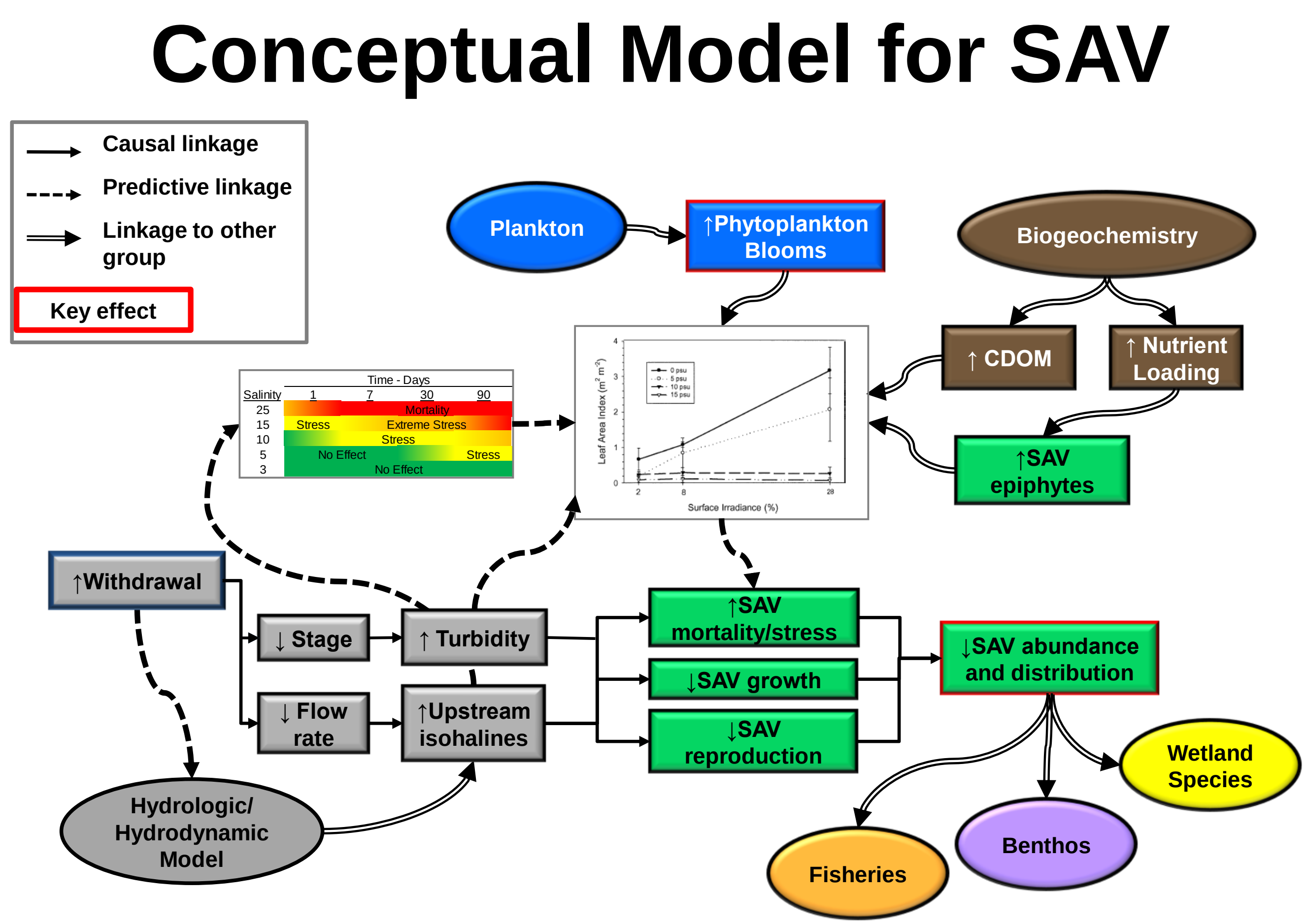


Figure 2–1. Conceptual model showing hydrologic drivers (gray), SAV response models (figures), SAV community responses (green), and information data flows among other ecological working groups (various colors, double arrows).

Long-term water level changes affect the spatial extent of lake or river bottom receiving adequate light to support SAV. If we assume that water column light attenuation is unchanged, then increasing water levels will tend to cause SAV to adjust by colonizing shallower areas. Conversely, decreasing water levels will result in colonization of previously deeper areas. The stage-area relationship of a water body determines whether the potential spatial extent of the SAV habitat increases or decreases with these vertical adjustments.

Both freshwater and euryhaline SAV species colonize the upper reaches of the lower St. Johns River estuary. Euryhaline species tolerate a wide range of salinity conditions. The interaction between salinity tolerance and ambient salinity conditions determines the spatial extent of each species. Short-term increases in salinity, due to reverse flow events, cause salt-intolerant grass beds to thin out or disappear. These responses have been thoroughly documented in the estuary (Sagan 2009) (Appendix 9.A). Because of sensitivity to salinity and the demonstrable effect of increased salinity on SAV, surface water withdrawals affecting ambient salinity would have a corresponding effect on SAV community abundance and distribution (see Figure 2–1).

The objective of this chapter is to describe the working group's analysis of potential effects on SAV that could result from surface water withdrawals from the St. Johns River. Environmental Fluids Dynamic Code (EFDC) hydrodynamic model results were used to identify important hydrologic and water quality differences among the different model scenarios (Table 2–2). We then inferred how differences among model scenarios would translate into potential ecological changes in the SAV community using simple physiological and habitat models. The end result is an analysis of which model scenarios (i.e., withdrawal rates) do and do not have the potential to cause appreciable ecological change in the littoral zone.

Table 2–2. River hydrodynamic model scenarios used in the WSIS study. The Submerged Aquatic Vegetation Working Group used only the Base1995NN, Full1995NN, and FWOR1995PS scenarios.

Scenario Name	Withdrawal Rate*	Land Use†	Upper Basin Projects‡	SLR§
Base1995NN	zero	1995	No	zero
Half1995NN	77.5 mgd	1995	No	zero
Full1995NN	155 mgd	1995	No	zero
Base1995PN	zero	1995	Yes	zero
Half1995PN	77.5 mgd	1995	Yes	zero
Full1995PN	155 mgd	1995	Yes	zero
Full1995PS	155 mgd	1995	Yes	+14 cm
Base2030PN	zero	2030	Yes	zero
Half2030PN	77.5 mgd	2030	Yes	zero
Full2030PN	155 mgd	2030	Yes	zero
Base2030PS	zero	2030	Yes	+14 cm
Half2030PS	77.5 mgd	2030	Yes	+14 cm
Full2030PS	155 mgd	2030	Yes	+14 cm
FwOR1995NN	262 mgd	1995	No	zero
FwOR1995PN	262 mgd	1995	Yes	zero
FwOR1995PS	262 mgd	1995	Yes	+14 cm
FwOR2030PN	262 mgd	2030	Yes	zero
FwOR2030PS	262 mgd	2030	Yes	+14 cm

[*] Water withdrawal rate from Lower Ocklawaha River and/or St. Johns River upstream of DeLand
[†] Year of land-use used to simulate runoff from contributing watersheds of St. Johns River
[‡] Whether expected 2030 structural changes to upper St. Johns River are used in scenario
[§] SLR = sea level rise; rise in mean sea level relative to 1995

3 METHODS

The SAV analysis used hydrologic and salinity results from the predetermined model scenarios (see Chapter 6. River Hydrodynamics Results). We ranked the scenarios according to the magnitude of their predicted effects on water level and ambient salinity. We did not assess scenarios with increases in water level or decreases in salinity because they represent augmentation effects rather than reduction effects. As opposed to reduction effects (i.e., effects associated with a reduction in freshwater flow rates), augmentation effects add water to the system, creating a different set of issues not addressed in this study.

The working group then assessed the effects of the model scenarios demonstrating the greatest hydrologic change upon the SAV. If we considered the effects of the top-ranked scenario biologically significant, then the effects of the next higher ranked scenario would be considered, and so on in an iterative fashion. If the effects of a given scenario were not deemed biologically significant, then the remaining scenarios with lesser magnitude hydrologic effects (lower ranks) were not evaluated because all remaining scenarios would have smaller effects. In this manner, analysis began with model scenarios most likely to affect SAV and stopped when a model scenario was judged to have minimal effects on SAV.

The main stem of the river was divided into 9 segments, based on morphological characteristics (Figure 3–1 and see Chapter 10. Wetland Vegetation). This chapter does not consider segment 9. Salinity effects occur entirely in segments 2 and 3. The greatest stage effects occur in segments 7 and 8.

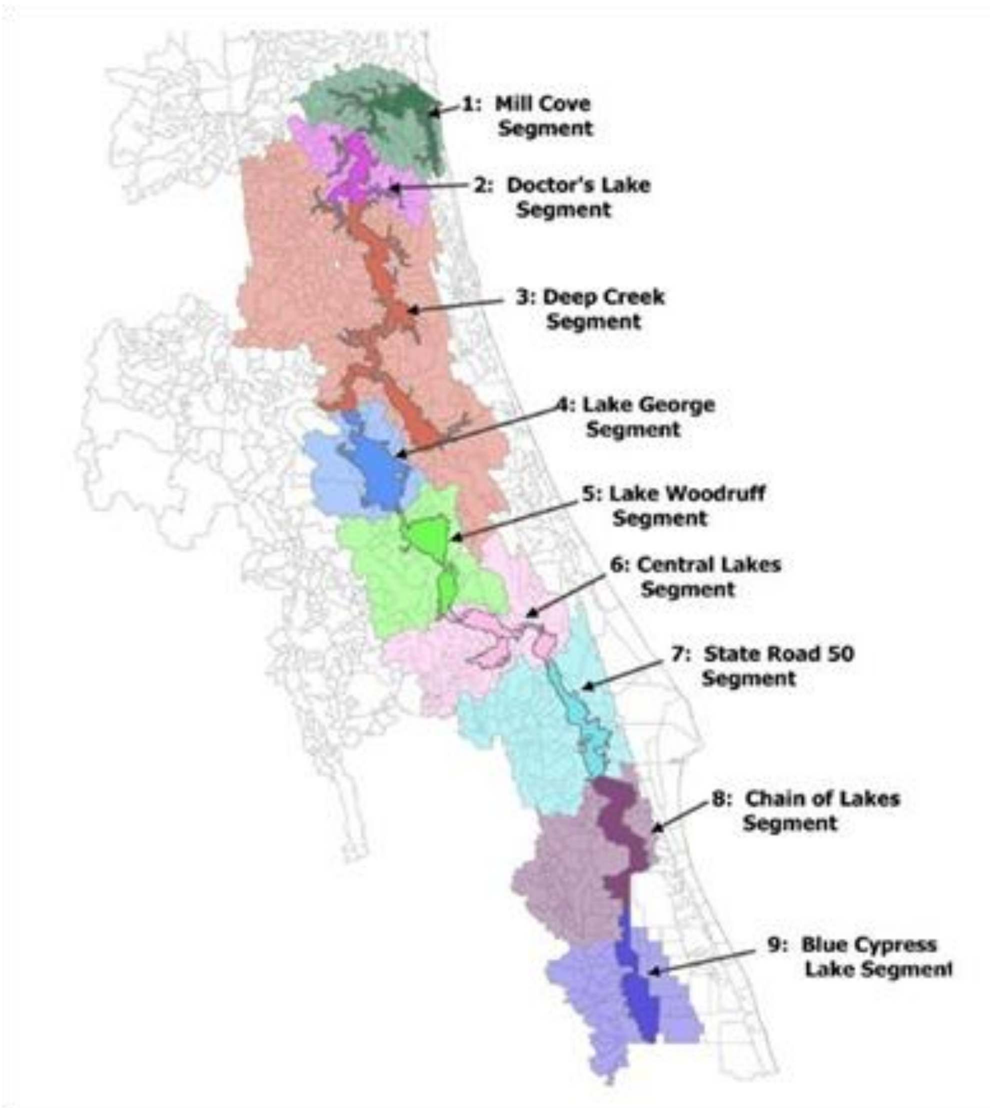


Figure 3–1. River segments 1 through 9 (see Chapter 10, Wetland Vegetation, for discussion). Segment 9 was not used in the submerged aquatic vegetation analysis.

3.1 Stage

The analysis began with an examination of the effects on SAV from the scenario showing the greatest reduction in average water level caused by surface water withdrawals (i.e., the top-ranked scenario). EFDC hydrodynamic modeling indicated that average stage reductions would be greatest in river segment 8 (see Chapter 6. River Hydrodynamic Results). Model results predicted that Lake Poinsett in segment 8 would have the greatest stage reduction (-5 cm) under the scenario with the highest withdrawal (Full1995NN). Lake Poinsett also contains an ephemeral SAV community and therefore represents the worst case effect of stage reduction on the SAV community. More moderate stage effects on Lake Harney (-4 cm), the next downstream lake with appreciable SAV habitat, were also examined.

There was insufficient data to determine SAV depth-stage relationships in Lakes Poinsett and Harney. Although there is anecdotal information regarding SAV in these two lakes, very little quantitative monitoring has been performed. By comparison, SAV in river segments 2 and 3 exists at a mean depth of approximately 85 cm and a maximum of 120 cm (Dobberfuhl 2007, Sagan 2009). Surveys in Lake Harney indicated that SAV grew at a similar average depth of approximately 90 cm (G. Eby, Seminole County Lake Management Program, pers. comm., 2011). Therefore, -85 cm was used as a target depth for the SAV analysis.

For both lakes, we developed a depth-area curve from bathymetric data entered into a geographic information system (GIS). Using the base scenario (Base1995NN), we calculated the spatial extent of the lake bottom between the average growing season water level and -85 cm. There is insufficient data to determine the actual extent of SAV in these lakes, so this calculated area was considered potential SAV habitat. We calculated the bottom area between average water level and --85 cm for the top-ranked scenario (Full1995NN). Potential habitat difference between the base scenario (Base1995NN) and top-ranked scenario (Full1995NN) was calculated as both absolute and relative area. From this comparison, we determined whether the habitat area change (positive or negative) would be biologically significant.

3.2 Salinity

We also assessed the effects of elevated salinity predicted for surface water withdrawals. Initial work focused on the salinity tolerance of *V. americana*. The working group reviewed the literature to develop a salinity exposure model (Appendix 9.B), and additional work refined the initial hypothesized stress thresholds. For example, the application of stress enzyme biomarkers in microcosm experiments allowed the identification of subcritical stress responses, and we adjusted stress thresholds accordingly (Appendix 9.C). Intensive weekly SAV sampling results also demonstrated the validity of rapid SAV responses to short-term salinity spikes (Appendix 9.D). Finally, in situ reciprocal transplant experiments investigated SAV recovery times to repeated salinity exposure (Appendix 9.E). As a result, the working group produced a predictive salinity exposure model for *V. americana*, supported by field observations, experimental observations, and the scientific literature (Figure 3–2).

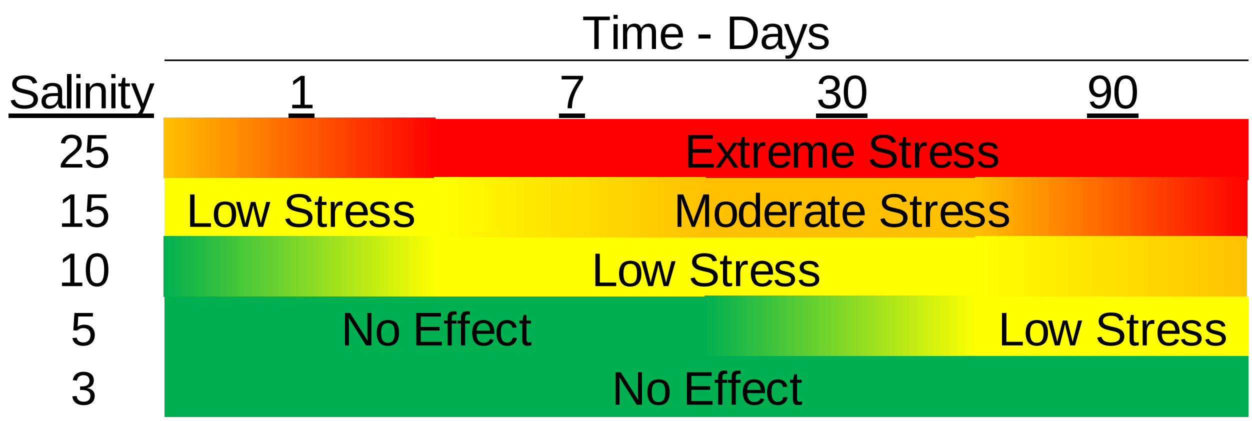


Figure 3–2. Salinity exposure model for *V. americana*

The salinity analysis used output from the EFDC hydrodynamic model for the lower basin of the St. Johns River (see Chapter 6. River Hydrodynamics Results). We used daily average salinity for the surface cells within the model domain. We also compared modeled littoral salinity to measured littoral salinity to verify the agreement between the two data sets. Because the EFDC hydrodynamic model requires a spin-up period to allow for adjustment of variables from an uncertain initial state, salinity data for the year 1995 was not used in the analysis.

The remaining modeled salinity output for the period from 1996 to 2005 was reduced in two ways. First, we limited the model output to include only cells approximately between river km 40 and 85, comprising river segments 2 and 3 (Figure 3–3). This river reach contains both historic and current SAV populations and sufficiently high salinity to affect SAV (see Chapter 6. River Hydrodynamics Results). Salinity concentrations deleterious to SAV do not occur upstream of this reach. Downstream of this reach, there is insufficient littoral habitat to support SAV, and salinities routinely exceed the tolerance limits of freshwater species of SAV (D. Dobberfuhl, unpublished data).

Second, we limited model output to include only littoral cells, which are those adjacent to the shoreline (Figure 3–4). Because most of the cells represent areas of the river that do not support SAV due to light limitation associated with deeper water, this criterion was imposed to eliminate bias in subsequent calculations involving relative differences in potential SAV habitat introduced by using pelagic (open water) cells where SAV would not be found. With this approach, we used 511,000 salinity data points for each model scenario considered (140 cells × 365 days × 10 years).

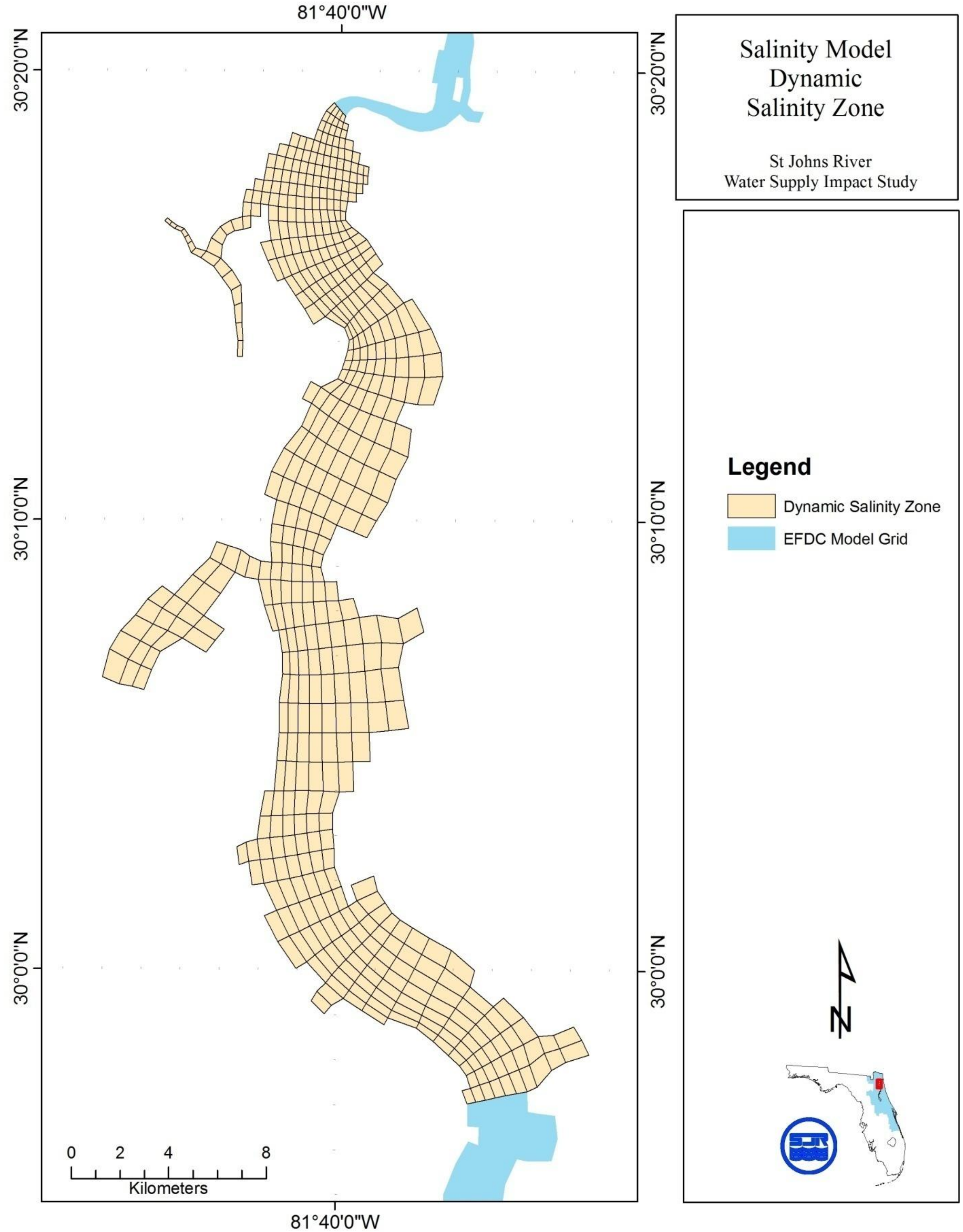


Figure 3–3. EFDC hydrodynamic model grid showing St. Johns River cells where salinity gradients are greatest.

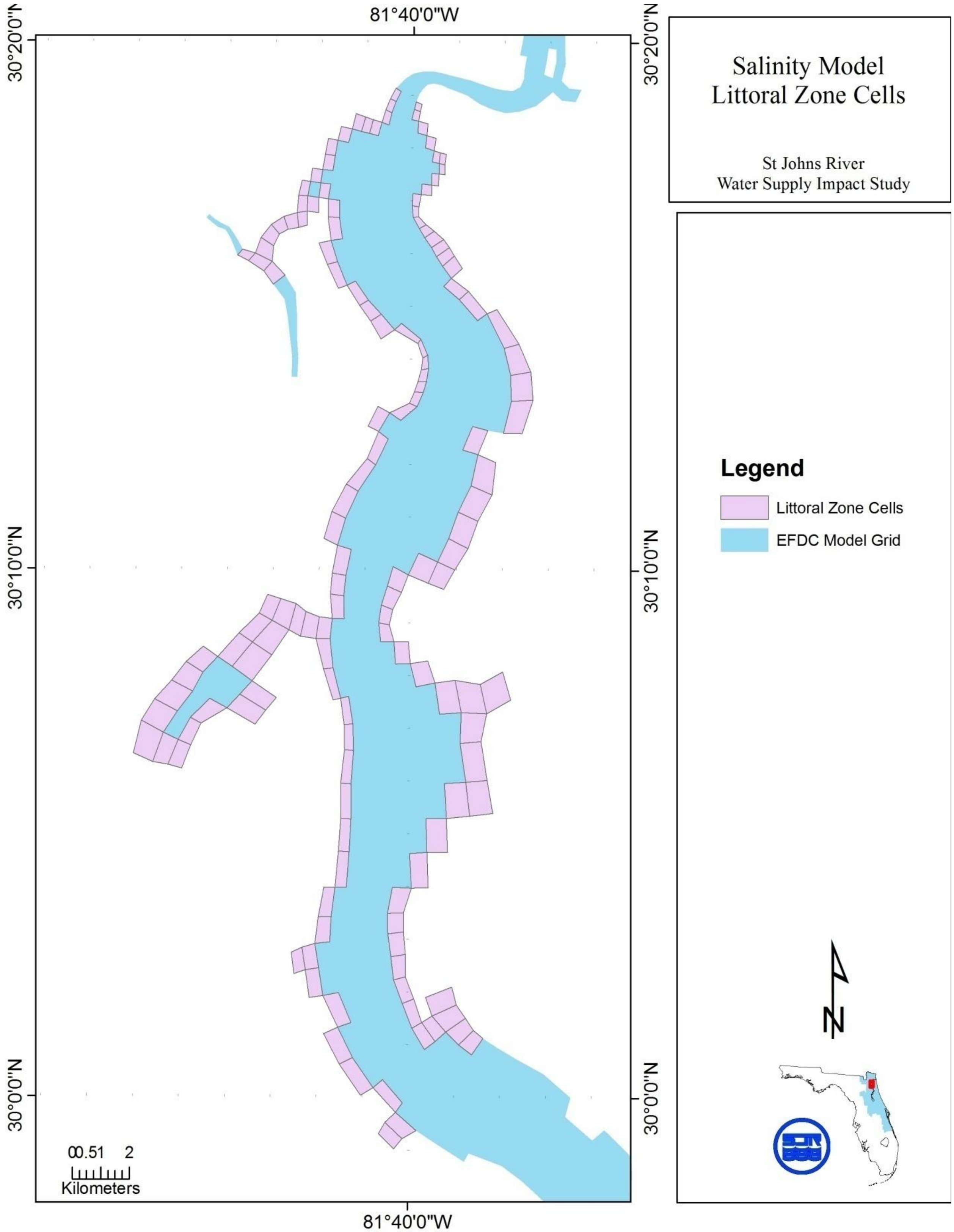


Figure 3–4. EFDC hydrodynamic model grid showing only the littoral cells highlighted, these cells were used to analyze stress frequency of freshwater withdrawal scenarios.

Each modeled salinity data point was then given a condition rating according to the SAV salinity exposure model. The working group defined four stress categories (Table 3–1).

Table 3–1. Stress categories for the SAV salinity exposure model and descriptions of generally observable SAV characteristics typical of each category.

Stress Category	Description
No Effect	SAV community shows no adverse effects of salinity stress
Low Stress	SAV community experiences some level of salinity stress that may result in physiological impairment and minor declines in SAV spatial coverage
Moderate Stress	SAV community experiences an increased level of salinity stress that results in physiological impairment and obvious declines in grassbed coverage
Extreme Stress	SAV community experiences a deleterious level of salinity stress that results in losing the majority or all of the above-ground biomass and some level of below-ground biomass.

In applying the condition rating to each cell, we developed a spatially explicit analysis of salinity effects for each model scenario. The final analysis used the frequency of stress ratings determined for each model scenario (Figure 3–5). We examined aggregate frequencies for each of the four stress categories among all littoral cells regardless of location. We also examined relative stress frequency changes within each cell to identify cells with higher risks of stress from salinity-induced changes. For the aggregate frequency and spatial frequency analysis we used 7-day and 30-day averaged model salinity, respectively. These time scales produced the largest differences between the base scenario (Base1995NN) and top-ranked scenario (FwOR1955NN). As with the water level analysis, each ranked scenario was considered sequentially until a model scenario was judged to produce biologically insignificant differences compared to the base scenario (Base1995NN).

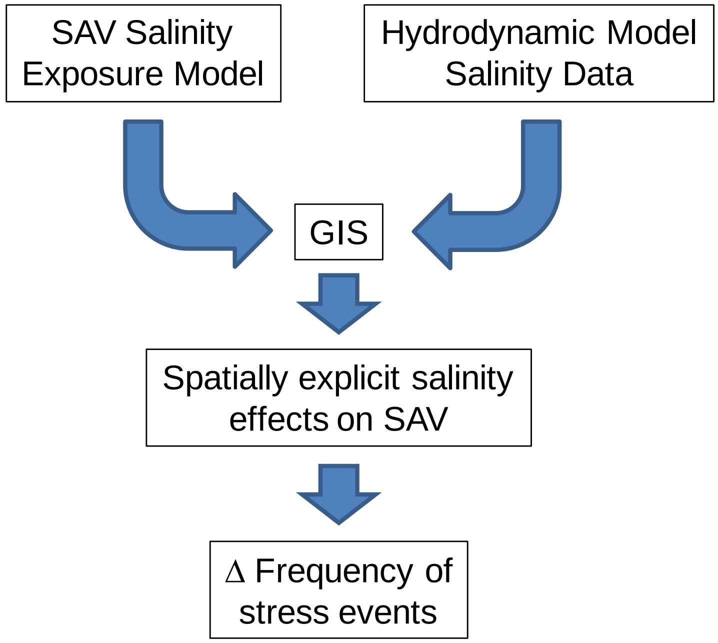


Figure 3–5. Schematic showing the analytical approach used to assess potential effects of salinity on the SAV community.

3.3 LITTORAL SALINITY MONITORING

The EFDC hydrodynamic model provided output for littoral cells, but it was calibrated using salinity sampling sites in the main channel of the river (see Chapter 5. River Hydrodynamics Calibration). The EFDC hydrodynamic model calibration accurately simulated mid-channel salinity data (see Chapter 5. River Hydrodynamics Calibration). To examine the differences between channel and littoral salinity, we deployed a YSI conductivity sensor (YSI, Inc., Yellow Springs, Ohio) in the littoral zone of the river at one of the long-term SAV sampling sites. Conductivity was continuously logged from October 2009 through March 2010. Conductivity was also continuously logged at a nearby mid-channel bridge site during the same period. We used daily average salinity to control for tidal fluctuations.

4 RESULTS AND DISCUSSION

4.1 LAKE STAGE AND POTENTIAL SAV HABITAT

After ranking the model scenarios according to stage reductions relative to the base scenario (Base1995NN), the Full1995NN scenario exhibited the greatest mean stage reductions in both Lake Poinsett and Lake Harney (Table 4–1).

Table 4–1. Mean annual lake stage changes relative to scenario Base1995NN. Scenarios showing increased stage indicative of augmentation effects were not ranked.

Scenario	Mean Stage Change (cm)*		Rank
	Lake Poinsett	Lake Harney	
Full1995NN	-5	-4	1
Half1995NN	-3	-2	2
FwOR1995NN	NA†	-4	3
Full1995PN	1	-3	4
FwOR1995PN	NA	-3	5
Half1995PN	4	-1	6
Base1995PN	7	1	NR‡
Full2030PN	6	2	NR
FwOR2030PN	NA	2	NR
Half2030PN	8	4	NR
Full1995PS	1	6	NR
Base2030PN	12	6	NR
FwOR1995PS	NA	6	NR
Full2030PS	6	12	NR
Half2030PS	8	14	NR
Base2030PS	12	15	NR

* Data in the table are taken from Chapter 6. River Hydrodynamic Results.
† NA = Not applicable
‡ NR = Not ranked

Comparing calculated bottom area between the base scenario (Base1995NN) and the top-ranked scenario (Full1995NN) in Lake Poinsett showed a small positive increase in potential SAV habitat (Figure 4–1, Table 4–2). The base scenario (Base1995NN) had 989 ha of potential SAV habitat, while the Full1995NN scenario showed 1,078 ha of habitat. The analysis for Lake Harney showed that the base scenario (Base1995NN) had 391 ha of potential SAV habitat, while the top-ranked scenario (Full1995NN) showed 382 ha of habitat. These represent 9% and -2% spatial differences, respectively

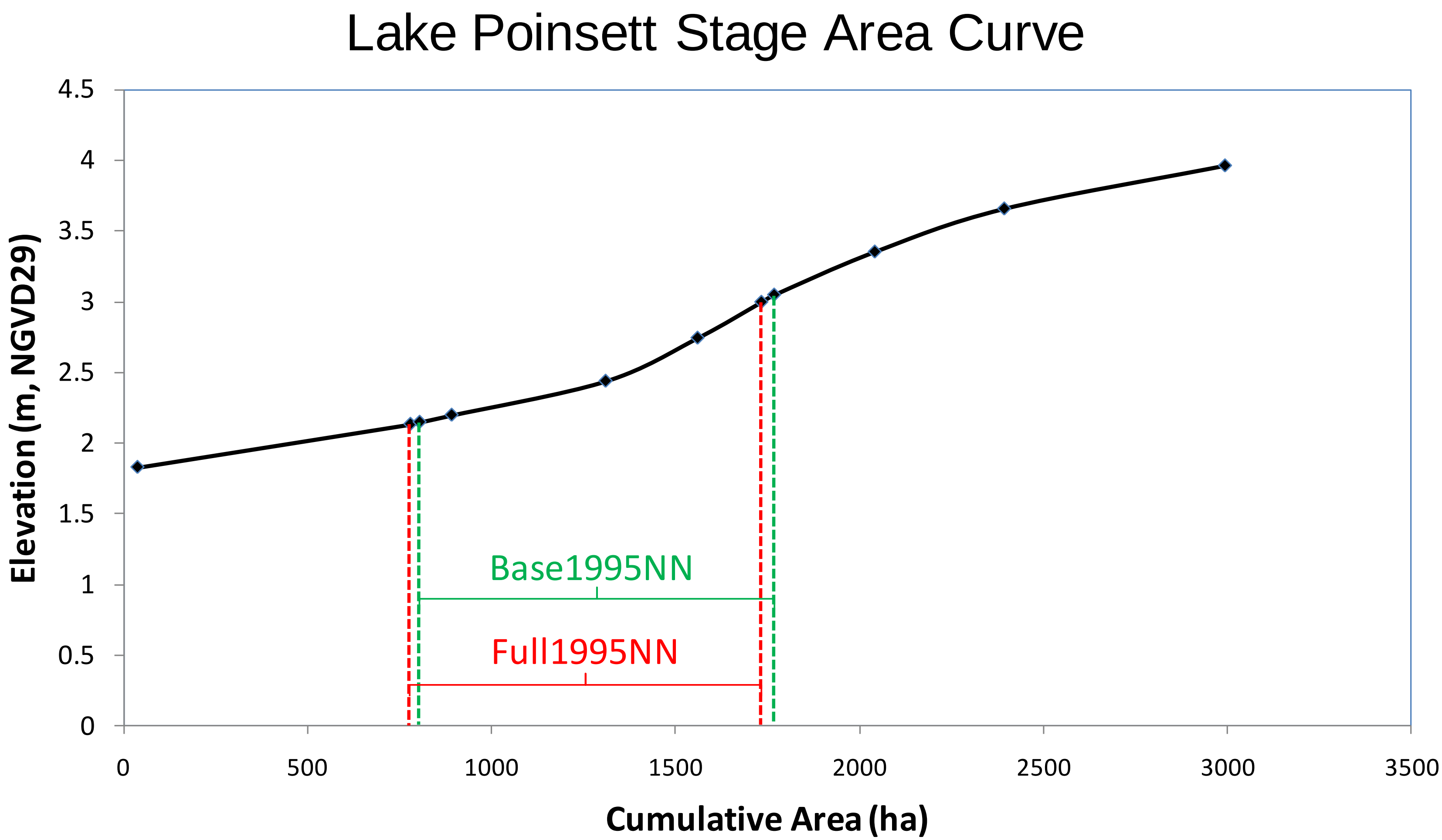


Figure 4–1. The stage-area curve for Lake Poinsett shows the current mean annual stage at an assumed 85 cm depth distribution for SAV (green dashed lines) and a 5 cm drop in stage commensurate with the water withdrawal (red dashed lines). Cumulative area refers to total lake bottom area.

Table 4–2. Potential SAV habitat calculated from the stage-area curve for Lakes Poinsett and Harney, an 85 cm depth was used to calculate the area.

Lake	Scenario		Difference
	Base1995NN	Full1995NN	
Poinsett	989 ha	1,078 ha	9%
Harney	391ha	382 ha	-2%

Lakes in the St. Johns River basin are generally shallow and have low slopes in their stage-area curves. If the stage-area relationship in the littoral zone has a nearly constant slope, then small changes in water level will not result in substantial changes to the area of potential SAV habitat. This condition applies to both Lakes Poinsett and Harney. If changes in water levels shifted the depth distribution of SAV into areas of the stage-area curve where the slope of the curve changes (i.e., inflection points), then larger spatial differences among scenarios would be expected. However, the largest modeled stage reductions would not encompass any inflection points in the stage-area curve. With a constant slope, reductions in habitat in shallow areas would be replaced by additions of habitat in once deeper areas that are now suitable for SAV because of the lower water levels in the lake. Hence, we would not expect potential SAV habitat to be substantially affected by the water withdrawals associated with the top-ranked scenario (Full1995NN), or any of the lower ranked scenarios. Because the top-ranked scenario (Full1995NN) did not indicate substantial effects, the lower ranked scenarios were not analyzed (see Section 3).

One important assumption of this stage-area analysis is that light attenuation in the water column does not change among scenarios. The three major light attenuating constituents are total suspended solids (TSS), phytoplankton, and colored dissolved organic matter (CDOM). Wind resuspension models indicated that small stage reductions would not result in increased TSS concentrations (see Alternative Water Supply Cumulative Impact Assessment Interim Report, SJRWMD 2008). The Plankton Working Group's analyses suggested that the small, ephemeral increases in phytoplankton standing stock would not materially affect light attenuation (see Chapter 8. Plankton). The Biogeochemistry Working Group's analyses indicated that none of the model scenarios produced discernible changes to dissolved organic carbon (DOC) exports from wetlands (see Chapter 7. Biogeochemistry). These findings support the assumption of unvarying light attenuation among model scenarios.

4.2 Salinity Exposure Model

We chose a highly sensitive cell (LIJ#3480) from the EFDC hydrodynamic model grid to rank model scenarios according to potential salinity changes. This cell is near the downstream terminus of the SAV community where salinity stress is most likely to occur, thus it represents a worst case situation. The ranking was based on maximum 7-day modeled salinity. The 7-day time scale was chosen because salinity spikes capable of impacting SAV (i.e., capable of increasing stress categories, (see Table 3–1) were most frequent at this time scale. Because the time series patterns of salinity were essentially the same among scenarios, a simple maximum sufficed to gauge relative effects. We did not rank any scenarios predicting reduced salinity because these were reflective of augmentation effects. Table 4–3 shows the final model scenario rankings.

Table 4–3. Maximum 7-day salinity calculated from the EFDC hydrodynamic model for cell LIJ#3480, near the downstream edge of SAV distribution. Model scenarios showing increased salinity relative to the base scenario were ranked; and scenarios with elevated salinity due solely to accelerated sea level rise were not ranked.

Scenario	7-day Maximum Salinity (PSU)*	Difference from Base Scenario (Base1995NN)	Rank Based on Relative Salinity Change
Base1995NN	15.46	0.00	NA†
FwOR1995PS	16.41	0.95	1
FwOR1995NN	16.36	0.90	2
FwOR1995PN	16.27	0.81	3
Full1995PS	16.02	0.55	4
Full1995NN	15.95	0.49	5
Full1995PN	15.86	0.40	6
FwOR2030PS	15.80	0.33	7
Half1995PS	15.77	0.30	8
Half1995NN	15.69	0.23	9
FwOR2030PN	15.64	0.18	10
Half1995PN	15.60	0.14	11
Base1995PS	15.53	0.06	12
Full2030PS	15.40	-0.06	NR‡
Base1995PN	15.36	-0.10	NR
Full2030PN	15.24	-0.22	NR
Half2030PS	15.15	-0.31	NR
Half2030PN	14.99	-0.48	NR
Base2030PS	14.91	-0.55	NR
Base2030PN	14.74	-0.72	NR

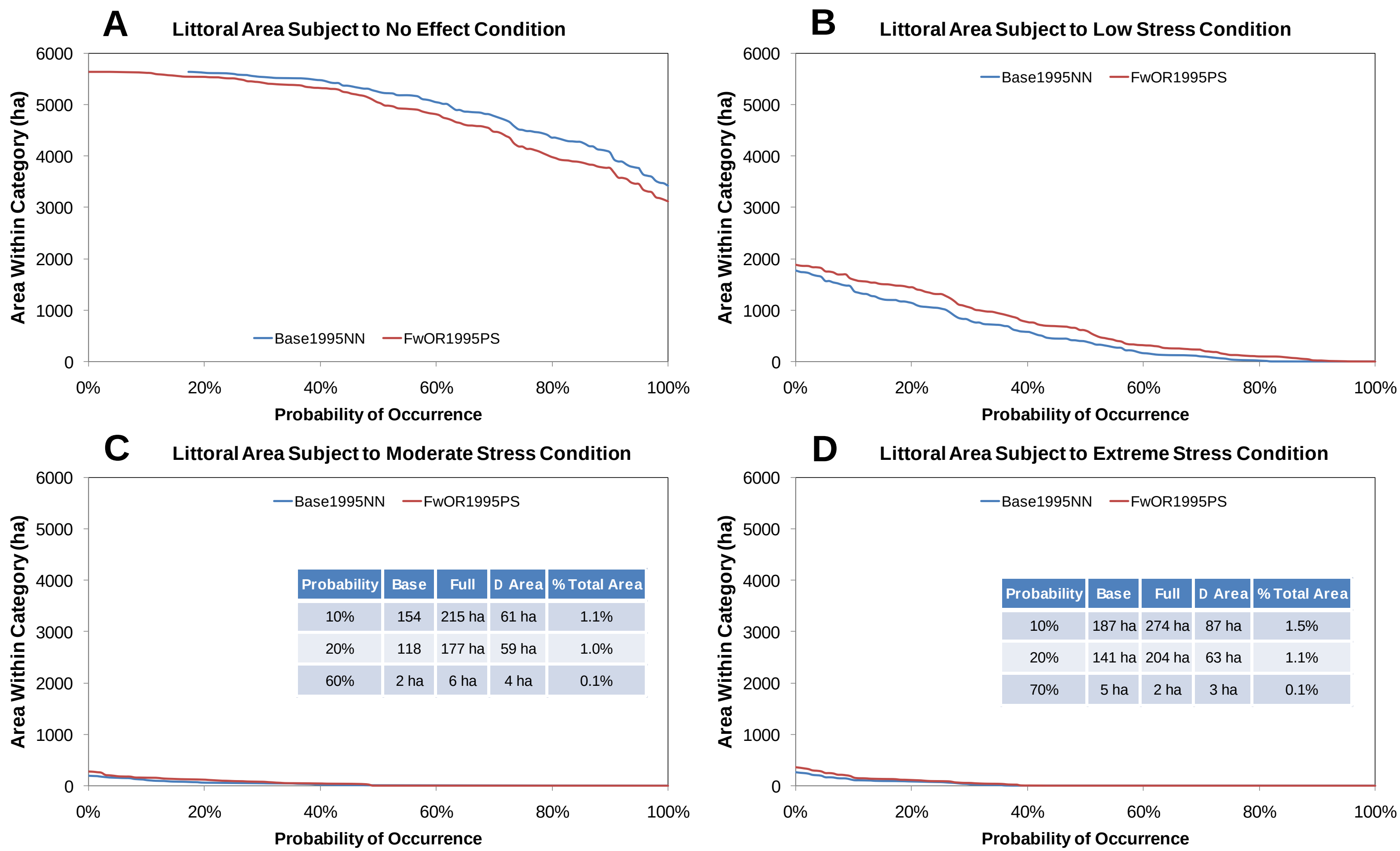
* PSU = practical salinity units
† NA = not applicable
‡ NR = not ranked

Analysis began with the top-ranked scenario FwOR1995PS because it showed the greatest increase in 7-day maximum salinity. Although we recognized that this scenario was regarded as an unlikely set of circumstances (see Chapter 6. River hydrodynamics Results), it provided the most extreme model conditions to test the response of the SAV community. Therefore, we refer to this scenario as the top-ranked scenario (FwOR1995PS).

Analysis of the base scenario (Base1995NN) and the top-ranked scenario (FwOR1995PS) revealed differences in the total area of the littoral zone subjected to increased levels of salinity stress. There was a relatively consistent probability of change from the no effect condition to one of the stressed conditions in approximately 199 ha, representing a 4% increase in the proportion of the total SAV habitat subjected to some degree of salinity stress (Figure 4–2A) (see Table 3–1) for a description of stress conditions). Approximately 3% of the total SAV area (162 ha) changed from no effect in the base scenario (Base1995NN) to low stress in the top-ranked scenario Figure 4–2B). Most (90%) of the time there was additional area subjected to low stress by the top-ranked scenario, while 10% of the time the base scenario (Base1995NN) and top-ranked scenario had equal areas subjected to low stress (Figure 4–2B). In other words, there was a 90% probability that 3% of the littoral habitat would change to the low stress condition from the no effect condition under the top-ranked scenario.

Scenario effects associated with higher stress levels become more attenuated. Under the top-ranked scenario, 10% of the time an additional 61 ha (1% of the total littoral habitat) were subjected to a moderate stress condition (Figure 4–2C), and 20% of the time 119 ha (2% of the total littoral habitat) experienced moderate stress (Figure 4–2C). It should be noted that during 60% of the time there was essentially no difference in the area exposed to moderate stress between the scenarios (Figure 4–2C). Therefore, there is a relatively low probability that a small area of the littoral habitat will experience a change to a moderate stress condition.

The additional area of littoral zone experiencing extreme stress was even lower. Under the top-ranked scenario (Full1995NN), an additional 87 ha (2% of the total littoral area) was exposed to extreme stress 10% of the time (Figure 4–2D), and 63 ha (1% of the area) was changed to an Extreme Stress condition 20% of the time. However, 70% of the time there was essentially no difference in littoral area between the scenarios (Figure 4–2D). Therefore, the top-ranked scenario (Full1995NN) caused a low risk of extreme stress to a very small additional area.



Probability	Base	Full	D Area	% Total Area
10%	154	215 ha	61 ha	1.1%
20%	118	177 ha	59 ha	1.0%
60%	2 ha	6 ha	4 ha	0.1%

Probability	Base	Full	D Area	% Total Area
10%	187 ha	274 ha	87 ha	1.5%
20%	141 ha	204 ha	63 ha	1.1%
70%	5 ha	2 ha	3 ha	0.1%

Figure 4–2. Cumulative probability of individual cell areas experiencing (A) No Effect, (B) Low Stress, (C) Moderate Stress, and (D) Extreme Stress categories. Each panel shows curves for both the base scenario (Base1995NN, blue) and full top-ranked scenario (FwOR1995PS, red). The full model run (140 littoral cells × 3652 model days) was considered for each scenario. Inset tables show various probability levels and associated differences in predicted areas under each scenario.

The stress frequencies were also spatially examined for the frequency that each littoral cell was flagged as either moderate or extreme stress. These two stress categories were combined, because in combination they represent a condition where deleterious effects are likely to significantly reduce ecological function. It was apparent that the largest changes in stress condition occurred in the downstream cells (Figure 4–3). Four cells showed a 5% to 6% increase in the stress frequency between the base scenario (Base1995NN) and top-ranked scenario (FwOR1995PS) (Figure 4–3). That frequency is equivalent to roughly 20 additional days annually with an elevated stress level. Although these cells represent an area of 48 ha, the cells are four to six times wider than the actual measured grassbed widths of approximately 50 m in this reach. Therefore, a more accurate area of impact is about 12 ha. Consequently, the model predicts that 12 ha of SAV habitat could experience visible grassbed effects 5% to 6% more frequently under conditions of the top-ranked scenario (FwOR1995PS). Likewise, nine cells showed a 4% to 5% increased risk of stress in 86 ha (Figure 4–3). Moving upstream, this pattern soon attenuates to very small changes in stress frequency. In summary, there is a small risk of increasing stress levels in the littoral zone, particularly in the most downstream cells. The risk of increased stress rapidly diminishes in cells further upstream.

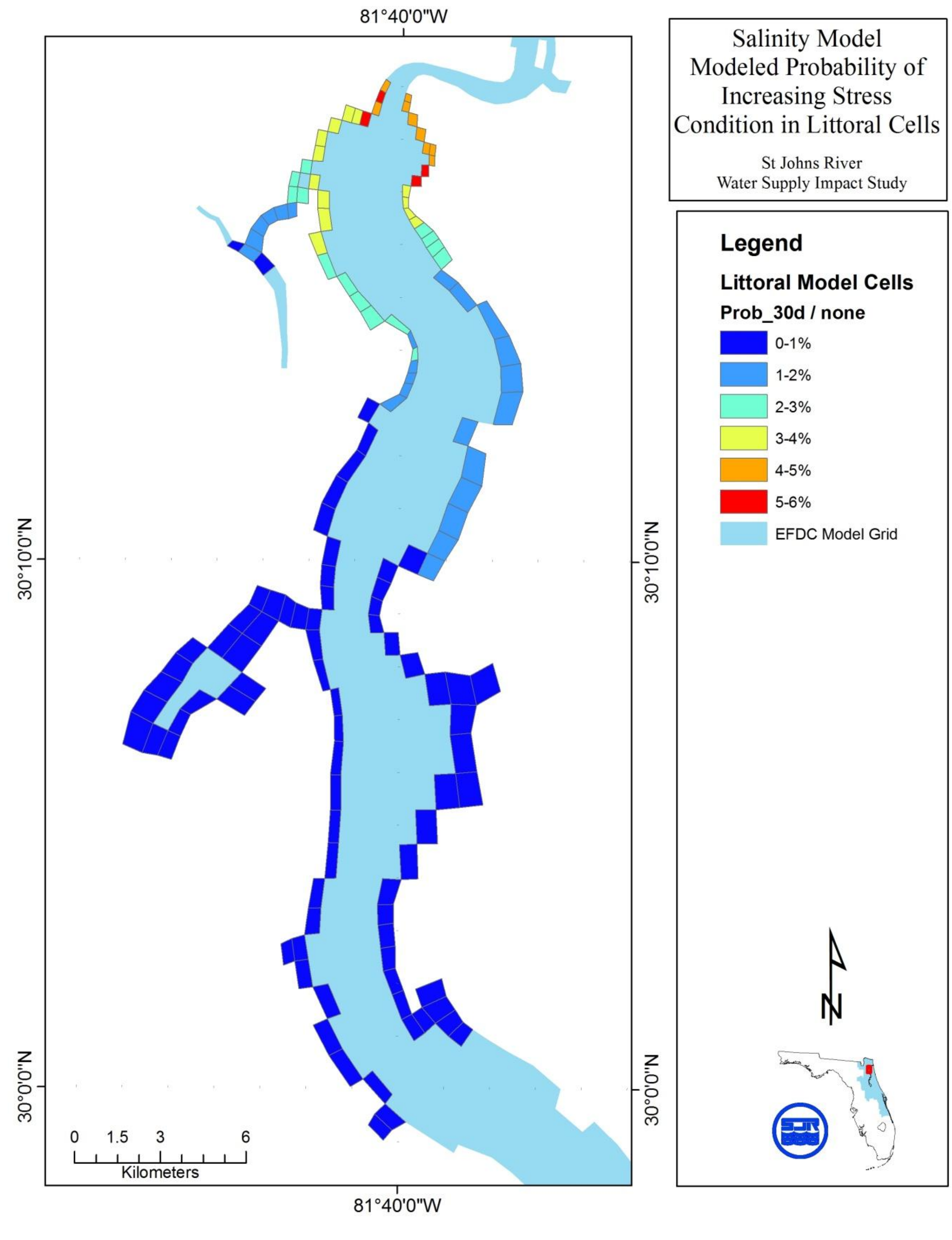


Figure 4–3. Probability of any given cell changing to a greater Moderate Stress or Extreme Stress category, indicating a physical decline in SAV condition (data for a 30-day model duration was used because it showed the most extreme deviation between scenarios).

What does this frequency analysis reveal about the potential effects of surface water withdrawals? The hydrodynamic modeling indicated that salinity would increase in the estuarine reach of the river with water withdrawals. In applying the salinity exposure model, we predicted that a corresponding change was possible in the SAV community. The predicted increase in stress frequency was small, however, as was the proportion of total littoral area affected. When we restricted the analysis to only moderate and extreme stress conditions, there was no predicted change in stress frequency > 50% of the time. When stress frequencies did increase, the changes affected < 2% of the total littoral area. Extreme stress conditions generally only affected < 1% of the total littoral zone. This model analysis reveals that there would be small increases in the frequency of stress events within a relatively small area, concentrated in the most downstream portion of the estuarine SAV habitat.

Imposing the water withdrawal associated with the top-ranked scenario (FwOR1995PS) did not change the overall dynamic pattern of the salinity time series (Figure 4–4); however, there were subtle changes in the salinity pattern of each event. For example, if we defined an event as >10 PSU for > seven days (low stress, see Figure 4–2), then some events persisted for one to three days longer in downstream cells. Maximum salinity in those cells during an event was approximately1 PSU higher in the top-ranked scenario (FwOR1995PS) than in the base scenario (Base1995NN). However, as with the frequency analysis, cells showed rapidly attenuated effects further upstream.

In relative terms, changes predicted by the top-ranked scenario (FwOR1995PS) are small. More than 60% of the time, noticeable stress conditions did not differ between scenarios (see Figure 4–2). When differences were predicted, the probability associated with those changes was only 10% to 20% (see Figure 4–2C and Figure 4–2D). This probability translates to between a one-in-ten- and a one-in-five-year return interval. Because SAV has been shown to recover and recolonize in two to three years in large areas where it had been completely extirpated (Dobberfuhl 2007), the return frequency associated with the top-ranked scenario (FwOR1995PS) would not appear to exceed the system’s ability to recover. In addition, results from intensive sampling suggest that even highly compromised grass beds can recover within weeks (Appendix 9.D). A thorough analysis of the frequency of salinity events among selected model scenarios indicates that return intervals for each stress category did not appreciably change (Appendix 9.F). Salinity event return intervals lacking the potential for temporal accumulation may be considerably shorter than one to two years for stress levels that leave any remaining viable biomass (Appendix 9.F).

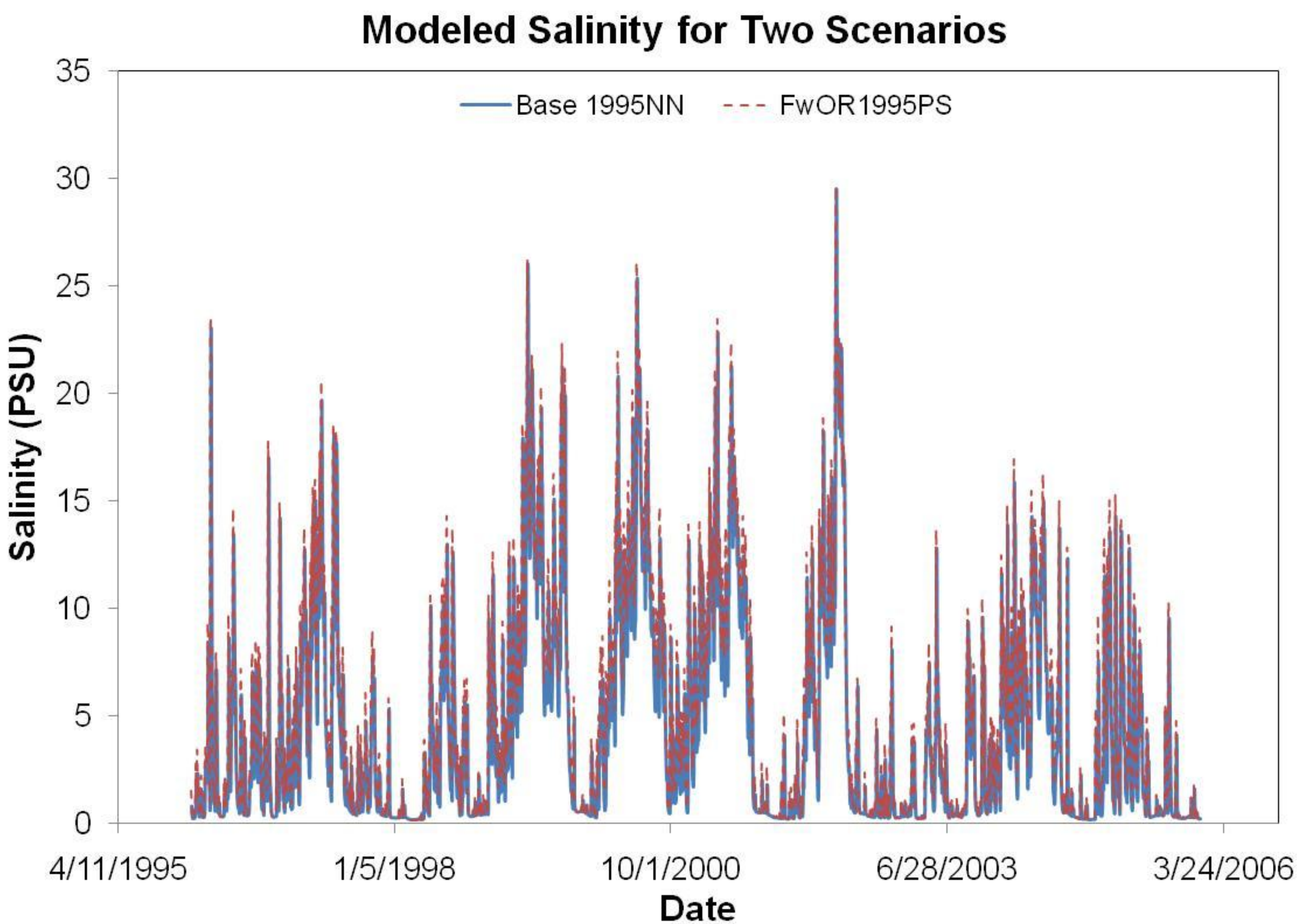


Figure 4–4. Salinity time series for an individual cell (LIJ#3480). Notice that there is virtually no difference in the patterns of either model scenario.

4.3 LITTORAL SALINITY PATTERNS COMPARED TO CHANNEL SALINITY PATTERNS

We compared a five-month period of continuous conductivity monitoring between a mid channel and littoral sampling site. Conductivity is a measure of the salinity in water and is expressed in units of micro-Siemens per cm (µS/cm). Although the sensor failed for nearly a month during the sampling, sufficient data were collected to make qualitative comparisons. Maximum daily conductivity values were generally higher in the channel than in the littoral zone (Figure 4–5A). During moderate conditions, channel and littoral conductivity measurements were relatively close. However, during high conductivity events (>5,000 µS cm^{-1}), littoral measurements were 30% to 60% lower than channel measurements. In contrast, daily minimum conductivity measurements were usually slightly higher than channel measurements (Figure 4–5B).

These results indicated that dynamic salinity patterns in the littoral zone were attenuated compared to mid-channel conditions. There are no continuous measurements in the littoral zone during the period of the EFDC hydrodynamic model runs, so the accuracy of the model in the nearshore environment cannot be ascertained. Because the EFDC hydrodynamic model was well calibrated to the channel and the channel overpredicted the littoral zone salinity, it is reasonable to assume that the EFDC hydrodynamic model also overpredicts littoral salinity to some degree. This difference suggests that the analysis of SAV stress frequency overestimates the potential effects. In other words, the actual stress frequency is likely to be lower than the model-predicted frequency for any given scenario.

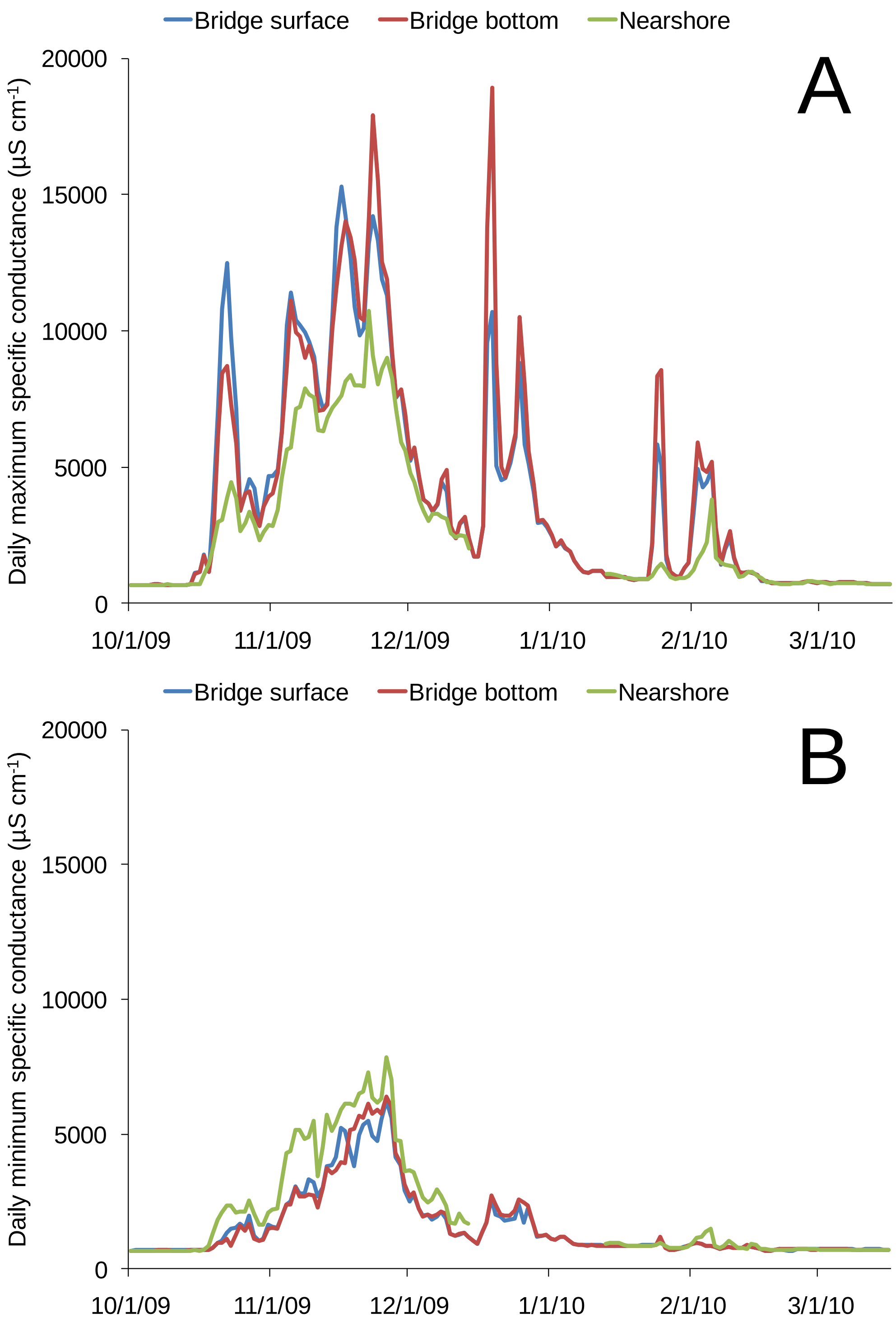


Figure 4–5. Daily (A) maximum and (B) minimum measured conductance at the mid-channel Buckman Bridge site and the littoral Buckman SAV monitoring site.

4.4 POTENTIAL FOR *RUPPIA MARITIMA* EXPANSION

The working group investigated whether the halophytic (salt-tolerant) species *Ruppia maritima* could functionally replace *V. americana* in areas likely to experience higher salinity under any water withdrawal scenario. In past SAV sampling, *R. maritima* was virtually never found in isolation. For example, only 73 of 7,924 sample transects showed *R. maritima* without any other species present (Table 4–4). The vast majority of transects showed *R. maritima* to be associated with *V. americana* (see Table 4–4). Data suggest that the dark waters of the St. Johns River likely maintain this pattern because of light limitation (Appendix 9.G). Although slight increases in salinity could benefit *R. maritima* to some degree, the frequent discharge of highly colored water would continue to limit expansion. Therefore, functional replacement of *V. americana* by *R. maritima* is not a probable outcome of increased salinity caused by surface water withdrawals.

Table 4–4. Number and percentage of SAV monitoring transects in the lower St. Johns River basin with various combinations of *V. americana* and *R. maritima*.

Species Combination	Number of Transects	Percentage of Transects
Total transects	7,924	100
V. americana present	6,477	82
V. americana + *R. maritima*	1,125	14
R. maritima + other spp. - *V. americana*	121	2
R. maritima alone	73	1

4.5 SALINITY AND LIGHT INTERACTIONS

Freshwater SAV can tolerate slightly higher salinity if sufficient light is present (French and Moore 2003). In the lower St. Johns River, higher water transparency and associated higher bottom illuminance occur during periods of low flow. These low flow periods are also times when salinity increases. Water quality data indicates that elevated salinity (5 to 8 PSU) and higher transparency ($K_d < 2.8\ m^{-1}$) simultaneously occur about 12% to 15% of the time. Thus, we investigated the potential for interactive effects between salinity and transparency to enhance the patterns generated by the salinity-duration model alone.

Partially based on previous work and partially based on water quality and SAV data from the St. Johns River, we developed a Relative Condition Index (RCI) (Appendix 9.H). The RCI assigns a numerical score concordant with water quality conditions over a defined interval of time. The frequency of RCI values under the base scenario (Base1995NN) and the top-ranked scenario (FwOR1995PS) at two specific river sites showed essentially the same patterns that the salinity-duration model analysis showed. Relative frequencies of extreme stress conditions at the Bolles School site increased by 3% (Appendix 9.H). The upstream sites, Buckman Bridge and Moccasin Slough, demonstrated lower frequency changes of 0.5% or less (Appendix 9.H).

When stress frequency changes are compared for the three sites for which RCI was computed (Appendix 9.H) and for the corresponding cells shown in Figure 4–3, there is essentially no difference. This similarity suggests that higher transparency would not ameliorate the deleterious effects of salinity in this reach of the river. If greater light availability had mitigated salinity effects, then the RCI analysis would have resulted in lower predicted stress frequencies than the salinity stress model, which it did not. The models suggest that salinity is the overwhelming factor causing differences in stress frequencies among model scenarios.

4.6 Summary and Conclusions

Water level changes predicted by the EFDC hydrodynamic model would have a negligible effect on the SAV in river segments 7 and 8 (see Table 4–2). The largest stage changes associated with the top-ranked scenario (Full1995NN) did not change the potential SAV habitat area. Lakes in downstream river segments are predicted to have smaller water level changes and, therefore, even less risk of SAV habitat change. Similarly, model scenarios with lower water withdrawal will also have lower risk of water level change and SAV habitat loss. Imposing nominal water level changes on the nearly linear stage-area relationship typical of the littoral areas of most lakes in the river is not likely to result in appreciable effects on the potential habitat area for SAV for any of the model scenarios. Therefore, the lack of appreciable change in any ecosystem components led us to conclude that there would be negligible effects within river segments 2-8 (Figure 4–6).

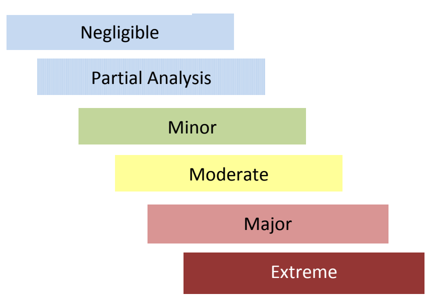
Uncertainty related to the water level analysis is a function of understanding the underlying mechanism, the amount of supporting evidence, and strength of the associated predictive model (see Chapter 2. Comprehensive Integrated Assessment). The primary assumption in this analysis is that the depth of water determines the light available to the lake bottom. It is well established, as documented in the literature (Appendix 9.B), that light availability determines the ultimate range of SAV. The predictive model relies on a light-depth relationship that, although quantified in other similar areas of the river, has not been directly measured in Lakes Poinsett and Harney. Because of the strong understanding of the mechanism, strong supporting evidence, and qualitative predictive model, the ecological portion of the water level analysis is considered to have medium uncertainty. The predictive model also relies on EFDC hydrodynamic model output, which has been designated as very low uncertainty for Lake Poinsett and low uncertainty for Lake Harney (see Chapter 6. River Hydrodynamics Results). Therefore, the overall water level analysis is considered to have medium uncertainty (Figure 4–6).

Evaluation of model scenarios shows negligible increases in salinity stress to very restricted areas in river segments 2 and 3. The frequency of deleterious stress conditions increases up to 6%, but only in approximately 12 ha under the top-ranked scenario (FwOR1995PS). There is a 2% to 6% increase in stress frequency in approximately 169 ha. These are small changes in terms of both frequency and proportional area. Moreover, the return interval of salinity events is much longer than the time spans necessary for *V. americana* to recover and recolonize. In addition, the analysis employed conservative aspects (e.g., overestimated littoral salinity and SAV habitat area) that likely inflated predicted changes. Model scenarios with lower withdrawal rates would be expected to have even smaller effects than the top-ranked scenario (FwOR1995PS). Therefore, we have concluded that the potential for salinity effects is negligible under the conditions of the model scenarios (Figure 4–6).

The role of salinity in affecting osmoregulation, plant health, and species distribution in SAV has been particularly well studied in estuaries worldwide (Appendix 9.B). In addition to documentation in the literature, a number of experiments and monitoring activities have been performed in the St. Johns River to verify and confirm in situ responses of SAV to elevated salinity (Appendices C to E). This information allows the construction of a robust quantitative predictive model. Because of the strong understanding of the mechanism, strong supporting evidence, and strong quantitative predictive model, the ecological portion of the salinity analysis is considered to have very low uncertainty. The littoral salinity analysis relies on salinity data generated from the EFDC hydrodynamic model, which has been designated as low uncertainty (see Chapter 6. River Hydrodynamics Results). Therefore, the overall salinity analysis is considered to have low uncertainty (Figure 4–6).

River Region	Stage	Salinity
1		
2	**	**
3	**	**
4	**	
5	***	
6	***	
7	***	
8	***	

Level of Effect



Uncertainty

*	Very Low
**	Low
***	Medium
****	High
*****	Very high

Figure 4–6. Ecological effects and levels of uncertainty for different model scenarios (shown in parentheses). Model scenarios with lesser magnitude effects were considered to have negligible ecological impacts and are not shown. Colors indicate level of ecological impact, and asterisks indicate levels of uncertainty.

5 REFERENCES

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French, G. T. and K. A. Moore. "Single and interactive effects of light and salinity stress on the growth, reproduction and photosynthetic capabilities of Vallisneria americana." *Estuaries*, 2003: 26:1255-1268.

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6 APPENDICES

APPENDIX 9.A. SUBMERGED AQUATIC VEGETATION PATTERNS IN THE LOWER ST. JOHNS RIVER BASIN

APPENDIX 9.B. SUBMERGED AQUATIC VEGETATION (SAV) IN THE LOWER ST. JOHNS RIVER AND THE INFLUENCES OF WATER QUALITY FACTORS ON SAV

APPENDIX 9.C. SALINITY-INDUCED ENZYMATIC STRESS RESPONSE IN VALLISNERIA AMERICANA

APPENDIX 9.D. INTENSIVE SUBMERGED AQUATIC VEGETATION MONITORING IN THE LOWER ST. JOHNS RIVER BASIN

APPENDIX 9.E. RESPONSE OF VALLISNERIA AMERICANA FOLLOWING REPEATED EXPOSURE TO DIFFERENT SALINITY REGIMES

APPENDIX 9.F. SURFACE SALINITY PARTIAL-DURATION FREQUENCY ANALYSES

APPENDIX 9.G. POTENTIAL FOR REPLACEMENT OF VALLISNERIA AMERICANA BY RUPPIA MARITIMA

APPENDIX 9.H. PREDICTED CHANGES IN *VALLISNERIA AMERICANA* HABITAT SUITABILITY INDICES USING MODELED SALINITY AND LIGHT CONDITIONS IN THE LOWER ST. JOHNS RIVER, FLORIDA