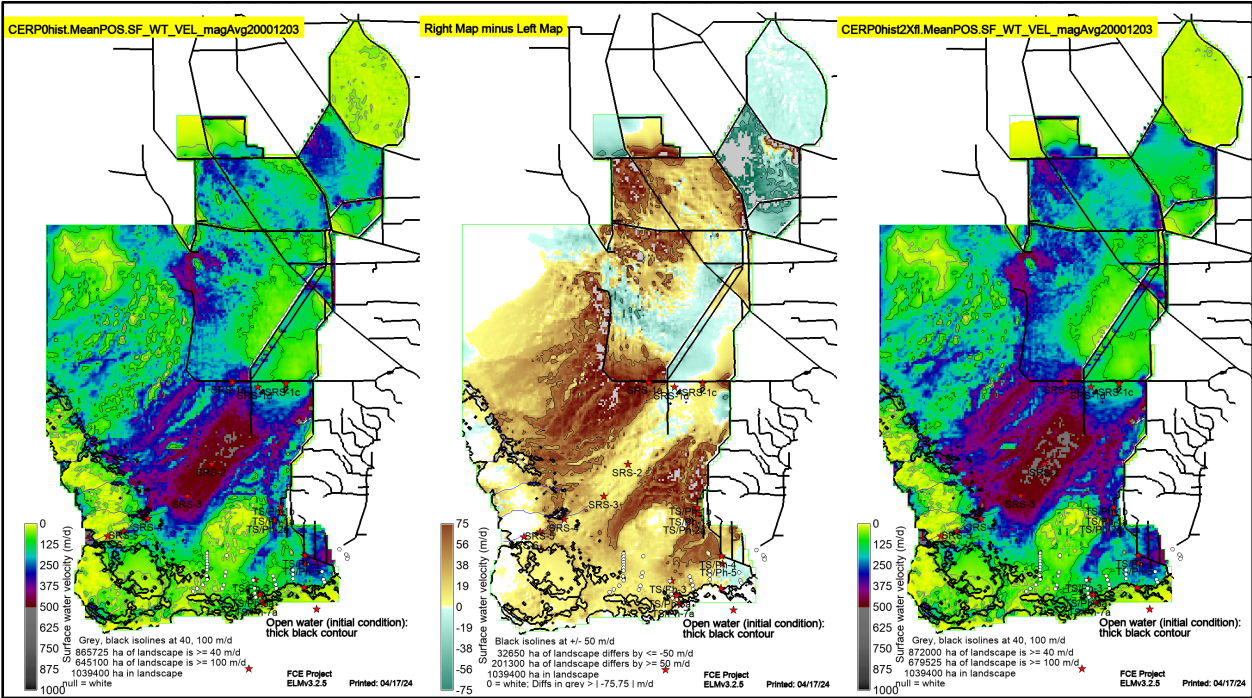


# Everglades Landscape Model v3.2.5: Scenarios and Updates

LTER: Coastal Oligotrophic Ecosystem Research - Integrated Modeling  
 Consulting Agreement No. 000418, Year 3



<http://www.ecolandmod.com>

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April 18, 2024

## Abstract

Understanding long term, cumulative interactions of ecosystem processes is fundamental to LTER goals, and we continued to advance a unique simulation tool for use in addressing integrative ecosystem dynamics across a heterogenous landscape. For EcoLandMod's Florida Coastal Everglades (FCE) LTER subcontract, this document describes the code updates and example hydro-ecological results of future scenario applications of the Everglades Landscape Model (ELM) v3.2.5. For this, we:

- "cleaned up" the revised C language algorithms, and updated unix shell scripts used in statistical & graphical post-processing; and
- compared two example future Comprehensive Everglades Restoration Plan (CERP) scenarios using the new ELM v3.2.5 model framework.

Code revision and maintenance is a fundamental (but unexciting) component of an advanced, useful scientific modeling framework, and these code update descriptions build upon decades of published experience in ELM revision and documentation. Likewise, we have extensively applied the ELM to CERP and other future management projects, and here show the results of comparing a standard CERP scenario to a CERP scenario with doubled managed inflows to the southern Everglades. The purpose of this is to show comparative output examples, perhaps giving FCE collaborators ideas for using the ELM framework to support novel hypotheses. We plan a range of future research and scenario applications of the updated ELM v3.2.5.

*Example output variables used here:*

- surface water depth
- surface water flow velocity magnitude
- surface water P concentration
- surface water chloride (Cl) concentration
- flocculent P:OM concentration
- soil porewater P concentration
- soil P concentration
- system P accumulation rate
- system OM soil accretion rate
- system Net Organic Matter Carbon Ecosystem Exchange

## Code Refinement/Clean-up

Model updates through v 3.2.5 involved both additions/revisions to the C language algorithms, and revisions to unix shell scripts used to post-process the model. The latter post-processing updates were due to updates to our operating system and associated unix applications, and in particular the GRASS v7.8 GIS used in our modeling system. For ELM v3.2.5, we generally "cleaned up" the C code following the algorithm additions/revisions made for the (Fitz 2021, 2023) v3.2.1 and v.3.2.4 updates. Figure 1 shows the region of most interest in those updates, particularly with respect to FCE research.

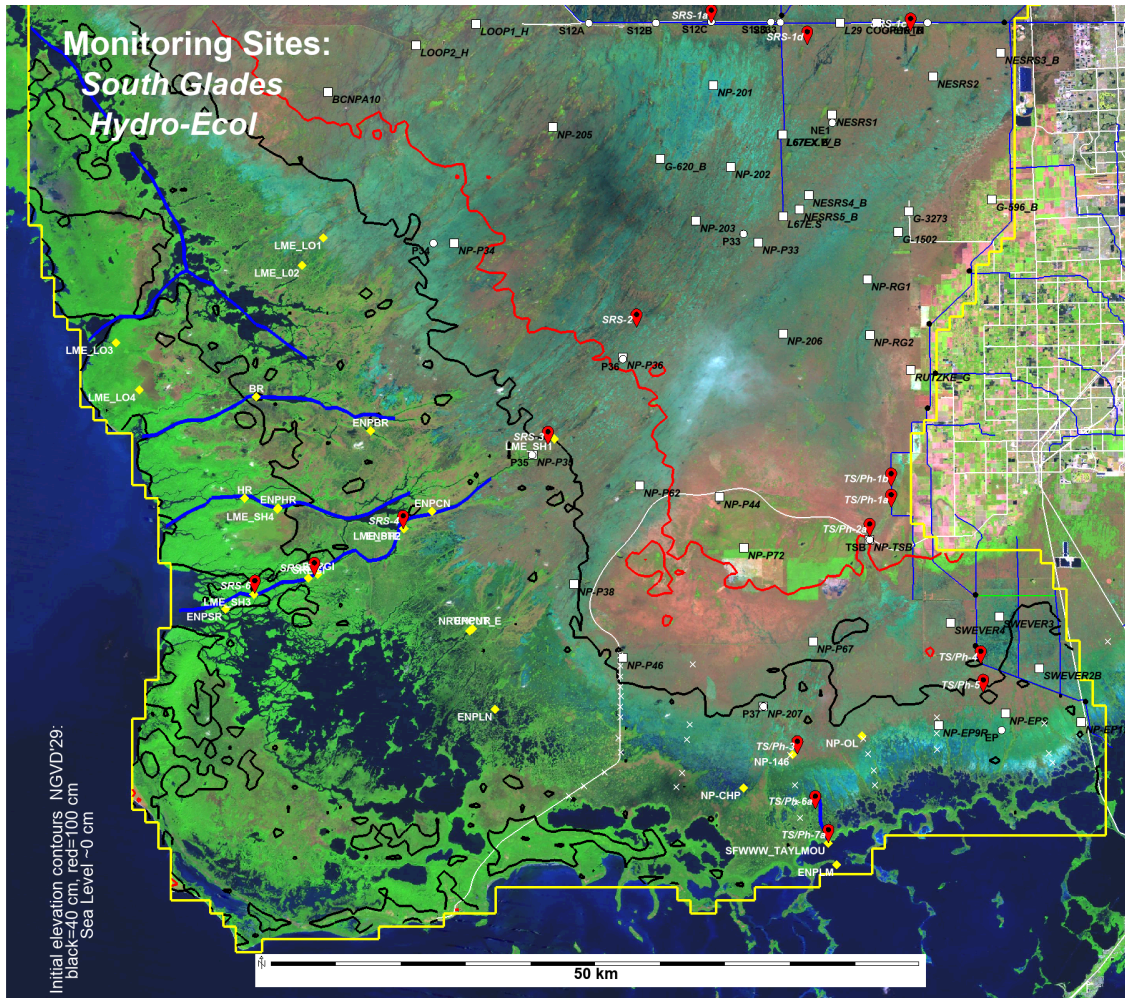


Figure 1. Monitoring sites in the southern domain of the regional ELM v3.2.\*. White box symbols are specific to stage; white circle symbols are specific to water quality. Sites added for ELM v3.2.1 and v3.2.4 are shown in yellow diamonds: these include stage observations, with some sites including salinity. Two contours of initial land surface elevation are shown for reference. Thick blue lines in mangrove region show the ELM simulated river vectors. The (partial) ELM domain boundary is the thick yellow line.

While those updates focused on refining and assessing model performance, this v3.2.5 update was focused on using the modeling system to evaluate future scenarios, and the range of updates to post-processing unix shell script associated with updated software. Those changes involved many detailed code refinements that are beyond the scope/interest of this summary document.

## Future Scenarios: CERP vs. CERP 2X-flows

For the example-purposes of this report, we compared the relative hydro-ecological performance of two CERP scenarios: standard CERP vs. CERP with double the external water control structure inflows to Water Conservation Areas 2-A & 3-A (WCA-2A, 3A) and Everglades National Park (ENP). WCA-3A is important here, as the full-CERP will remove all levees that block flows between WCA-3A and ENP, and thus managed inflows to (the old-footprint of) WCA-3A are effectively inflows to ENP. See Figure 2 for the active canals/levees in the CERP infrastructure. Details of scenario-specific parameters, boundary conditions, management infrastructure, and other relevant information can be found elsewhere (e.g., see <http://www.ecolandmod.com/projects/ELMreg500SERES>, and journal publications such as Orem et al. (2014)) - but those details are not necessary for the simpler, example-purposes of this report.

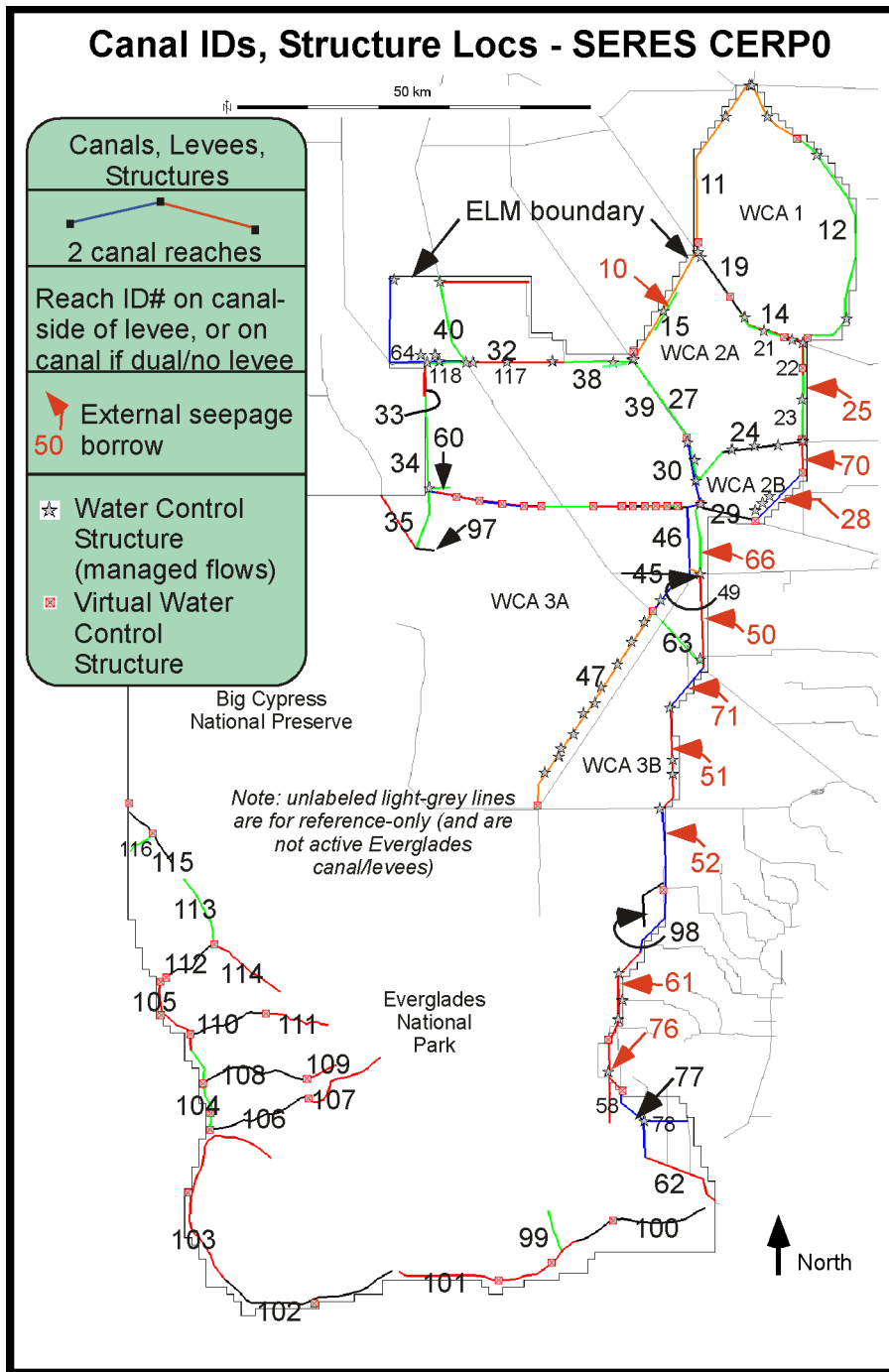


Figure 2. Map of the individual canals (& estuarine rivers), levees, and water control structures that are active in the regional ELM application of the CERP0 scenario. Reference to SERES is from CERP0 use in scenario evaluations by Osborne et al. (2017).

### Scenario CERP0hist

The baseline of comparison here is the latest "full-CERP" implementation, designated CERP0 in past efforts by the Federal and State managers (multiple citations, see Osborne et al. (2017)). Because we have simulated future CERP0 scenarios driven by both historical (observed 1965-2000) and future (General Circulation Model, GCM, ensemble scenarios) climate inputs (Fitz et al. 2021), here we denote the standard CERP0 run with the historical suffix, i.e., CERP0hist. It is important to understand that all Federal/State agency *CERP runs are future projections of*

*how the system may respond under proposed management, if the system is exposed to the same (i.e., recurring) climate that was observed historically.*

### Scenario CERP0hist2Xfl

The comparison scenario here is identical to the CERP0hist scenario in all respects - but we doubled all of the daily water control structure flow volumes that entered new (external-to-model) water into WCA-2A&3A and ENP, i.e., CERP0hist2Xfl. Normally, all managed flow input data are output data from the South Florida Water Management Model (SFWMM), as we have done routinely for multiple projects. Here, we simply doubled each relevant daily external inflow (i.e., external water into the model domain) value to produce an altered water control structure flow input file. It is important to note that this double-flow is a purely hypothetical scenario, as *real-world constraints include the potential that levee seepage to the east of the ENP would flood urban/ag regions, and there would often likely be inadequate supply water volumes to support these increased inflows to the Everglades.*

### CERP0hist vs. CERP0hist2Xfl

Table 1 shows the resulting simulated inflow water budgets for the CERP0hist and CERP0hist2Xfl scenarios. Note that the system is largely rain-driven, as doubling the external structure inflows under CERP0hist2Xfl resulted in about a 1.2x increase in total inflows to WCA-3A and ENP\_fresh.

	569.2 km <sup>2</sup>	429.0 km <sup>2</sup>	1977.8 km <sup>2</sup>	2976 km <sup>2</sup>	2344.5 km <sup>2</sup>
	WCA-1	WCA-2A	WCA-3A	3WCAs	ENP_fresh
CERP0hist_IN	1,093	1,692	4,288	7,073	7,103
CERP0hist2Xfl_IN	1,091	1,906	5,190	8,188	8,662

Table 1. Simulated water budget total inflows (rain, structure, overland, groundwater, levee-seepage) for selected basins, in units of 36-year annual mean flows per basin (thousands of acre-feet). The ENP\_fresh basin is the freshwater (non-mangrove) section of the ENP within the ELM domain. While CERP removes levees bounding WCA-3A, we use the footprint of that WCA for budget comparisons without-CERP.

As indicated above, the purpose of this report is to demonstrate the types of quantitative spatio-temporal comparisons that can be made using the ELM framework. Thus, we show examples of (a subset of) possible comparisons, using maps and point/subregion time series. We have collaborated with a number of agency and academic partners in developing the selection of comparative spatial statistics/graphics, using attributes such as: end-of-season snapshots for the wet and dry seasons of years that were wet, dry, and normal; and Period-Of-Simulation means or rates; and other metrics. The rationale for these selections is found elsewhere, as indicated in the introduction to this section.

Other science/management objectives can lead to a variety of other spatial and temporal summaries; all of the map comparison Performance Measures are fully scripted, and relatively quick/easy to modify as needed for new objectives.

***See the Appendix-Results section for all Performance Measure graphics.***

## Collaborator-access to Scenario Output Data

As detailed in the below User's Guide, there are a variety of output file types, which span the spatial range of points, subregions (Basins/Indicator-Regions), and regional maps, at daily/monthly/decadal/Period-Of-Simulation temporal scales, all with various User-defined run-time statistical summaries. These are available for all budget and hydro-ecological variables simulated by the model, but generally (unless it is one of the usual-outputs) must be requested by the User/Collaborator prior to the execution of a model run. (With 41,576 active grid cells in the regional application, disk storage of a large number of output variable 2D arrays at daily time scales would be prohibitive for multiple runs; it is almost trivial to re-run a scenario with new output requests: a (currently standard) 36-yr regional simulation takes 148 minutes (on an Intel Core i9 laptop), or about 4 minutes per simulation year).

These output data files include, but are not limited to:

- text-file (tab-delimited for MS Excel etc) point time series,
- text-file (tab-delimited for MS Excel etc) canal/river-vectors time series,
- text-file (tab-delimited for MS Excel etc) Basins/Indicator Regions time series,
- generic-binary (floating point or integer) spatial array map time series,
- netCDF (self-describing, machine-independent) spatial array map time series,
- and other text-file run-specific attribute files.

The netCDF output file(s) may be particularly informative for collaborators, as the highly-recommended (Fitz 2023) USGS's EverView software allows the user to fully explore, and animate, netCDF spatial time series output data.

### *User's Guide*

Detailed information on the use and interpretation of the model output is found in the Chapter 10 User's Guide of ELM v2.8.4 Documentation Report (Fitz and Paudel 2012) (still applicable to v3.2.\*) at:

<http://www.ecolandmod.com/publications/index.html#ELM284>

This User's Guide is also used to install and execute the (v2.8.4) model code & data; such potential (unix/linux) users should contact cfitz for the newer version's code & installation scripts.

See the below section for the sources of comprehensive model documentation.

### **ELM Documentation**

Adobe pdf (multi-chapter) documentation reports of all major updates (v2.5 through v3.2.\*) are available at:

<http://www.ecolandmod.com/publications/>

Changes to the model from v2.8.3 to the current v3.2.\* involved additional modules, refinement of selected parameters, and other changes that are described in the above-referenced FCE reports - with few modifications relevant to the below hyperlinked graphical descriptions.

*Comprehensive ELM v2.8.3-4 algorithms via hyperlinked conceptual models with descriptions and equations:*

[http://www.ecolandmod.com/models/algorithms\\_ELM/MainControllerModule.html](http://www.ecolandmod.com/models/algorithms_ELM/MainControllerModule.html)

*Comprehensive hyper-linked Doxygen-generated ELM v2.8.3-4 source code documentation:*

[http://www.ecolandmod.com/models/algorithms\\_ELM/MainControllerModule.html](http://www.ecolandmod.com/models/algorithms_ELM/MainControllerModule.html)

*Download of complete ELM v2.8.3-4 source code (Ansi C, unix shell scripts) and historical-simulation data:*

<http://www.ecolandmod.com/models/getmodel.html>

## Summary & Plans

Comparisons of hydro-ecological dynamics in CERP vs. double-flow-CERP show that measurable improvements can be a result of the flow increases, but that crude doubling can also lead to occasional detrimental responses, e.g., via excess ponding in some regions at some times. The comparative output examples shown here may provide FCE collaborators with ideas for ELM application relevant to their research objectives. We plan on continuing to use the ELM v3.2.5 for further hypothesis development and scenario applications, in collaboration with FCE and others.

For this and next year, we had planned on further exploring, and extending, the GCM-ensemble future scenarios that used a range of Representative Concentration Pathway (RCP) climate assumptions - scenario runs and conclusions that we published in conference-abstract form (Fitz et al. 2021). However, the model collaborators at the Everglades Foundation have since left that employment, and it appears unlikely that we will be able to continue to use/publish the ELM simulations that were driven by boundary conditions from the GCM-climate and SFWMM-management models for which those collaborators were responsible.

Other scenario frameworks are feasible. For socio-ecological realism, it would be most desirable to further collaborate with agencies responsible for water management simulations that determine the (Everglades externalities of) constraints of water availability and flood control associated with moving water in this complex system with multiple stakeholders.

However, other possibilities involve simpler scenarios that assume no such external constraints, and which use ELM water management algorithms to (strive to) optimize simulated hydro-ecological Performance Measures within the Everglades.

### *ELM water management algorithms*

We developed code that allows us to manage water control structure flows in order to target a stage regulation schedule graph for a particular basin/region. With management algorithms that are much simpler than those in models developed for water management (e.g., SFWMM, RSM), a fundamental assumption of our simple, single-basin algorithm is that there is no influence of conditions external to the target-basin boundaries. For example, to explore novel restoration mechanisms in WCA-1 (Fitz 2008), we developed a suite of managed water recycling options to



meet targeted stage regulation schedules (plus increased flow velocities). We used simple stage regulation targets to control water control structure inflows and outflows of the basin (ignoring external water conditions). A subsequent collaboration used the modeling framework to explore new stage regulation schedules to enhance WCA-2A suitability for wading birds (Fitz 2015).

Those WCAs were isolated basins. While the ENP is open and effectively has no managed outflows, it is feasible to use ELM stage regulation schedule targets to assess the relative hydro-ecological benefits of altering managed upstream flows. This document's doubling of all managed CERP flows without regard to a particular goal is simplistic; using a water management algorithm to modify inflows according to stage targets can provide more optimal water inputs.

For scenario testing, the ELM also has the ability to annually increase sea level boundary conditions, allowing the scenario-inclusion of various rates of sea level rise in the system (Flower et al. 2017, Flower et al. 2019), exploring the ELM-managed upstream flows and opposing press of sea level rise.

Optimizing local water management is just one of the potential uses of the ELM framework to assess novel FCE hypotheses. For future years of this collaboration, one of our priorities remains to explain spatio-temporal trends in the relationships among fast-scale P & C pools, and some of the slower-scale pools that tend to integrate those in long term fluxes. We will also strive to advance additional future scenarios evaluations using the updated ELM v3.2.5.

## References

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## Appendix-Results

*There are several multi-page groups of output comparisons, separated by group captions:*

- A. Seasonal snapshot means*
- B. Period-of-Simulation (POS) means*
- C. Period-of-Simulation (POS) mean rates*

*Example output variables mixed within those groups:*

- *surface water depth (variable name is "SfWat")*
- *surface water flow velocity magnitude (variable name is "SF\_WT\_VEL\_mag")*
- *surface water P concentration (variable name is "TPSfWat")*
- *surface water chloride (Cl) concentration (variable name is "SaltSf")*
  
- *floc P:OM concentration (variable name is "FlocP\_OM")*
  
- *soil porewater P concentration (variable name is "TPSedWat")*
- *soil P concentration (variable name is "TPtoSOIL")*
  
- *system P accumulation rate (variable name has rate change of "P\_SUM\_CELL")*
- *system OM soil accretion rate (variable name has rate change of "SED\_ELEV")*
- *system Net Organic Matter Carbon Ecosystem Exchange (variable name is "NOMCEE")*

**A. Seasonal snapshot means.** Useful for example "fast" variables. Between-scenario comparisons: Monthly-aggregation. The following map data are daily mean values within a 30-day period that was close to the end of the wet or end of the dry season, with the ending date of that 30-day period indicated in the figure headings.

All figures follow the same format:

left frame is daily Mean within the 30-day period (MeanRaw) - scenarioA;

right frame is daily Mean within the 30-day period (MeanRaw) - scenarioB;

middle frame is daily Mean within the 30-day period (MeanRaw) - difference = scenarioB minus scenarioA.

Variables:

SfWatAvgYYYYMMDD = Surface water depth, interval ending on YYYYMMDD

TPSfWatAvgYYYYMMDD = Surface water TP concentration, interval ending on YYYYMMDD.

Selected wet/dry seasons, years:

Average Year: 1978

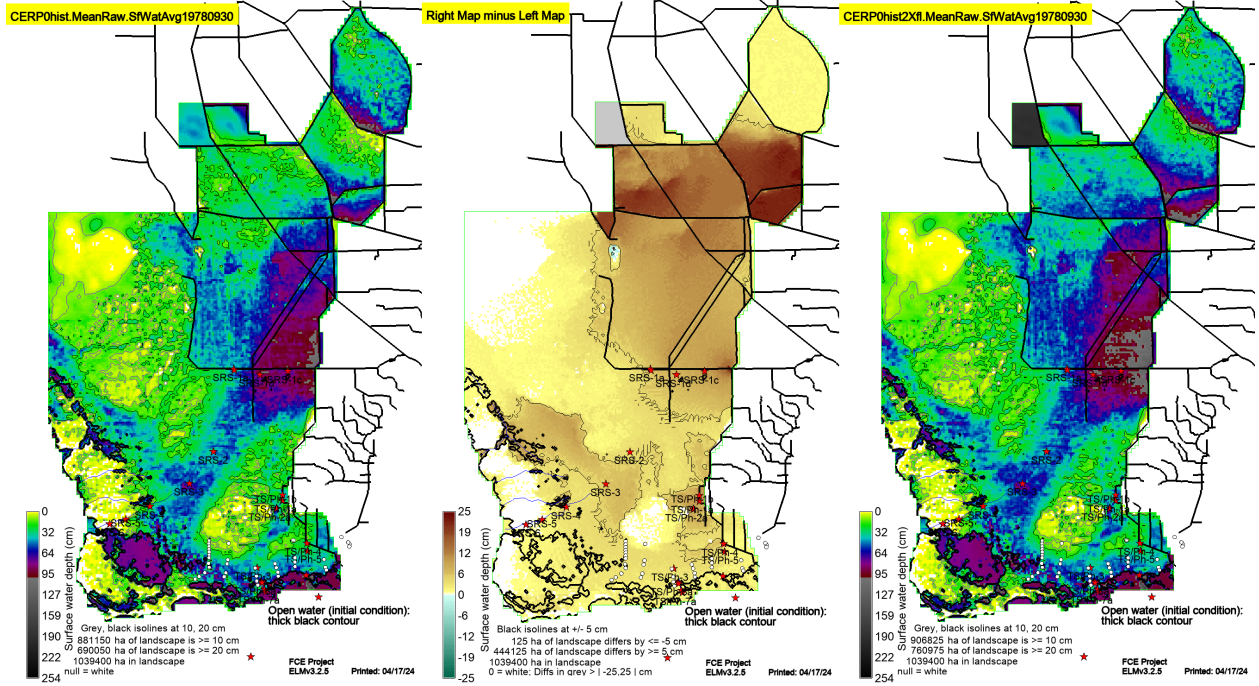
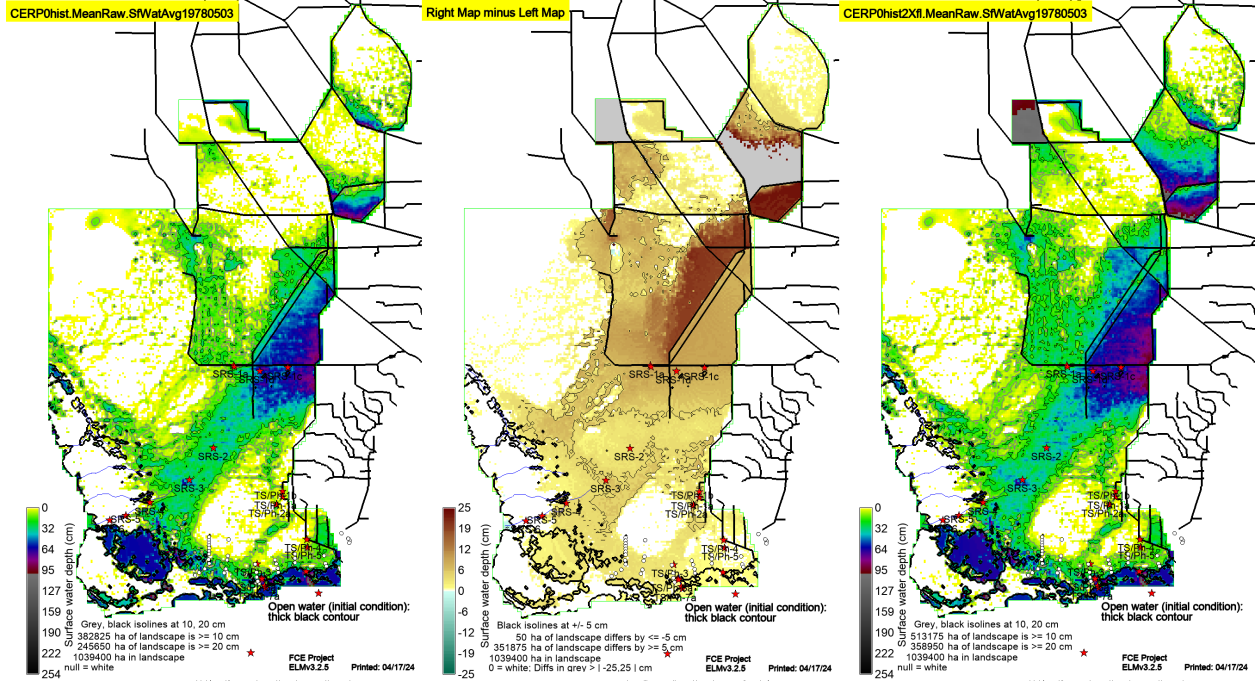
Dry Year: 1989

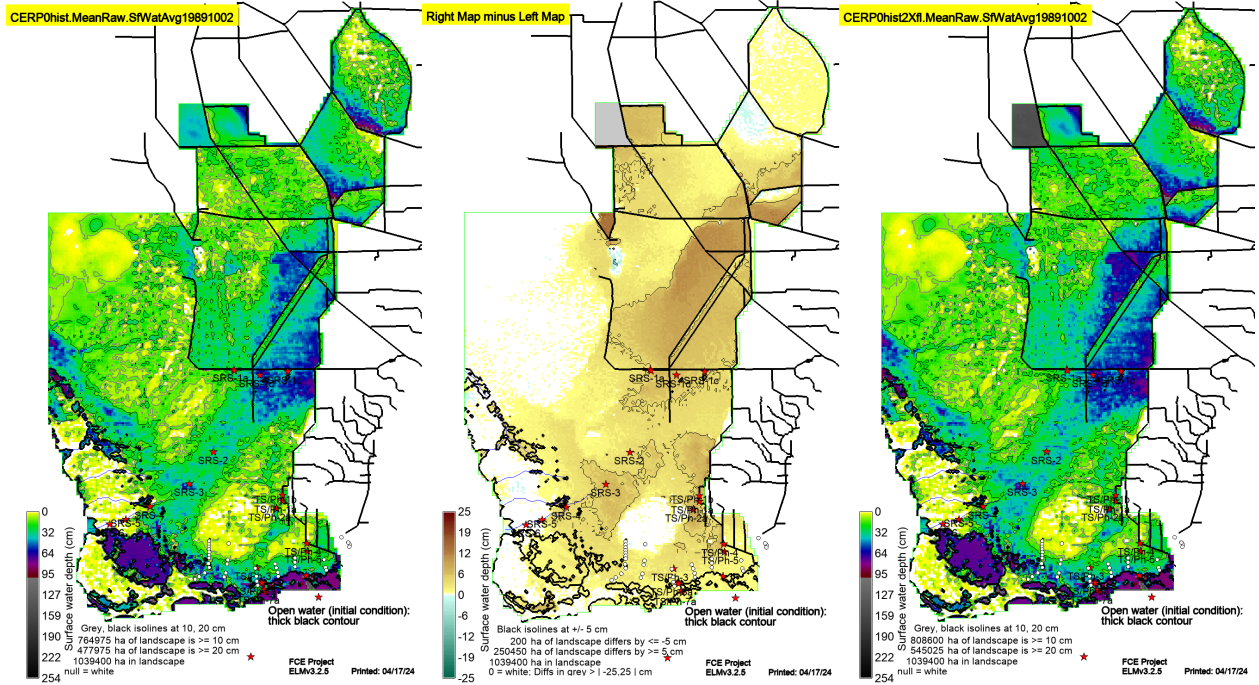
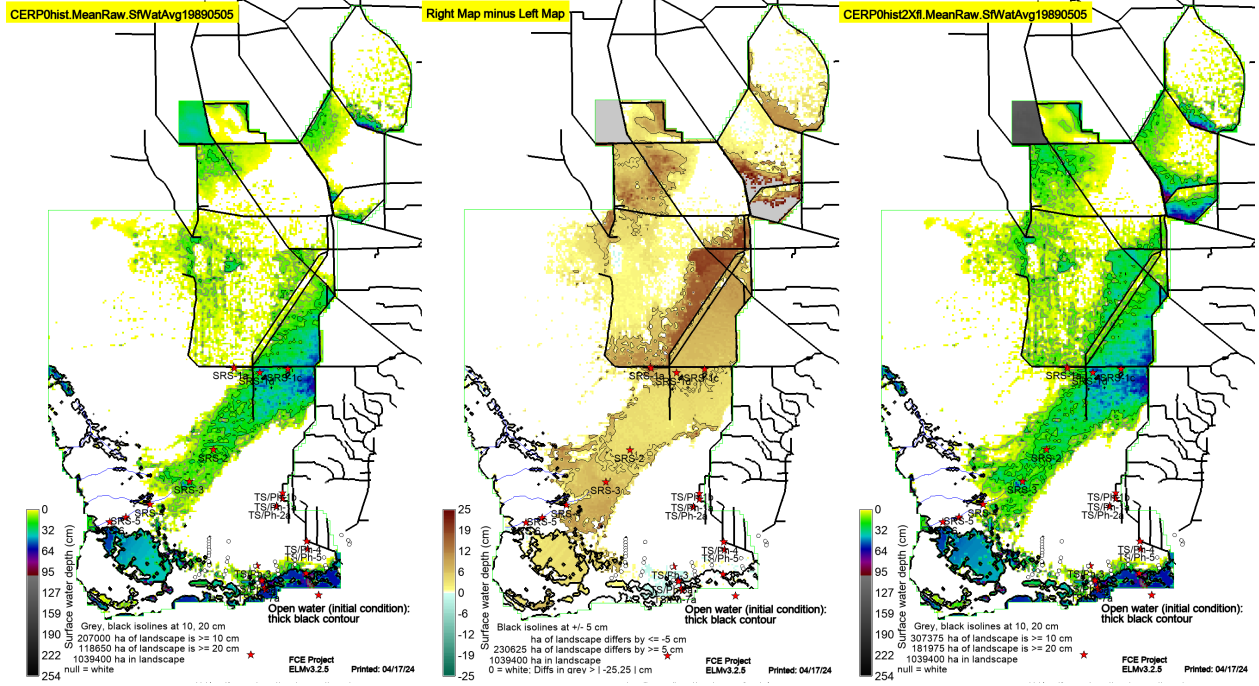
Wet Year: 1994

Wet season: ends on ~October 31 of any given year.

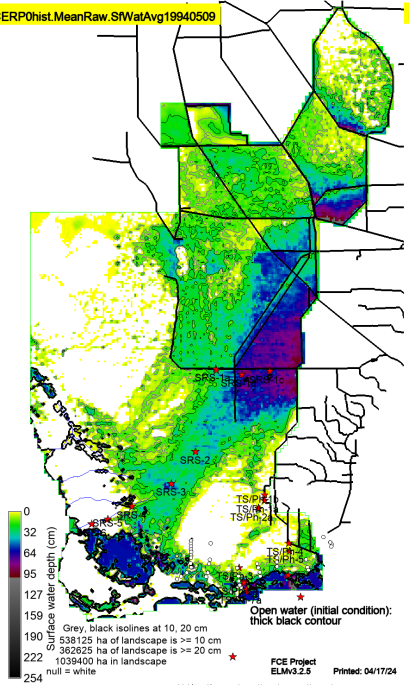
Dry season: ends on ~May 31 of any given year.

Calculation methods: The 'raw' ELM output used here were daily mean values of each variable within 30-day intervals (output every 30 days); for difference maps (middle frame), the difference was calculated between 'raw' output maps

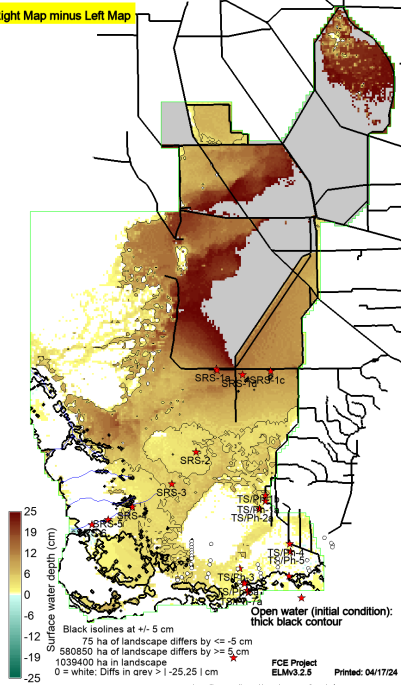




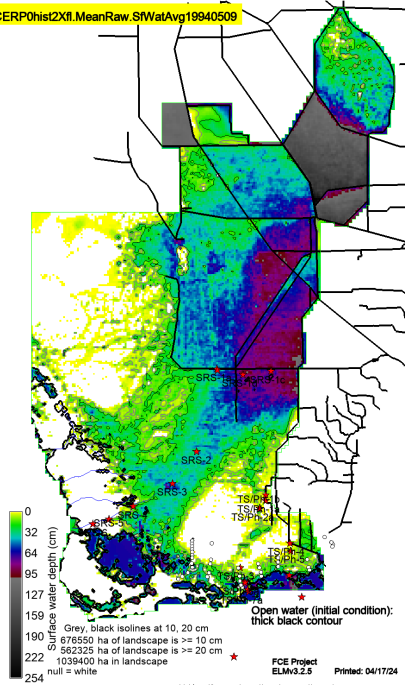
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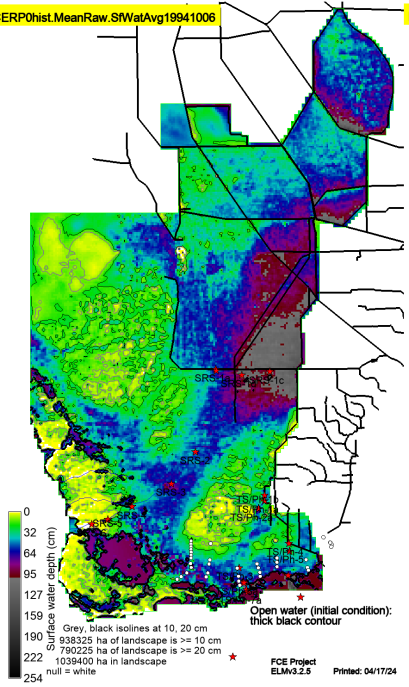
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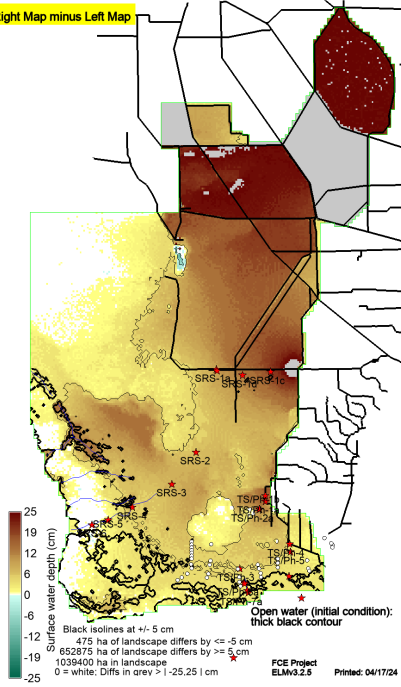
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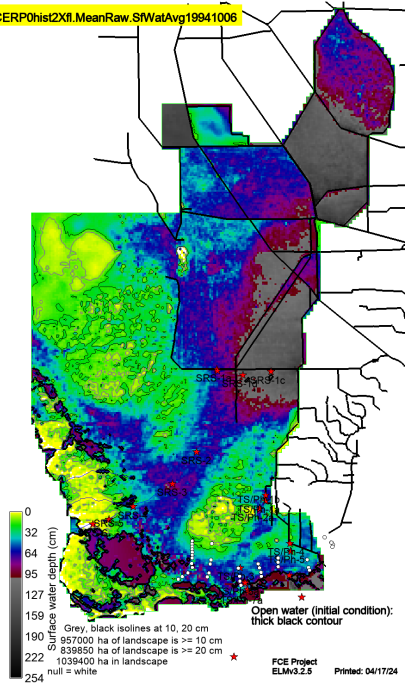
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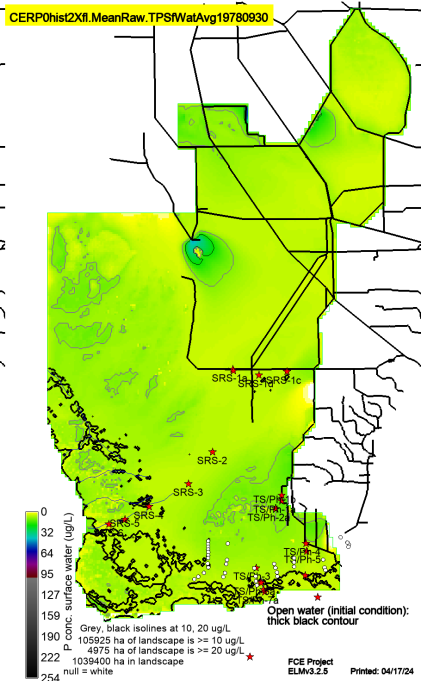
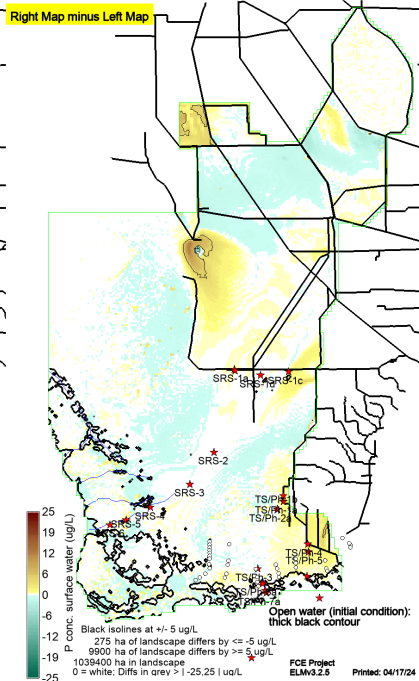
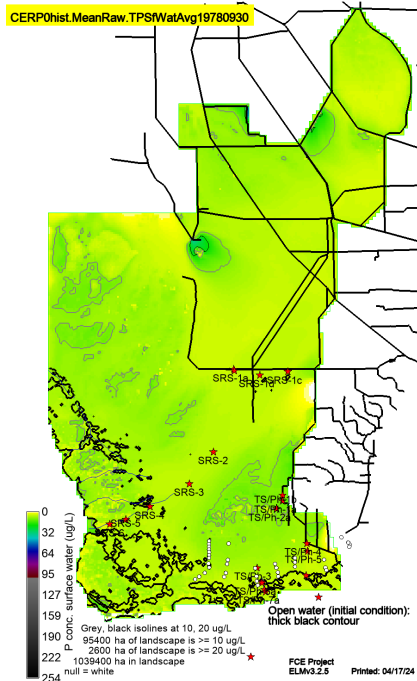
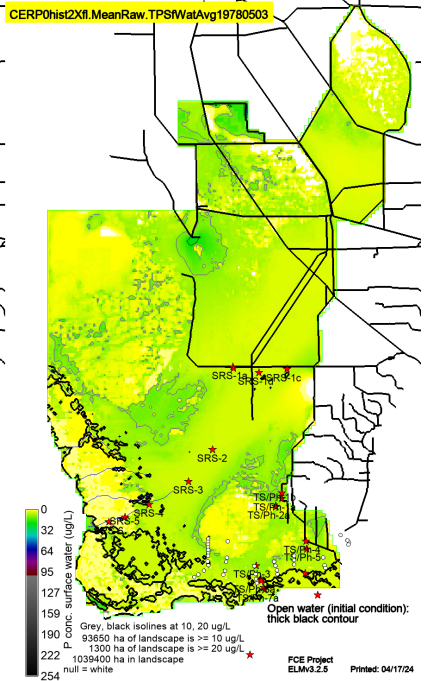
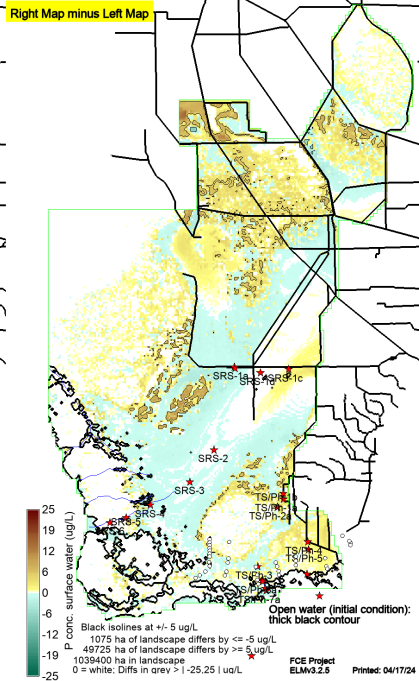
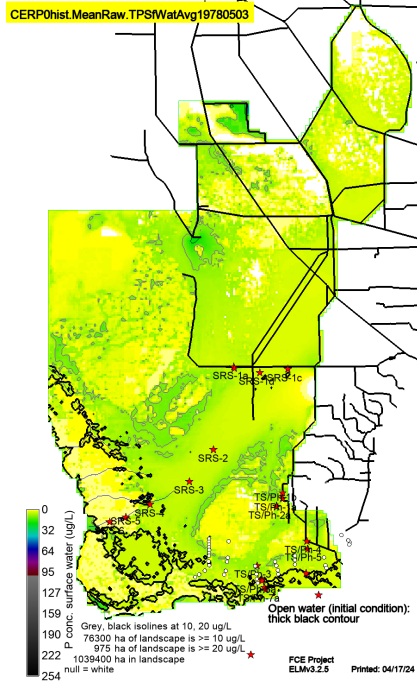


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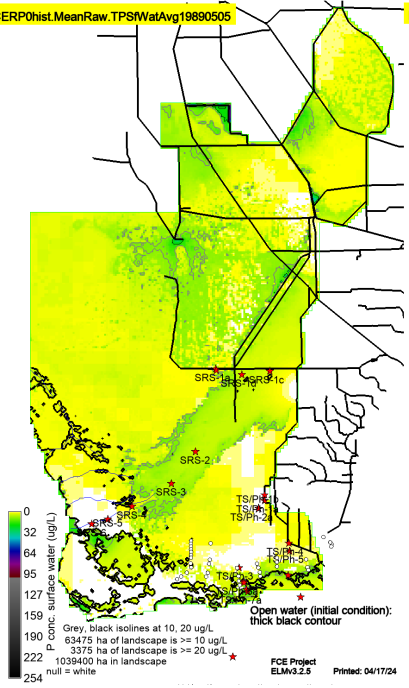
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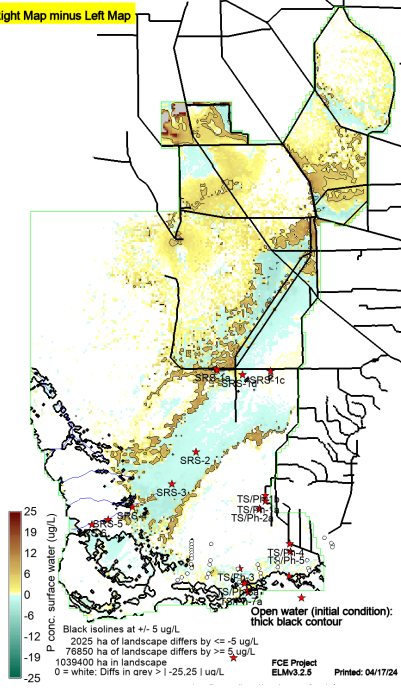




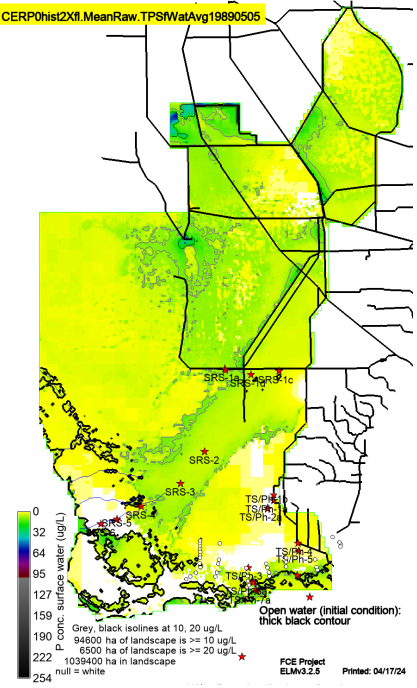
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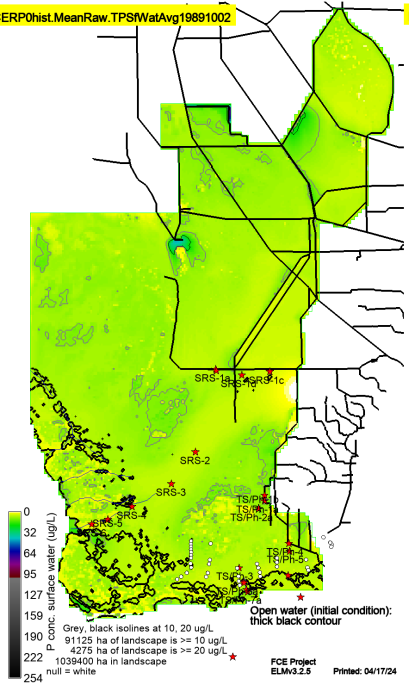
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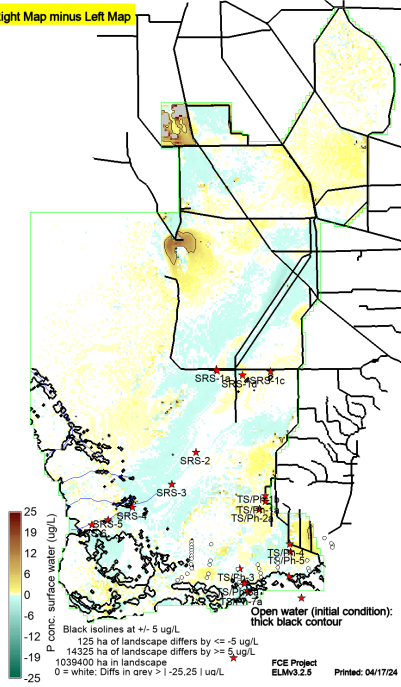
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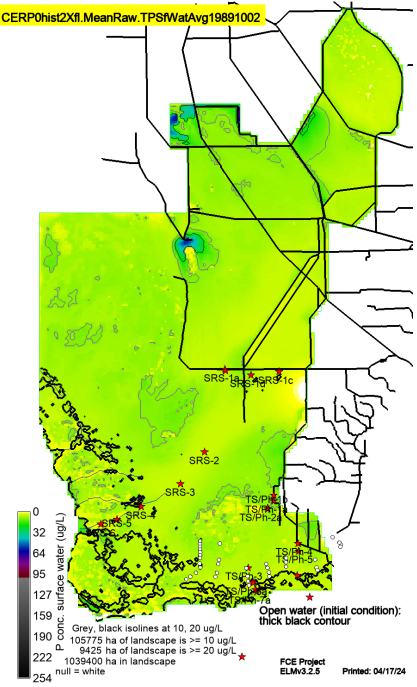
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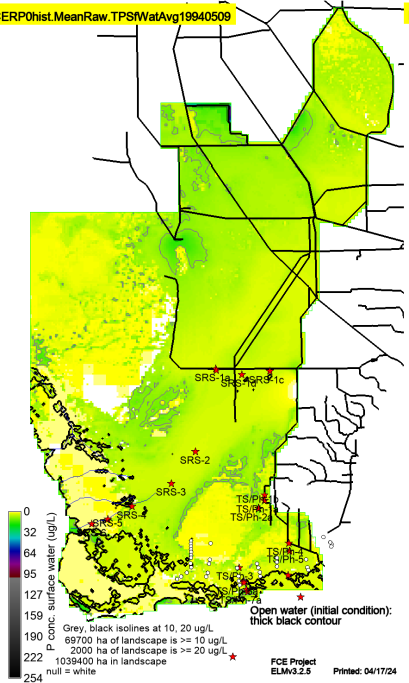
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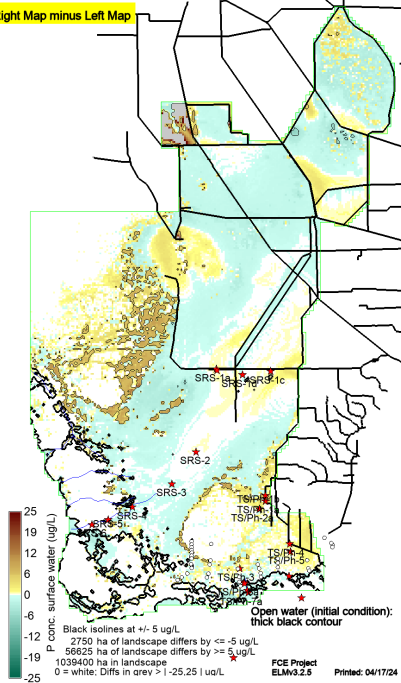
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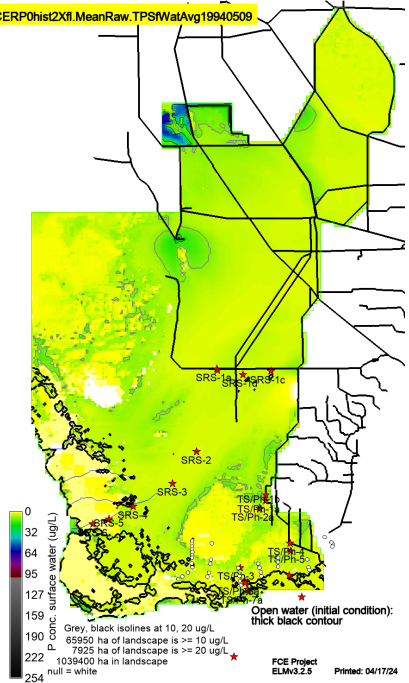
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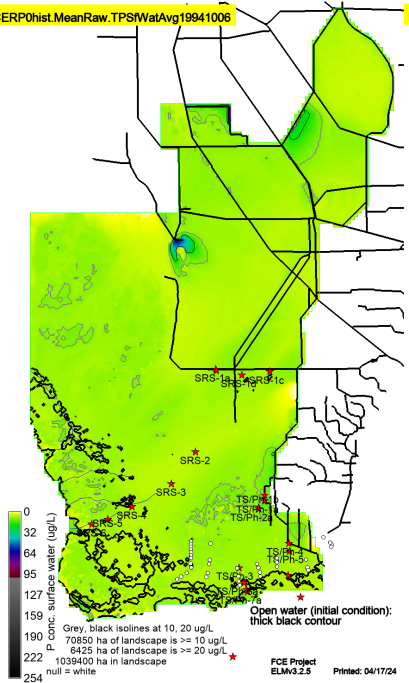
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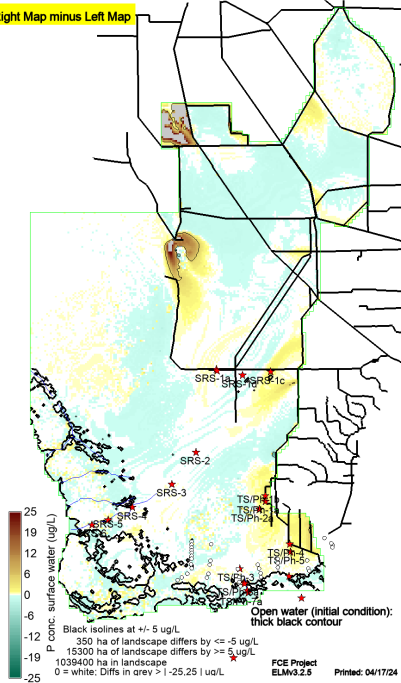
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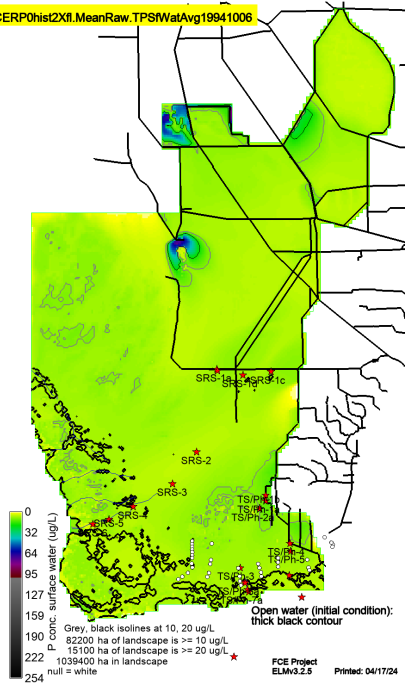
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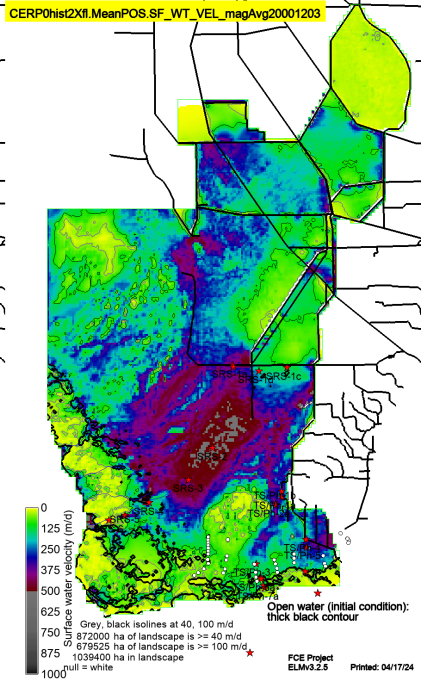
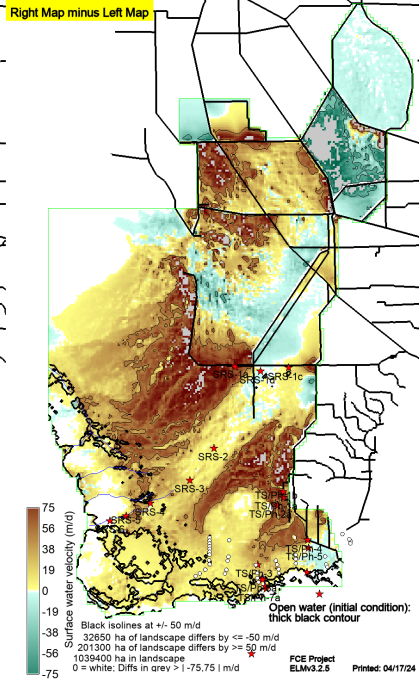
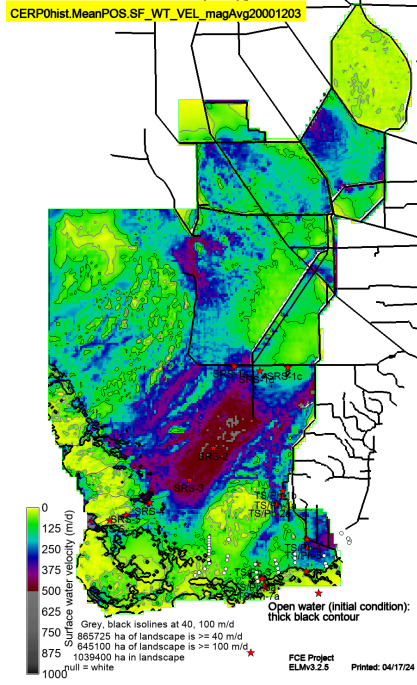
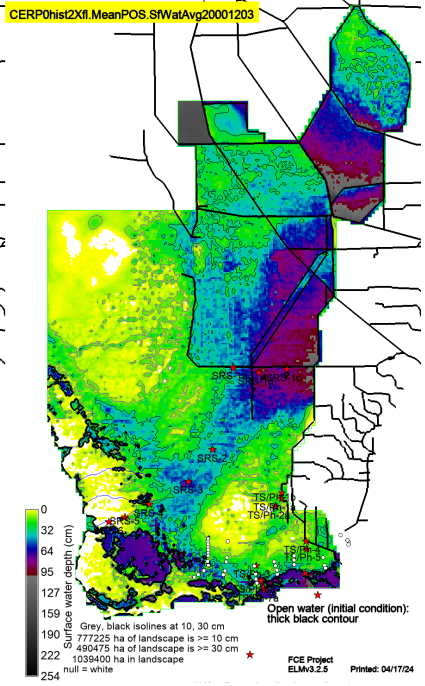
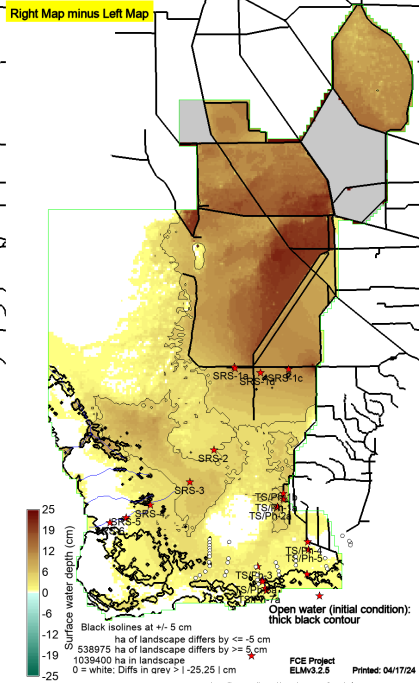
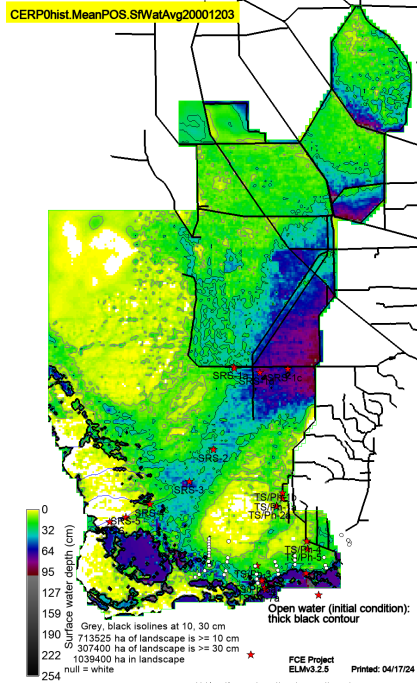
Right Map minus Left Map



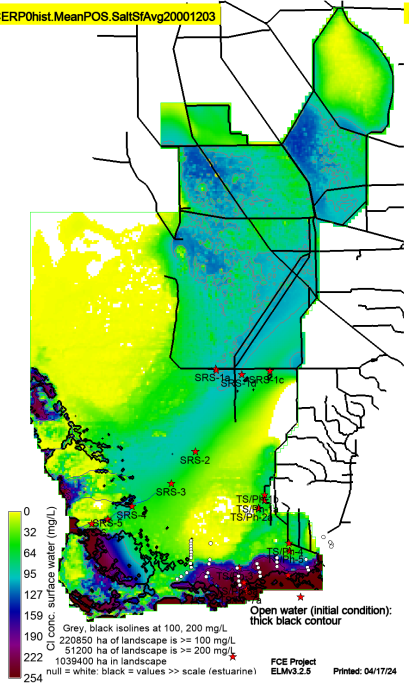
CERP0hist2Xfl.MeanRaw.TPSfWatAvg19941006



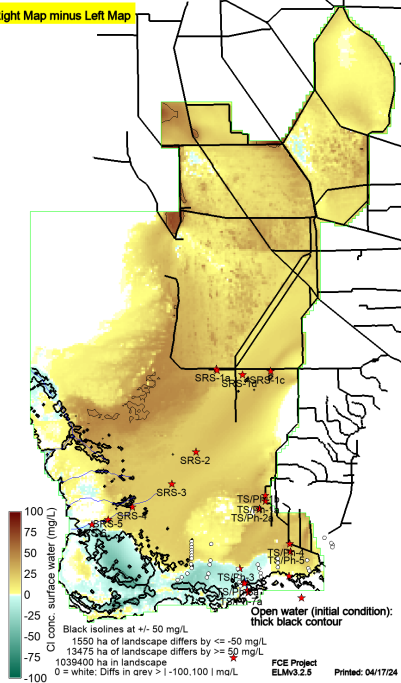
**B. *Period-of-Simulation (POS) means.*** High temporal aggregation examples shown here include both "slow" and "fast" variables, for brevity of this example report. Between-scenario comparisons: Multi-decadal-aggregation. The following map data are 36-yr means of daily data. Variables and naming conventions described above.



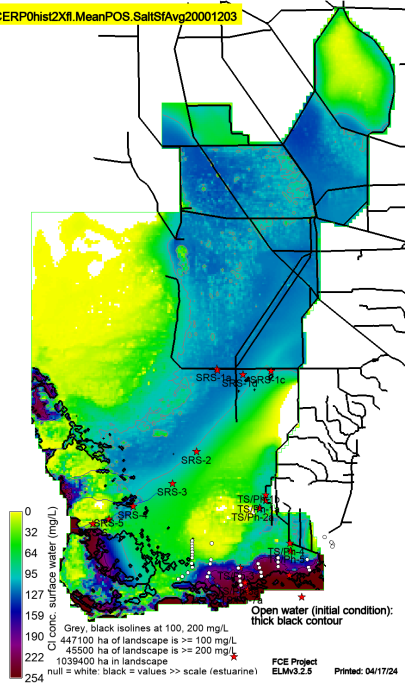
CERP0hist.MeanPOS.SaltSI(Avg20001203)



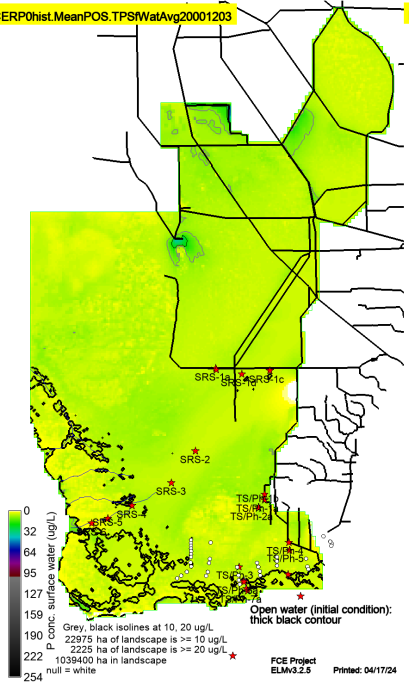
Right Map minus Left Map



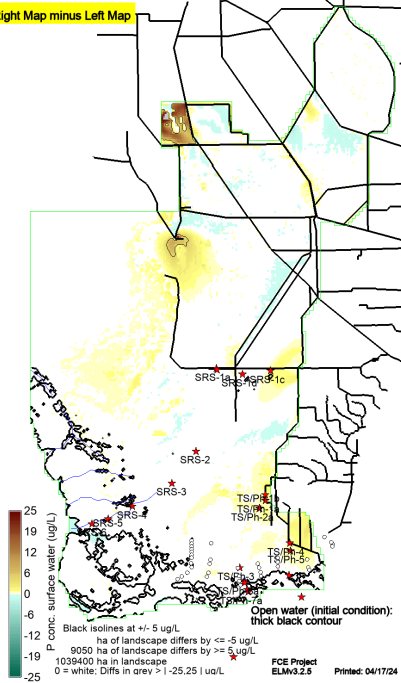
CERP0hist2X1f.MeanPOS.SaltSI(Avg20001203)



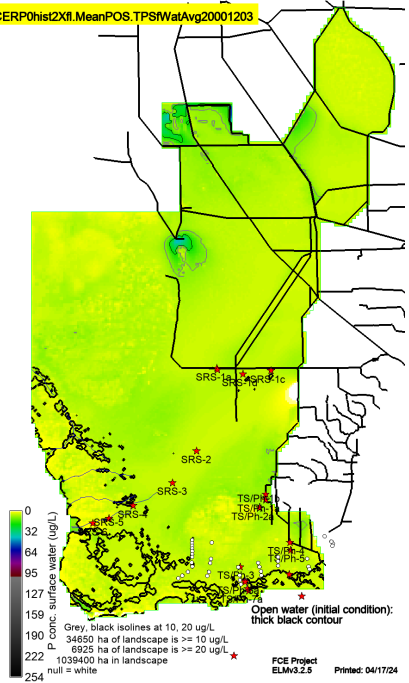
CERP0hist.MeanPOS.TPSfWat(Avg20001203)

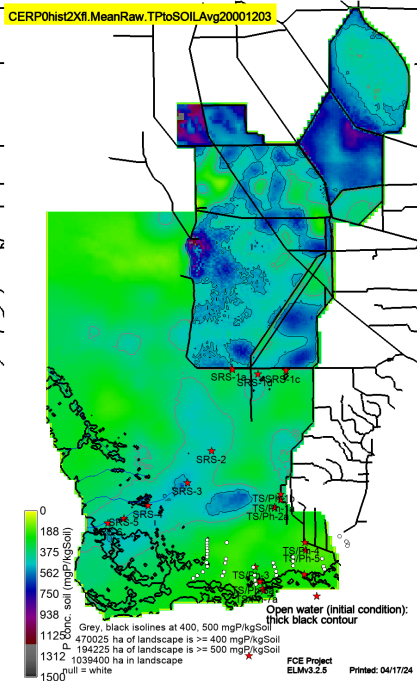
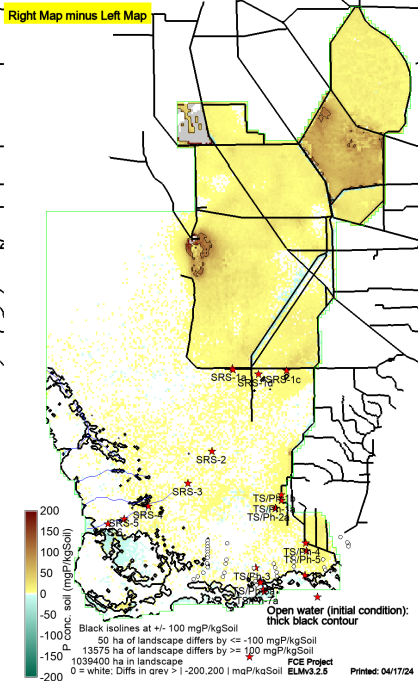
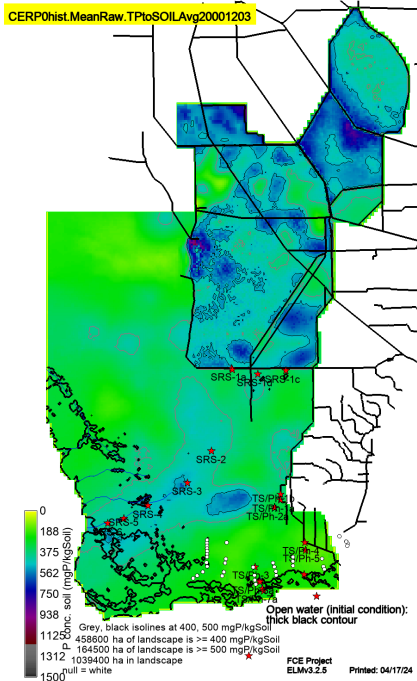
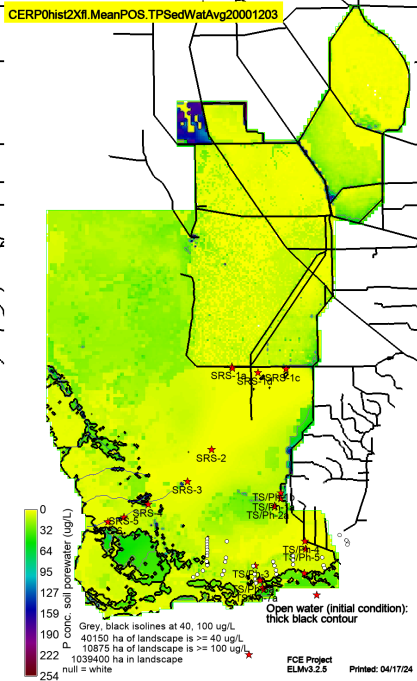
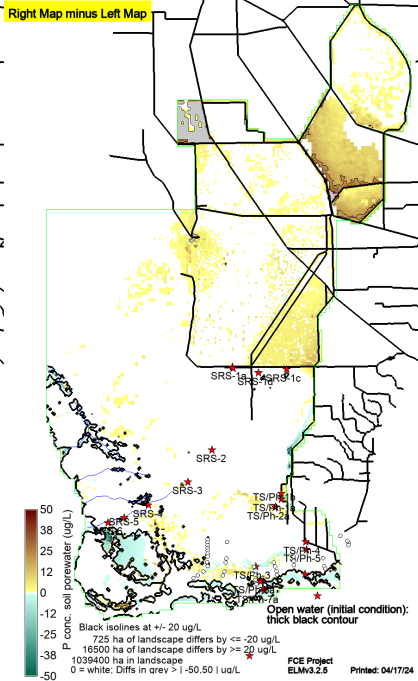
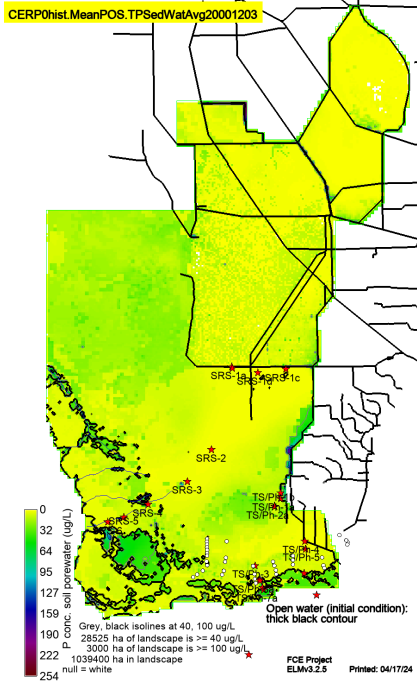


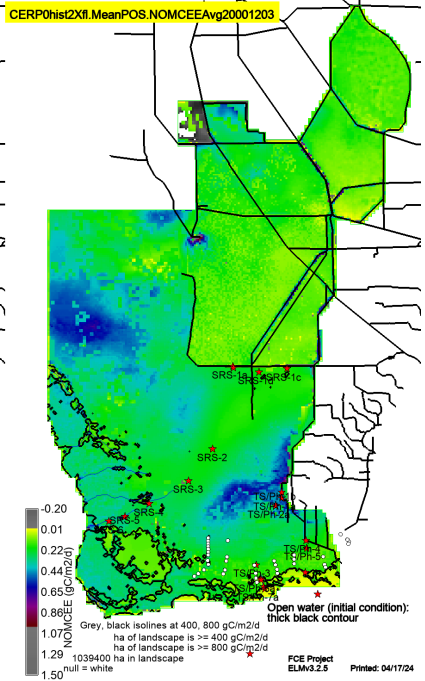
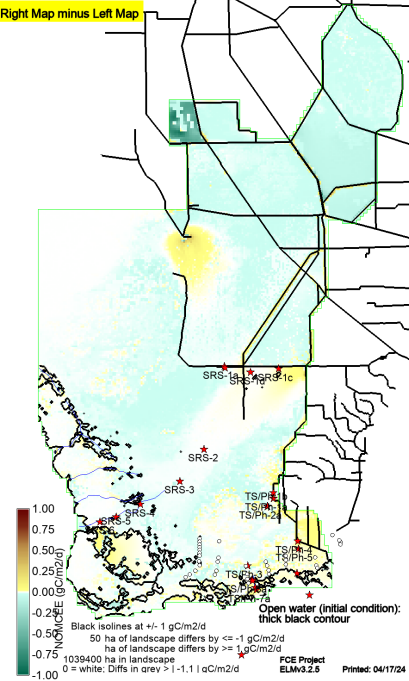
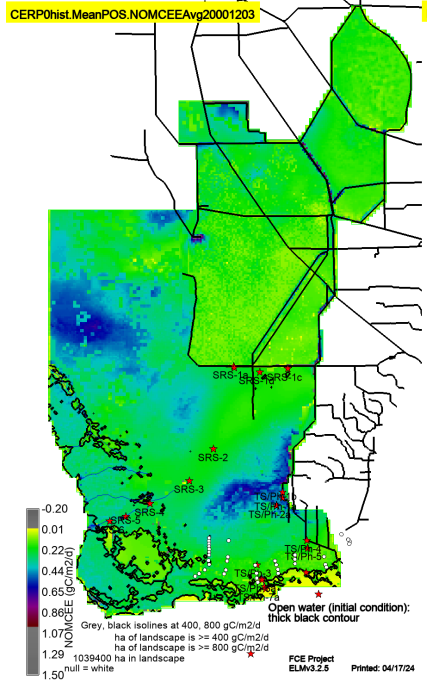
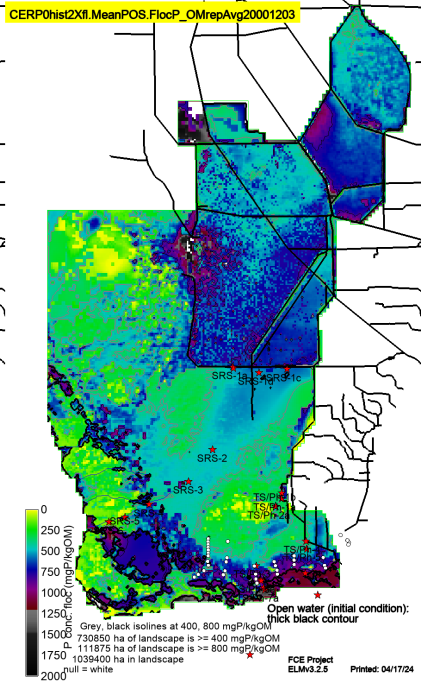
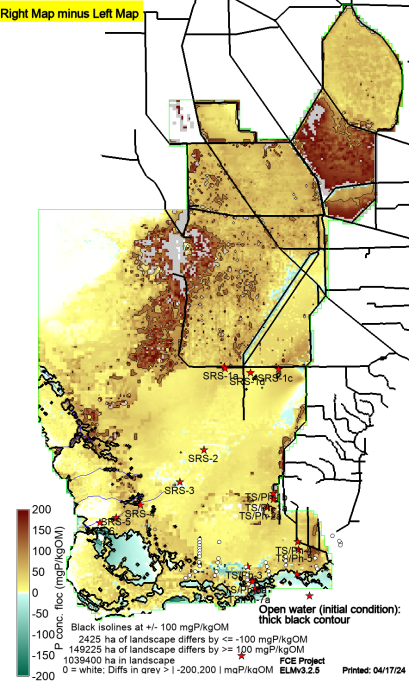
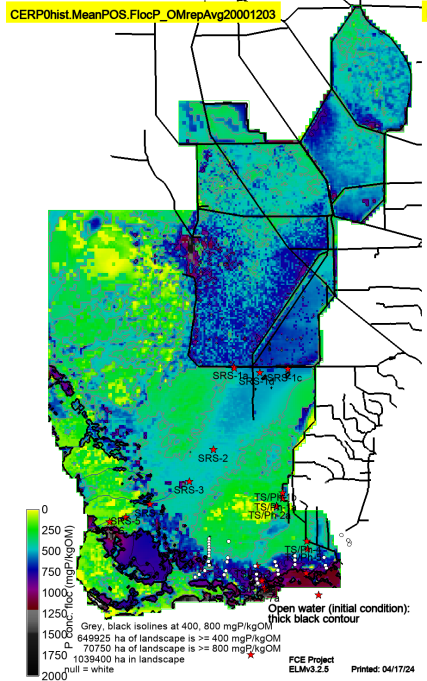
Right Map minus Left Map



CERP0hist2X1f.MeanPOS.TPSfWat(Avg20001203)







**C. Period-of-Simulation (POS) mean rates.** These two Performance Measures are the best integrative metrics of the system health. Between-scenario comparisons: Multi-decadal-synthesis. The following map data are 36-yr mean rate of change in the data. Variables and naming conventions described above.

