CHAPTER 11. BENTHIC MACROINVERTEBRATES, APPENDIX 11.G STAGE DURATION ANNUAL FREQUENCY ANALYSES AND BOTTOM SALINITY PARTIAL DURATION FREQUENCY ANALYSES

by

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APPENDIX 11.G

Stage Duration Annual Frequency Analyses and Bottom Salinity Partial Duration Frequency Analyses

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Introduction

There is concern that the St. Johns River (SJR) macroinvertebrate (benthos) community will decrease in abundance, diversity, and/or spatial extent due to an increase in the magnitude, frequency, and/or duration of stage or salinity events resulting from proposed surface water withdrawals from the SJR. Areas of concern were determined in Phase I of the Water Supply Impact Study. In order to determine whether it is likely that the benthos may be impacted, the modeled stage and salinity conditions resulting from several potential water management scenarios (Chapter 3. Watershed Hydrology and Modeling; Chapter 6. River Hydrodynamics Results) were compared at several sites using annual and partial-duration frequency analyses, respectively. In freshwater reaches of the river, the two main effects of hydrologic alteration to benthic communities would be changes in water flow and changes in water level. In the estuary, hydrologic change (i.e., changes in freshwater inflow) would primarily affect benthic communities through changes in salinity.

The modeled stage data were investigated in relation to vegetation habitats of selected macroinvertebrate target taxa at Lake Monroe in the middle SJR basin (MSJRB) and Lake Poinsett in the upper SJR basin (USJRB), with annual stage frequency analyses. Crayfish (as a group) and the Florida apple snail, *Pomacea paludosa,* were chosen as target taxa for the freshwater reaches of the SJR to evaluate the effects of surface water withdrawals. The former were chosen due to their importance in the diets of many aquatic vertebrates; the two main taxa of crayfish in the upper and middle river are *Procambarus alleni* and *P. fallax* (Hobbs 1942). The apple snail was chosen due to its importance in the diet of the Everglades snail kite and other vertebrate taxa (Darby et al. 2008).

The potential impacts to estuarine benthic habitat caused by reduced freshwater inflows to the LSJRB were assessed by completing partial-duration frequency analyses of maximum daily bottom salinity concentrations modeled for different water management alternatives at three LSJRB monitoring stations.

Methods

Site Selection

Salinity Stations

The SJR Water Supply Impact Study (WSIS) model created for the LSJRB was based on 10 years worth of physicochemical and hydrologic data (1996-2005).

The JAXSJR17 station (Figure 1) is the St. Johns River Water Management District's (SJRWMD) water monitoring station located mid-channel at SJR river mile 17 near downtown

Jacksonville. This station is the most downstream station with the highest magnitude, duration, and frequency of salinity events.

The JAXSJR40 station (Figure 1) is the SJRWMD's water monitoring station located mid-channel between the Buckman Bridge and the Fuller Warren Bridge. Benthic organisms can be associated with submerged aquatic vegetation (SAV). SAV at JAXSJR40 (mainly Vallisneria) was documented in the littoral zone near that station from 1996-1998 (*Personal communication*, Dean Dobberfuhl, SJRWMD Technical Program Manager Upper SJR Basin). SAV has since been extirpated in this area. This is thought to have occurred due to an increase in the magnitude, duration, and/or frequency of high salinity events. It is evident from this information that the salinity in this zone is highly variable, depending upon conditions in the river basin. Benthic communities in this river reach would be tolerant of these variable salinity conditions.

The SJSR16 station (Figure 1) is the most upstream station investigated with the lowest magnitude, duration, and frequency of salinity events.

Stage Stations

The SJR WSIS model developed for the LSJRB and MSJRB Environmental Fluid Dynamic Code (EFDC) model simulates 10 years (1996 – 2005) and USJRB Hydrologic Simulation Program Fortran (HSPF) model simulates 33 years of data (1975-2008).

Two modeled WSIS SJR stations were analyzed for changes in river stages between WSIS model scenarios (Figure 2) and these were located at the current United States Geologic Survey (USGS) monitoring stations. The USGS has a water level station on the St. Johns River at the outlet of Lake Monroe (Lake Monroe near Sanford, FL; USGS 02234499) and at the outlet of Lake Poinsett (St. Johns River near Cocoa; USGS 02232400) (Figure 2). The modeled daily average water level data for these USGS station locations were used to assess potential impacts to crayfish and apple snails in Lake Poinsett and Lake Monroe.

Model Scenario Selection

Modeled daily maximum bottom salinity (Table 1) at the JAXSJR17, JAXSJR40, and SJSR16 stations were downloaded from the SJRWMD Time-Series Web Intranet data interface (SJRWMD 2010). Modeled daily average water levels from Lake Monroe and Lake Poinsett were provided by S. F. Baird (Hydrologic Data Services, SJRWMD)(Table 1). The modeled scenarios analyzed are listed below and in Table 2.

Lake Poinsett

- "**Base1995NN**" - 1995 land use with no extra withdrawals, no upper basin projects, and no sea level rise
- "**Full1995NN**" – 1995 land use with full modeled SJR withdrawal, no upper basin projects, and no sea level rise

- "**Full1995PN**" - 1995 land use with the full modeled SJR withdrawal, upper basin projects, and no sea level rise
- **"Full2030PN"** - 2030 land use with the full modeled SJR withdrawal, upper basin projects, and no sea level rise

Lake Monroe

- "**Base1995NN**" - 1995 land use with no extra withdrawals, no upper basin projects, and no sea level rise
- "**Full1995NN**" **–** 1995 land use with full modeled SJR withdrawal, no upper basin projects, and no sea level rise
- "**Full1995PN**" - 1995 land use with the full modeled SJR withdrawal, upper basin projects, and no sea level rise
- "**Full2030PS**" - 2030 land use with the full modeled SJR, upper basin projects, and sea level rise

Salinity Stations: JAXSJR17 / JAXSJR40 / SJSR16

- "**Base1995NN**" - 1995 land use with no extra withdrawals, no upper basin projects, and no sea level rise
- "**FwOR1995NN**" - 1995 land use with the full modeled SJR and Ocklawaha River withdrawal, no upper basin projects, and no sea level rise
- "**FwOR2030PS**" - 2030 land use with the full modeled SJR and Ocklawaha River withdrawal, upper basin projects, and sea level rise

The "Base1995NN" scenario represents something of an "existing conditions" scenario against which other alternatives were compared. These modeled water management scenarios were deemed to be representative of the range of hydrologic and salinity conditions expected for all other scenarios.

Frequency Analyses

The hydrologic and salinity simulations performed for the SJR WSIS produced time series of daily data (e.g., stages, discharges, surface and bottom salinities) for various locations along the SJR. Of interest are the frequency of occurrence of specific events, such as stages exceeded (or not exceeded) for certain durations and bottom salinities continuously exceeded for certain durations. The WSIS simulations were performed for a number of water management scenarios (Table 2). This section briefly describes the concepts of frequency analysis and presents the methods used to evaluate stage and salinity events from the daily time series data.

Frequency analysis estimates how often, on average, a given event will occur. If annual series hydrologic data were used to generate the statistics, frequency analysis estimates the probability of a given hydrologic event happening in any given year.

A simple example illustrates some of the concepts basic to frequency analysis. A frequently used statistic with respect to water level is the yearly peak stage of a water body. If a gauge has been monitored for 10 years, then there will be 10 yearly peaks $S_1, S_2, \cdots, S_{10}$. Once sorted and ranked, these events can be written as $\hat{S}_1, \hat{S}_2, \cdots, \hat{S}_{10}$, with $\hat{S}_1$ being the highest peak. Based on this limited sample, the estimated probability of the yearly peak being greater than or equal to $\hat{S}_1$ would be

$$P(S \geq \hat{S}_1) = \frac{1}{n} = \frac{1}{10} = 0.1\,; \qquad \text{Equation (1)}$$

the probability of the 1-day peak stage in any year being greater than $\hat{S}_2$

$$P(S \geq \hat{S}_2) = \frac{2}{10} = 0.2\,; \qquad \text{Equation (2)}$$

and so on. The probability of the stage equaling or exceeding $\hat{S}_{10}$ would be

$$P(S \geq \hat{S}_{10}) = \frac{10}{10} = 1.0\,. \qquad \text{Equation (3)}$$

Because this system of analysis precludes any peak stage from being lower than $\hat{S}_{10}$, the usual convention is to divide the stage continuum into 11 parts: nine between each of the 10 peaks, one above the highest peak, and one below the lowest peak (*n* – 1 + 2 = *n* + 1=11). This suggests what is known as the Weibull plotting position formula:

$$P(S \geq \hat{S}_m) = \frac{m}{n+1} \qquad \text{Equation (4)}$$

where,

$P(S \geq \hat{S}_m) =$ probability of S equaling or exceeding $\hat{S}_m$

$m =$ rank of the event

Thus, in the example, the probability of the peak in any year equaling or exceeding $\hat{S}_1$ would be

$$P(S \geq \hat{S}_1) = \frac{1}{n+1} = \frac{1}{11} = 0.0909\,; \qquad \text{Equation (5)}$$

the probability of the 1-day peak stage in any year being greater than $\hat{S}_{10}$

$$P(S \geq \hat{S}_{10}) = \frac{10}{11} = 0.9091\textbf{;} \qquad \text{Equation (6)}$$

and so on. The probability the stage in any year is smaller than $\hat{S}_{10}$ would be

$$P(S < \hat{S}_{10}) = 1 - P(S \geq \hat{S}_{10}) = 1 - \frac{10}{11} = 1 - 0.9091 = 0.0909 \qquad \text{Equation (7)}$$

The return period (in years) of an event, T, is defined as

$$T = \frac{1}{P} \qquad \text{Equation (8)}$$

so the return period for $\hat{S}_1$ would be

$$T(\hat{S}_1) = \frac{1}{P(S \geq \hat{S}_1)} = \frac{1}{\frac{1}{11}} = 11 \qquad \text{Equation (9)}$$

Said another way, $\hat{S}_1$ would be expected to be equaled or exceeded, on average, once every 11 years.

As the size of the sample increases, the probability of $\hat{S}_1$ being equaled or exceeded decreases. Thus, with $n = 20$,

$$P(S \geq \hat{S}_1) = \frac{1}{n+1} = \frac{1}{21} = 0.048 \qquad \text{Equation (10)}$$

and

$$T(\hat{S}_1) = \frac{1}{P(S \geq \hat{S}_1)} = 21 \qquad \text{Equation (11)}$$

The stage or flow characteristics of a water body can be summarized using the Weibull plotting position formula and a frequency plot (Figure 3).

Definition of "Events"

Figure 4 presents a daily stage hydrograph for Lake Poinsett for the period 1975 – 1982 and Figure 5 the modeled daily maximum salinities for JAXSJR40 near Jacksonville for the period 1996 – 2005 (Scenario: Base1995NN). From these figures, one may observe that a given stage or salinity concentration was continuously exceeded (or not exceeded) for a number of days one or more times in a given year. Such occurrences are defined as "**events**" for the present analysis.

Evaluation of stage events

In the case of stages, annual maximum and minimum values for different durations (1- day to 365-days) are considered as the "events" in the analyses. For evaluating these "events," it is also necessary to choose a reference year. In this part of Florida, maximum stages generally occur during the period June – November, coinciding with the hurricane season; therefore, a reference year starting June 1 and ending on May 31 (of the following year) is chosen for evaluating the maximum events. On the other hand, drought conditions generally occur during the period November – May; therefore, a reference year October 1 through September 30 (of the following year) is chosen for evaluating the low stage events.

Computer programs written in FORTRAN language scan the daily data for each year and evaluate the defined events. Table 3 presents Lake Poinsett maximum and minimum stage events. Example: If the event of interest is the maximum stage continuously exceeded for 30 days, the program first evaluates all the stages that are exceeded continuously for 30 days during the year, and chooses the maximum of those values (e.g., 13.86 feet National Geodetic Vertical Datum [ft NGVD] for observed data from 1976, Table 3).

Evaluation of salinity events

The standard hydrologic frequency analysis is one based on the annual series of events. This presumes that there is one maximum (or minimum) event per year. However, often there might be more than one event that exceeds a given threshold in any given year. This is certainly the case with salinity where there may be a number of salinity peaks of consequence in a given year. This eventuality is provided for in partial-duration series analysis. The assigning of probability of occurrence of events in partial-duration series analysis (USGS 1982) is much like with annual-series analysis, except that all events above a given threshold are ranked and sorted. However, the divisor in the Weibull plotting-position formula remains the number of years of record plus one (See Equation 10).

For the partial-duration frequency analysis of salinity events, various threshold salinity values (TSV) were selected (1.0, 2.0, 3.0, 5.0, 10.0, 15.0. 20.0, 25.0 practical salinity units [psu]; Table 4). The data were analyzed to determine the number of days and the number of times the TSV was exceeded during the period of model simulation (1996 – 2005). For example, a TSV of 15-psu was exceeded 29 times and the TSV of 20-psu was exceeded 12 times for different durations (events) during the simulation period of 1996 – 2005 for the FwOR2030PS modeled for surface salinity at JAXSJR40 scenario (Table 4). The analysis also determined the duration of each event and the time elapsed between the consecutive events.

Weibull Plots

For stages, the annual events are arranged in order of magnitude (i.e., ranked) and the probabilities for each event are calculated by Equation 4. These data are plotted on a probability graph (Figure 3, Weibull probability plot). As mentioned previously, event probabilities are calculated in much the same way for the partial-duration analysis of salinities and the probability plots are built in the same way as for stages.

Results and Discussion

Annual Frequency Analyses - Stage

One way to examine different hydrologic regimes and target taxa community effects is through frequency analysis. Frequency analysis estimates how often, on average, a given event will occur. An event is typically a high or low water level, which either floods or dewaters a target elevation for a specific duration significant to the ecological survival of the target fauna and/or habitat at that elevation. For example, adult apple snail mortality may occur when dewatering happens for more than 12 weeks in their preferred shallow marsh habitat (Darby et al. 2008).

Frequency analysis provides a method for simple comparisons between the different hydrologic scenarios estimating how often, on average, a given event will occur. An event as described for apple snails and crayfish is typically a low water level, which dewaters a target elevation for a specific duration significant to the ecological survival of the apple snails or crayfish and/or habitat at that elevation.

The following sections describe the results of frequency analysis for ecological thresholds identified for the protection of apple snail and crayfish populations and habitat at Lake Poinsett in the USJRB and Lake Monroe in the MSJRB.

Lake Poinsett

The event of importance for adult apple snail habitat occurs when the minimum shallow marsh ground elevation (i.e., 10.2 ft NGVD) remains dry for 90 continuous days. The adult apple snail event criteria are based upon pre-reproductive adult snail survival of up to 12 weeks in dry (non-flooded) conditions in mesocosm experiments (Darby et al. 2008). Figure 6 illustrates the target shallow marsh elevation at Lake Poinsett with the river stage frequencies for the St. Johns River at Cocoa for the WSIS base modeled stage data (Base1995NN), the modeled 1995 stage data with the full withdrawal scenario and no upper basin project and no sea level rise (Full1995NN), the modeled 1995 stage data with the full withdrawal scenario and the upper basin project and no sea level rise (Full1995PN), and the 2030 modeled stage data withdrawal scenario and the upper basin project and no sea level rise (Full2030PN). This dry event is predicted to occur approximately 43 times in 100 years at the base modeled stage regime, 48 times in 100 years under the Full1995NN scenario, 25 times in 100 years under the Full1995PN regime, and 20 times in 100 years for the Full2030PN regime (Figure 6). The Full1995PN and Full2030PN alternatives provide progressively fewer dewatering events for the adult apple snail target elevation of 10.2 ft NGVD, as compared to the Base1995NN and Full1995NN scenarios, resulting in wetter snail habitat. This fulfills the criteria for adult apple snails that dewatering events occur less often than every 2-3 years to ensure optimum survival (Chapter 11. Benthic Macroinvertebrates – Table 11.10).

An event of interest for juvenile apple snail habitat is the minimum shallow marsh ground elevation (i.e., 10.2 ft NGVD) that remains dry for 60 continuous days. Survival of juvenile apple snails under dry-down conditions was lower (4-8 weeks) than for adults (Darby et al. 2008). Figure 7 illustrates the 60-day minimum continuously not exceeded dry event at the target shallow marsh elevation (10.2 ft NGVD) with the river stage frequencies for the St. Johns River at Cocoa. The Base1995NN modeled river stage data analysis estimated a frequency at the target shallow marsh minimum elevation at Lake Poinsett of approximately 60 times in 100 years, 64 times in 100 years for the Full1995NN scenario, 43 times in 100 years under the Full1995PN regime, and 27 times in 100 years according to the Full2030PN regime. As observed for the adult apple snails, the Full1995PN and Full2030PN alternatives provide progressively fewer dewatering events for the juvenile apple snail target elevation of 10.2 ft NGVD, as compared to the Base1995NN and Full1995NN scenarios, resulting in wetter snail habitat.

Key elevations and durations identified by Acosta and Perry (2001) for crayfish (*P. alleni)* are $\leq$0.5 m below the shallow marsh maximum elevations with a 5-month dry duration (150 days). Acosta and Perry (2001) evaluated the impacts of shortened hydroperiod (duration of inundation) and depth to groundwater during droughts on populations of *P. alleni* in marl prairie habitats in the Everglades. Abundance and mean size of crayfish was higher in medium (7 months of inundation/ 5 months dry) and long (9 months of inundation/3 months dry) hydroperiod sites than at short (3 months inundation/ 9 months dry) hydroperiod sites Acosta and Perry (2001). Based on their data, Acosta and Perry (2001) suggested that survival of *P. alleni* populations required $\geq$ 7 months of inundation and a seasonal low groundwater table of $\leq$ 0.5 m below ground surface. A duration of 150 continuous days of dewatering (5-months) was used in the present analysis. The 150-day minimum continuously not exceeded dry event with a target elevation 0.5 m below the shallow marsh maximum elevation at Lake Poinsett (i.e., 11.6 ft NGVD), is predicted to occur 64 times in 100 years under the base modeled hydrologic regime (Base1995NN), 64 times in 100 years for the Full1995NN scenario, 62 times in 100 years under the Full1995PN regime, and 60 times in 100 years at the Full2030PN regime (Figure 8). The Base1995NN and Full1995PN are predicted to have very similar frequencies of dewatering events for *P. alleni* habitat. However, the Full2030PN alternative provides fewer dewatering events than the other three scenarios, resulting in wetter crayfish habitat.

The crayfish, *P. fallax*, prefers wetlands with intermediate to long-duration hydroperiods (11 to 12 months per year after Hendrix and Loftus 2000, Lowe 1986, and Dorn and Trexler 2007). Because of its apparent inability to tolerate wetland dry down as well (Dorn and Trexler 2007), areas of deeper water depth (> 0.3 m) appear to be needed to support continued existence of *P. fallax* populations, although it is capable of living in shallower water depths. Mace (2011) determined the elevation range of deep marsh plant communities at Lake Poinsett, thought to be the most likely habitat for *P. fallax*. Based on this information, the following hydrologic thresholds were developed for *P. fallax* habitat at Lake Poinsett:

- 11.0 ft NGVD (maximum deep marsh elevation), 365-day flooding (exceedence) duration
- 11.0 ft NGVD (maximum deep marsh elevation), 30-day dewatering (non-exceedence) duration

The 365-day continuous flooding of the maximum elevation of deep marsh (11.0 ft NGVD) was predicted to occur with similar frequency for all four of the scenarios (~5 times in 100 years under the Base1995NN and Full1995NN scenarios, and 4 times in 100 years under the Full1995PN and Full2030PN scenarios, Figure 9). The Full1995NN provides the same flooding events as the base scenario (Base1995NN), and the Full1995PN and Full2030PN scenarios have one fewer flooding event for the *P. fallax* target elevation of 11.0 ft NGVD, as compared to the Base1995NN base case.

The frequency of 30-day continuous dewatering of the maximum deep marsh elevation (11.0 ft NGVD) was predicted to be greater for the Full1995NN and Full1995PN scenarios than the Base1995NN base-case scenario (~90 times in 100 years for Full1995PN scenario, 91 times in 100 years for Full1995NN, and 88 times in 100 years for the Base1995NN scenario, Figure 10), and decreases to approximately 86 times in 100 years at the Full2030PN regime (Figure 10), indicating wetter conditions. The Full2030PN scenario provides fewer dewatering events for the *P. fallax* elevation of 11.0 ft NGVD, as compared to the Base1995NN base case, resulting in wetter crayfish habitat. The Full1995NN and Full1995PN modeled scenarios slightly increase (difference of 2-3 events in 100 years) the number of 30 day duration dewatering events at 11.0 ft NGVD in comparison with the base scenario.

Lake Monroe

The event of importance for adult apple snail habitat occurs when the minimum shallow marsh ground elevation (i.e., 0.0 ft NGVD) remains dry for 90 continuous days. The adult apple snail event criteria are based upon pre-reproductive adult snail survival of up to 12 weeks in dry (non-flooded) conditions in mesocosm experiments (Darby et al. 2008). Figure 11 illustrates the target shallow marsh elevation at Lake Monroe with the river stage frequencies for the 1995 base modeled stage data (Base1995NN); the modeled 1995 stage data with the full withdrawal scenario with no upper basin projects and no sea level rise (Full1995NN), the modeled 1995 stage data with the full withdrawal scenario and the upper basin project and no sea level rise

(Full1995PN); and the 2030 modeled stage data withdrawal scenario and the upper basin project and sea level rise (Full2030PS). The differences in lake stages between the Base1995NN, Full1995NN, andFull1995PN water management alternatives are predicted to be small (0 to 0.1 ft), with the Full2030PS scenario showing approximately a 0.5 ft to 0.6 ft increase in stages over the other modeled scenarios (Figure 11). However, the stages predicted for all four scenarios markedly exceed the 90-day continuous non-exceedence threshold stage of 0.0 ft NGVD required for the protection of adult apple snail habitat (Figure 11). This, of course, fulfills the criterion for adult apple snails because the target elevation of 0.0 ft NGVD (minimum elevation of shallow marsh) is not dewatered for 90 continuous days within the period of record of the model simulation, ensuring optimum survival (Chapter 11. Benthic Macroinvertebrates – Table 11.10).

An event of interest for juvenile apple snail habitat is the minimum shallow marsh ground elevation (i.e., 0.0 ft NGVD) that remains dry for 60 continuous days. Survival of juvenile apple snails under dry down conditions was lower (4-8 weeks) than for adults (Darby et al. 2008). Figure 12 illustrates the 60-day minimum continuously not exceeded dry event at the target shallow marsh elevation (0.0 ft NGVD) with the river stage frequencies for Lake Monroe. The differences in lake stages between the Base1995NN, Full1995NN, and the Full1995PN water management alternatives are predicted to be small (<0.2 ft), with the Full2030PS scenario showing approximately a 0.4 ft to 0.5 ft increase in stages over the other modeled scenarios (Figure 12). However, the stages predicted for all four scenarios fulfill the criterion for juvenile apple snails because the target elevation of 0.0 ft NGVD (minimum elevation of shallow marsh) is not dewatered for 60 continuous days within the period of record of the model simulation, protecting juvenile apple snail habitat (Figure 12).

Key elevations and durations identified by Acosta and Perry (2001) for crayfish (*P. alleni)* are ≤ 0.5 m below the shallow marsh maximum elevations with a 5-month dry duration. Acosta and Perry (2001) evaluated the impacts of shortened hydroperiod (duration of inundation) and depth to groundwater during droughts on populations of *P. alleni* in marl prairie habitats in the Everglades. Abundance and mean size of crayfish was higher in medium (7 months of inundation/ 5 months dry) and long (9 months of inundation/3 months dry) hydroperiod sites than at short (3 months inundation/ 9 months dry) hydroperiod sites. Based on their data, Acosta and Perry (2001) suggested that survival of *P. alleni* populations required ≥ 7 months of inundation and a seasonal low groundwater table of ≤ 0.5 m below ground surface. One of the standard durations in hydrologic analysis is 180-days (6 months). This duration was used in the present analysis as a divide between the medium and long hydroperiod sites and the short hydroperiod sites. The differences in lake stages between the Base1995NN, Full1995NN, and the Full1995PN water management alternatives are predicted to be small (<0.2 ft), with the Full2030PS scenario showing approximately a 0.1 ft to 0.5 ft increase in stages over the other modeled scenarios (Figure 13). However, the stages predicted for all four scenarios fulfill the criterion for *P. alleni* because the target elevation of 0.9 ft NGVD (maximum elevation of shallow marsh minus 0.5 m) is not dewatered for 180 continuous days within the period of record of the model simulation, protecting *P. alleni* populations and habitat (Figure 13).

The crayfish, *P. fallax*, prefers wetlands with intermediate to long-duration hydroperiods (11 to 12 months per year after Hendrix and Loftus 2000; Lowe 1986; and Dorn and Trexler 2007). Because of its apparent inability to tolerate wetland dry down as well (Dorn and Trexler 2007), areas of deeper depth (> 0.3 m) appear to be needed to support continued existence of *P. fallax* populations, although it is capable of living in shallower depths. Mace (2007) determined the elevation range of deep marsh plant communities at Lake Monroe, thought to be the most likely habitat for *P. fallax*. Based on this information, the following hydrologic thresholds were developed for *P. fallax* habitat at Lake Monroe:

- 1.0 ft NGVD (maximum deep marsh elevation), 365-day flooding (exceedence) duration
- 1.0 ft NGVD (maximum deep marsh elevation), 30-day dewatering (non-exceedence) duration

The 365-day continuous flooding of the maximum elevation of deep marsh (1.0 ft NGVD) was predicted to occur with similar frequency for the Base1995NN, Full1995NN and Full1995PN scenarios (~18 times in 100 years under the Base1995NN, Full1995NN, and Full1995PN, Figure 14). The frequency of flooding of the maximum deep marsh elevation was predicted to increase (~35 times in 100 years) for the Full2030PS regime (Figure 14), creating more favorable conditions for *P. fallax* populations.

The frequency of 30-day continuous dewatering of the maximum deep marsh elevation (1.0 ft NGVD) was predicted to be similar for the Base1995NN, Full1995NN, and Full1995PN scenarios (~40 times in 100 years, Figure 15), and decreases to approximately 10 times in 100 years at the Full2030PS regime (Figure 15), indicating wetter conditions. The Full2030PS scenario provides fewer dewatering events for the *P. fallax* elevation of 1.0 ft NGVD, as compared to the other scenarios , resulting in wetter crayfish habitat.

Partial-Duration Frequency Analyses – Salinity

Although the salinity regime at a location is certainly not the only factor influencing the presence and abundance of benthic invertebrates, it is one of the principal factors in the LSJR that affect submerged aquatic vegetation (SAV) and benthic invertebrates. Three monitoring stations were chosen to assess impacts of water withdrawals on the benthic invertebrate populations: JAXSJR17, JAXSJR40, and SJSR16 stations. No SAV beds occur at JAXSJR17 due to channel morphology and high salinity. JAXSJR40 is a location where SAV previously occurred under favorable salinity conditions during 1996-1998, but has since been extirpated due to the magnitude, duration, and/or frequency of high salinity events. SJSR16 is located upstream in a river reach that experiences relatively low salinities and has SAV in the area (Chapter 9. Submerged Aquatic Vegetation).

Generally speaking, the SJR becomes less saline with distance upstream; meaning that long duration events of higher salinities are more common towards the mouth of the river than they are upstream. The modeled changes in salinity at each station caused by different water management alternatives can be determined by examining the corresponding salinity partial-duration series events for various model simulations at each station (Figures 16 - 18).

The Base1995NN (i.e., black symbols on Figures 16-18) modeled scenario is the baseline scenario and represents something of an “existing conditions” scenario against which other alternatives can be compared. The FwOR1995NN (red symbols on Figures 16-18) modeled scenario has the most affect, mainly by increasing the duration of salinity events for the lower exceedence probabilities (i.e., < 60%, Figures 16-18). The increases in duration of salinity were generally small (i.e., 0 to 20 days) for salinities greater than 15 psu, and small to large (i.e., 0 – 75 days) for salinities less than 15 psu. The FwOR2030PS (i.e., blue symbols on Figures 16 – 18) modeled scenario moderates that affect and generally predicts durations of salinity exposure equal to the Base1995NN scenario or that fall between the Base1995NN and FwOR1995NN modeled scenarios for the range of salinities evaluated (Figures 16-18).

The largest modeled changes in maximum daily bottom salinity regimes occurred at JAXSJR40, which is already in an area of frequent salinity fluctuations. Most of the time (> 30% of the annual exceedence probability) there is little to no difference in event durations between modeled scenarios (Figure 17). At low exceedence probabilities (<30% annual exceedence probability), durations of 5 - 10psu salinity events may increase by 40 - 60 days (Figure 17) between the FwOR1995PN and the base modeled scenarios. The duration of exposure of higher salinity events (i.e., 15 – 25psu) are not as affected by water withdrawals and were predicted to have increases in duration of exposure of only 2 – 5 days (Figure 17). JAXSJR40 is already in an area of high salinity fluctuations, evident by the previous occurrence of SAV and current extirpation. These shifts between modeled event durations substantiate that this area of the river is subjected to a range of salinity magnitudes, durations, and frequency of events and continues to be an area of fluctuating salinity under modeled scenarios, especially at lower salinity events (i.e., <15psu).

The smallest modeled changes in maximum daily bottom salinity regimes occurs at SJSR16. The durations of the 1psu salinity events generally showed the greatest increases in the durations of exposure (i.e., 5 – 12 days, Figure 18), while durations of exposure for salinities between 2 – 4psu generally showed very small increases (i.e., 0 – 3 days, Figure 18).

The benthos communities at both the JAXSJR17 and JAXSJR40 stations are expected to be unaffected by surface water withdrawals because the river reaches are subjected to daily fluxes in salinity that naturally occur under current conditions. While the modeled scenarios predict some increases in the duration of these salinity events, the events themselves occur rather frequently within this zone of high salinity fluctuation and the benthic invertebrates present should be adapted to this.

Conclusions

Frequency analysis indicated that all four water management modeled scenarios produce hydrologic conditions that are protective of critical shallow marsh habitat at Lake Poinsett in the USJRB and Lake Monroe in the MSJRB for adult and juvenile apple snails and for crayfish (*P. alleni* and *P. fallax*) populations.

Frequency analysis indicated that the Full1995PN and Full2030PN modeled water management alternatives will produce less frequent dewatering of the critical marsh elevation at Lake Poinsett for adult and juvenile apple snails and for *P. alleni*, as compared to the Base1995NN and Full1995NN conditions, and thus provide more favorable habitat conditions for these ecological indicator species (Figures 6 - 10). The 365-day continuous flooding of the maximum elevation of deep marsh was predicted to occur with similar frequency for all four of the modeled scenarios for *P. fallax* habitat. Model simulations also indicated the Full1995NN and Full1995PN scenarios would slightly increase the frequency of 30-day continuous dewatering of the maximum deep marsh elevation (Figure 9). However, the Full2030PN alternative is predicted to improve hydrologic conditions over the other three alternatives due to increased freshwater runoff in the 2030 alternative that offsets effects from withdrawals.

Frequency analysis indicated that all four water management alternatives produced hydrologic conditions that were protective of critical shallow marsh and deep marsh habitats at Lake Monroe for adult and juvenile apple snails and for crayfish populations (Figures 11 - 15). The stages predicted for all four scenarios exceed the 60-day, 90-day and 180-day continuous non-exceedence threshold stages required for the protection of apple snail and *P. alleni* habitat, respectively. The 365-day continuous flooding and the 30-day continuous dewatering of the maximum elevation of deep marsh was predicted to occur with similar frequency for the Base1995NN, Full1995NN, and Full1995PN scenarios for *P. fallax* habitat. . The Full2030PS alternative is predicted to improve hydrologic conditions for *P. fallax* habitat over the other three alternatives due to the interaction of sea level rise and increased freshwater runoff in the 2030 alternative that offsets effects from withdrawals.

The partial-duration frequency analysis of the modeled LSJRB salinity regime indicated that the daily exposure in mid- (≤ 10-psu) and high-range (≥ 15-psu) salinities are expected to show increases in days of exposure resulting from upstream surface water withdrawals from the SJR. Mid-range salinities (≤ 10-psu) showed small increases (i.e., 5 - 15 days) for annual exceedence probabilities generally greater than 50%, and larger increases in exposure (i.e., 5 - 35 days) were predicted to occur less frequently (i.e., at exceedence probabilities less than 50%). The daily exposure of high-range salinities (≥ 15-psu) are predicted to increase only slightly (i.e., ~2 days).

The results clearly show that mid-range salinities are more sensitive to decreases in river discharges resulting from surface water withdrawals. However, the increase in the duration of exposure to mid-range salinities is not expected to impact benthos because the greatest increases (i.e., > 20 days) occurred in areas with large natural salinity fluctuations. These modeled changes in events occur less frequently (i.e., recurrence intervals > 5 years) and should provide adequate time for benthic invertebrate movement and/or population recovery. High-range salinities ($\geq$ 15 psu) showed only slight increases in durations of exposure, because ocean intrusions into the LSJR dominate high-range salinities. Decreased SJR discharge in the range represented by the water management modeled scenarios has very little influence on these storm-driven events.

Generally speaking, salinity changes for the “FwOR2030PS” (future case) scenario are less severe than those for the “FwOR1995NN” scenario. The FwOR2030PS alternative is predicted to improve hydrologic conditions over the other two alternatives due to a predicted increased in freshwater runoff that offsets effects from both withdrawals and sea level rise.

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Table 1. Station site names and locations

Site	Modeled Station Name	Location Description
JAXSJR17	JAXSJR17	SJRWMD data recorder mid-channel at St. Johns River mile 17 in Jacksonville
JAXSJR40	JAXSJR40	SJRWMD data recorder mid-channel between the Buckman Bridge and the Fuller Warren Bridge near Jacksonville
SJSR16	SJSR16	SJRWMD data recorder mid-channel near SR16, near Green Cove Springs
Lake Monroe	SJR near Sanford	Lake Monroe near Sanford, FL (USGS 02234499), located at the St. Johns River outlet of Lake Monroe
Lake Poinsett	SJR near Cocoa	St. Johns River near Cocoa (USGS 02232400), located at the St. Johns River outlet of Lake Poinsett

Table 2. Definitions of model scenario acronyms analyzed using annual and partial-duration frequency analyses

Modeled Station	Model Scenario Name	Land Use Year	Withdrawal Type	Upper Basin Project?	Sea Level Rise?	Data	Data Type
JAXSJR17	Base1995NN	1995	Baseline: no additional withdrawals	No	No	Bottom Salinity	Daily Maximum
	FwOR1995NN	1995	Full SJR withdrawal + Ocklawaha withdrawal	No	No	Bottom Salinity	Daily Maximum
	FwOR2030PS	2030	Full SJR withdrawal + Ocklawaha withdrawal	Yes	Yes	Bottom Salinity	Daily Maximum
JAXSJR40	Base1995NN	1995	Baseline: no additional withdrawals	No	No	Bottom Salinity	Daily Maximum
	FwOR1995NN	1995	Full SJR withdrawal + Ocklawaha withdrawal	No	No	Bottom Salinity	Daily Maximum
	FwOR2030PS	2030	Full SJR withdrawal + Ocklawaha withdrawal	Yes	Yes	Bottom Salinity	Daily Maximum
SJSR16	Base1995NN	1995	Baseline: no additional withdrawals	No	No	Bottom Salinity	Daily Maximum
	FwOR1995NN	1995	Full SJR withdrawal + Ocklawaha withdrawal	No	No	Bottom Salinity	Daily Maximum
	FwOR2030PS	2030	Full SJR withdrawal + Ocklawaha withdrawal	Yes	Yes	Bottom Salinity	Daily Maximum
SJR near Sanford [Lake Monroe]	Base1995NN	1995	Baseline: no additional withdrawals	No	No	Water Level	Daily Average
	Full1995NN	1995	Full SJR withdrawal	No	No	Water Level	Daily Average
	Full1995PN	1995	Full SJR withdrawal	Yes	No	Water Level	Daily Average
	Full2030PS	2030	Full SJR withdrawal	Yes	Yes	Water Level	Daily Average
SJR near Cocoa [Lake Poinsett]	Base1995NN	1995	Baseline: no additional withdrawals	No	No	Water Level	Daily Average
	Full1995NN	1995	Full SJR withdrawal	No	No	Water Level	Daily Average
	Full1995PN	1995	Full SJR withdrawal	Yes	No	Water Level	Daily Average
	Full2030PN	2030	Full SJR withdrawal	Yes	No	Water Level	Daily Average

Table 3. Example results of annual stage frequency analysis for Lake Poinsett observed stages (USGS 1975 – 1983, feet NGVD)

Highest stages equaled or exceeded continuously for the following number of days in year ending May 31										
Year	**Duration (days)**									
	1	**7**	**14**	**30**	**60**	**90**	**120**	**180**	**270**	**365**
1976	14.08	14.05	14.02	13.86	13.07	12.69	12.23	11.33	9.91	8.92
1977	15.18	15.03	14.80	14.43	14.17	14.03	13.31	12.27	10.96	8.81
1978	13.28	13.20	13.17	13.12	12.79	12.79	12.54	11.82	10.98	9.01
1979	15.85	15.71	15.48	15.18	14.15	13.08	12.01	10.93	10.37	9.95
1980	16.72	16.65	16.52	15.93	14.55	13.15	12.82	12.32	11.32	10.33
1981	10.66	10.50	10.21	9.91	9.79	9.43	9.41	8.98	8.64	8.64
1982	13.70	12.59	12.45	12.38	11.67	10.81	10.79	10.79	9.92	8.77
1983	15.51	15.37	15.26	15.10	14.80	14.28	14.12	12.43	11.44	11.44
Lowest mean stages for the following number of consecutive days in year ending September 30										
Year	**Duration (days)**									
	1	**7**	**14**	**30**	**60**	**90**	**120**	**180**	**270**	**365**
1976	9.04	9.11	9.13	9.22	9.41	9.67	9.84	10.39	11.37	12.14
1977	8.81	8.86	8.89	8.93	9.07	9.16	9.23	9.54	10.21	10.93
1978	10.89	10.98	11.14	11.37	11.58	11.76	12.03	12.37	12.37	12.87
1979	9.95	9.99	10.03	10.27	10.88	11.28	11.55	11.50	11.73	12.25
1980	8.97	9.04	9.10	9.19	9.28	9.27	9.46	9.92	10.58	11.50
1981	8.64	8.67	8.69	8.74	8.81	8.94	9.07	9.33	9.38	9.41
1982	10.62	10.70	10.72	10.74	10.89	10.90	10.94	11.01	11.69	12.51
1983	11.44	11.53	11.62	11.74	11.96	12.11	12.34	12.82	12.84	12.92
Lowest stages equaled or not exceeded continuously for the following number of days in year ending September 30										
Year	**Duration (days)**									
	1	**7**	**14**	**30**	**60**	**90**	**120**	**180**	**270**	**365**
1976	9.04	9.17	9.32	9.41	9.85	10.45	10.75	12.12	14.08	15.18
1977	8.81	8.92	8.93	9.04	9.35	9.43	9.63	10.75	12.02	14.54
1978	10.89	11.11	11.40	11.76	11.92	12.51	13.09	13.28	13.28	15.85
1979	9.95	10.08	10.27	10.90	11.56	12.18	12.53	12.82	12.91	16.69
1980	8.97	9.11	9.17	9.30	9.53	9.59	10.64	11.52	12.59	16.72
1981	8.64	8.70	8.72	8.86	8.98	9.22	9.41	10.18	10.32	10.79
1982	10.62	10.73	10.77	10.81	10.98	11.07	11.28	11.77	15.34	15.51
1983	11.44	11.61	11.77	11.91	12.43	12.56	13.02	14.55	14.62	14.62

Table 4. Example results of partial duration frequency analysis for SJR WSIS modeled maximum daily surface salinity at SAV station JAXSJR40 (FwOR2030PS)

Threshold Salinity Value (psu)	Event No.	Start Date	Event Duration (days)	Ranked Event Duration (days)	Probability
15	1	3/11/1996	3	34	9.1
	2	3/25/1997	1	21	18.2
	3	4/11/1997	1	13	27.3
	4	4/15/1997	4	13	36.4
	5	5/29/1997	2	12	45.5
	6	6/7/1997	3	8	54.5
	7	4/13/1999	3	8	63.6
	8	4/25/1999	13	6	72.7
	9	5/11/1999	13	6	81.8
	10	6/8/1999	8	6	90.9
	11	6/19/1999	3	4	100.0
	12	8/31/1999	6	4	109.1
	13	9/15/1999	1	3	118.2
	14	3/19/2000	8	3	127.3
	15	5/15/2000	4	3	136.4
	16	5/28/2000	21	3	145.5
	17	7/3/2000	3	3	154.5
	18	7/8/2000	3	3	163.6
	19	2/19/2001	1	3	172.7
	20	3/8/2001	6	3	181.8
	21	3/19/2001	3	2	190.9
	22	5/1/2001	12	2	200.0
	23	5/15/2001	1	1	209.1
	24	5/17/2001	6	1	218.2
	25	5/25/2001	3	1	227.3
	26	4/6/2002	2	1	236.4
	27	5/6/2002	1	1	245.5
	28	5/20/2002	34	1	254.5
	29	2/2/2004	1	1	263.6
20	1	3/11/1996	2	13	9.1
	2	4/30/1999	5	7	18.2
	3	5/18/1999	2	5	27.3
	4	9/4/1999	1	4	36.4
	5	9/15/1999	1	3	45.5
	6	5/30/2000	7	2	54.5
	7	6/8/2000	3	2	63.6
	8	3/19/2001	1	2	72.7
	9	5/8/2001	2	1	81.8
	10	5/20/2002	13	1	90.9
	11	6/4/2002	1	1	100.0
	12	6/9/2002	4	1	109.1
25	1	5/2/1999	2	5	9.1
	2	5/30/2000	3	3	18.2
	3	5/21/2002	5	2	27.3

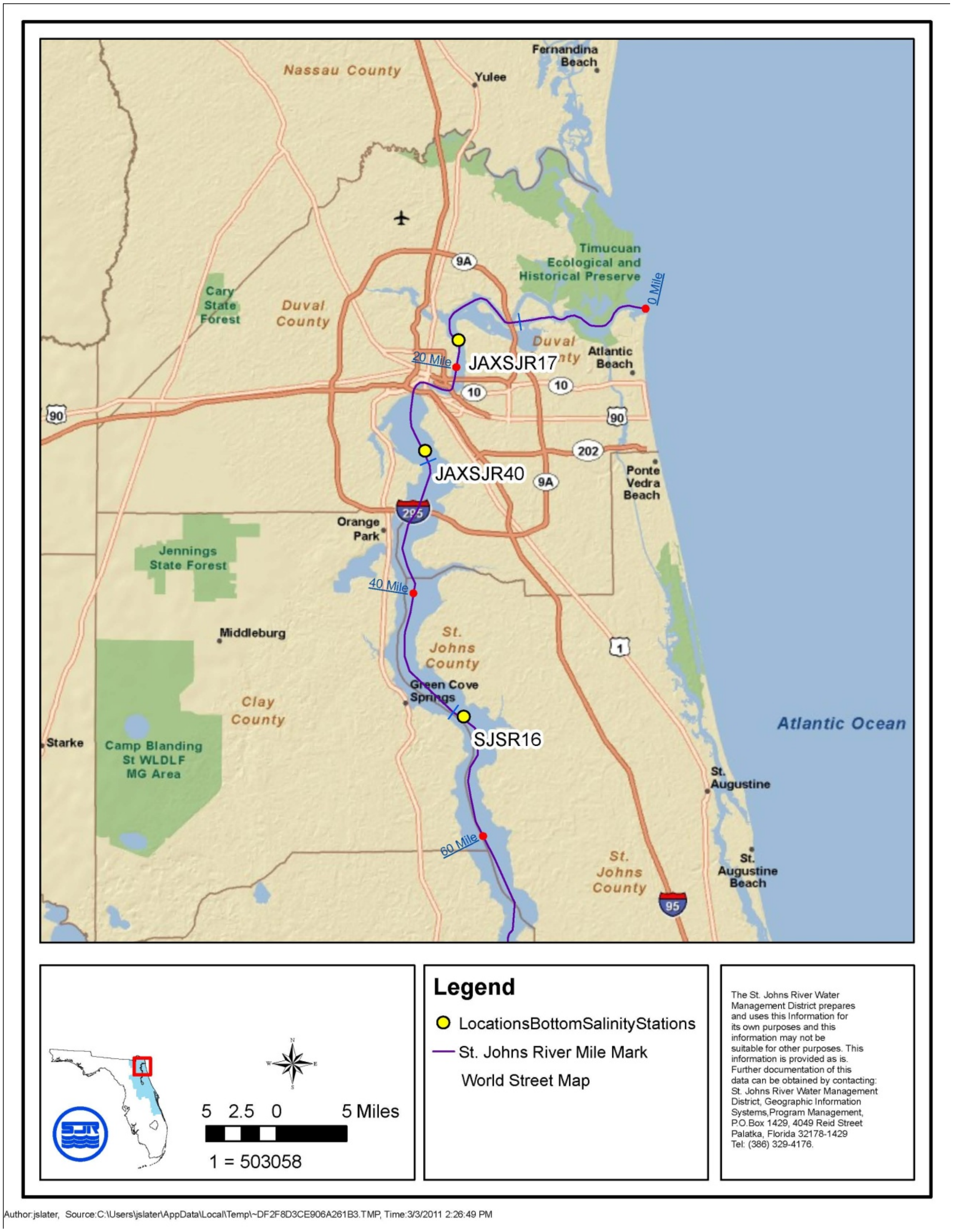

Figure 1. Location of three modeled stations [JAXSJR17, JAXSJR40 and SJSR16] considered for daily maximum bottom salinity partial-duration frequency analysis

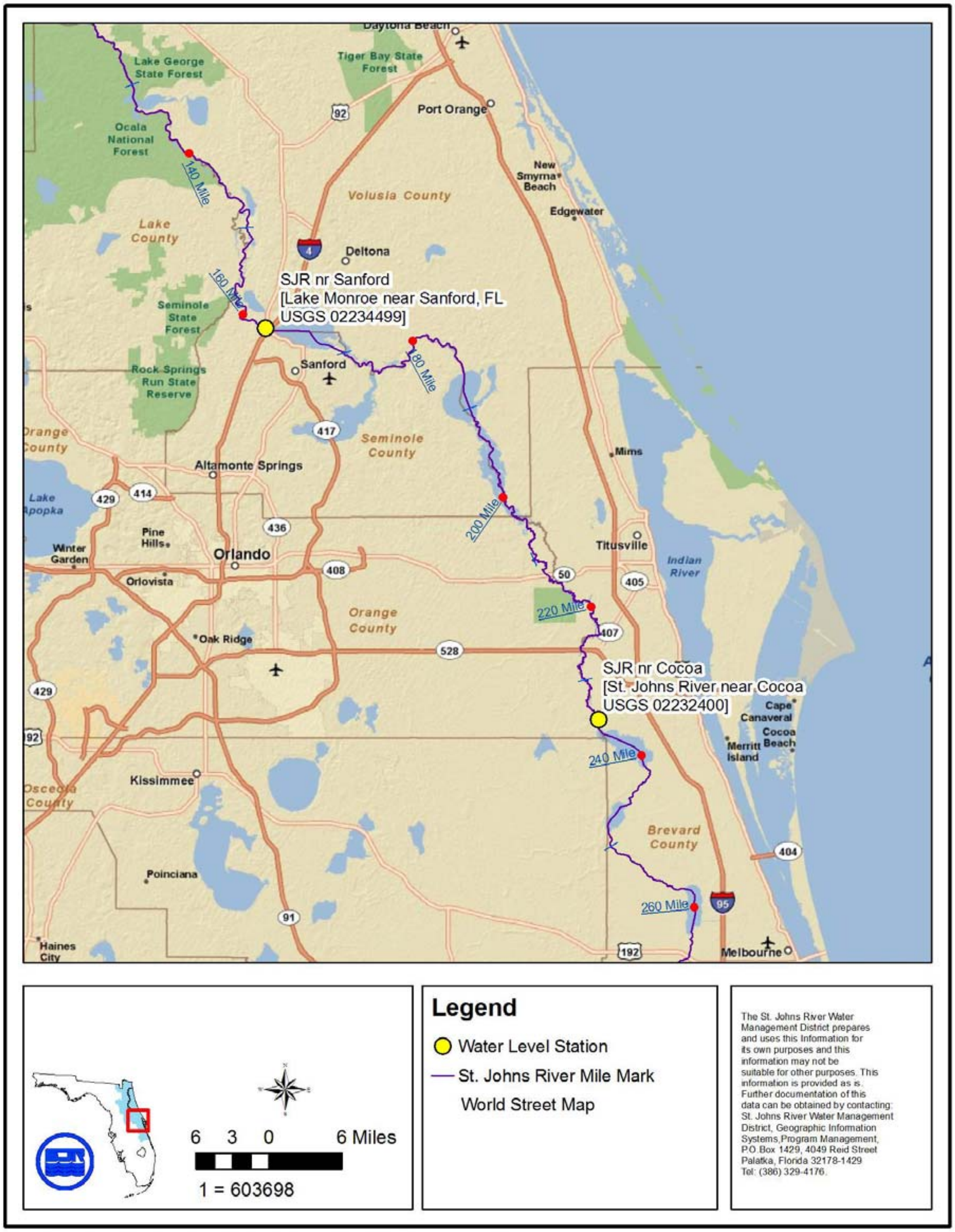

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Figure 2. Location of two stage stations considered for modeled daily average water level annual frequency analysis

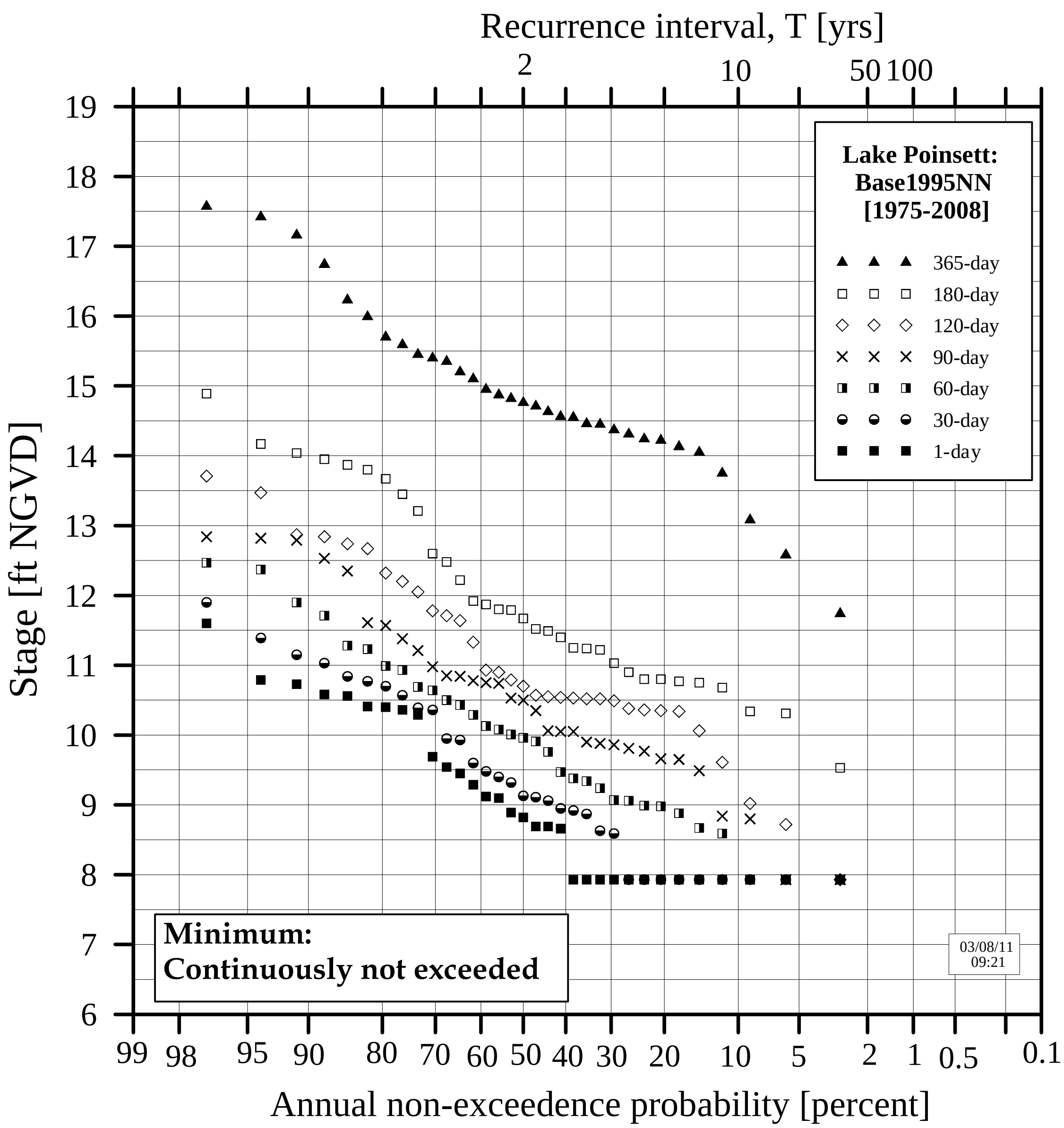


Figure 3. Example of stage frequency analysis for the St. Johns River near Cocoa (Lake Poinsett)

Figure 4. St. Johns River at Lake Poinsett stage hydrograph: 1975 – 1982 (USGS, feet National Geodetic Vertical Datum [ft NGVD])

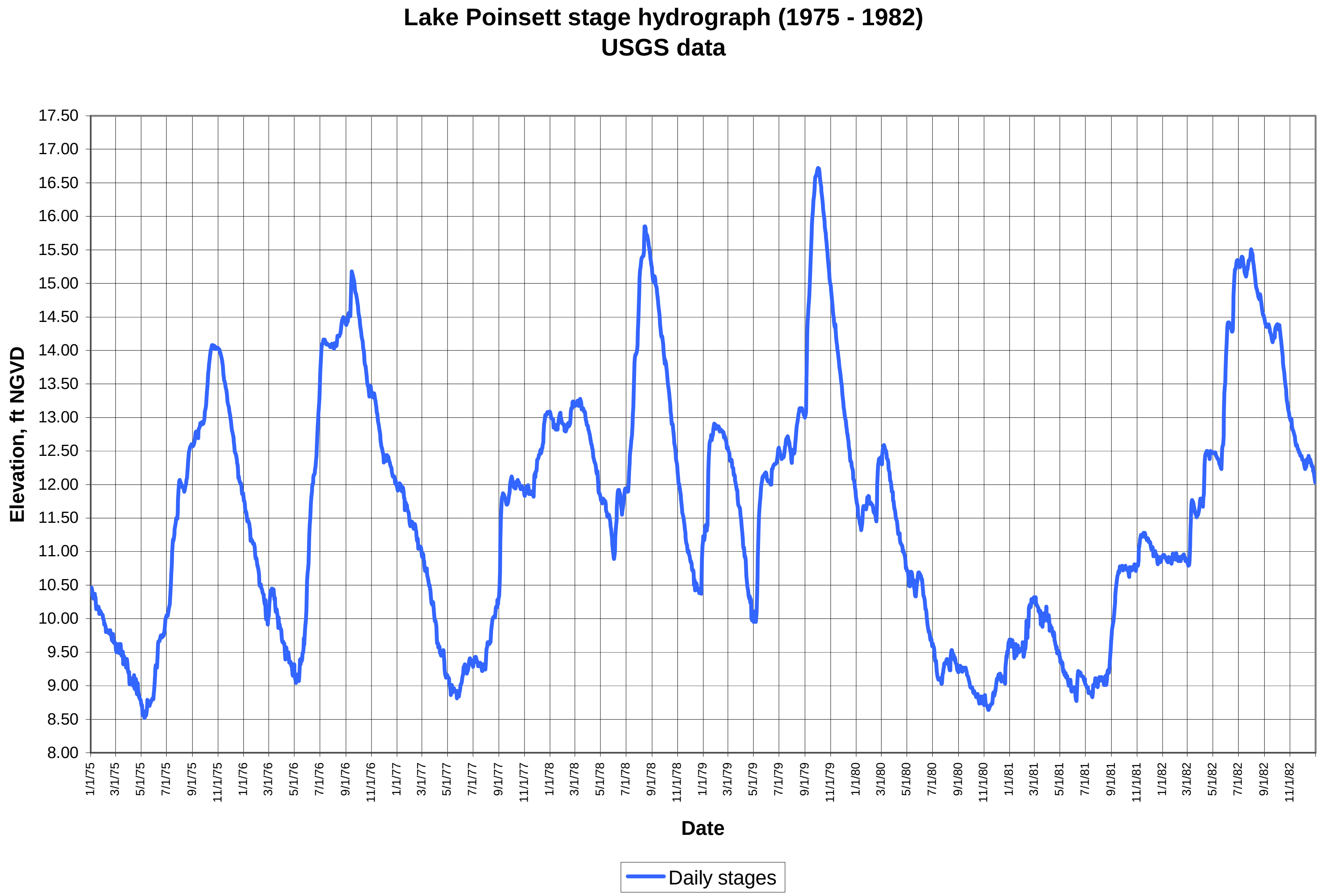
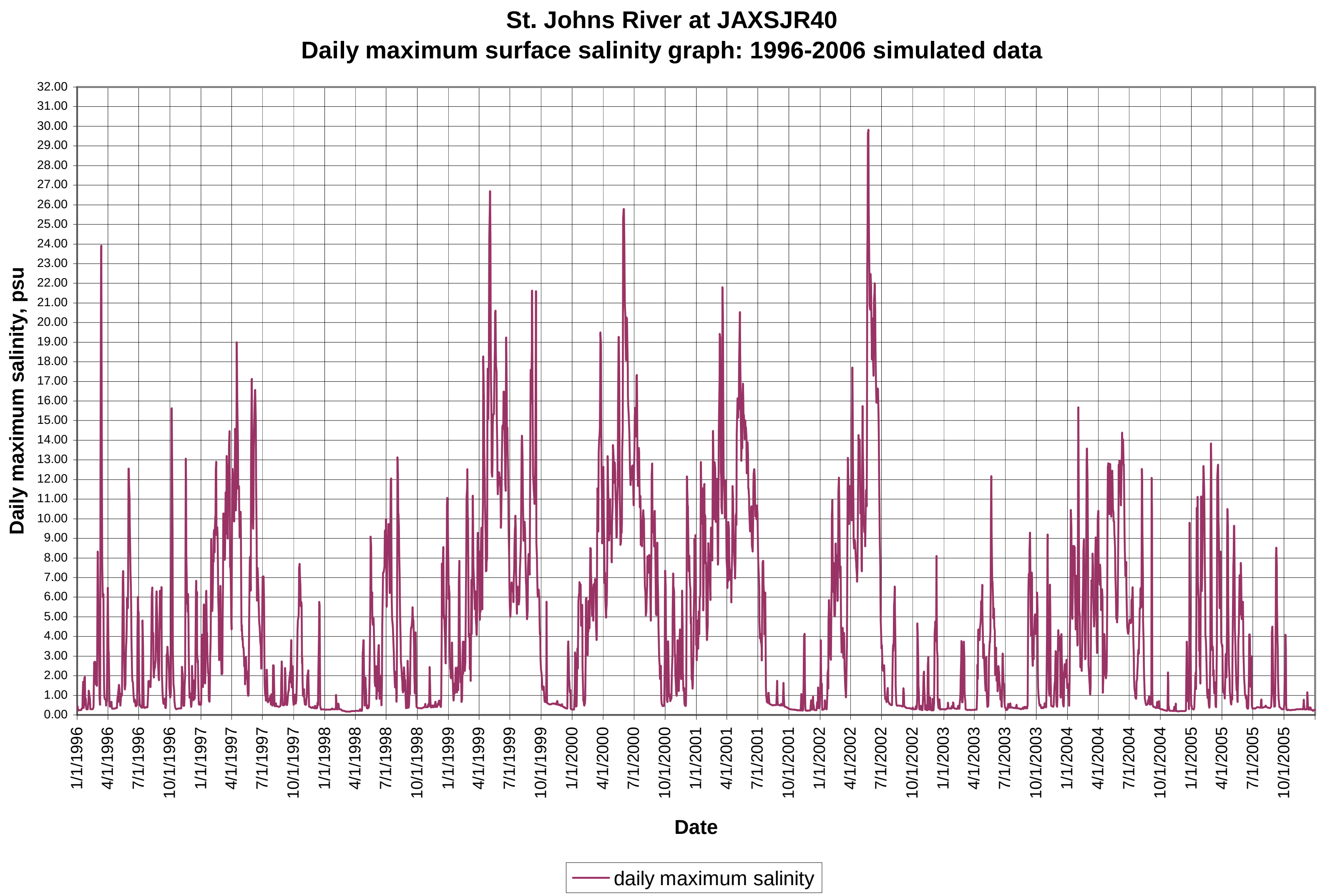
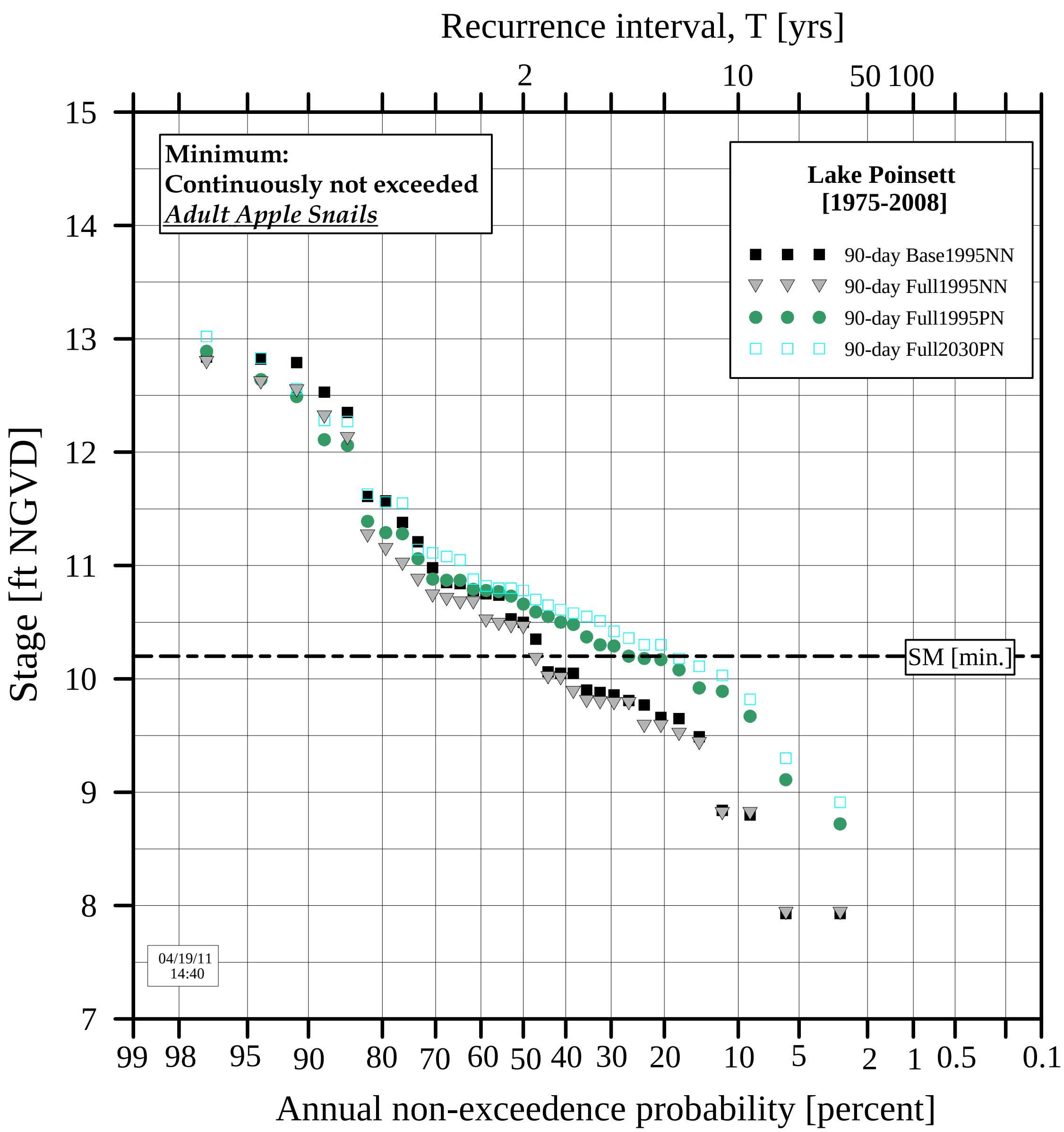


Figure 5. St. Johns River at JAXSJR40 near Jacksonville: Modeled daily surface salinity maximum (psu, practical salinity units) for 1996 - 2005

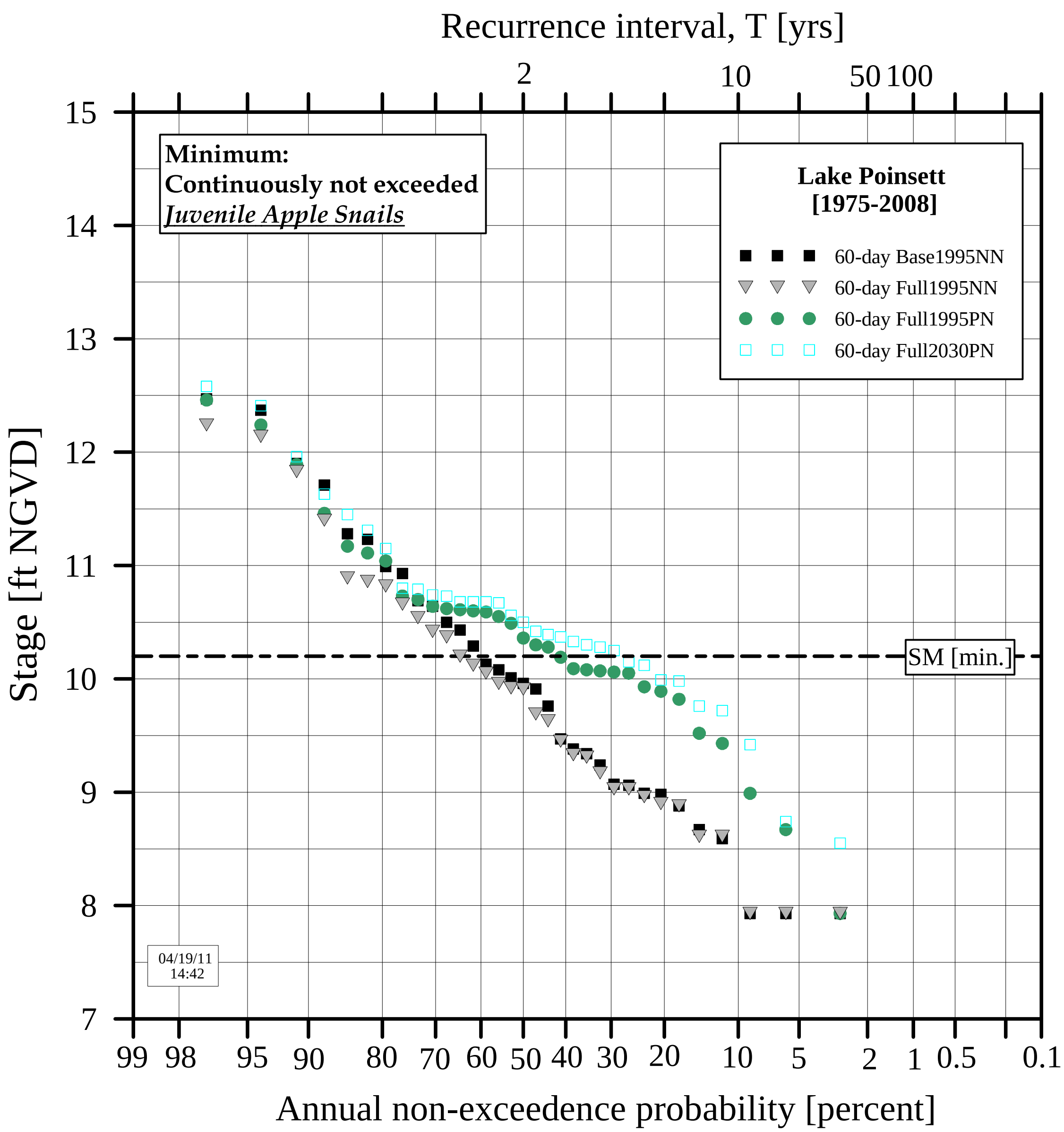




Key elevation – SM minimum elevation 10.2 ft NGVD

Base1995NN occurs 43x/100 yrs
Full1995NN occurs 48x/100 yrs
Full1995PN occurs 25x/100 yrs
Full2030PN occurs 20x/100 yrs
SM=shallow marsh

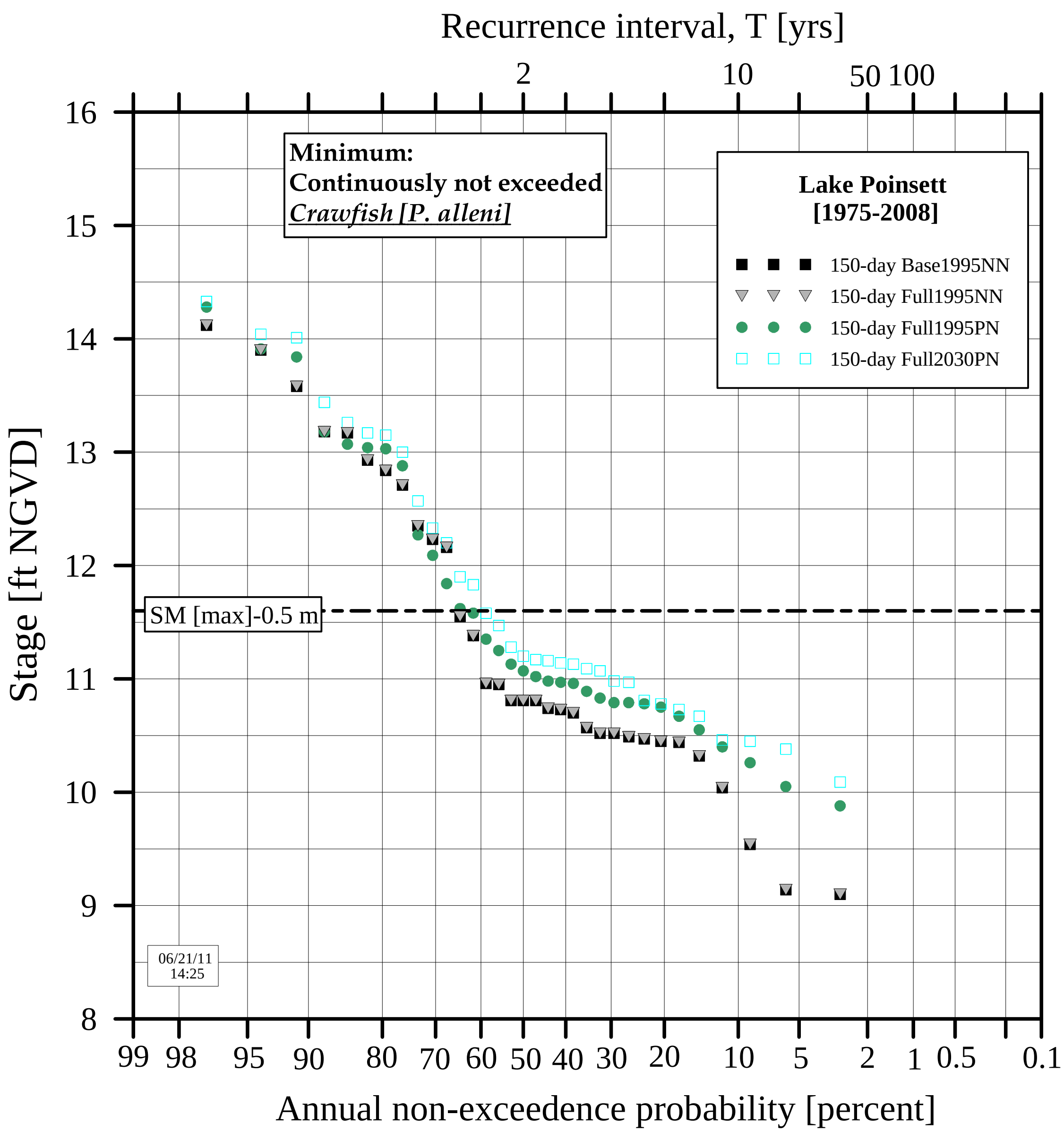
Figure 6. Lake Poinsett: Adult apple snail frequency analysis criteria with a 90 day duration dewatering (continuously non-exceeded) event with minimum shallow marsh (SM) elevation criterion



Key elevation – SM minimum elevation 10.2 ft NGVD

Base1995NN occurs 60x/100 yrs
Full1995NN occurs 64x/100yrs
Full1995PN occurs 43x/100 yrs
Full2030PN occurs 27x/100 yrs
SM=shallow marsh

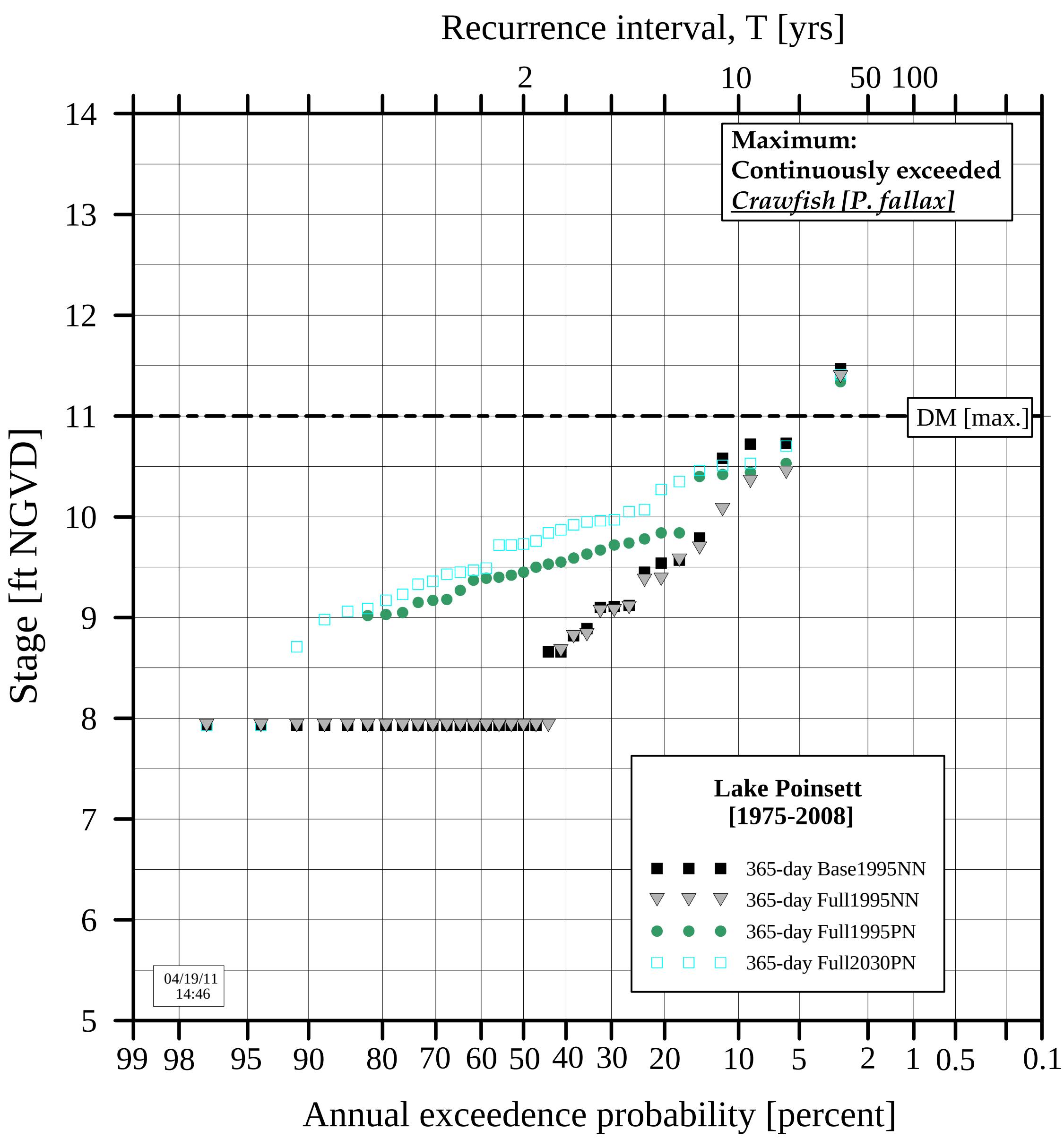
Figure 7. Lake Poinsett: Juvenile apple snail frequency analysis criteria with a 60-day duration dewatering (continuously non-exceeded) event with minimum shallow marsh (SM) elevation criterion



Key elevation – SM max minus 0.5m

Base1995NN occurs 64x/100 yrs
Full1995NN occurs 64x/100 yrs
Full1995PN occurs 62x/100 yrs
Full2030PN occurs 60x/100 yrs
SM=shallow marsh

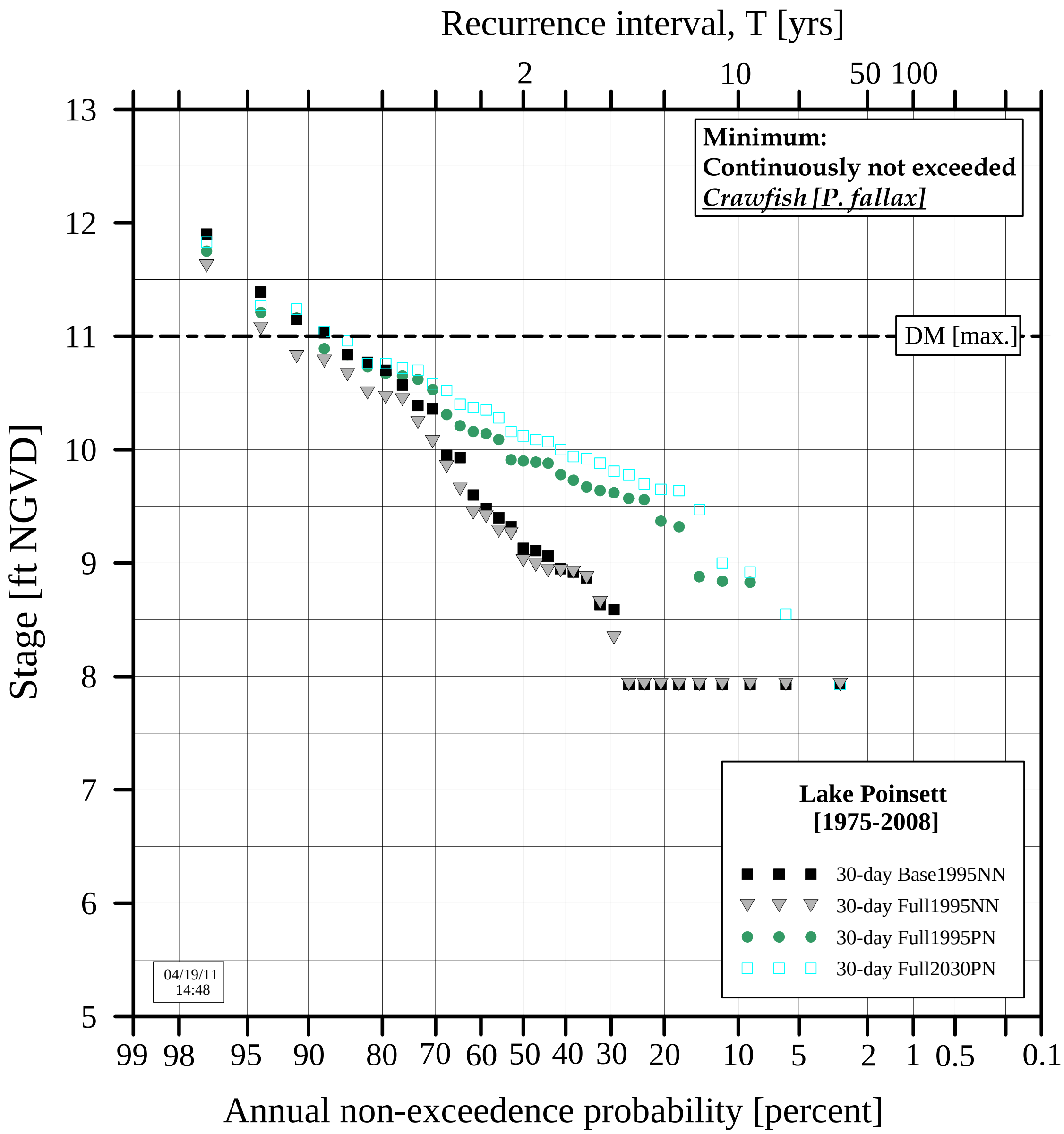
Figure 8. Lake Poinsett: Crayfish (*P. alleni*) frequency analysis criteria with a 180-day duration dewatering (continuously non-exceeded) event with shallow marsh (SM) elevation criterion



Key elevation – DM max

Base1995NN occurs 5x/100 yrs
Full1995NN occurs 5x/100 yrs
Full1995PN occurs 4x/100 yrs
Full2030PN occurs 4x/100 yrs
DM=deep marsh

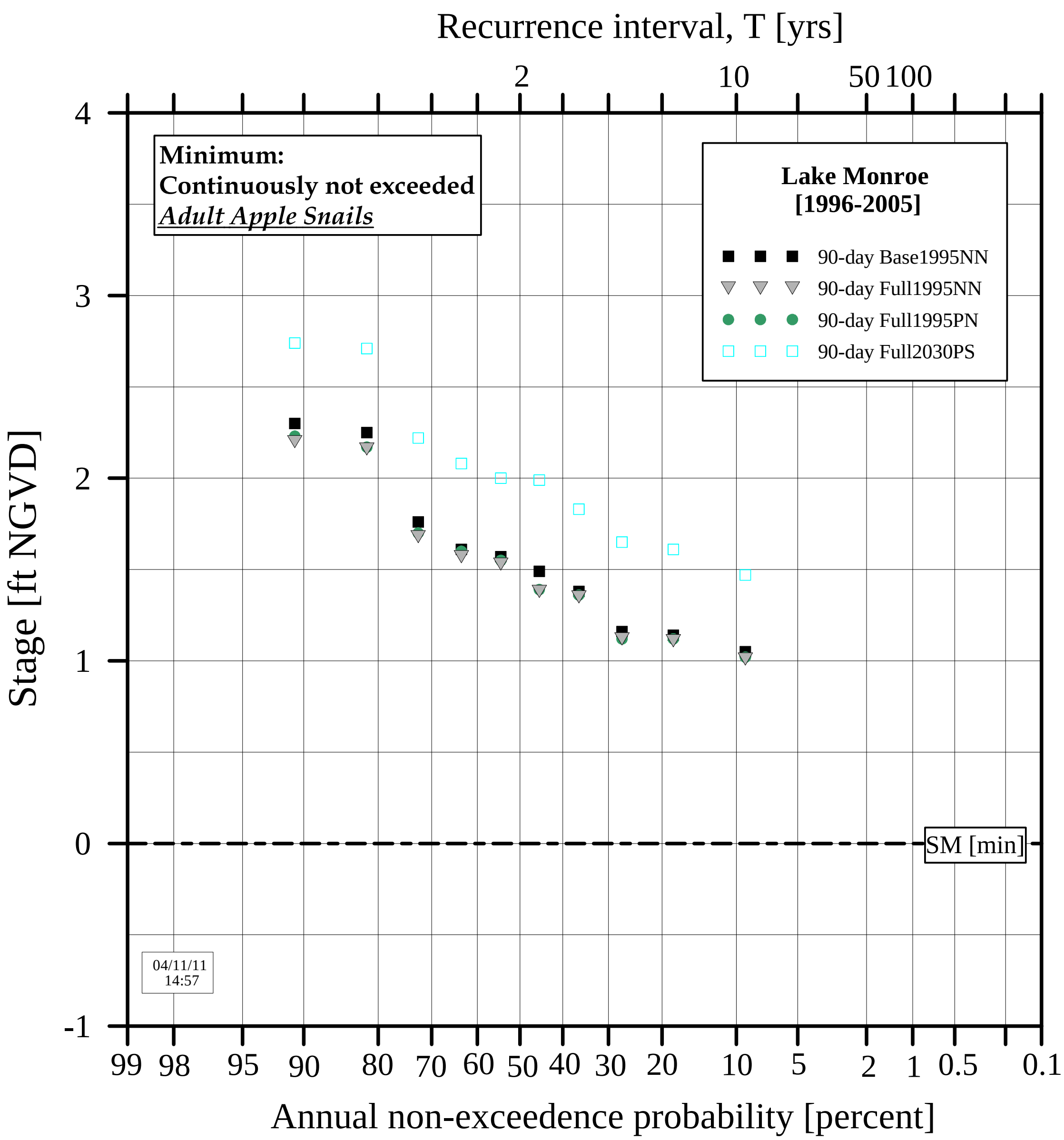
Figure 9. Lake Poinsett: Crayfish (*P. fallax*) frequency analysis for the deep marsh (DM) maximum elevation target of 11.0 ft NGVD with a 365-day flooding duration (continuously exceeded event)



Key elevation – DM max

Base1995NN occurs 88x/100 yrs
Full1995NN occurs 91x/100 yrs
Full1995PN occurs 90x/100 yrs
Full2030PN occurs 86x/100 yrs
DM=deep marsh

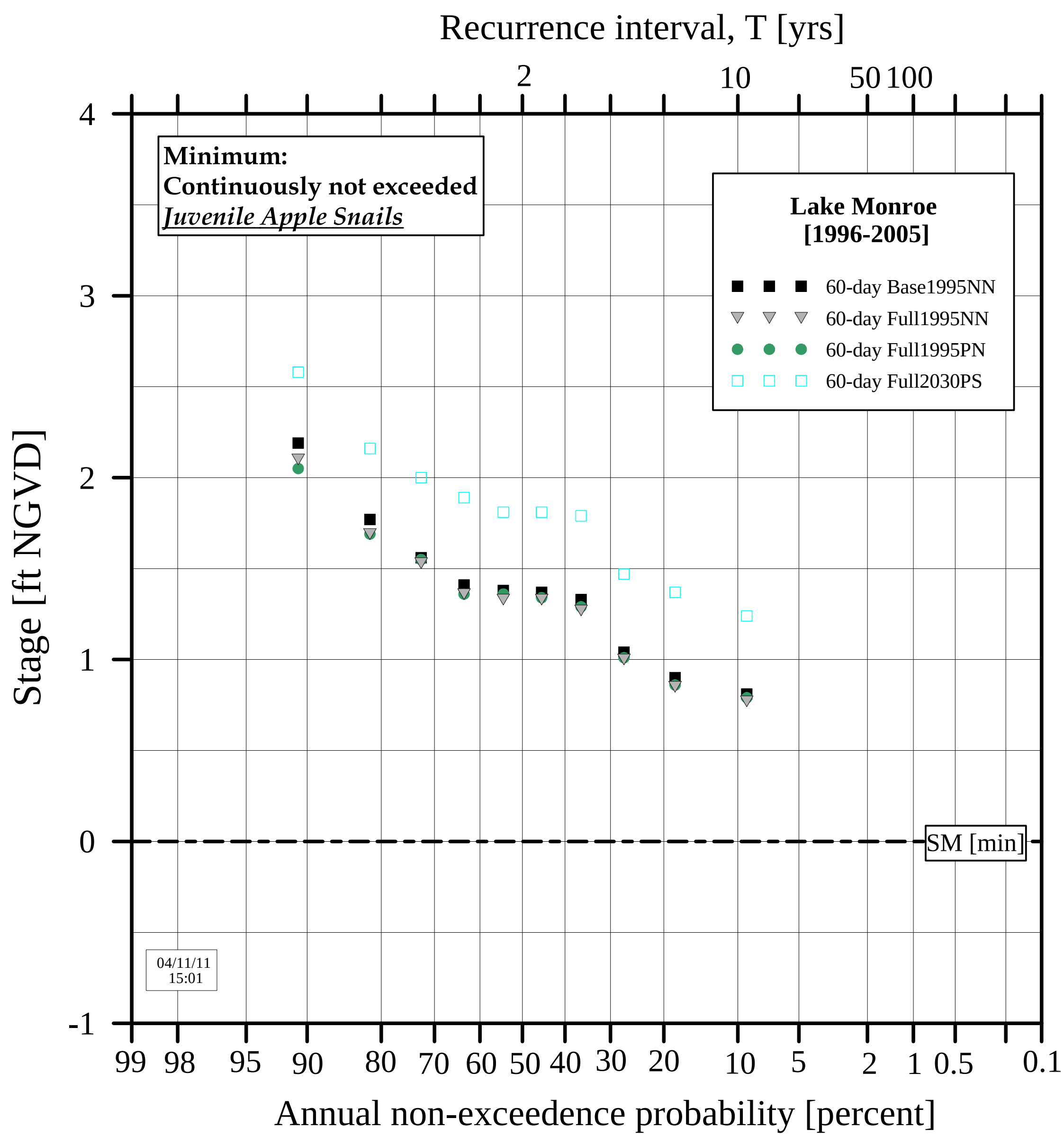
Figure 10. Lake Poinsett: Crayfish (*P. fallax*) frequency analysis for the deep marsh (DM) maximum elevation target of 11.0 ft NGVD with a 30-day dewatering duration (continuously non-exceeded event)



Key elevation – SM min

Base1995NN occurs < 1x /100 yrs
Full1995NN occurs < 1x/100 yrs
Full1995PN occurs < 1x /100 yrs
Full2030PS occurs < 1x /100 yrs
SM=shallow marsh

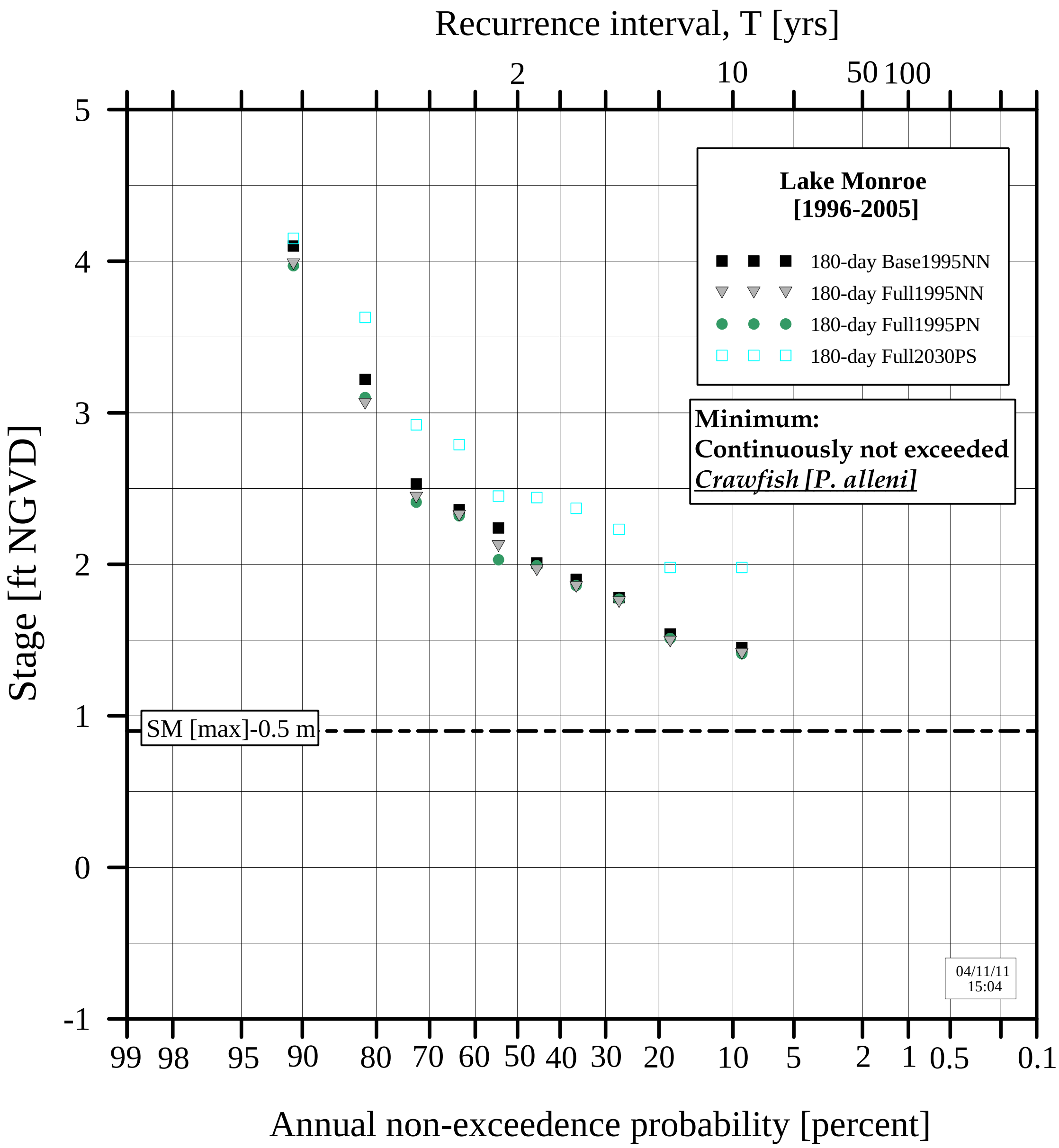
Figure 11. Lake Monroe: Adult apple snail frequency analysis for the shallow marsh (SM) minimum elevation target of 0.0 ft NGVD with a 90-day duration dewatering (continuously non-exceeded event)



Key elevation – SM min

Base1995NN occurs < 1x/100 yrs
Full1995NN occurs < 1x/100 yrs
Full1995PN occurs < 1x /100 yrs
Full2030PS occurs < 1x /100 yrs
SM=shallow marsh

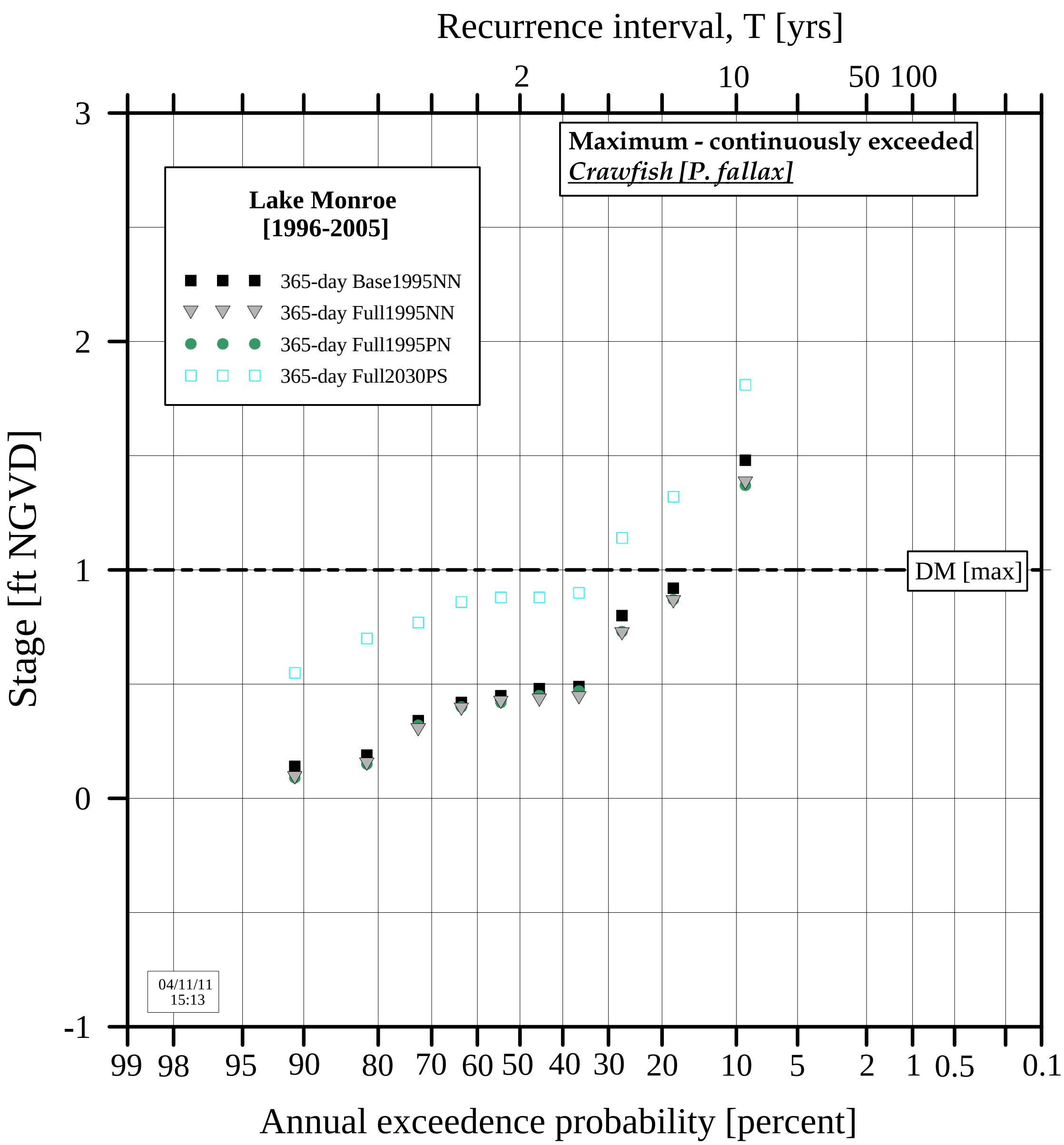
Figure 12. Lake Monroe: Juvenile apple snail frequency analysis for the shallow marsh (SM) minimum elevation target of 0.0 ft NGVD with a 60-day duration dewatering (continuously non-exceeded event)



Key elevation – SM max – 0.5 m

Base1995NN occurs 2x /100 yrs
Full1995NN occurs 2x/100 yrs
Full1995PN occurs 2x /100 yrs
Full2030PS occurs < 1x /100 yrs
SM=shallow marsh

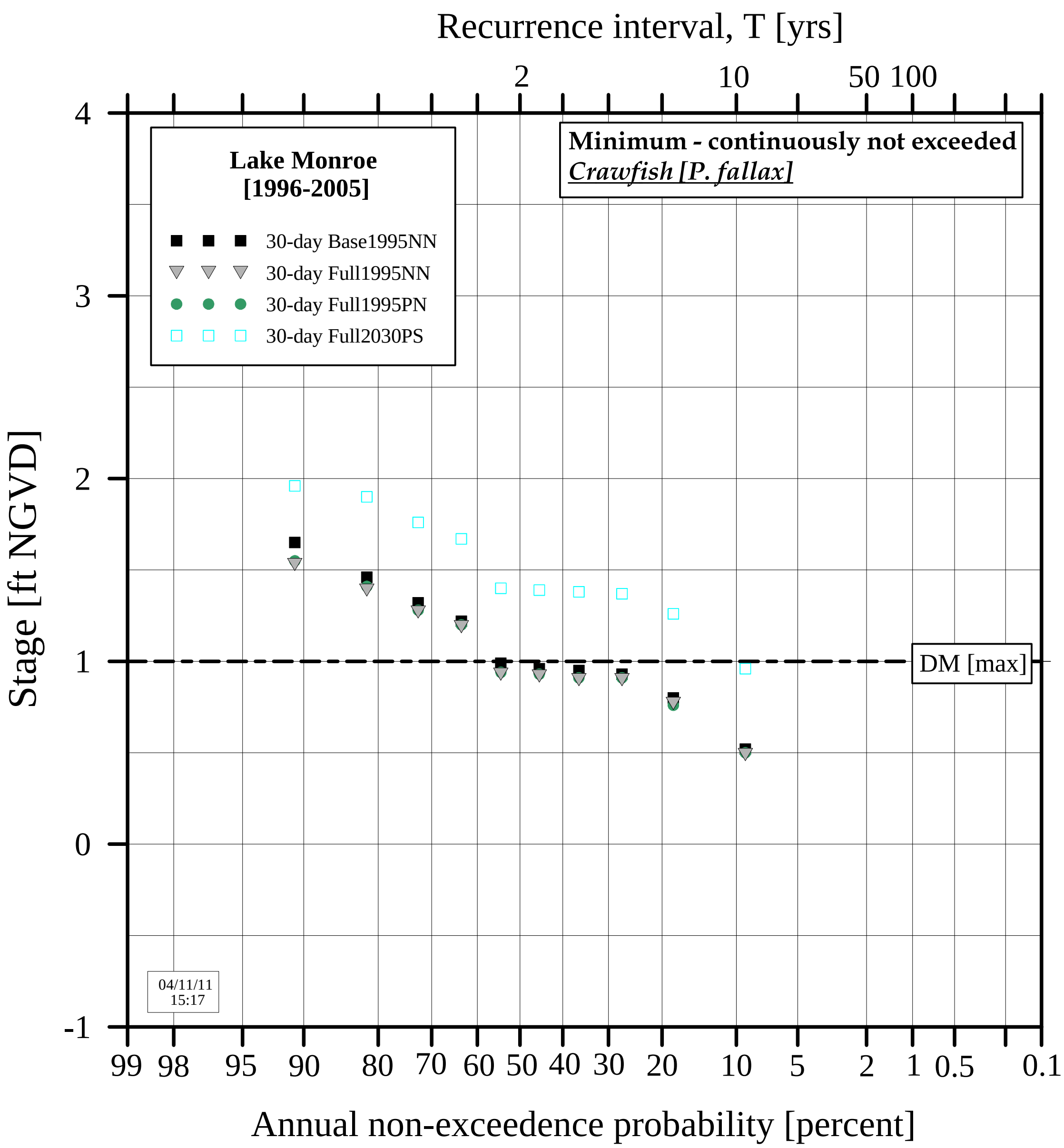
Figure 13. Lake Monroe: Crayfish (*P. alleni*) frequency analysis for the shallow marsh (SM) maximum elevation target of 0.9 ft NGVD with a 180-day duration dewatering (continuously non-exceeded event)



Key elevation – DM max

Base1995NN occurs 18x/100 yrs
Full1995NN occurs 18x/100 yrs
Full1995PN occurs 18x/100 yrs
Full2030PS occurs 35x/100 yrs
DM=deep marsh

Figure 14. Lake Monroe: Crayfish (*P. fallax*) frequency analysis for the deep marsh (DM) maximum elevation target of 1.0 ft NGVD with a 365-day flooding duration (continuously exceeded event)



Key elevation – DM max

Base1995NN occurs 40x/100 yrs
Full1995NN occurs 40x/100 yrs
Full1995PN occurs 40x/100 yrs
Full2030PS occurs 10x/100 yrs
DM=deep marsh

Figure 15. Lake Monroe: Crayfish (*P. fallax*) frequency analysis for the deep marsh (SM) maximum elevation target of 1.0 ft NGVD with a 30-day dewatering duration (continuously non-exceeded event)

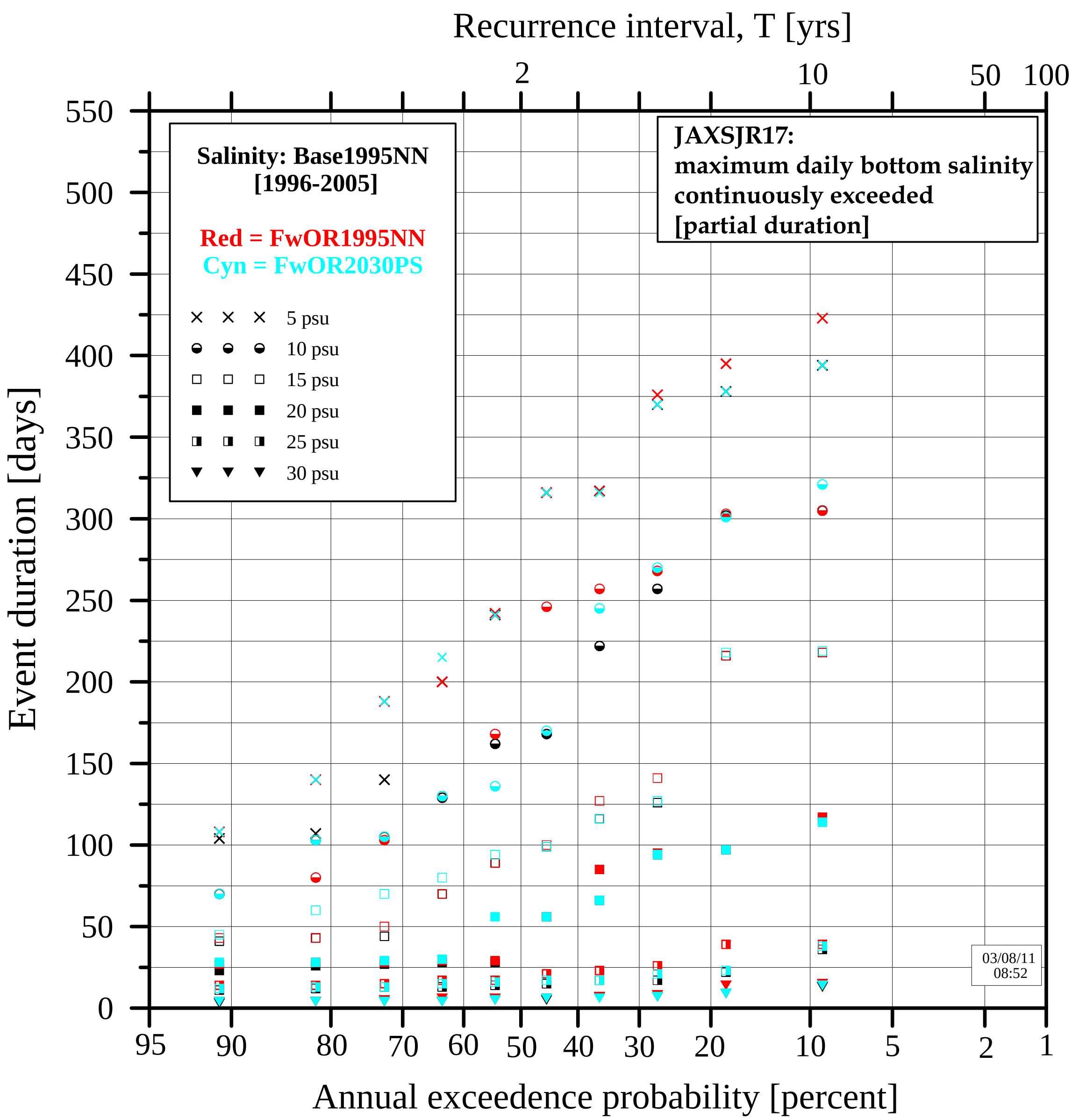


Figure 16. Partial-duration frequency analyses of maximum daily bottom salinity (continuously exceeded) at JAXSJR17

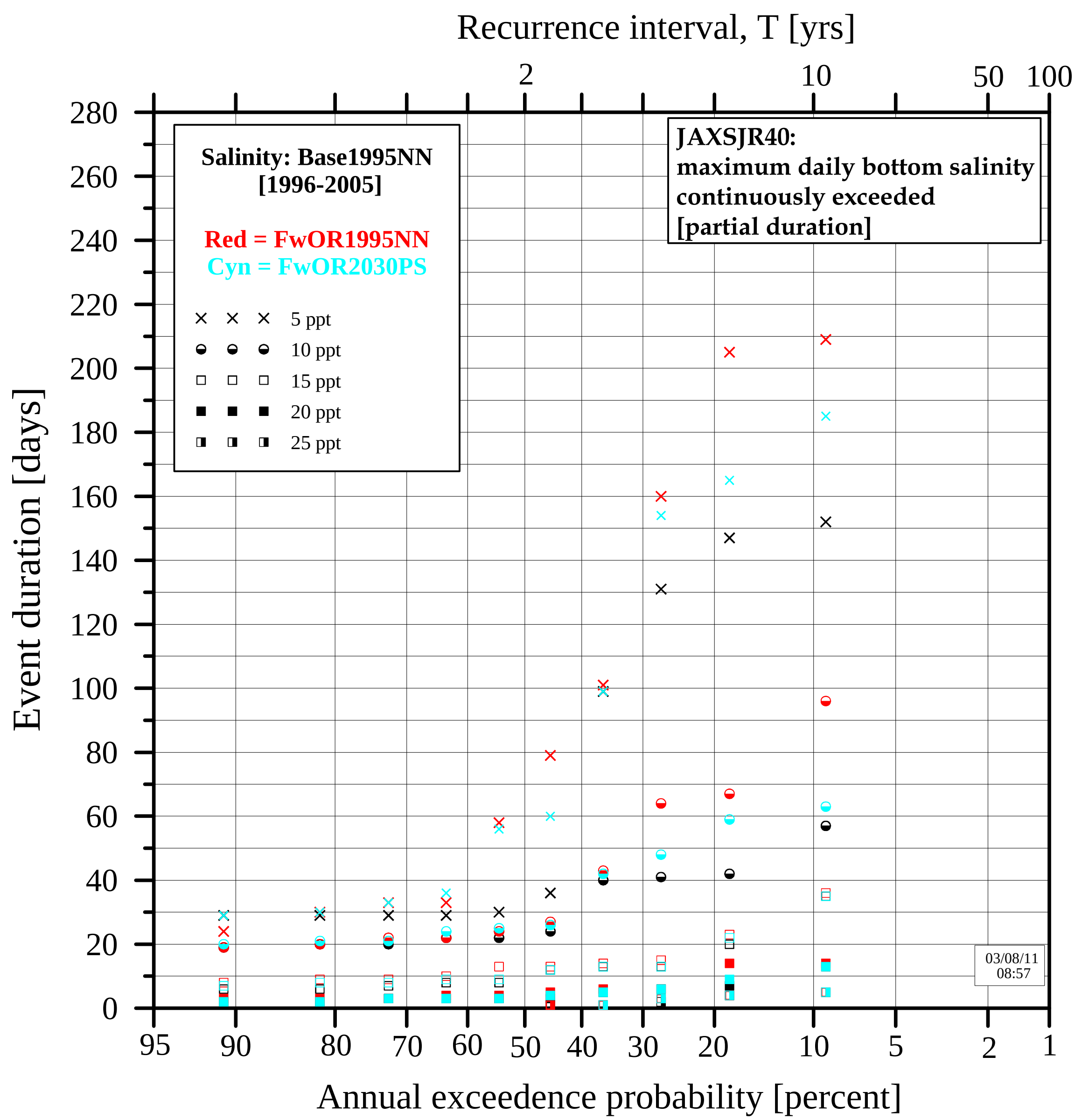


Figure 17. Partial-duration frequency analyses of maximum daily bottom salinity (continuously exceeded) at JAXSJR40

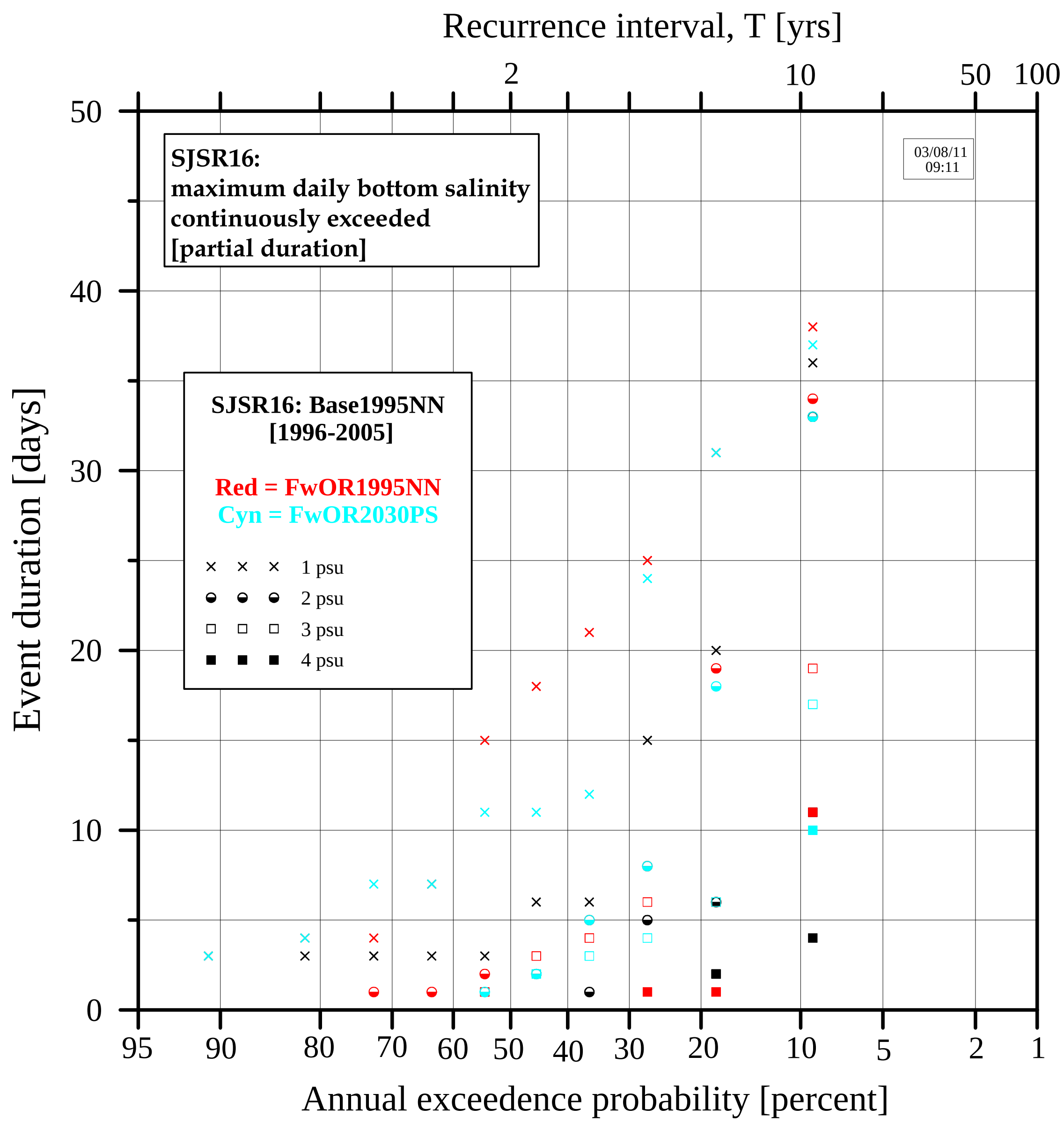


Figure 18. Partial-duration frequency analyses of maximum daily bottom salinity (continuously exceeded) at SJSR16