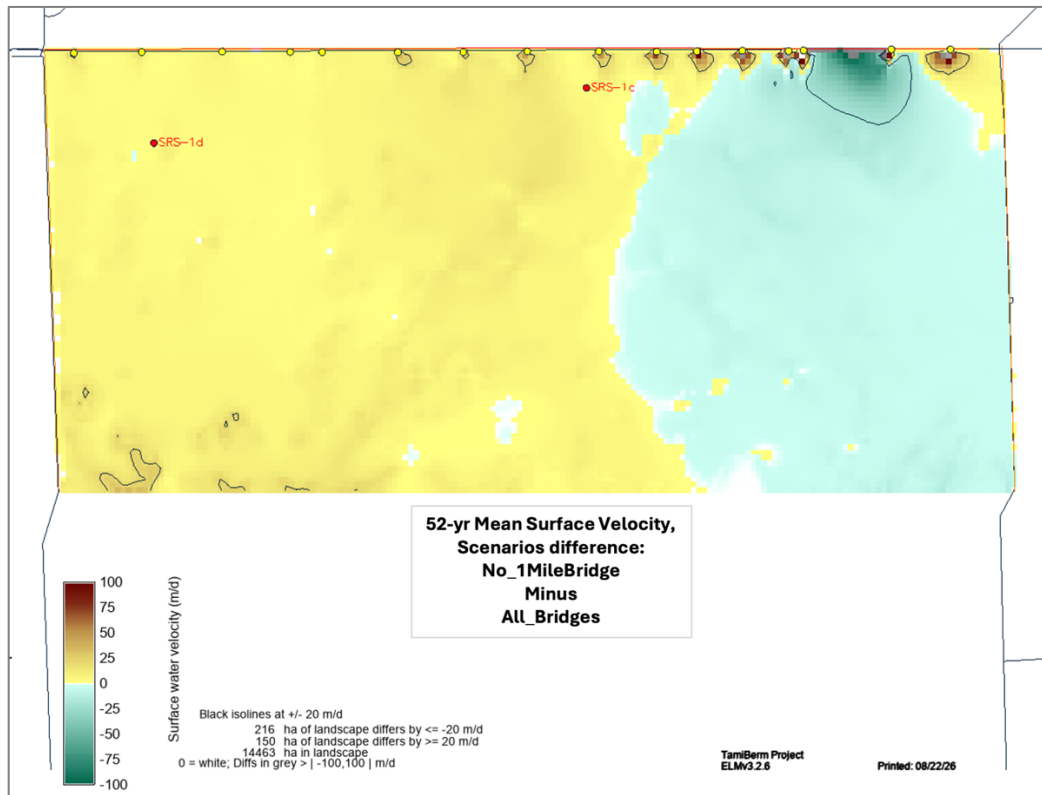


ELM Scenario Evaluations in Northeast Shark River Slough in Support of Florida Coastal Everglades LTER Research



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1.1 Introduction

This subregional application evaluated hydrologic flow and ecological (hydro-ecological) characteristics in the Northeast Shark River Slough (NESRS) of the southern Everglades. Our primary interest is the influence of the culverts and bridges breaching the elevated berm (road) that is the Tamiami Trail (US highway 41). These various gaps in the berm/road allow water to pass from a source canal into NESRS. The L-29 source canal is on the north side of this Tamiami Trail berm/road. The L-29 levee, which impounds the Water Conservation Area 3B, bounds the north side of the L-29 canal. There are several water control structures that pass water into the L-29 canal, from sources of the Everglades and the Lower East Coast urban area.

Water is allowed to flow unimpeded from the L-29 canal to the south into NESRS, depending on the status of berm/road gaps made via culverts (small gaps) and bridges (much larger gaps).

We evaluated hydro-ecological responses to scenarios of altered gaps & flows (and associated water quality constituents).

The EcoLandMod (<https://www.ecolandmod.com/>) system was used to develop a new fine-scale (100 m grid) hydro-ecological simulation model for the NESRS subregion. The model domain was defined by levees on the west, north, and east sides of a rectangle. The southern boundary of the model domain was just north of the "8.5 Square Mile Area", and that southern boundary allowed unconstrained overland outflow.

With this subregional (16,150 ha, 1 ha grid cells) Everglades Landscape Model ELM3nesrs_100 application, we evaluated the relative hydro-ecological effects of alternative scenarios of changes to the gaps in the Tamiami Trail berm/road, the structure flow capacities, and the phosphorus loads. Managed hydrology of these future scenarios were all driven by a marsh stage regulation schedule of NSM-like stage targets at the NESRS2 gauge, using ELM water management algorithms. All daily managed inflows into the basin were assigned generalized mean (temporally constant) values of chloride and phosphorus concentrations in the flows introducing new water to the model domain.

This application evaluated the extent to which future scenarios affected fundamental hydro-ecological dynamics at multiple spatial and temporal scales within the NESRS. This documentation serves as the necessary foundation that ***supports ongoing/future hypothesis generation-evaluation involving the spatio-temporal interactions among system variables under a) altered (broad-scale and local-scale) flows, b) altered P loading, and c) concomitant hydro-ecological process interactions that lead to altered ecosystem evolution.***

Here we describe the model data & assumptions for future scenarios, and the model results. The ELM has been rigorously documented at many levels of detail, in Report formats and online hyperlinked tools (and journal articles). Those documentation products fully described the characteristics of the Input Data, Code, Results, and User's Guide, including statistical & graphical model performance of the model calibration/validation in multiple regions and spatio-temporal scales.

Comprehensive Documentation Reports for ELM versions 2.5.2 through 3.2.5 (2006 - 2024) are found at:

<https://www.ecolandmod.com/publications/index.html#documentation>.

Hyperlinked conceptual models with pseudo-code (and data) descriptions are found at https://www.ecolandmod.com/models/algorithms_ELM/MainControllerModule.html.

While this report presents primary (most informative) model results of the NESRS basin modeling - and provides a synthesis - the full set of quantitative Performance Measure results are will be available at: https://www.ecolandmod.com/projects/ELM_FCE/.

1.2 Input Data

Aside from region-specific maps, most of the ELM data is generic, so that the same (model "C" code and) data may be used in a range of model applications. This Input Data section describes any changes (including input maps) that are specific to future scenarios for this ELM3nesrs_100 application.

1.2.1 Fixed parameters (text data files)

- **GlobalParms** == Parameters that are globally applied (across space) for hydrologic and ecological equations. With the exception of the numeric dispersion parameter that is specific to the 100m grid, we use the *same data from historical, calibration/validation of ELM v3.2.1-3.2.4 for the regional application*.
 - **IMPORTANT: to consider only surface overland flows in our scenario evaluations, we "turned off" all horizontal groundwater flows** (by setting GP_calibGWat = 0.0). See later section on NESRS hydraulic conductivity, and current/future seepage/groundwater flow infrastructure management.
- **HabParms** == Parameters for hydrologic and ecological equations that are specific to each model Habitat type (delineated via the Initial Condition Habitat Map below). We used the *same data from historical, calibration/validation of ELM v3.2.1-3.2.4 for the regional application*.
- **CanalData.chan** == Canal vector location-topology (in UTM geographic coordinates), with multiple attributes such as levee-presence, canal depth & width, etc. For this ELM3nesrs_100 application, some fine-scale coordinates were changed from those used in the regional application; but for the model domain-relevant canal/levees, we effectively use the same data from historical, calibration/validation of ELM v3.2.1-3.2.4 for the regional application. Figure 1 shows the infrastructure of the ELM3nesrs_100 model, including the canal/levee vectors and water control structures.
- **CanalData.struct** == Water control structure locations (in model-specific grid cell coordinates), with multiple attributes such as source & destination of flow, and phosphorus and chloride concentration (if the source is an exterior inflow into basin). The data file also includes structure "flags" denoting (historical or SFWMM) data driven flow vs. ELM-calculated managed flow (see code documentation, ELM v2.9.0). Figure 1 locations of the S355A, S355B, S359,

S334 structures are at exact locations; the model-visualization of the location of S333 is modified for this NESRS application (as the S333 simply introduces water and constituents into L29 canal (ELM Reach_54) of the model domain).

- **Structure's constant-in-time phosphorus and chloride concentrations** for inflows from exterior sources. We used assumed generalized (temporally constant) concentrations for each structure. Note that, as stated elsewhere, our schedule-driven simulations **used only the inflows from S333** into the L29 canal to drive the system. The SFWMM output that drove the ELM-LOSOM simulation (not used in our evaluations) also used the other structures (although there was effectively no flow via S335A&B in the SFWMM LOSOM simulation).

Struct	TP ug/L	Cl g/L
S333	10	0.050
S355A	10	0.050
S355B	10	0.050
S356	20	0.130

- **Structure's schedule-driven managed flow capacities:** the (single) managed structure was driven by ELM management algorithm(s) for future scenarios, based on an NSM-derived stage regulation schedule graph (**CanalData.graph**). For the structure's flow calculation, the algorithm(s) used a (CanalData.struct) flow coefficient (flow_c) to approximate maximum cfs capacity flows of the structure. For some future scenarios, below is a summary of the relative flow proportions (of flow_c) relative to the maximum flow capacity, for *four future scenarios* of flow capacities.

Struct	flowProp	Scenario
S333	1.0	sched_base
S333	0.2	sched_base_loFlo
S333	0.5	sched_base_midFlo
S333	1.5	sched_base_hiFlo

- **CanalData.graph:** Stage regulation Schedule, which is an annually repeating graph of daily stage targets (Figure 2). This schedule is an approximation of the average **NSM daily stage**. This time series was used to calculate ELM schedule-driven water control structure flows for all future scenarios in this work. The water management infrastructure and operations associated with the schedule (for all Schedule-driven simulations) are:
 - Inflow sources: S333
 - Outflow sources: none (no structure outflows)
 - Evaluate time-varying Target stage (NAVD '88) at NESRS2 gauge
 - Inflow when stage < (Target - Offset) [2 cm Offset]
 - **All Inflows assume unlimited sources** (i.e., no limits of water availability, nor water quality constraints, for inflows)

- **All Outflows are unregulated** (i.e., unconstrained overland outflows into downstream marshes)

1.2.2 Boundary condition flows (text or SFWMD-grid_io data files)

- **CanalData.struct_wat: Unused.** *Daily water control structure flow time series data are not relevant in future scenarios that are driven by the regulation schedule, and are only used in the ELM LOSOM simulation that is driven by SFWMM output of daily structure flows.*
- **CanalData.struct_TP and .struct_TS: Unused.** *Daily water control structure observed historical (calibration/validation) phosphorus and chloride time series data are not relevant in future scenarios.*
- **BoundCond_stage: Unused** *for the future scenario evaluations. However, for the ELM-LOSOM simulation (that was not used in these future scenario evaluations), this is the simulated daily grid_io binary spatial time series (2x2 mile grid), with stage data from the **LOSOM** future scenario run of the SFWMM v7.3.3, and is used only to calculate head-tail difference along ELM peripheral boundary cells for fluxing (ground)water in-out of the model domain boundary cells.*
- **rain.bin and pET.bin: Unused** *for the future scenario evaluations in this grid_io format at 2x2 mile scale..* Observed daily grid_io binary spatial time series (2x2 mile grid), provided by SFWMD for rainfall (daily, 1914 - 2016) and potential ET (daily, 1948 - 2016).
 - Because of the spatial artifacts induced by the 2x2 mile grid_io data input onto the 100 m ELM3nesrs_100 model grid, we extracted the grid_io daily time series data at the centroid point of each 2x2 mile grid within the ELM3nesrs_100 domain, to create a daily time series text file for each of 9 site locations. We then employed an existing ELM algorithm to dynamically interpolate each daily value across the 100 m grid. These **fine-scale climate/weather (rainfall and potential ET) data** were used in our future scenarios,. As with all of the models that use these data in future assessments, we assume stationarity in climate/weather, and thus past conditions are replicated in the future (see below section on Assumptions).

1.2.3 Initial Condition (IC) maps (generic binary spatial data files)

-- **Elevation:** Initial (dynamic in simulation) land elevation. The basin-wide baseline elevation map was developed using a Regularized Spline with Tension (RST, v.surf.rst, GRASS v8.5.0) interpolation of 2003 USGS-EDEN HAED point survey data. We then applied an overlay of fine-scale (10 m grid) LiDAR Tamiami Trail-specific observed elevation data (within a Tamiami Trail berm/road "mask"). The end result of that Tamiami Trail berm/road, single-cell 100 m width elevation, was a constant elevation of 2.70 m for the berm/road surface, and a constant elevation of 1.40 m for all culvert or bridge gaps. That 2.70m model elevation is consistent with the Florida DOT design threshold of 2.49 m.

See **Appendix 1: Elevation development** for details on the derivations of the EDEN LiDAR elevation (Simons et al. 2024), unused here EXCEPT for the berm/road data, and the EDEN HAED point survey elevation (Jones and Price 2007), used in these simulations.

Figure 3 shows the final elevation data interpolated (at 100 m resolution) from HAED survey points, and the (unused) version of the original (10 m resolution) EDEN LiDAR collection.

Elevation gaps and surface flows: Rather than employing formal culvert structures and specific culvert-flow calculations, we simply **allowed surface water in the canal (ELM Reach_54) to flow into adjoining marsh cells that "belong" to the canal** (calculated via complex geometric internal initialization), **using Manning's** roughness of the cell's habitat type (all dense sawgrass in the Tamiami Trail mask). High elevation along the Tamiami Trail road (i.e., within the Tamiami Trail elevation mask) prevents most over-roadbank flows, while low elevation gaps of culverts and bridges allows much more frequent and significant flow to occur depending on relative stage depths along the canal and adjoining cells. See ELM v2.5 Documentation, Model Structure Chapter 5 (url provided earlier), for description of the canal-cell vector-raster flux algorithm.

-- **HAB:** Initial (static in simulation) habitat type. The original map data were from the 50 meter grid 2009 EVER_VegMap (Ruiz et al. 2021) vegetation classes. We crosswalked those classes to correspond with existing ELM habitat types. Those 50 meter grid data were then filtered (r.neighbors of GRASS v8.5.0) using a 3x3 cell moving window, then the result was resampled at 100 m grid resolution within the ELM3nesrs_100 domain. Because the original data did not include all ELM3nesrs_100 cells to the north and the east, we filled in missing data outside of the levees to simply be sawgrass habitats. We did not consider any model results outside of the levees (but still inside the domain). Because of this, for consistency we also replaced data to the west of the L-67 extension levee with sawgrass habitats.

Figure 4 shows the habitat type data for the entire basin, both at the original 50 meter resolution and the resampled 100 meter resolution.

-- **MacBio:** Initial (dynamic in simulation) macrophyte total biomass, using a 15-year (1980) "spin-up" value from a 1965-2016 baseline simulation.

-- **soilTP:** Initial (dynamic in simulation) phosphorus concentration in the 0-10 cm layer of soil, using a 15-year (1980) "spin-up" value from a 1965-2016 baseline simulation. That baseline spin-up was initialized with a soilTP map that was RST interpolated from point sample data collected within NESRS (and elsewhere) in 2003 (Osborne et al. 200? - I'll get correct ref).

-- **soilBD, soil_orgBD:** Initial (static in simulation) soil bulk density, and organic bulk density (adjusted for percent ash-free) in the 0-10 cm layer of soil. Both maps were RST interpolated from point sample data collected within NESRS (and elsewhere) in 2003 (Osborne et al. 200? - I'll get correct ref).

-- **HydrCond:** Initial (static in simulation) hydraulic conductivity of the subsurface aquifer up to land elevation. Map was resampled-rescaled from ELMreg500 v3.2.4 (which was resampled from SFWMM v5.4). However, as stated above (**GlobalParms** section), for our specific evaluation goals we turned off all groundwater flows, and thus this map is not relevant to our evaluations.

-- **SfWt, Unsat:** Initial (dynamic in simulation) surface water and unsaturated water depths, respectively. Using the 10 d "spin-up" value of a 1965-2016 baseline simulation (that was based on ELM3reg500 1965-2010 simulation, that was based on 2x2mile SFWMM output).

-- **other maps:** Initial (static in simulation) maps of Basin/Indicator Regions (BIRs, Figure 5), boundary-flow-allowances, model domain delineation. .

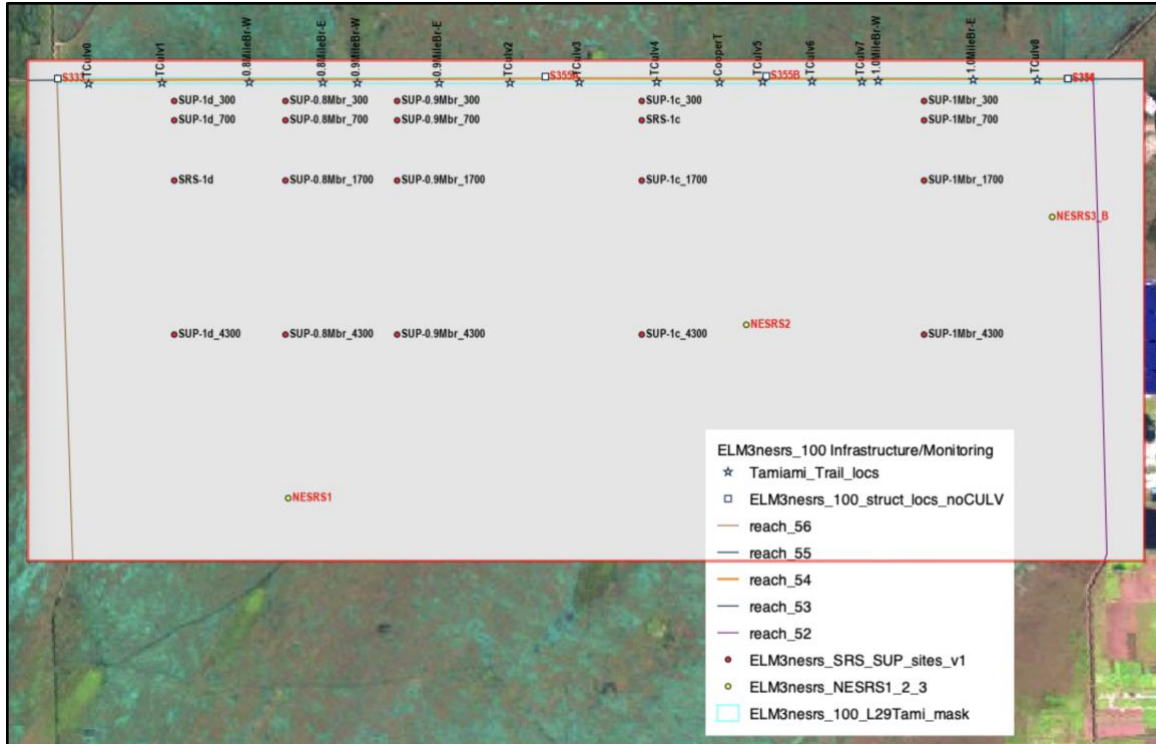


Figure 1. ELM3nesrs_100 domain (gray) infrastructure, showing: the operating canal/levee vectors (reach_52 - reach_56); water control structures; Tamiami Trail culverts and bridge-end-points; and marsh monitoring sites (including model "SUPplemental" sites created along transects, including the two FCE sites). Reach_54 is the L-29 canal/levee, with the WCA-3B bounding levee on its north side. Reach_52 is the L-31 canal/levee, with the basin-bounding levee on its west side. Reach_56 is the L-67extension canal/levee, with the basin-bounding levee on its east side. The 100m (cell) wide L29Tami_mask vector rectangle is for visualization-only, outlining the grid cells whose elevations were modified to create the gaps of culverts and bridges (see IC Elevation map description).

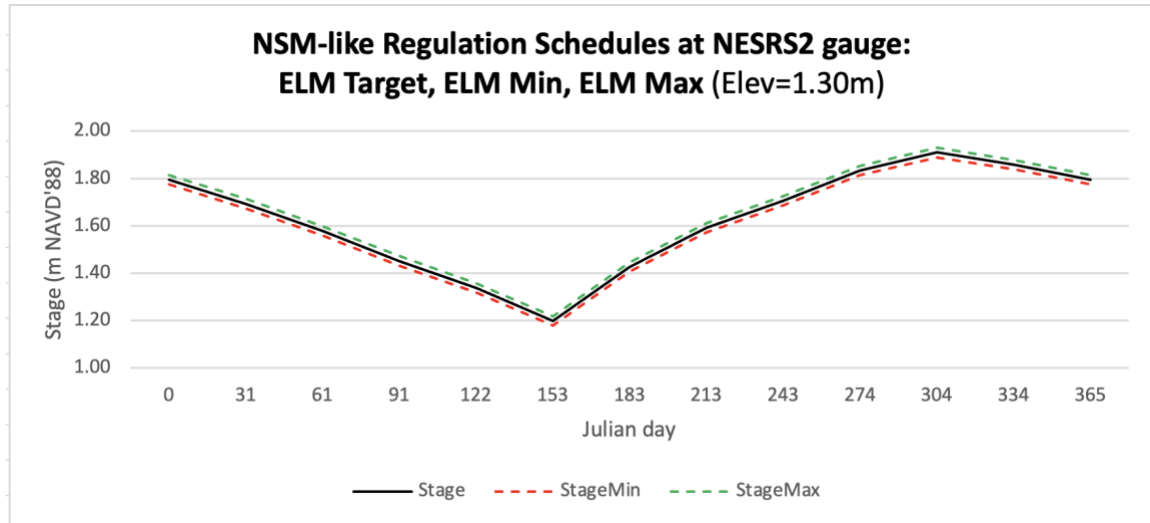


Figure 2. The stage regulation schedule for the NESRS2 gauge in NESRS, derived from the Natural System Model (NSM) commonly used in Everglades restoration targets. This annual (repeating) time series is the targeted head or tail water stages for calculated flows of rule-based water control structures. However, we did **not use the "ELM Max" curve**, as there was no operating managed outflow structure.

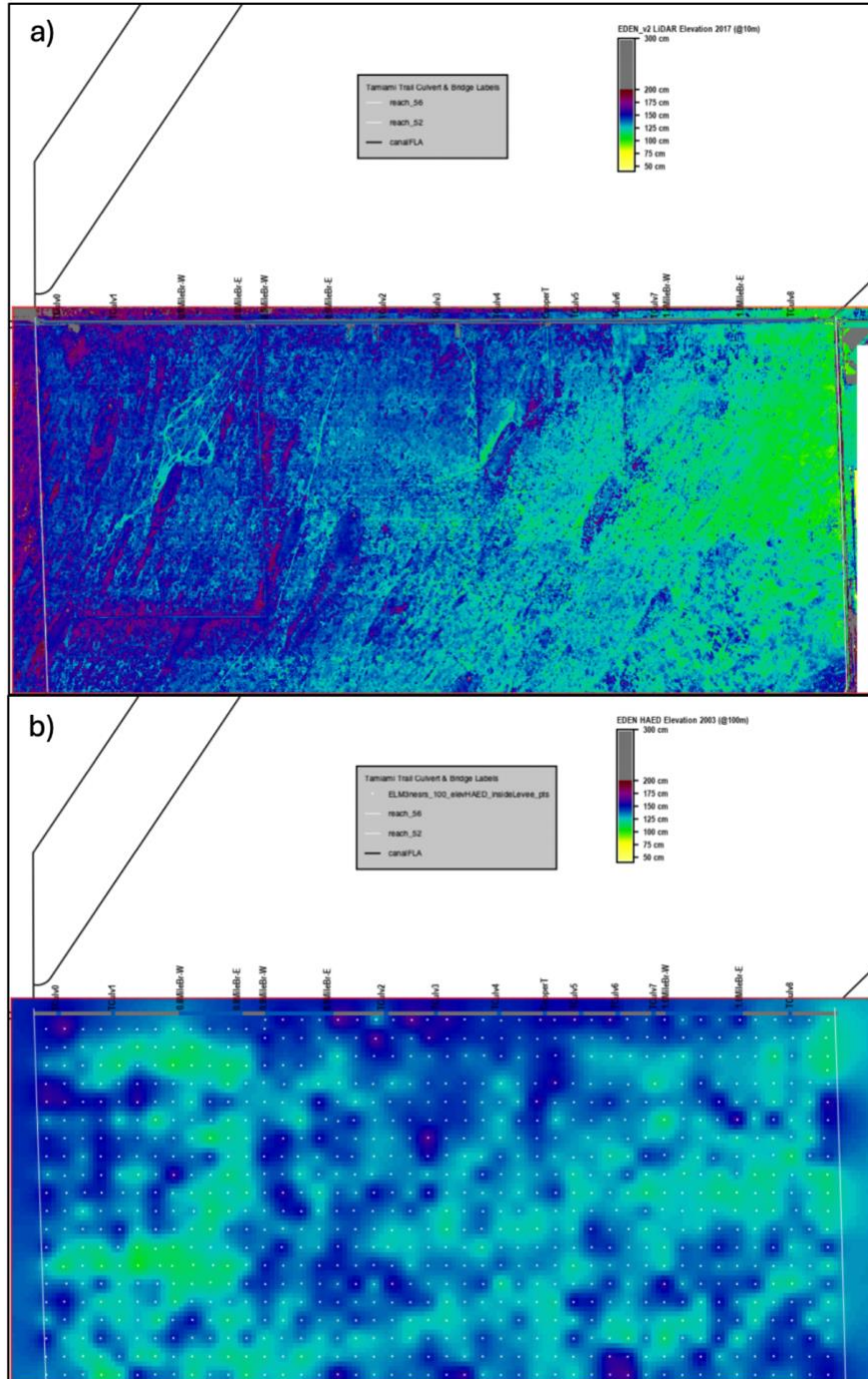


Figure 3. The initial land surface **Elevation**, two versions. **a)** is the unused EDEN v2 LiDAR map, original data at 10 m grid resolution (note that the data do not extend to the ELM3nesrs_100 eastern boundary in this unedited version). **b)** is the 100 m grid resolution version used in these simulations, interpolating HAED survey points (superimposed here) that are located only inside the ELM3nesrs_100 levees. For b) outside the levees, we allowed the RST interpolation to extend to the model domain boundaries. **Appendix 1: Elevation development** shows the severe bias trends in east-west elevation profiles of the LiDAR data, assuming that the HAED survey points have the documented accuracy. As noted elsewhere, we do not evaluate model output that extends outside of these levees. The Tamiami Trail culvert and bridge point symbols are not shown, allowing visualization of the elevation gaps in b).

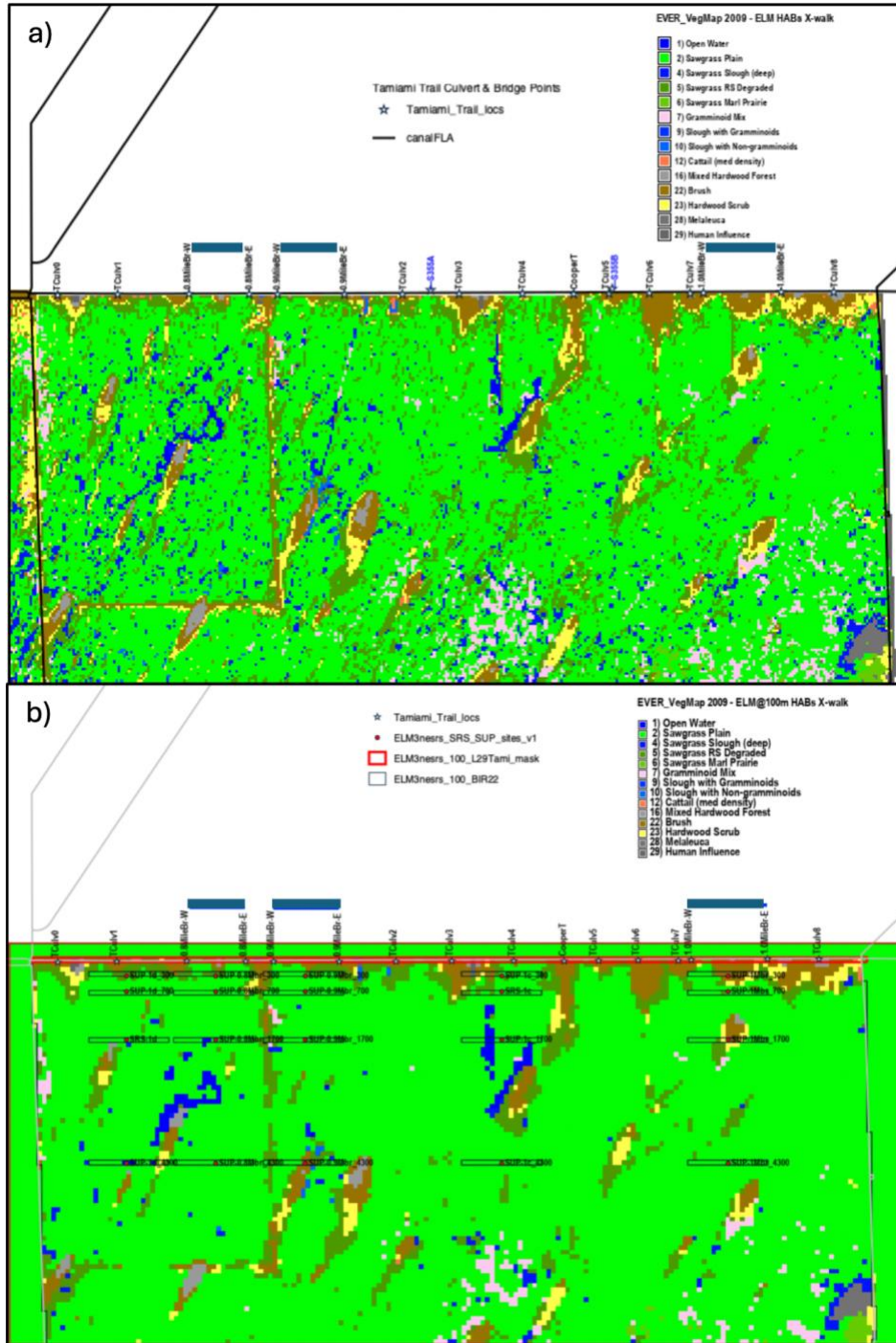


Figure 4. The initial Habitat (**HAB**) type, two versions. **a)** is the original 50 m grid resolution EVER_VegMap, with their original vegetation classes cross-walked to correspond with existing ELM habitats. Note that the data do not extend to the ELM3nesrs_100 eastern nor northern boundaries in this unedited spatial version. **b)** is the modal-filtered 50 m data that were resampled at 100 m grid resolution. Note that we filled-in or replaced all data outside of the ELM3nesrs_100 levees to be all sawgrass habitat. For reference, b) also shows the transect marsh monitoring sites, and the associated vector outlines of the ELM BIRs (see next map figure of BIRs).

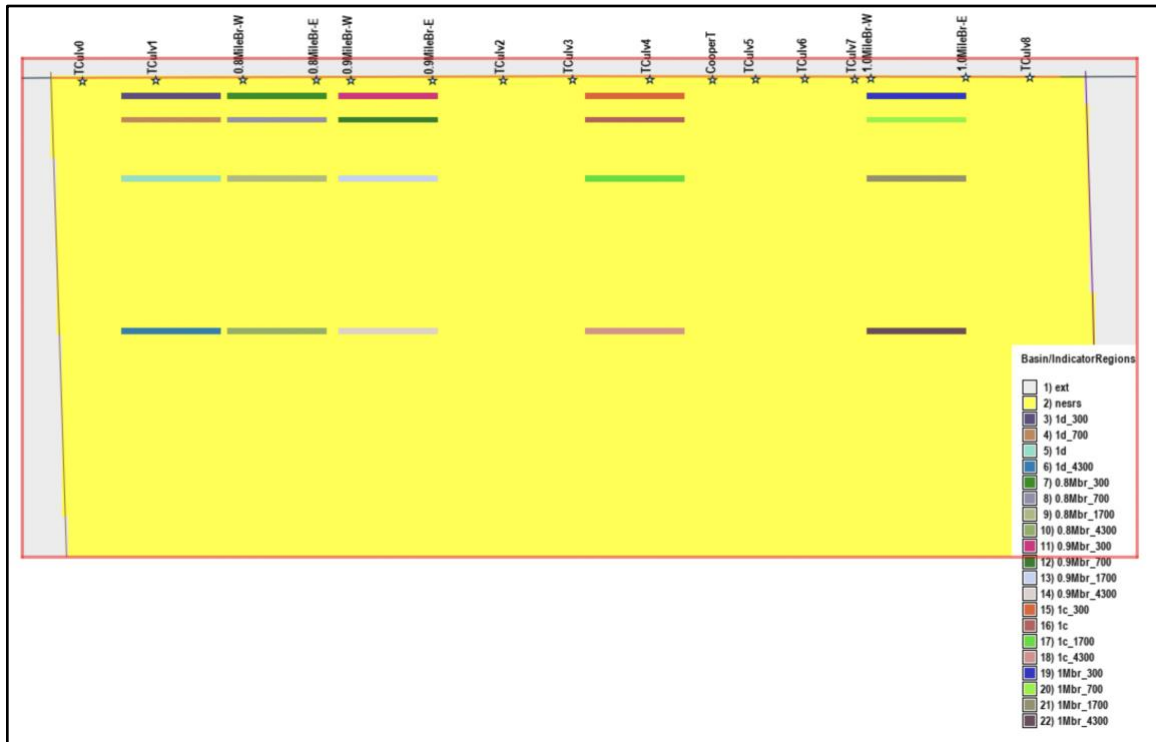


Figure 5. The delineation of ELM3nesrs_100 Basin/Indicator Regions (**BIRs**). ELM "Basins" are hydrologic basins. There are two in the ELM3nesrs_100 model: cells that are inside the levees of NESRS ("nesrs", BIR=2), and model cells that are external to the levees ("ext", BIR=1). ELM "Indicator Regions" are independent sub-sets of a single ELM Basin, and provide mean values (or budget sums) of selected variables within each Basin and Indicator Region. The overall Basin (nesrs) value(s), however, is the mean (or the budget sum) of all contained-Indicator Regions (3 through 22), plus that of the area shown in yellow of the graphic. In other words, the BIR=2 is the true mean (or budget) of the entire hydrologic basin inside the levees of NESRS (and not merely that of the area shown in yellow of the graphic).

1.3 Assumptions - General

In simulating future scenarios, the ELM (and SFWMM, RSM, others) uses the climate record that was observed between 1965 and 2016. This 52-year period encompasses periods of both extreme rainfall and drought conditions. *Relative differences in system behavior under different future project alternatives reflect how the system would likely respond in the future to the alternative management, if driven by the same climate forcing data that has been observed in the past.* In other words, we (all) assume climate stationarity, in that the future climate will be approximated by recent historical climate.

An often-confusing characteristic of this stationarity assumption is the use of the historical 1965-2016 dates in model output for future scenarios: future scenario output dates simply reflect the "re-used" historical climate, and users must remember these are NOT historical simulations.

The ELM uses spatio-temporal databases of 1965-2016 rainfall and potential evapotranspiration that are identical to inputs to the SFWMM. In applying the ELM to evaluate future conditions, a number of other assumptions are generally required for initializing and simulating ecological dynamics. As with the SFWMM, the specific assumptions for the ecological simulation must be determined for each project application.

By design, the full suite of model and data assumptions are generically the same for all ELM applications, as fully described in the ELM v2.5 - v3.2 Documentation Reports. (See Model Structure Chapters in ELM v2.5 through v2.9 Documentation Reports, with added-module updates to v3.2, at <https://www.ecolandmod.com/publications/index.html#documentation>).

Assumptions that are specific to this project are indicated in the above **Input Data** section, and in the below scenario-specific sections of this report.

1.4 Assumptions - Alternative Scenarios

As stated in the **Introduction** section, the area of interest in this Project is the Northeast Shark River Slough (NESRS), and, in particular, the various gaps that have been introduced into the berm/road that historically restricted flows from upstream into NESRS.

The Alternative scenarios evaluated differences in elevation gaps in the Tamiami Trail berm/road, altered the upstream water control structure (S333) flow capacity, and/or altered the S333 inflow structure's phosphorus concentration. No changes were made to the canals/levees (**CanalData.chan**) nor the water management criteria (**CanalData.graph**). Most other data were likewise unchanged for Alternative scenarios, as documented for all of the input data files in the above **Input Data** section. Table 1 provides an overview of the future Base and future Alternative scenarios..

ScenarioName	BridgeStatus	InflowTP	FlowStatus
sched_base	All 3 bridges	10	Nominal
sched_base_5ppb	All 3 bridges	5	Nominal
sched_base_15ppb	All 3 bridges	15	Nominal
sched_base_loFlo	All 3 bridges	10	20%Nominal
sched_base_midFlo	All 3 bridges	10	50%Nominal
sched_base_hiMidFlo	All 3 bridges	10	75%Nominal
sched_base_hiFlo	All 3 bridges	10	150%Nominal
sched_no1Mi	West 2 bridges	10	Nominal
sched_08mi	West 1 bridge	10	Nominal
sched_08mi_loFlo	West 1 bridge	10	20%Nominal
sched_noBridg	No bridges	10	Nominal
sched_noBridg_loFlo	No bridges	10	20%Nominal

Table 1. The future Alternative scenarios (including the future Base scenario, sched_base) used in this work. All simulations encompassed the 52 year, January 1965 - December 2016 climate record. The BridgeStatus is either all 3 bridges present (base*), only the western 2 bridges present (no1Mi), only the most-western bridge present (08mi), or no bridges present (no_Bridg). The InflowTP is the S333 inflow TP concentration being either 5, 10, or 15 ppb TP concentration in the inflow. The FlowStatus is either the Nominal (which is similar to the SFWMM LOSOM flow), or 20%, 50%, 75%, or 150% of that Nominal flow. See **Input Data** section above for further definitions of these data.

1.5 Performance Measures

Table 2 describes all of the Performance Measures that were developed for evaluating relative differences among the future Base and Alternative scenarios. The matrix describes the spatial and temporal characteristics of each Performance Measure, and brief documentation of the associated model variable. More detailed understanding of the variables, and their interactions, is found in the ELM v2.5 (through v2.9) documentation (url provided earlier).

ELM3nesrs_100 Performance Measures						
Basin mapset: has 3 maps for a variable: left=Base; right=Alternative; middle=Difference (one .png graphic file per mapset)						
- Base & Alternative maps have contours at 2 thresholds; Difference map has (2) contours of "meaningful" $\pm$ differences						
- The marsh-area of each of the above contour values are shown in brief table on each map						
- Each Alternative scenario suite (multiple variables) of mapsets includes a tab-delimited .txt file table w/ all above marsh-areas, all variables						
BIR graphs: for each BIR, a comparative monthly time series graph of a variable's values for the Base vs. the Alternative (1 .xlsx file per variable)						
Variable	Spatial_a	Temporal_a (#mapsets)	Spatial_b	Temporal_b (#graphs)	Units	Variable Description [Output Variable's BaseFileName]
Hydrology						
Surface water depth	Basin mapset	SRWD (4), POS_mean (1)			m	Surface water depth [Positive values of HydRelDepPosNegAvg=depth relative to land elevation, $\pm$]
Surface water velocity	Basin mapset	SRWD (4), POS_mean (1)			m/d	Surface water flow velocity of net daily horizontal advection (all directions) [SF_WT_VEL_magAvg]
Surface water Cl conc	Basin mapset	SRWD (4), POS_mean (1)			g/L	Chloride ("salt") concentration in surface water (when depth $\geq$ 10cm) [SaltSfAvg]
Hydroperiod	Basin mapset	POS_mean (1)			days	During water-year (begin/end julian day=273), days that surface water depth is > 0.01 m [HydPerAnn]
Phosphorus						
Surface water P conc	Basin mapset	SRWD (4), POS_mean (1)			mg/L	Phosphorus concentration in surface water (when depth $\geq$ 10cm) [TPSfWatAvg]
Floc P conc	Basin mapset	SRWD (4), POS_mean (1)			mgP/kgOM	Phosphorus concentration in the flocculent organic matter [FlocP_OMrepAvg]
Soil P conc	Basin mapset	EndValue (1)			mgP/kg_soil	Phosphorus concentration in soil total mass (0-10cm) [TPtoSOILAvg]
Integrated Ecology						
P accumulation rate	Basin mapset	POS_rate (1)			mg/m2/yr	Phosphorous mass change rate in ecosystem (live/dead/water storage) [PaccummRate]
Peat accretion rate	Basin mapset	POS_rate (1)			mm/yr	Land elevation change rate in ecosystem (assumes constant soil bulk density) [PeatAccreteRate]
SRWD=Sets_of_Representative_Wet_Dry seasons, for HiFlow year & LowFlow year (30-d means at ~end-of-wet-season, ~end-of-dry-season)						
BIR=Basin/IndicatorRegion - swaths of model grid cell aggregations (see previous map Figure of 22 BIRs, focused on gradient from Tamiami Trail berm/road)						
POS=Period of Simulation; Tseries=Time series graphs						
All raw output data available in tab-delimited text (BIR, TSeries @ monthly intervals) or netCDF (maps, most TSeries @30d mean intervals)						

Table 2. The hydro-ecological Performance Measures used to evaluate the relative differences between future Base and future Alternative scenarios.

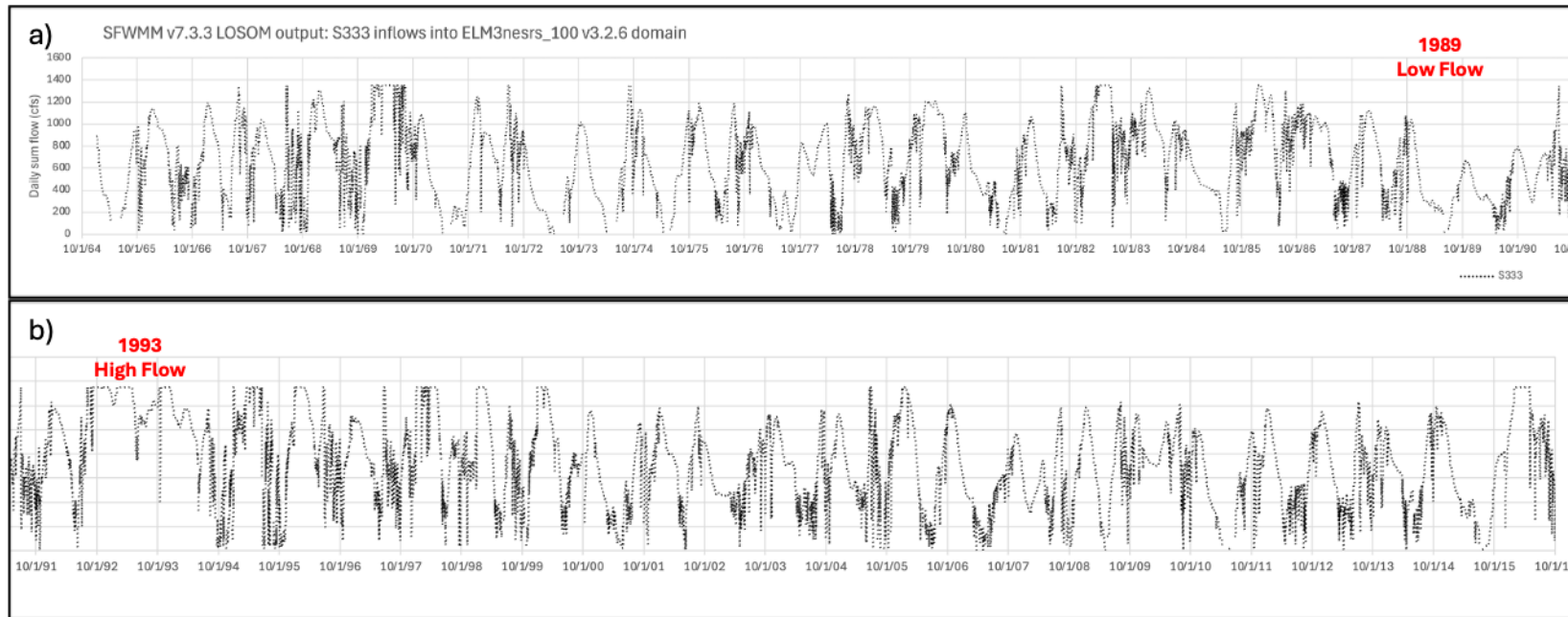


Figure 6 a&b. The simulated SFWMM-LOSOM daily flows in the S333, for an (unused) ELM-LOSOM Base run. The 52 year time series is split into two sections (a&b) for visualization. Notations (in red font) show the selected Low Flow year and High Flow year. The relevant ELM spatial output maps are 30-day mean values from the years' dry-seasons and wet seasons, with 30-day mean output files on 05/05 & 10/02 1989, and 05/14 & 10/11 1993. See explanation in text for map output dates..

The temporal attribute selection of the **Sets_of_Representative_Wet_Dry** seasons (SRWD, referenced in Table 2) was based on the magnitudes of the schedule-driven flows for the S333 structure for a Base run (Figure 6). Whereas water-year rainfall magnitudes is one component of determining years of high vs. low managed flows, we determined that temporal pulses of managed flows - which consider both the antecedent water levels and rainfall - were most appropriate for our objectives. The above Figure 6 shows the selection of **high-flow** and **low-flow** years, with SRWD output map dates¹ which most effectively captured the types of S333 flow events.

1.6 Results - Scenario evaluations -- examples

This section shows the **most informative example scenario comparisons** using ELM3nesrs_100 results, allowing *relative comparisons* of the future Alternative scenarios to the future Base. The full set of Performance Measure results are will be available at: https://www.ecolandmod.com/projects/ELM_FCE/.

Difference Map Figure caption, common to all:

Each variable's difference-mapset shows the color-scaled raster results, and vector contours of the area of marsh that exceeds selected ecologically-meaningful thresholds for the variable, and vector contours of the marsh area of the ecologically-meaningful (+/-) differences between the Base and Alternative for the variable. Simple tables in each map graphic show those area calculations.

*****See Table 1 and Table 2** above for definitions of the Scenarios and Performance Measures.

Map header-label syntax is in either 2 or 3 dot (".") separated parts, depending on whether it is a Period Of Simulation (POS) statistic:

2-part) **ScenarioName.VariableNameOutputDate** denotes the Scenario, and the Variable's daily mean over a 30-day bin ending on the OutputDate, or simply the Variable's calculated rate of change between the 52-year simulation's beginning and end (for rates of P accumulation and peat accretion).

3-part) **ScenarioName.VariableName.POSmean** denotes the Scenario, and the Variable's mean over the 52-year Period Of Simulation.

1.6.1 Difference Maps

As indicated in the **Introduction**, our goals focus on the influence of the culverts and bridges breaching the elevated Tamiami Trail berm/road, along with water control structure capacities and P concentrations. Towards that focus, this *section quantifies the spatial, integrated hydro-ecological responses* to future Alternative scenarios in the NESRS basin.

For the difference-map results of the sched_base compared to four selected-example Alternative scenarios (sched_no1Mi, sched_noBridg, sched_base_5ppb, and

¹ ELM coding for map time series output requires use of julian-calendar map output dates, which gradually become offset from standard-calendar dates; judgments must be used to choose 30-d mean dates of interest relative to the standard-calendar (see Figure 6).

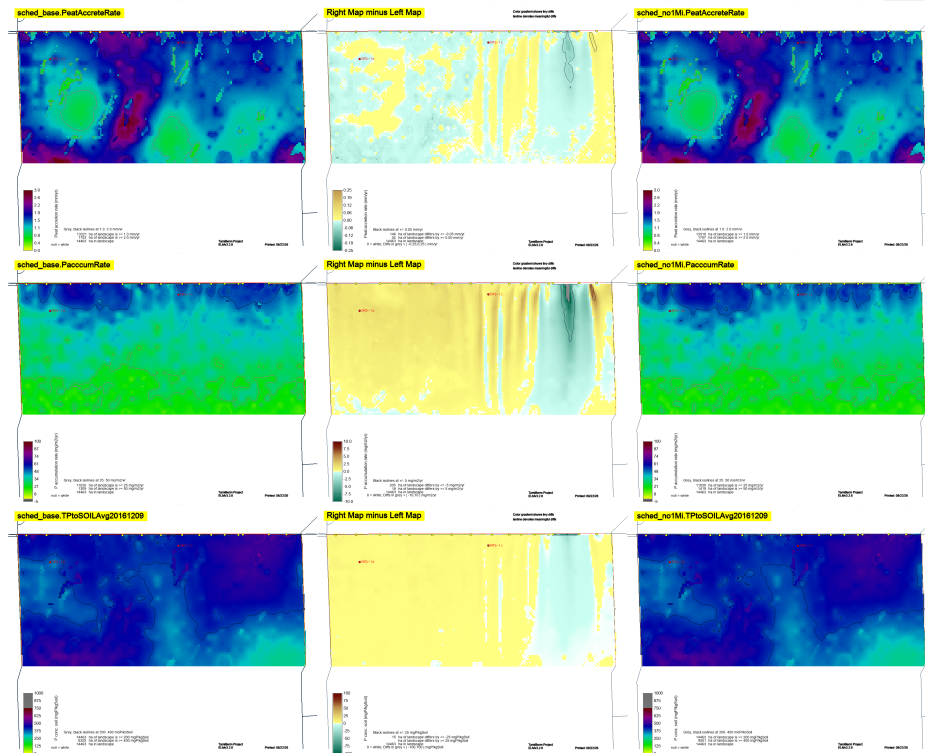
sched_base_15_ppb), we show results for 9 Performance Measure (see Table 2 for definitions) variables, with the difference-maps for each variable displayed in this order, for each future Base vs. Alternative comparison:

1. **Peat accretion rate**
2. **P accumulation rate**
3. **Soil P concentration**
4. **Surface water velocity**
5. **Hydroperiod**
6. **Surface water depth²**
7. **Surface water Cl concentration**
8. **Floc P concentration**
9. **Surface water P concentration**

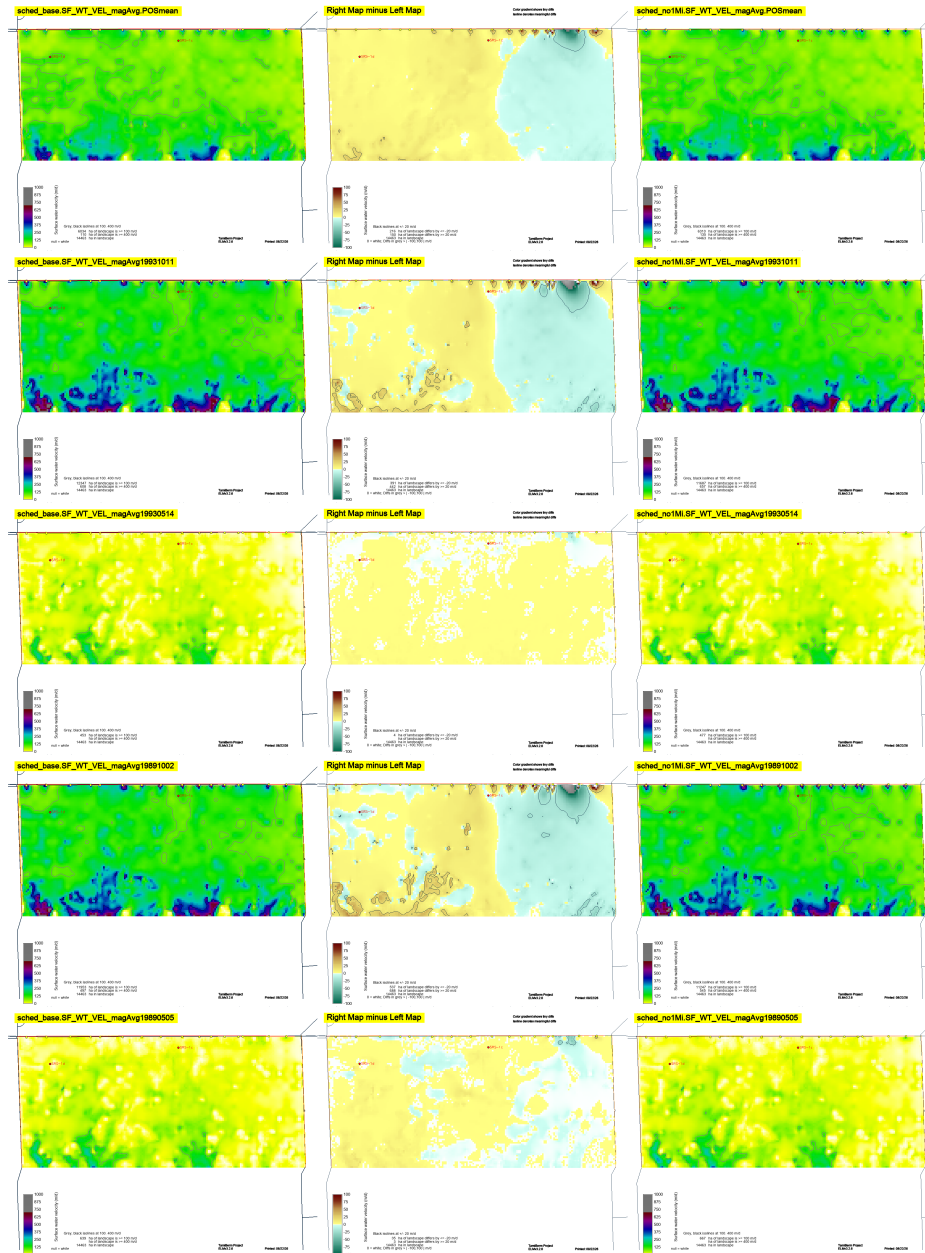
For an example descriptive summary of spatial results patterns, see **Appendix 2: Difference Map Summary Example**. The example is a comparison between the sched_base and the sched_no1Mi scenarios, providing a template for exploring the complexities of these difference map Performance Measures.

² The maps displaying surface water depth show ONLY positive values of the variable "HydRelDepPosNeg" (i.e., not their negative, below-ground depths). Their **difference maps (middle in fig)** calculate ALL differences (above and below ground) and thus may display differences in absence of surface water in the left and/or right maps.

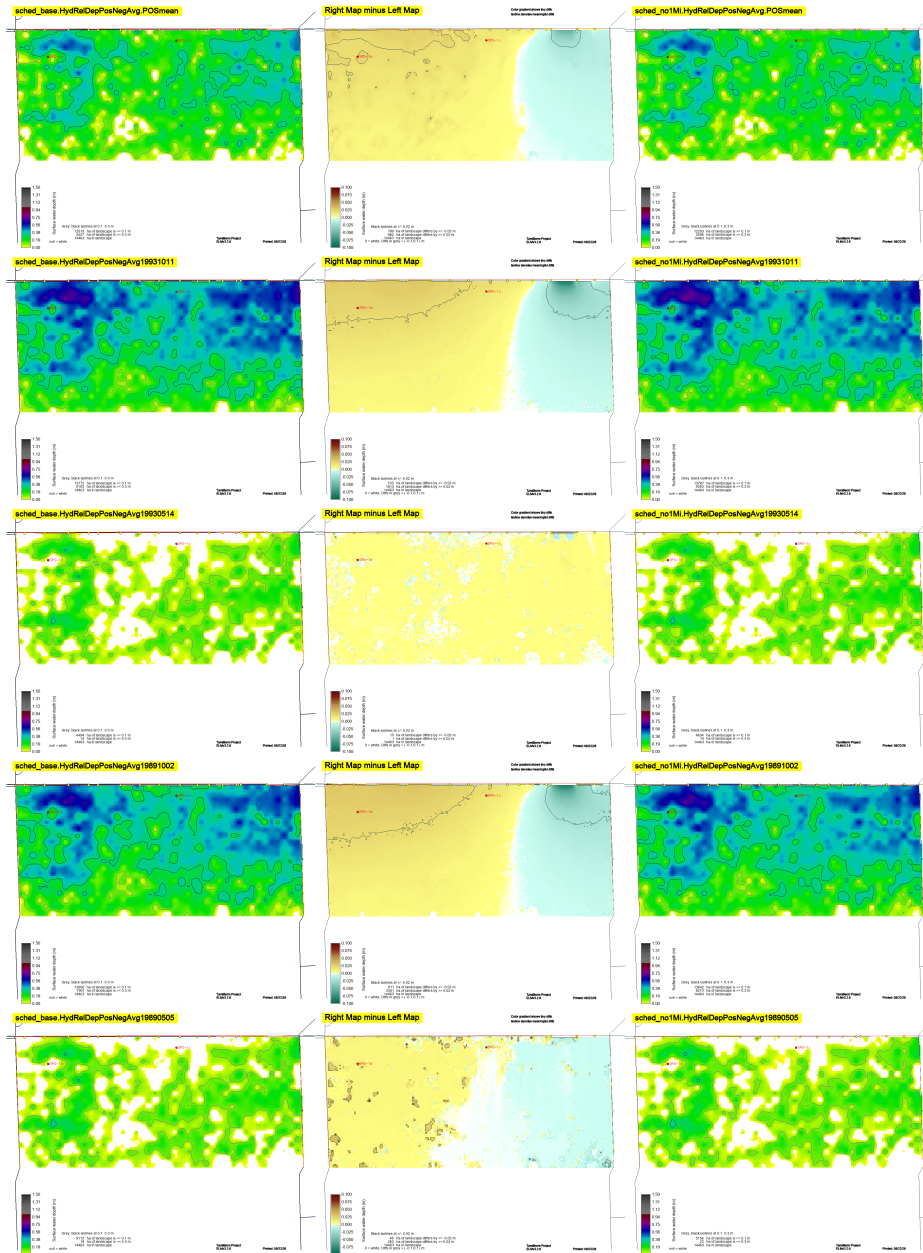
1.6.1.1 Scenario: sched_no1Mi



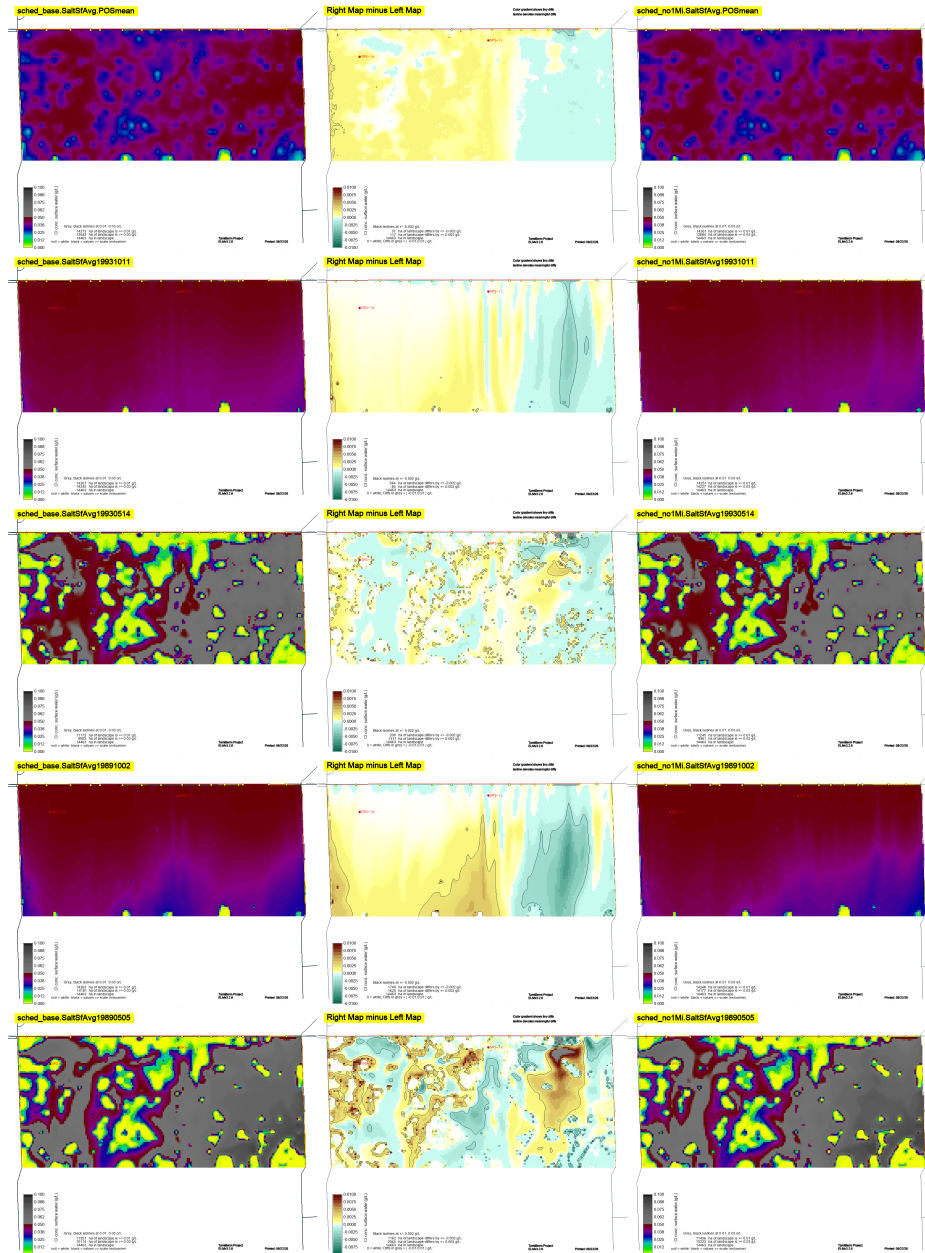
ELM3ners_100: Application Documentation

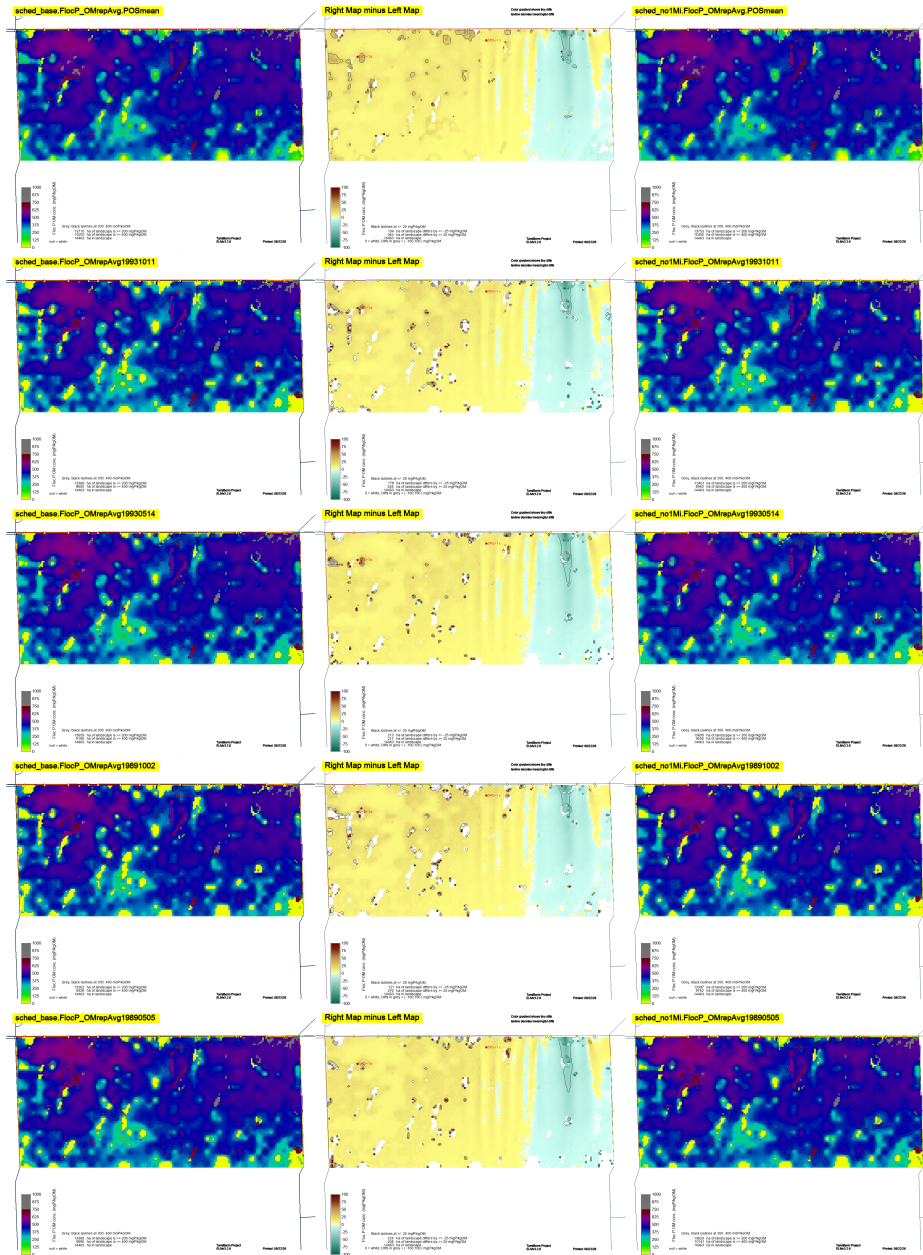


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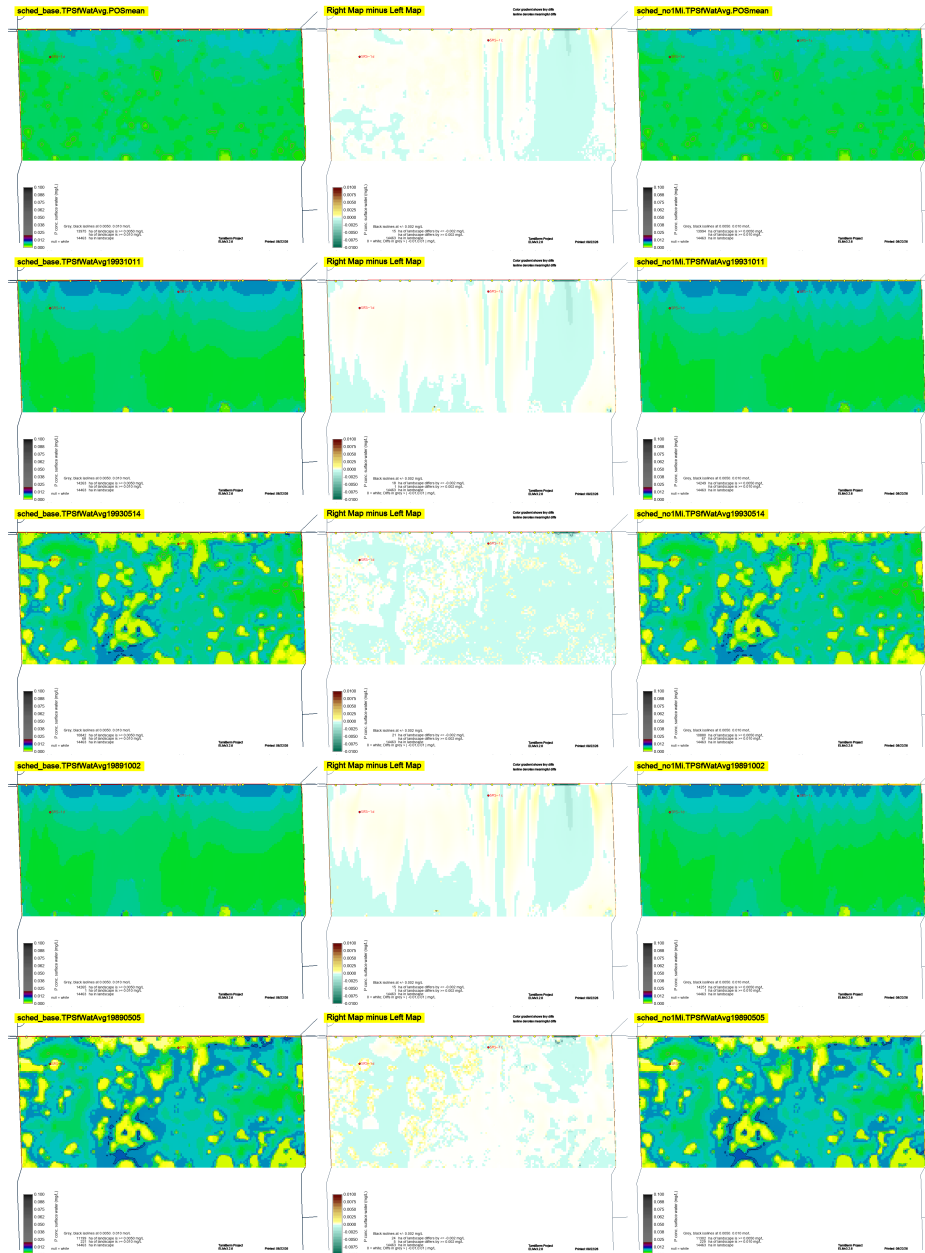


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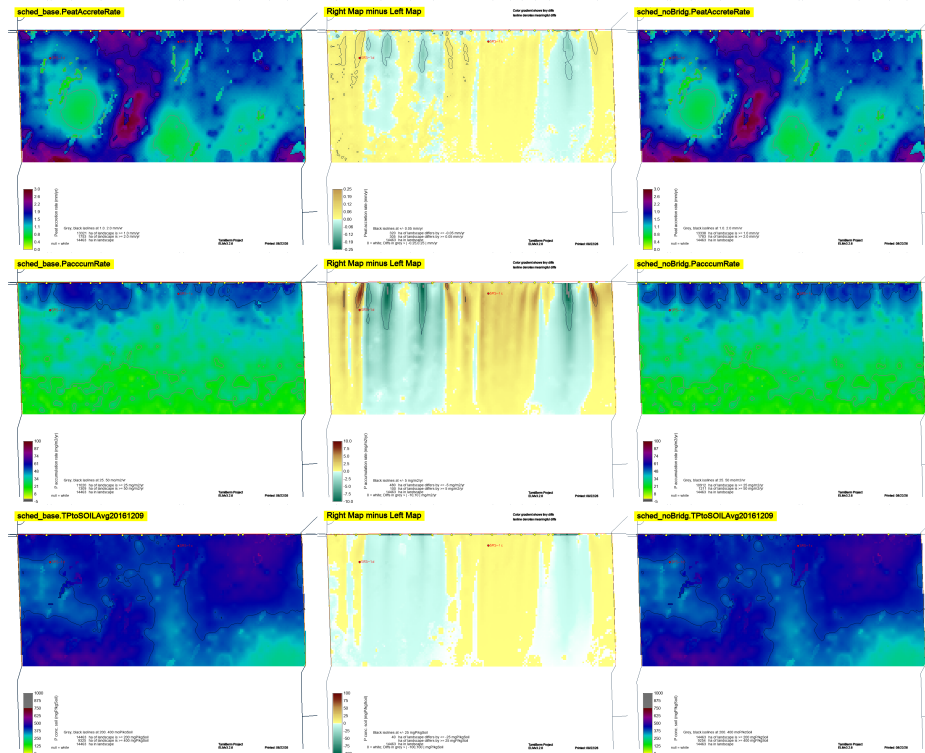




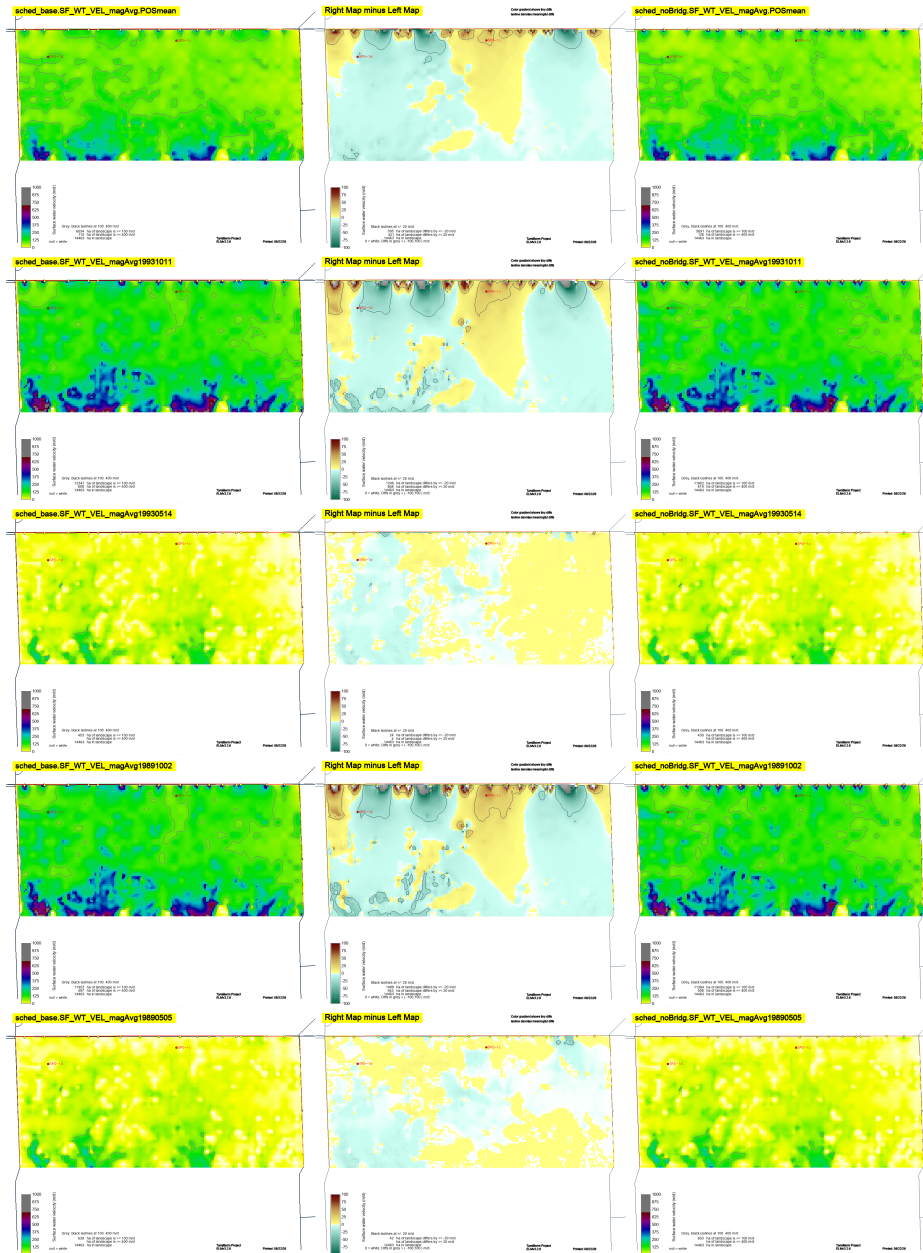
ELM3neers_100: Application Documentation



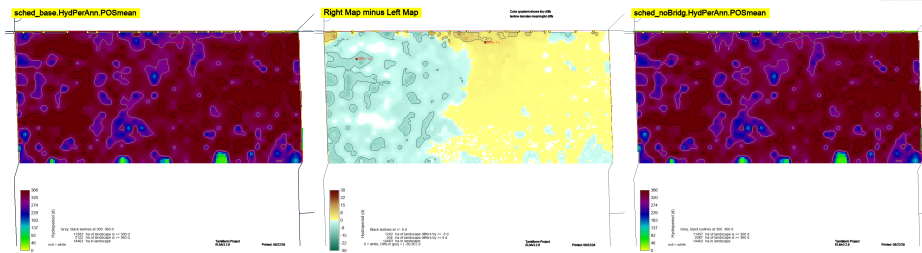
1.6.1.2 Scenario: sched_nobridg

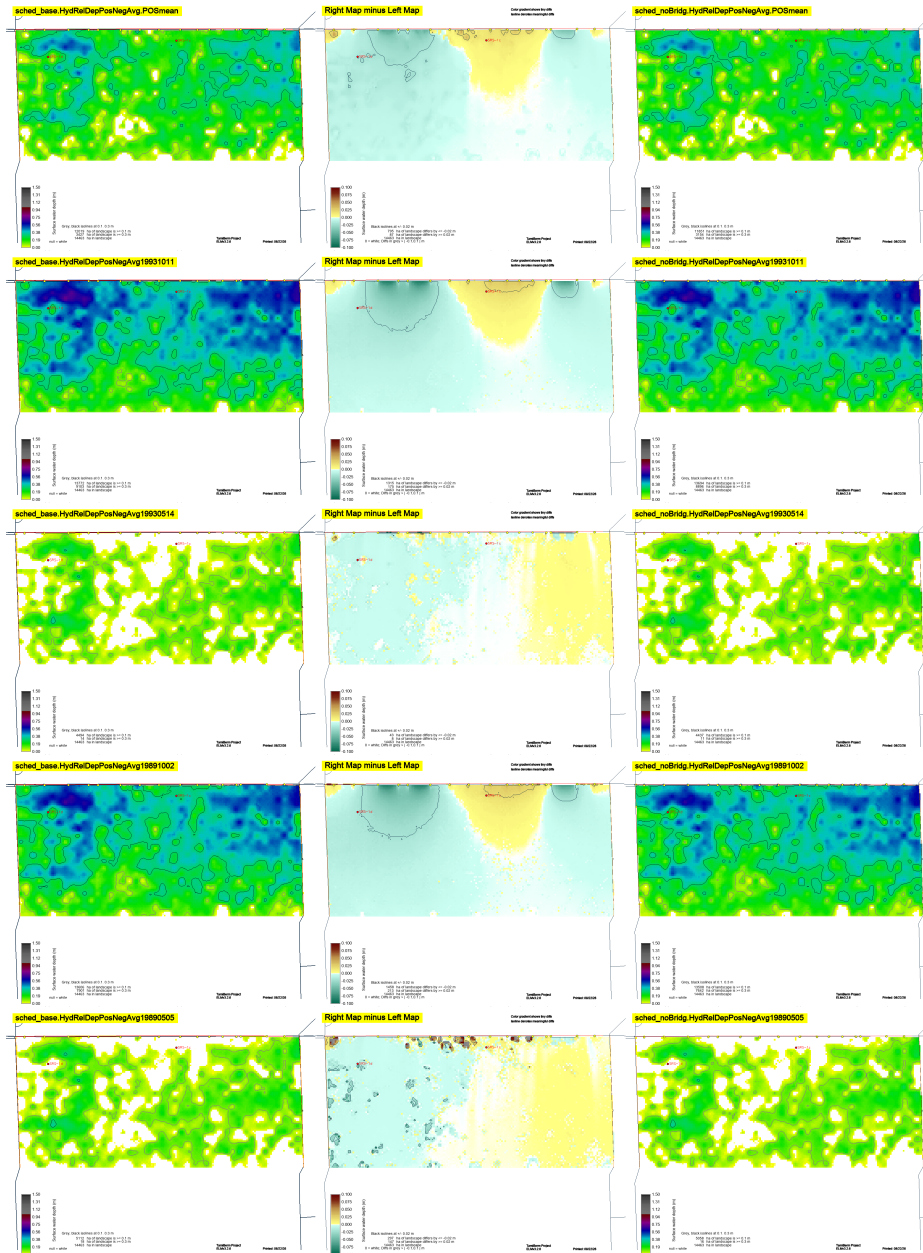


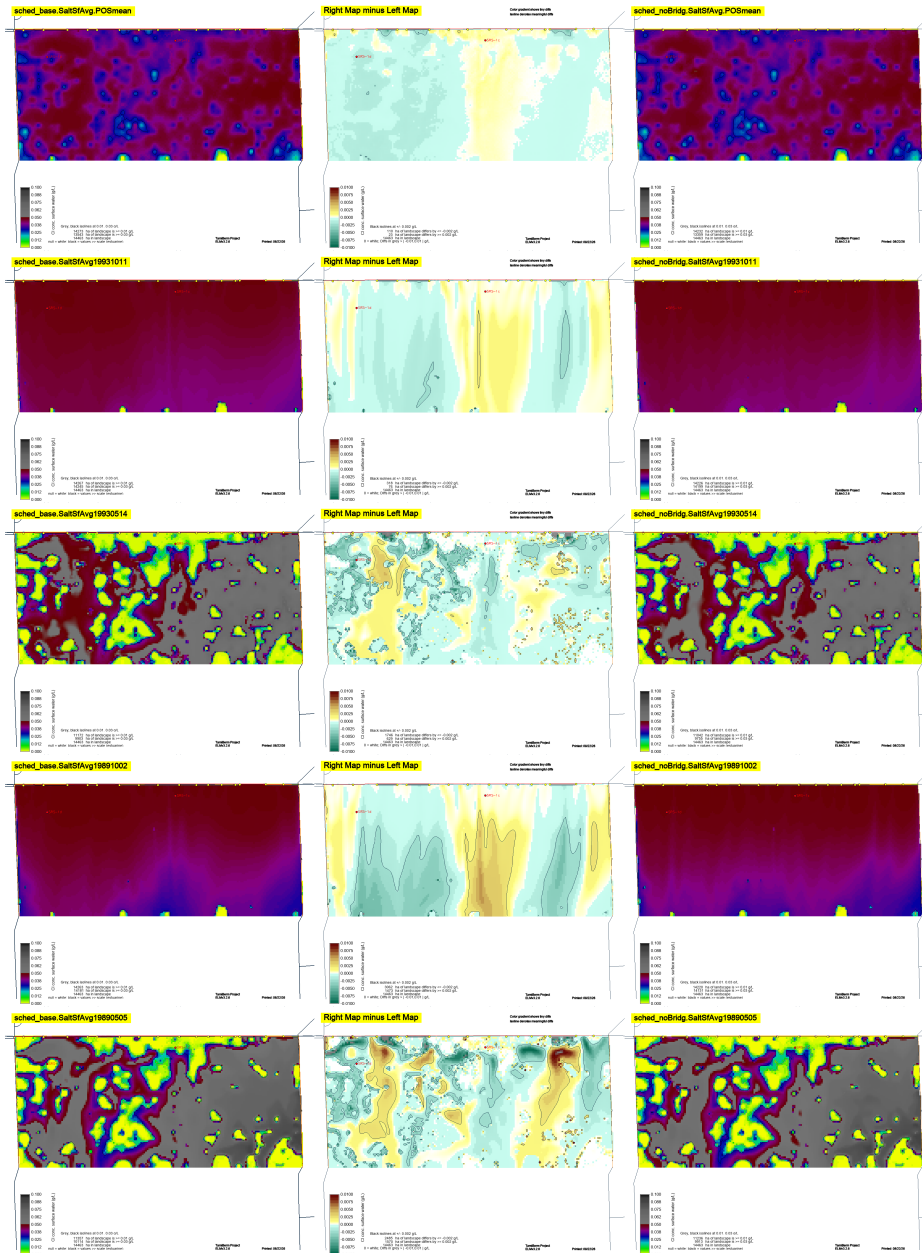
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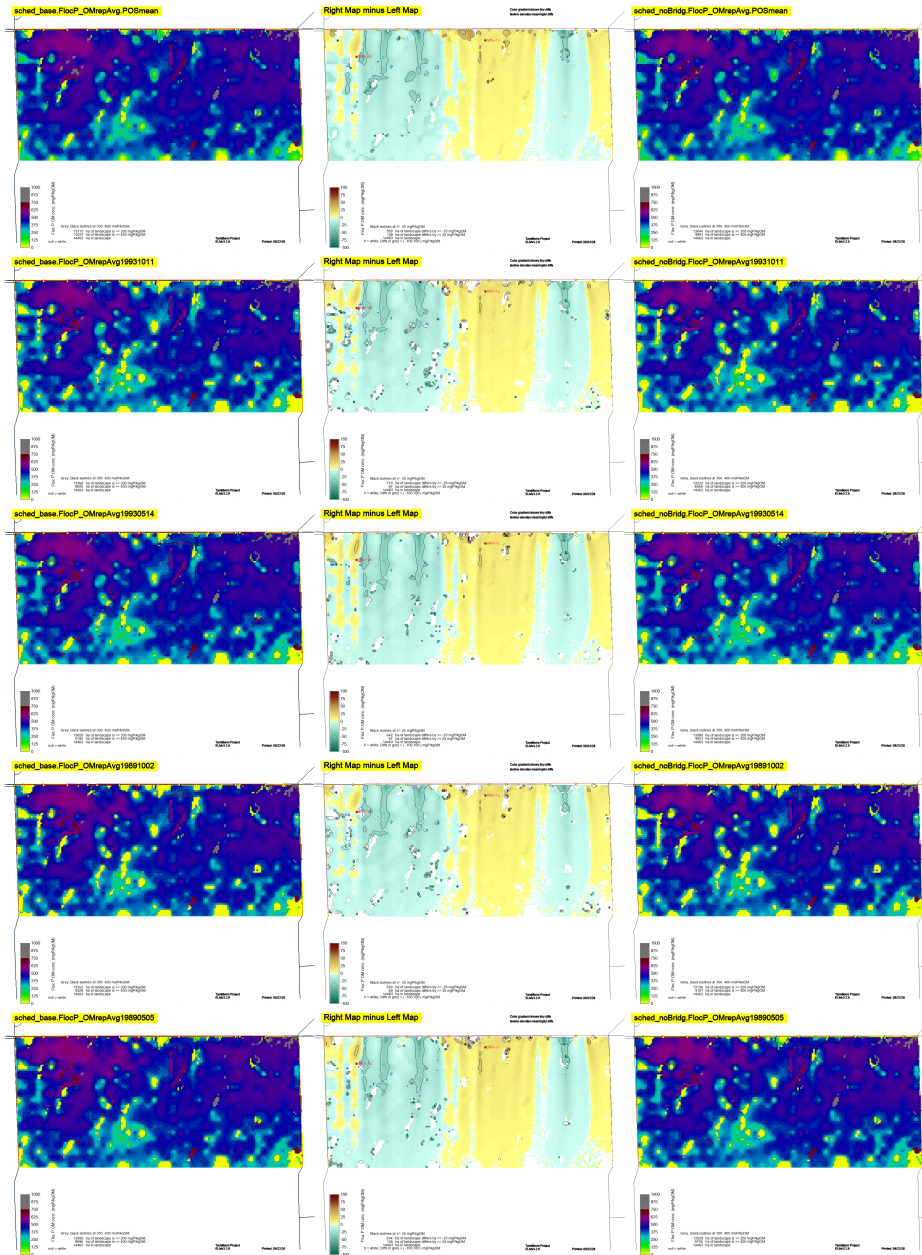


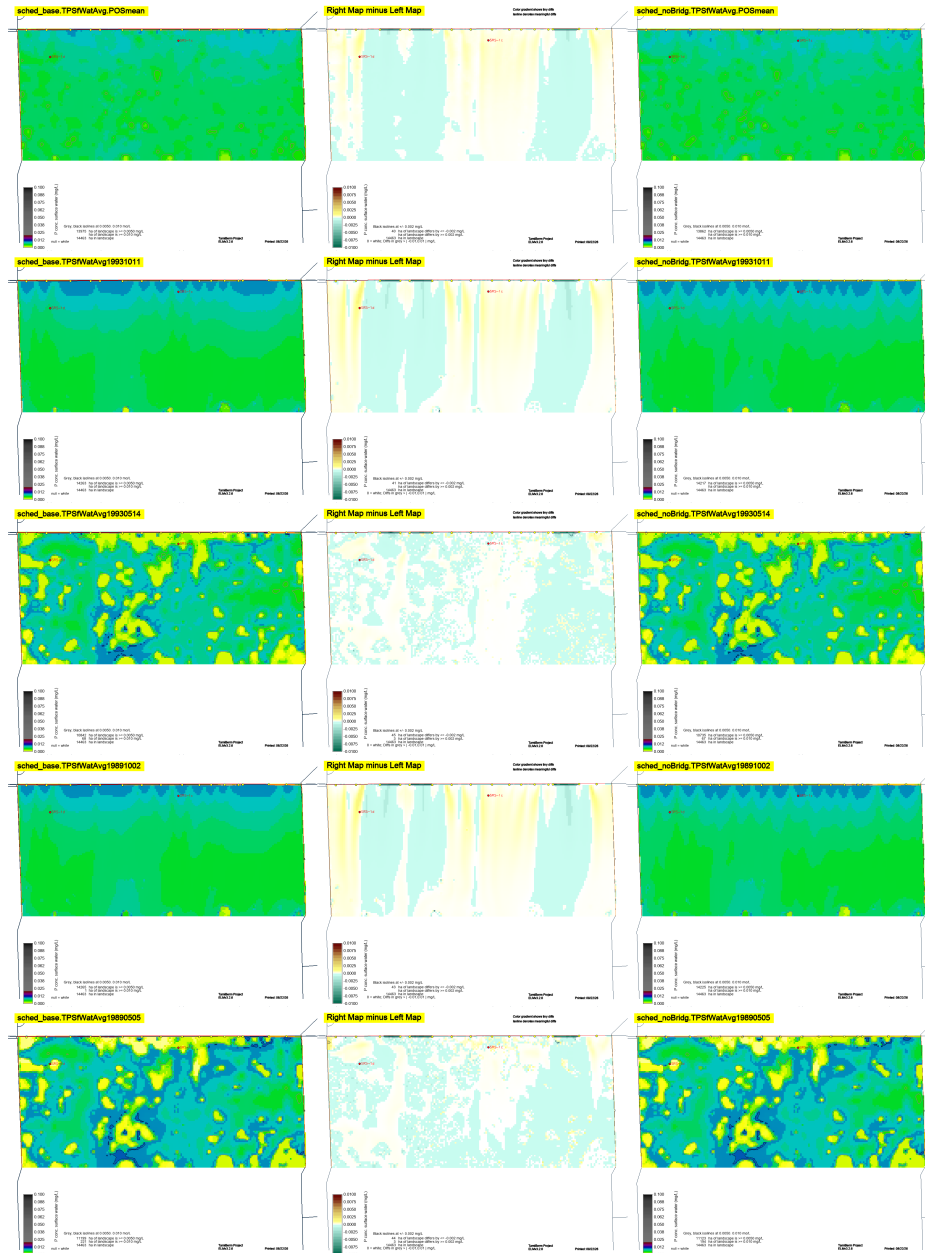
ELM3nesrs_100: Application Documentation



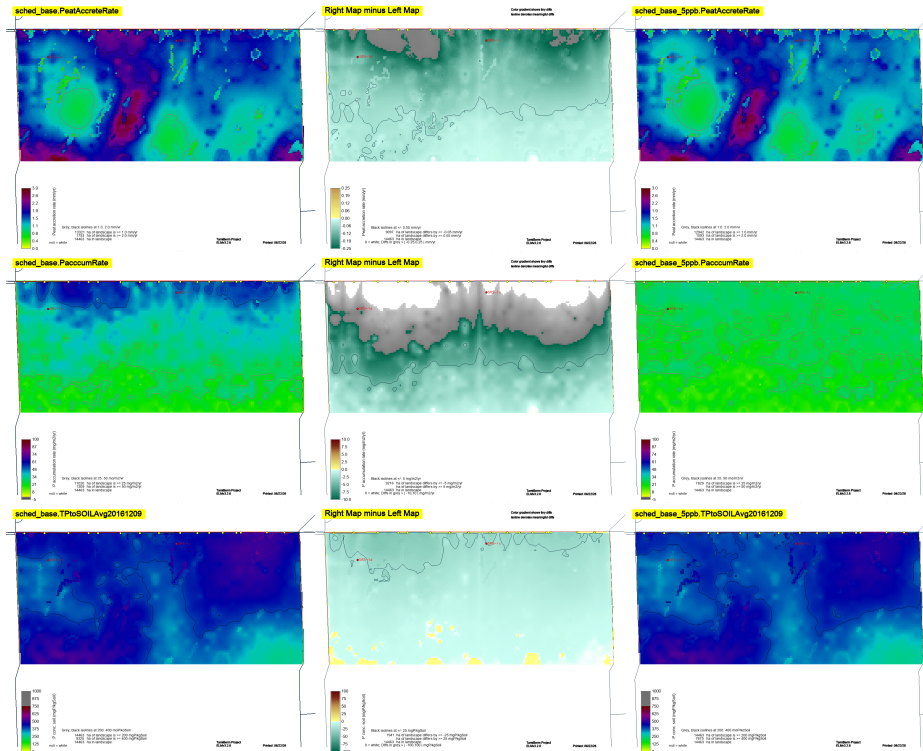


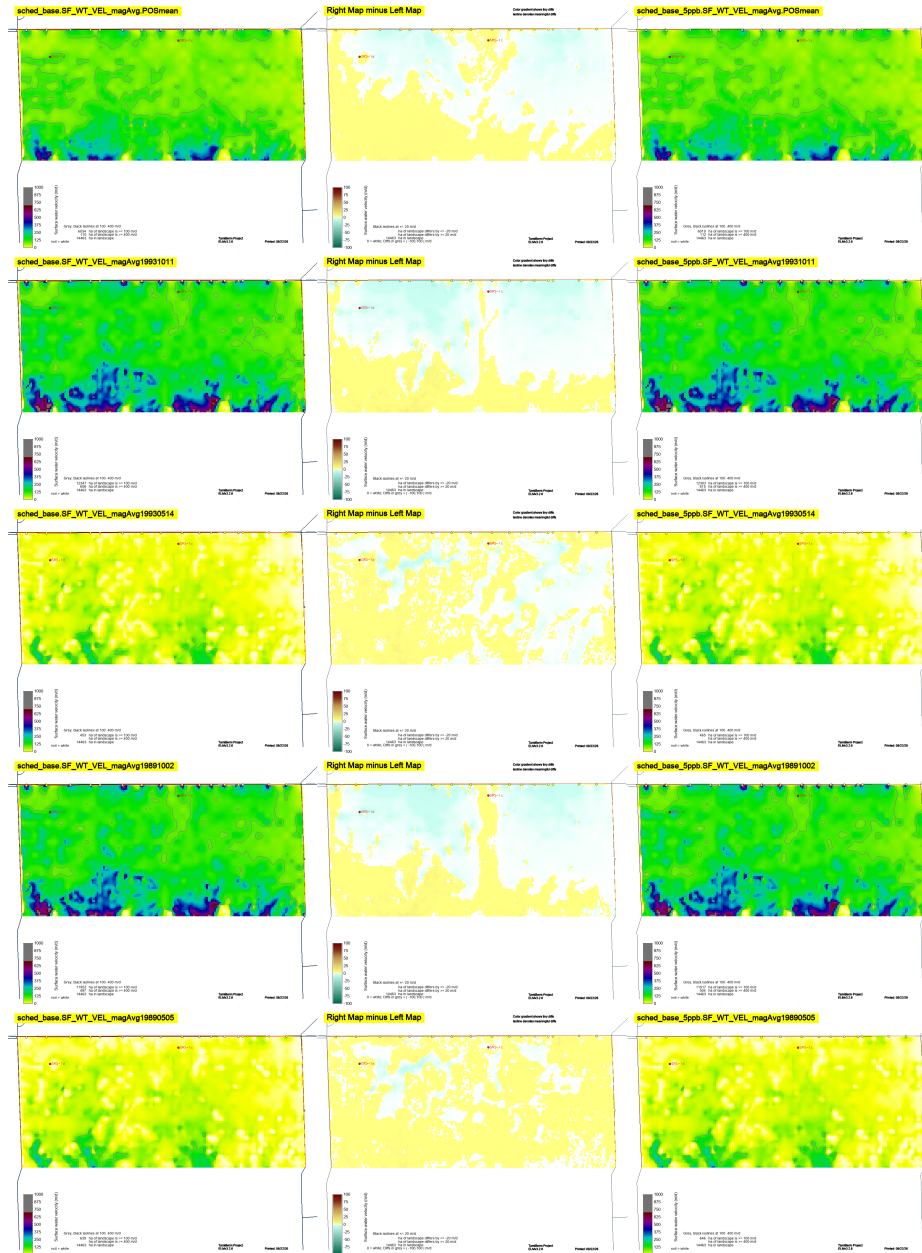




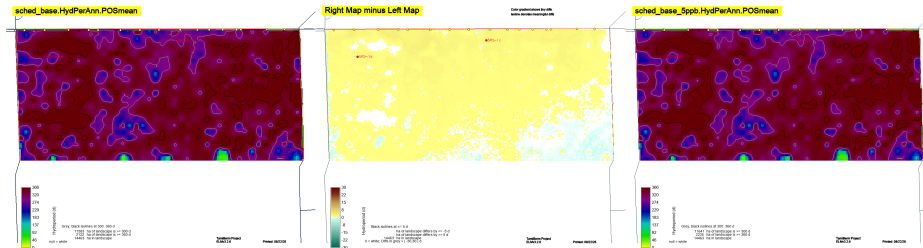


1.6.1.3 Scenario: *sched_base_5ppb*

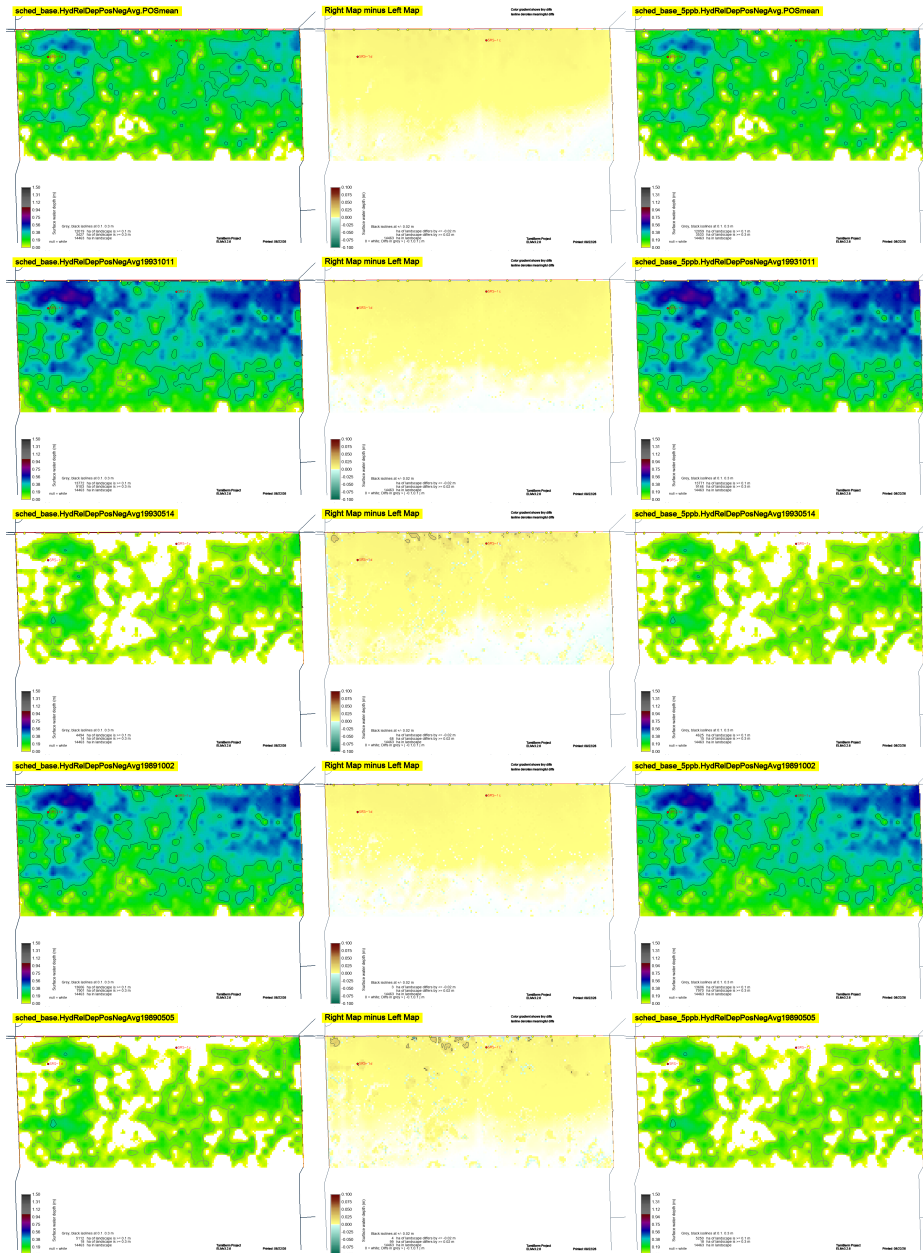


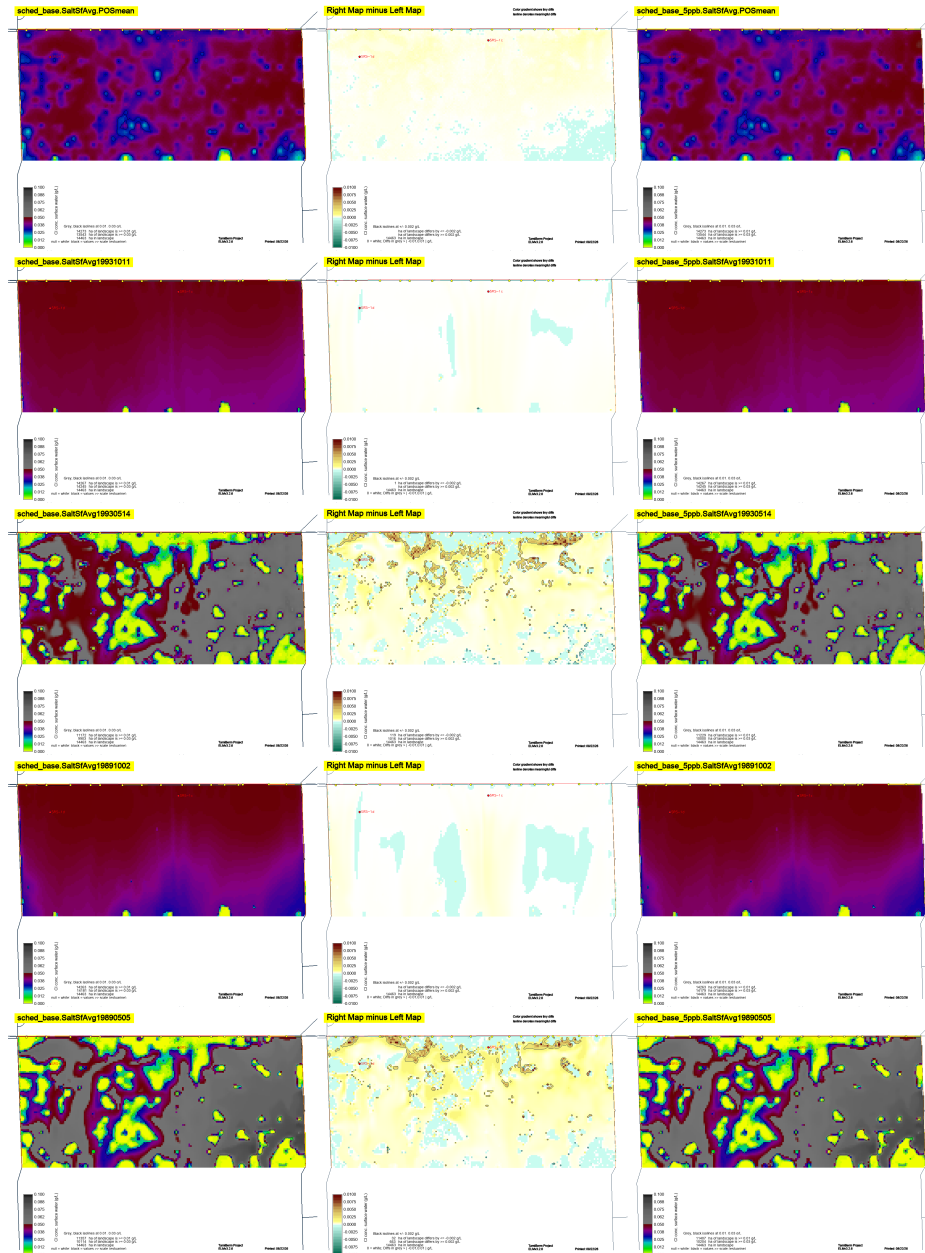


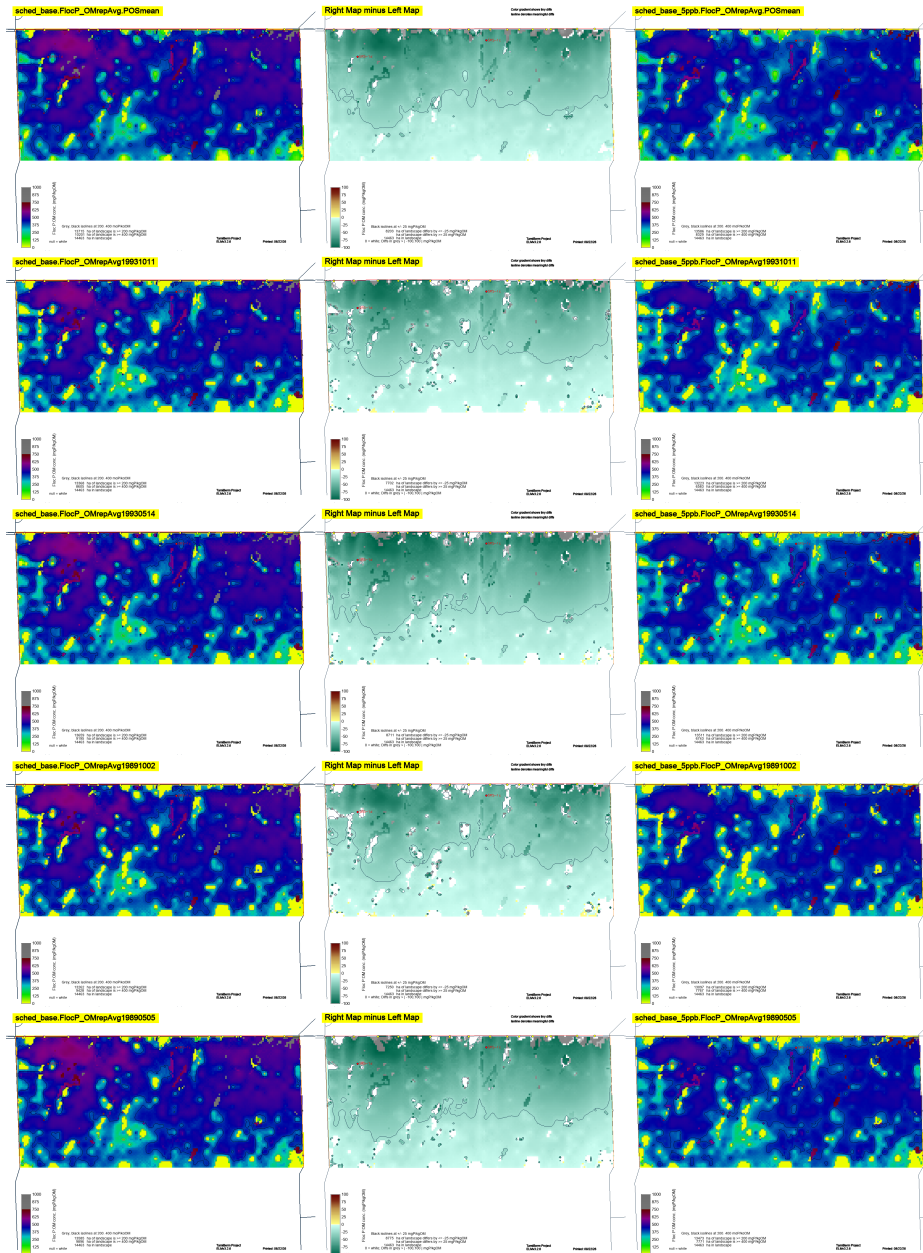
ELM3nesrs_100: Application Documentation



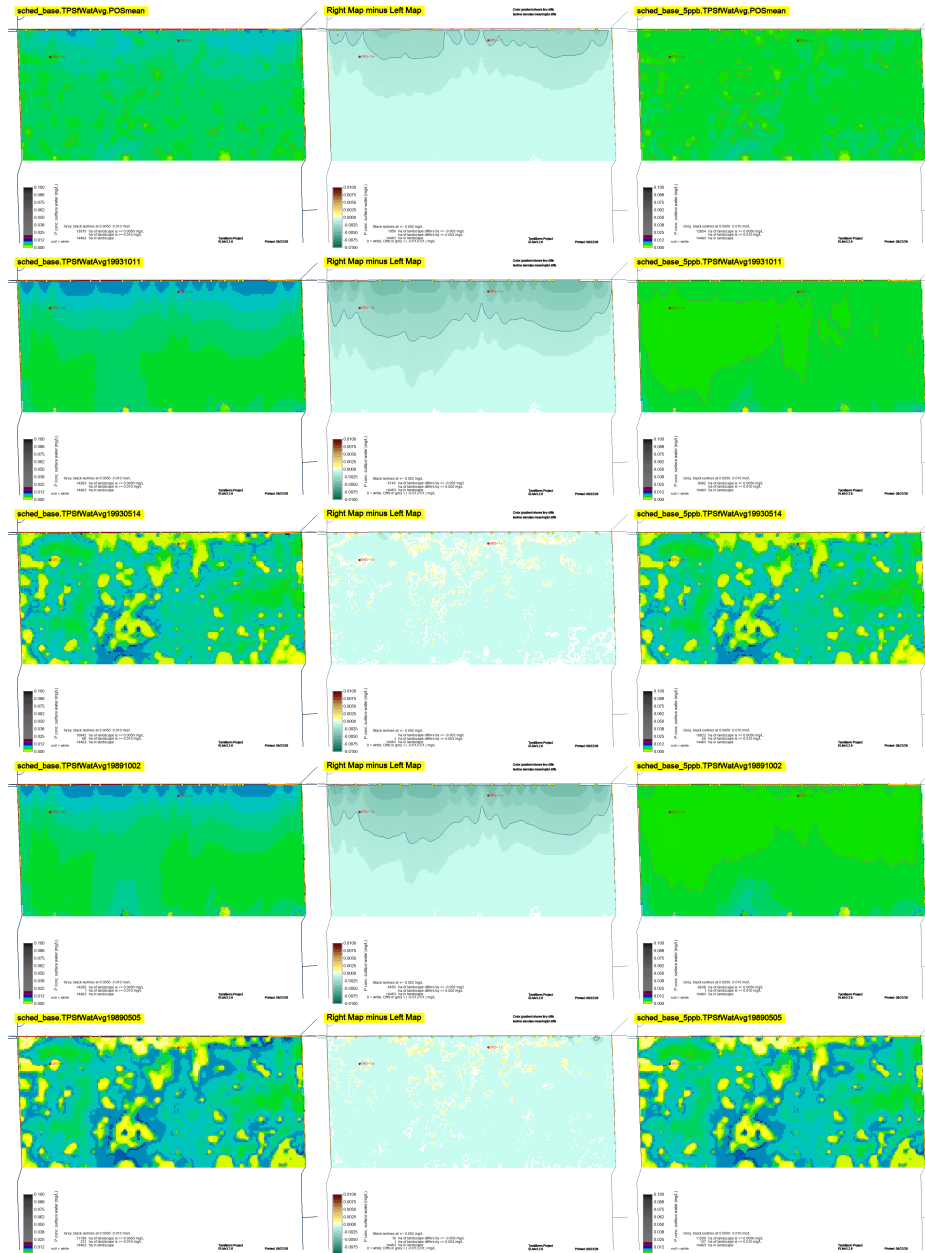
ELM3nrs_100: Application Documentation



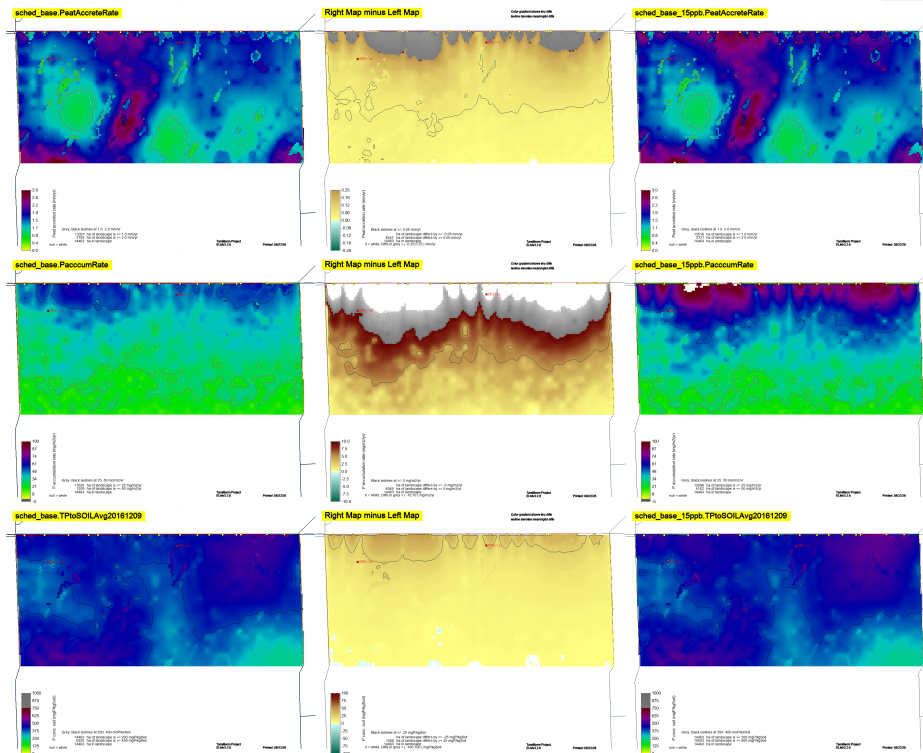




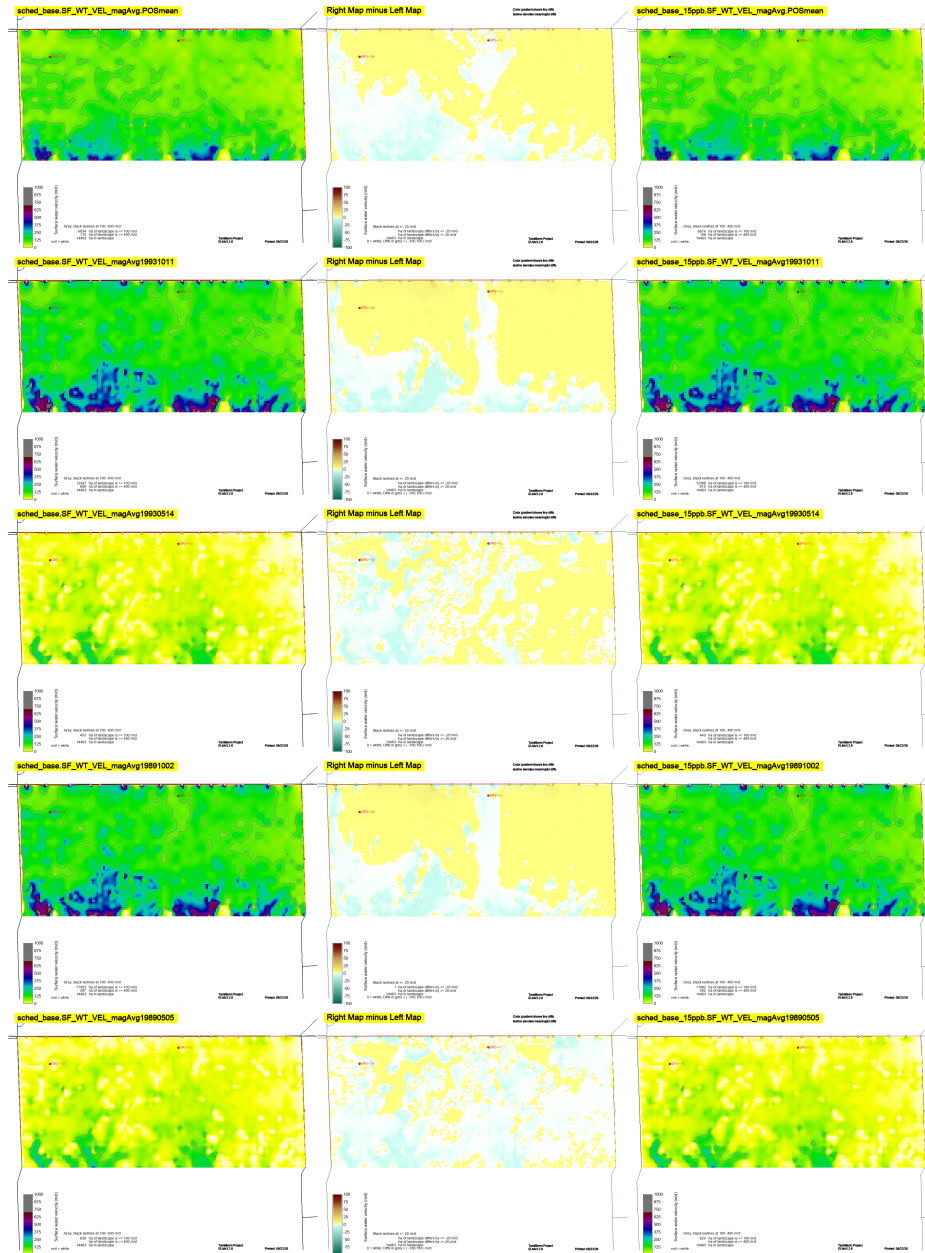
ELM3neers_100: Application Documentation



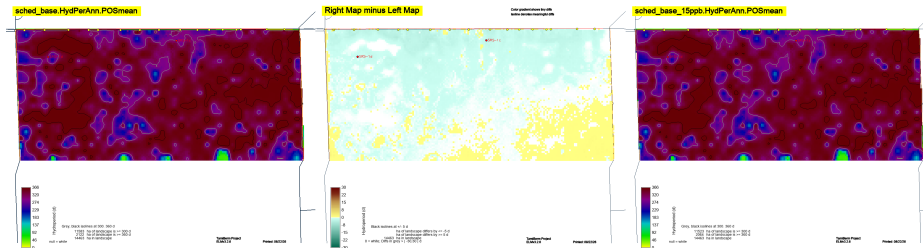
1.6.1.4 Scenario: *sched_base_15ppb*



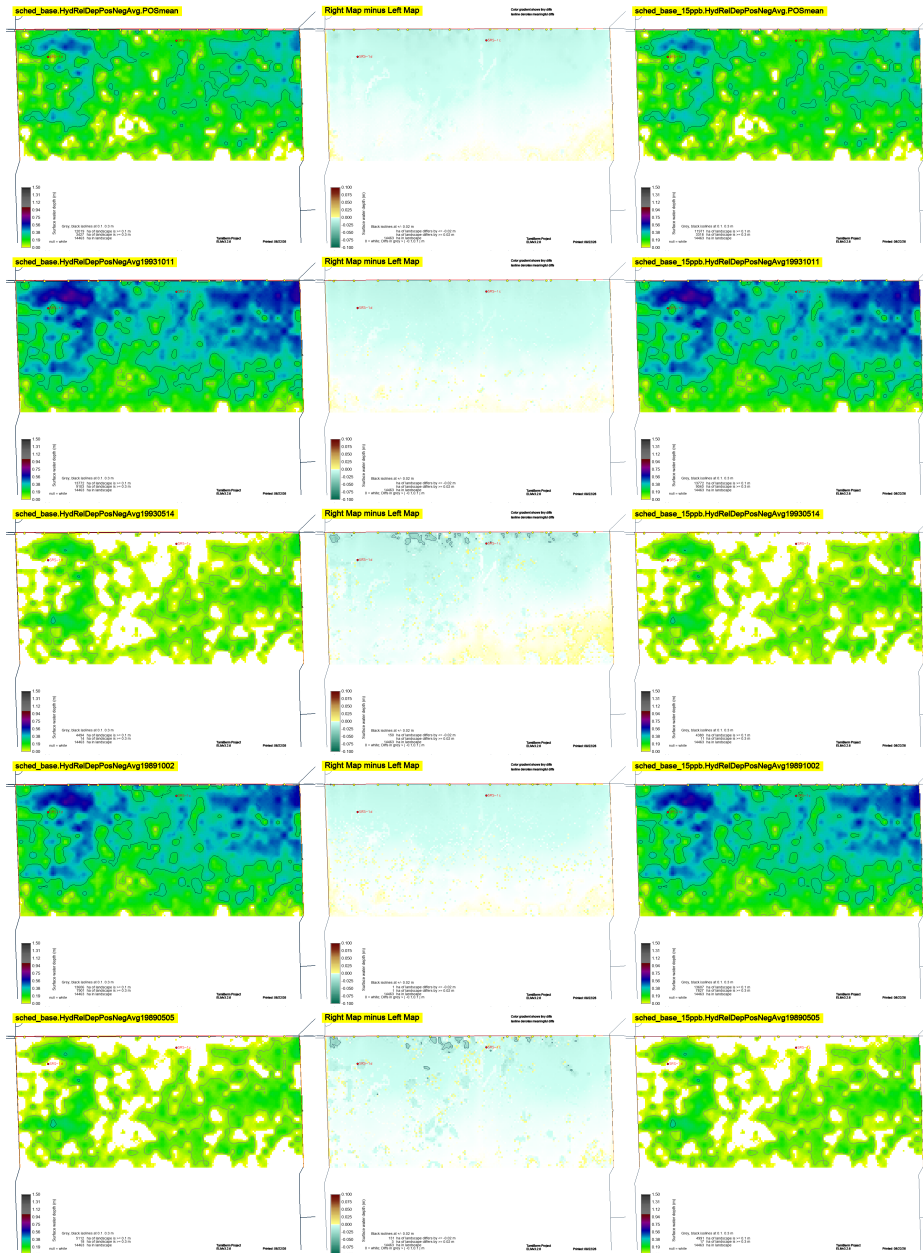
ELM3nrsr_100: Application Documentation

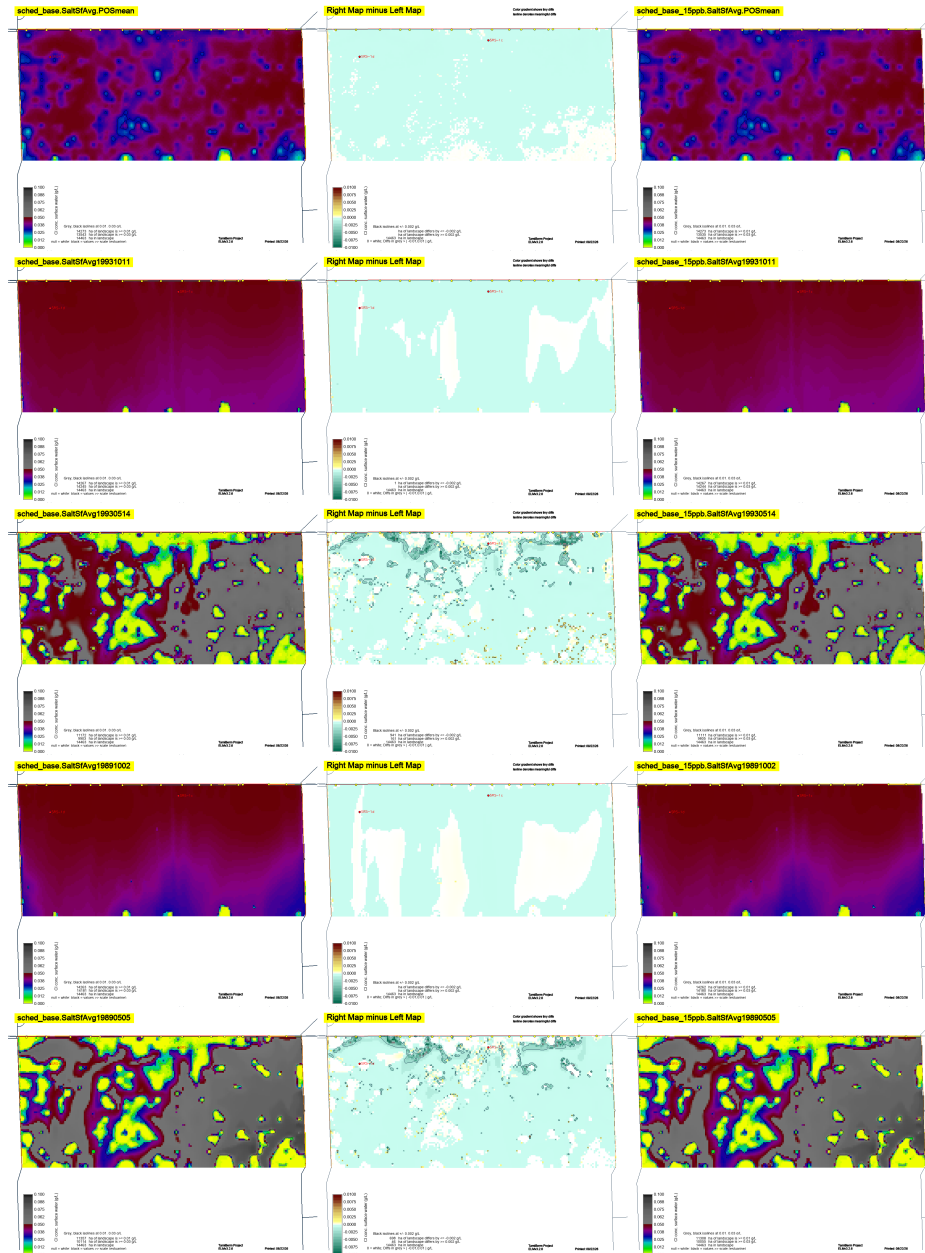


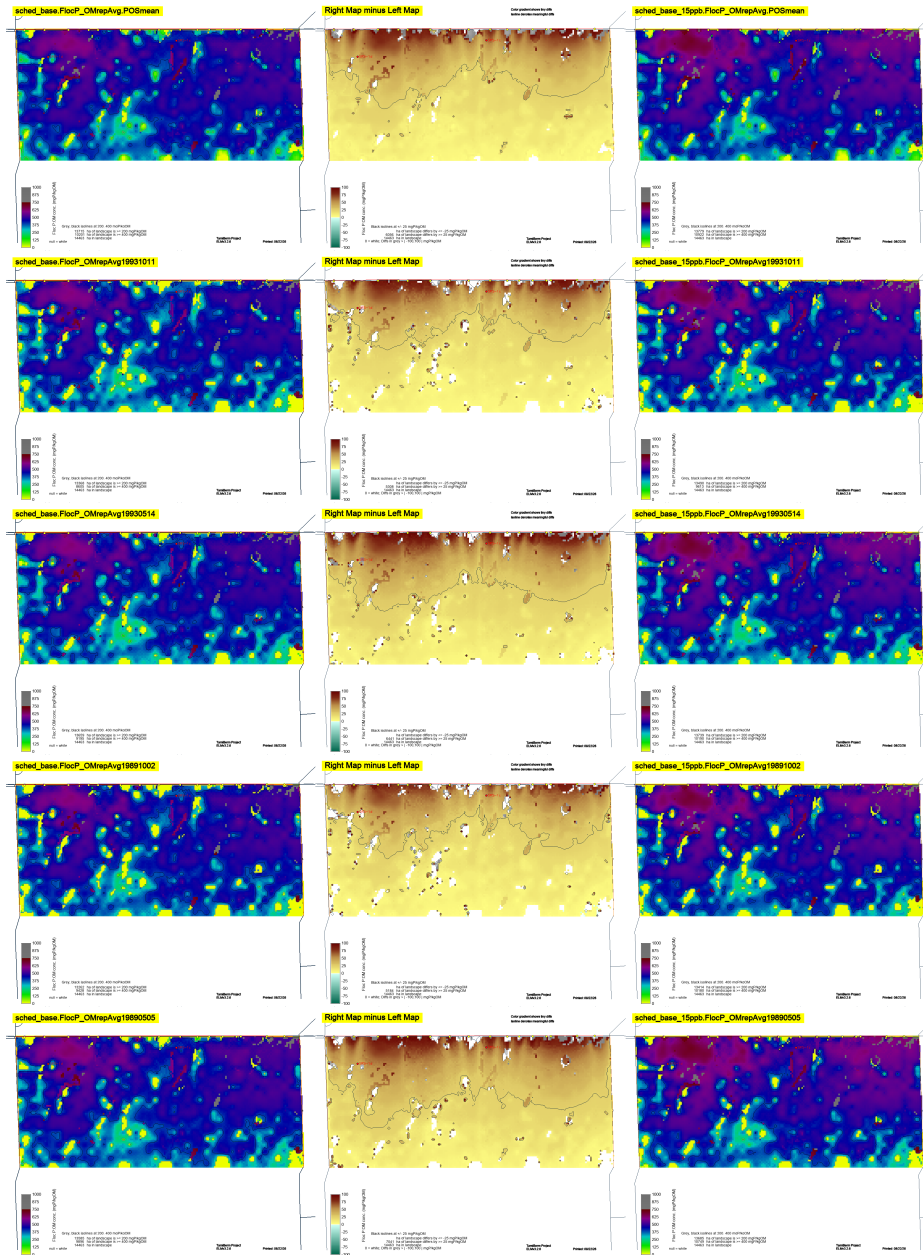
ELM3hesrs_100: Application Documentation



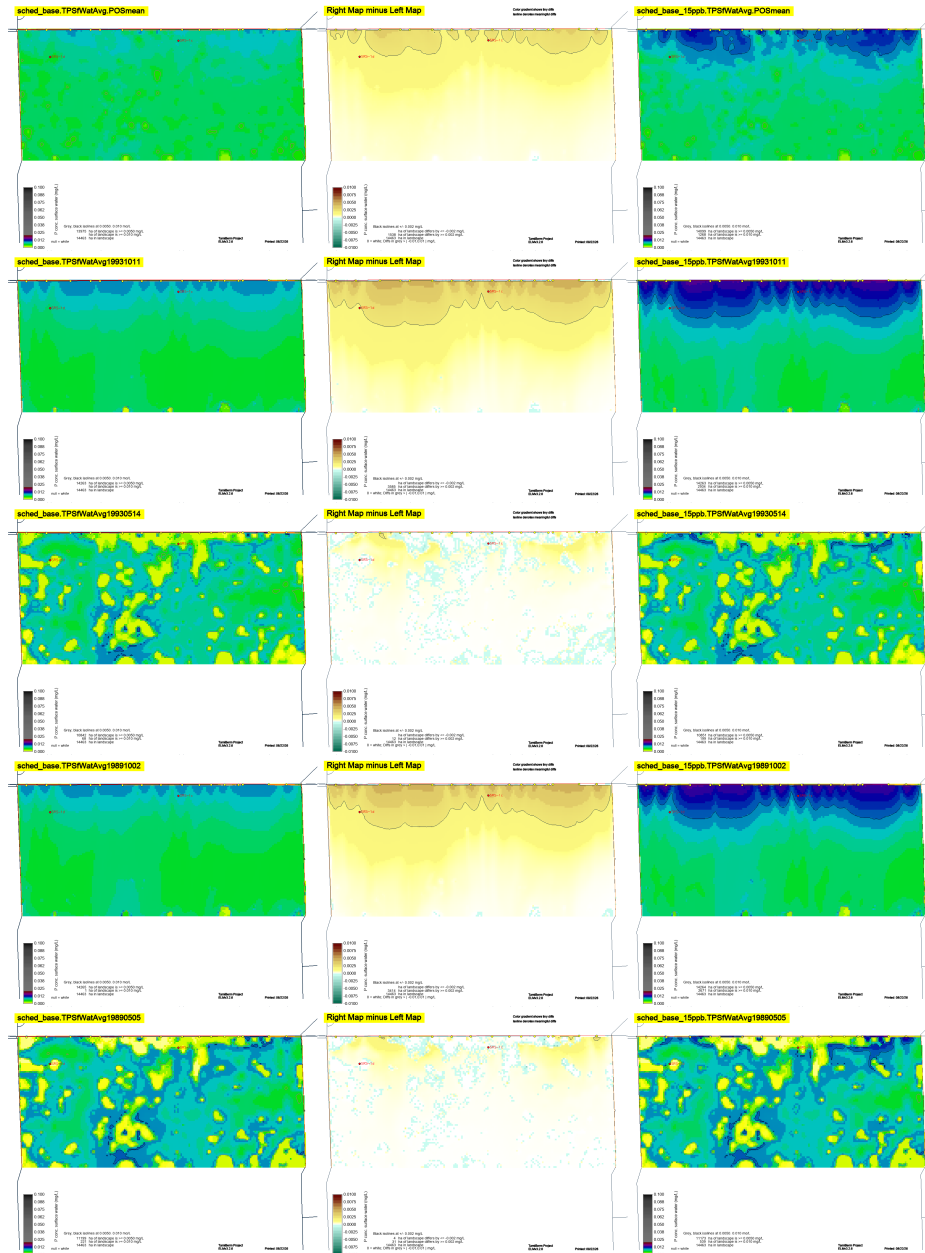
ELM3nrsr_100: Application Documentation







ELM3neers_100: Application Documentation



1.6.2 Difference Graphs in BIR transects

As indicated in the **Introduction**, our goals involved an improved understanding of hydro-ecological variables downstream of the altered gaps in the Tamiami Trail. Towards that focus, the Basin/Indicator Regions (BIRs) were defined as a series of five North-South, generally down-elevation, transects associated with the three existing bridge gaps and the two FCE monitoring sites (see above Figure 5 in Input Data section). The transect distances from the Tamiami Trail gap inflows increased roughly-geometrically (including FCE SRS-1c and SRS-1d distances): 300 m, 700 m, 1700 m and 4300 m.

For this work, the BIRs were used to explore Period of Simulation (POS) means and time series details of hydro-ecological variables along spatial BIR gradients.

For these ELM3nesrs_100 applications, we always output a wide variety of hydro-ecological variables for all BIRS, at a (calendar) monthly outstep. Individual BIR budgets of water, phosphorus, and chloride are always calculated, using a variety of mass and volume units for use in a variety of evaluation objectives. Moreover, we also always output a set of "primary", most-used, hydro-ecological variables that are averaged within each BIR within an outstep period. All of these BIR files are output as tab-delimited text files (for easy copy-paste into MS Excel spreadsheets).

We used MS Excel ELM-output templates to copy-paste Base vs. Alternative scenario BIR output for a range of selected variables. There is a very large number of BIR time series graphs (20 BIR graphs per Alternative scenario, per BIR output variables' file), and here we only present some examples.

1.6.2.1 Regulated stage near NESRS2

Prior to describing the BIR-based results, we first show an example of the water stages at the transect point that is very close to the NESR2 stage regulation monitoring site. The below Figure_Graph1 shows that:

- There were virtually no meaningful differences in realized stage among several scenarios (sched_base, sched_no1Mi, sched_noBridg), due to the schedule-driven algorithm that regulates the targeted stage.
- Stage was maintained reasonably well, in accordance with a seasonal schedule.
- ***Land elevation gradually increases during the 5 simulated decades; because the stage regulation targets do not evolve with land elevation, marsh water depths necessarily decrease*** (inferred, not shown here).

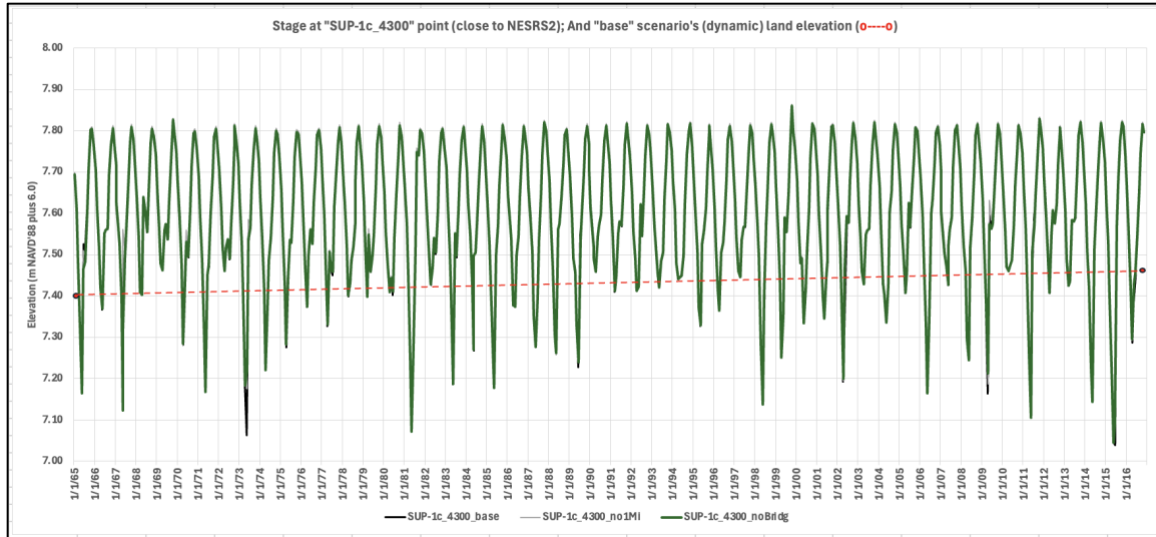


Figure Graph1. Simulated stage at the transect point near NESRS2 for 3 future scenarios. Simulated land elevation for the future sched_base scenario is shown for reference. Note that the elevation shown here includes the addition of the ELM base_datum of 6.0 m, added to NAVD '88..

1.6.2.2 BIR transect from 1 Mile Bridge: Surface water velocity time series

- *sched_base* vs. *sched_no1Mi* comparisons - below Figure Graph2.
 - In this transect downstream of the 1 Mile Bridge area: relative to the *sched_base*, the *sched_no1Mi* scenario had consistently much-lower peak velocities @300 m distance, and lesser-magnitude but meaningful lower velocities @700 m distance. Generally the differences dropped off to near-no-difference @4300 m.

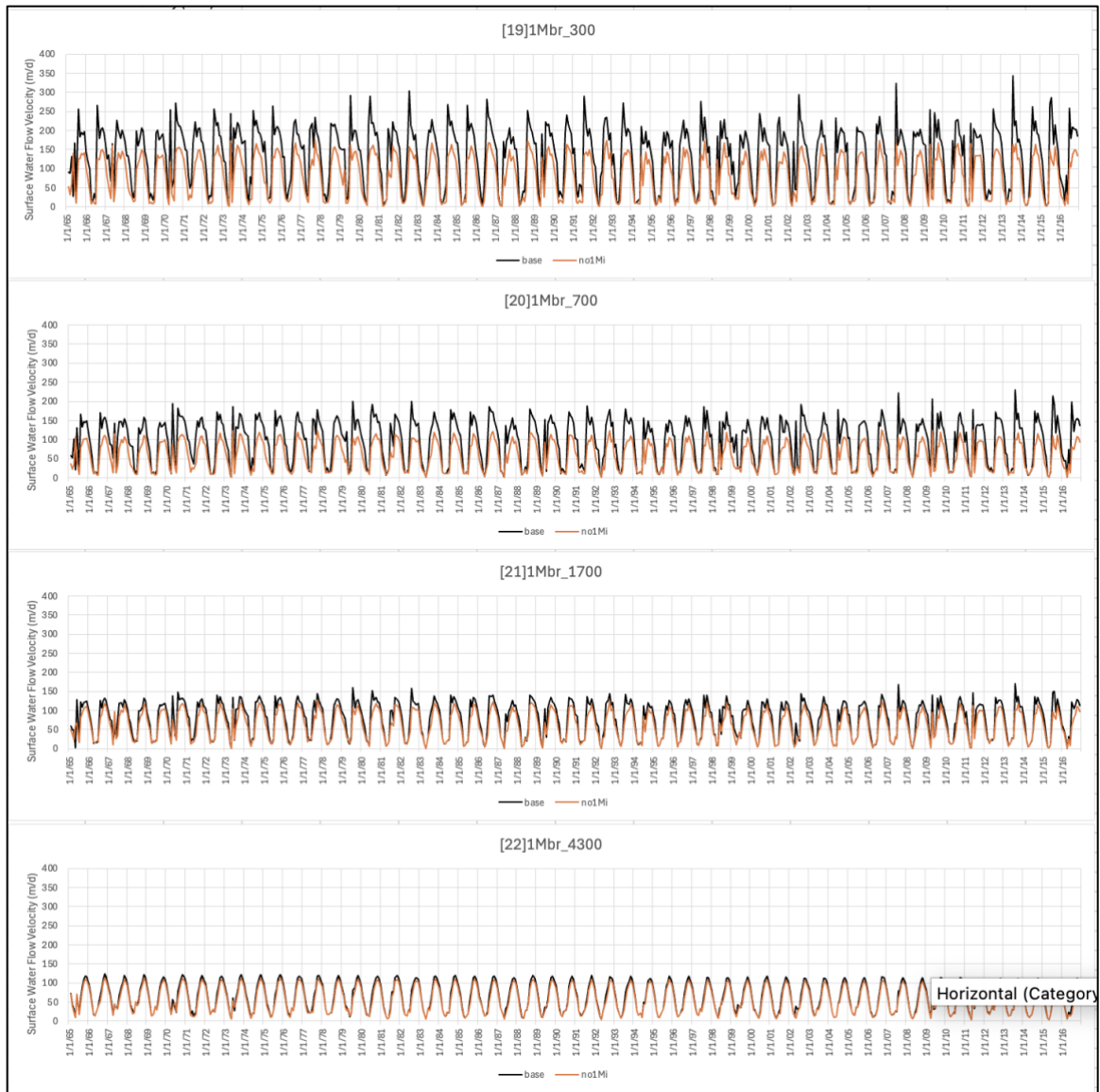


Figure Graph2. Simulated surface water velocities along the BIR transect south of the 1 Mile Bridge area, comparing the sched_base and sched_no1Mi future scenarios.

1.6.2.3 All BIR transects: Surface water velocity POS means

- *sched_base* vs. *sched_no1Mi* and *sched_noBridg* comparisons - Period of Simulation (POS) mean values shown in below Figure Graph3.
 - Compared to the *sched_base*, the *sched_no1Mi* and *sched_noBridg* scenarios had dramatically lower velocities @300 m and @700 m distances downstream of the 1 Mile Bridge area, with some decline in those differences further south.
 - In contrast, the other transects to the west of 1 Mile Bridge area generally had marginally higher velocities in the *sched_no1Mi* vs. the *sched_base* at all distances.

- The sched_noBridg scenario had generally lower velocities than the sched_base in most transects, but results varied depending on transect and transect distance.

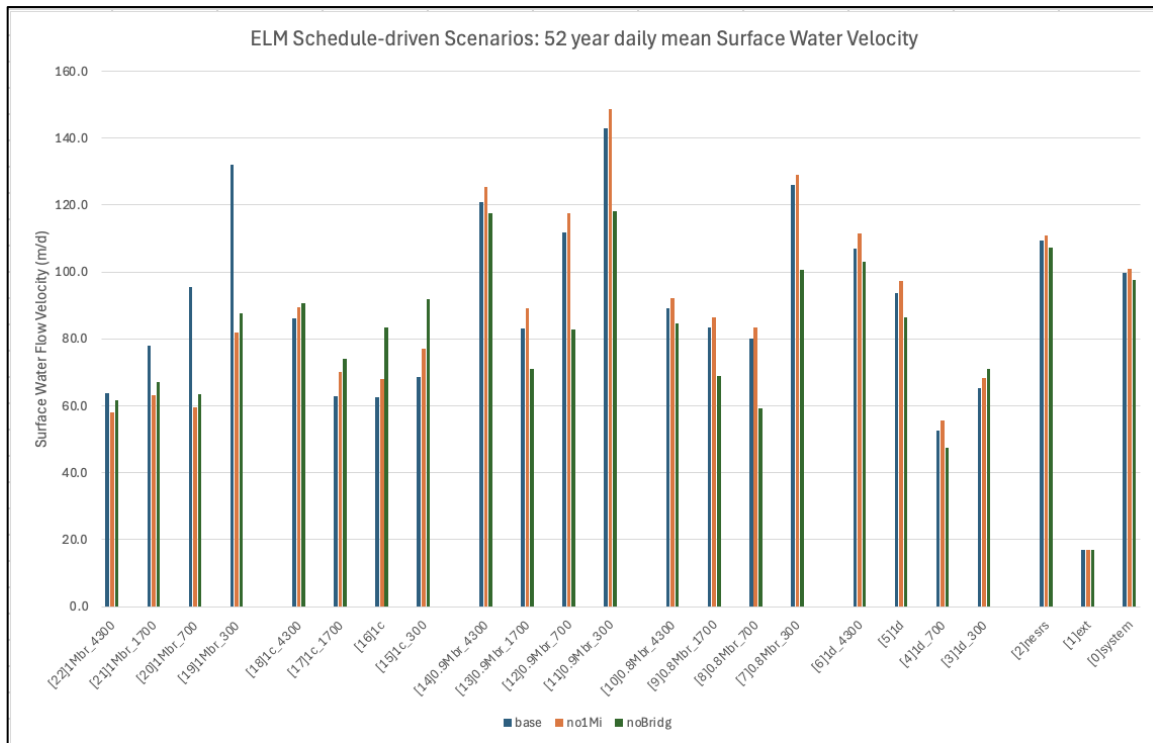


Figure Graph3. Simulated Period of Simulation (POS) mean surface water velocities along all BIR transects, comparing the sched_base, sched_no1Mi, and sched_noBridg future scenarios.

1.6.2.4 All BIR transects: P accumulation POS rates

- *sched_base* vs. *sched_no1Mi* and *sched_noBridg* comparisons - Period of Simulation (POS) mean rates shown in below Figure Graph4.
 - In all scenarios, P accumulation rates decreased down-transect in all 5 BIR-transects, at roughly similar distance-decreases, down to slightly exceeding the ambient atmospheric P deposition rate.
 - At the eastern-most transect (downstream of the 1Mi Bridge area), the sched_no1Mi and sched_noBridg scenarios always had noticeably lower (than sched_base) P accumulation throughout the transect; these differences were possibly ecologically meaningful.
 - In the sched_no1Mi scenario, the 4 western transects had slightly higher P accumulation than the sched_base throughout each transect, but the differences were probably not ecologically-meaningful.
 - In the sched_noBridg scenario, the 4 western transects often had slightly lower P accumulation than the sched_base throughout each transect, but the differences were variable across transects, and were probably not ecologically-meaningful.

- P accumulation in the sched_base exceeded the 50 mg/m²/yr threshold @300 m and @700 m distances in all BIR transects except for the transect immediately west of the 1 Mile Bridge area.
- In the sched_no1Mi and sched_noBridg scenarios at those @300 m and @700 m distances, the eastern-most (1 Mile Bridge) transect P accumulation was lower than the 50 mg/m²/yr threshold.

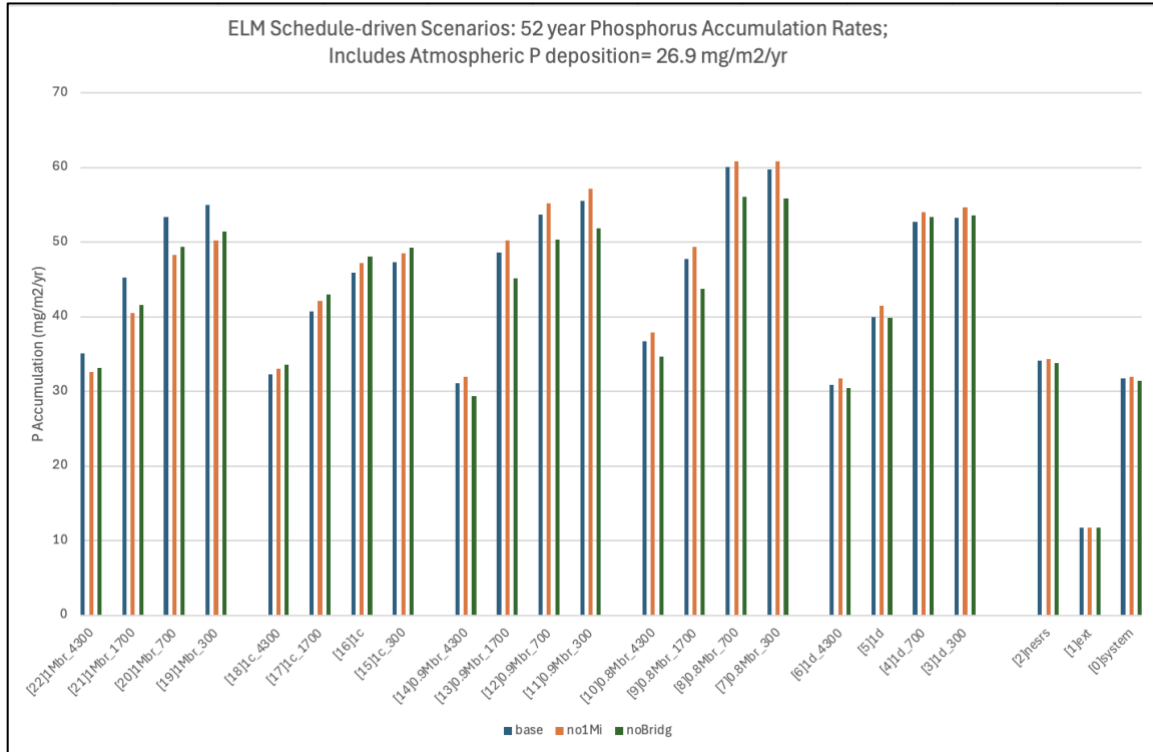


Figure Graph4. Simulated Period of Simulation (POS) rates of P accumulation along all BIR transects, comparing the sched_base, sched_no1Mi, and sched_noBridg future scenarios.

1.6.2.5 All BIR transects: peat accretion POS rates

- *sched_base* vs. *sched_no1Mi* and *sched_noBridg* comparisons - Period of Simulation (POS) mean rates shown in below Figure Graph5.
 - In all scenarios, 3 of 5 transects had accretion rates that decreased down-transect
 - In all scenarios, the 2 eastern transects had lower accretion rates @300 m vs at the down-transect @700 m distance, contrary to the decreased downs-transect rates seen in other 3 transects; that appeared to be related to the modal habitat type in those BIR cells, which contained more brush & related habitats.
 - In the sched_no1Mi (vs. sched_base) scenario, the eastern transect (downstream of the 1 Mile Bridge area) had slightly smaller accretion rates in the @700 through @4300 m locations.

- Overall, there were no ecologically meaningful differences in peat accretion rates among scenarios.

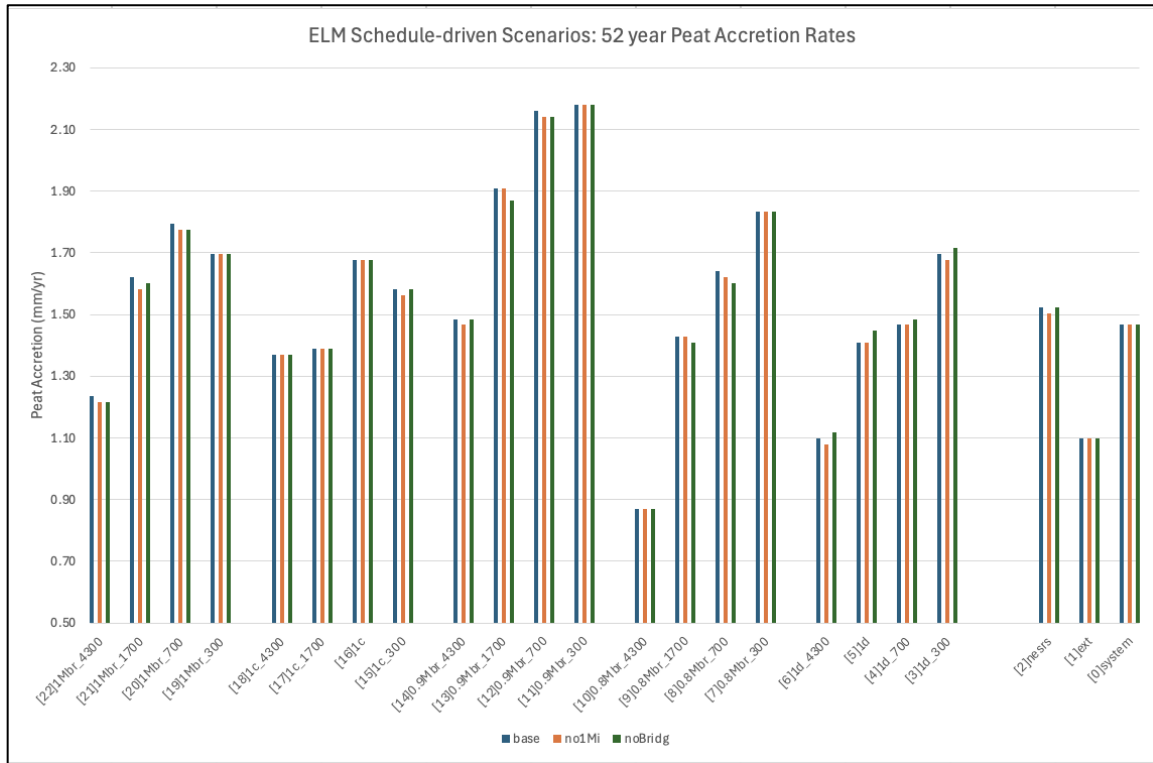


Figure Graph5. Simulated Period of Simulation (POS) rates of peat accretion along all BIR transects, comparing the sched_no1Mi, sched_noBridg, and sched_base future scenarios.

1.7 Synthesis

This purpose of this documentation report is to simply describe the new ELM3nesrs_100 model application to Northeast Shark River Slough. Beyond the atmospheric inputs, the primary drivers of the system were water control structure inflows and dynamic spatial land elevation. Habitat type and dynamic soil properties were critical spatial attributes that significantly influenced hydro-ecological model dynamics.

In our model scenario applications, gap-modifications to land elevation along the 100 m resolution Tamiami Trail berm/road defined several of the simulation scenarios. Two other scenarios increased or decreased water control structure inflow P concentrations from the baseline 10 ppb ($\text{ug} \cdot \text{l}^{-1}$). While the (informative) results are not documented here, other scenarios that we made involved increased or decreased flow capacity of the S333 inflow water control structure (see Table 1: scenarios).

Our future scenarios' "removals" of existing Tamiami Trail gap infrastructure do not judge the efficacy of any particular component: after extensive analyses, these bridge-gaps will certainly advance Everglades restoration via improved flows into Everglades National Park. We simply used these infrastructure scenario changes to explore the hydro-ecological dynamics associated with altered spatio-temporal flow regimes.

Removing 1 Mile Bridge gap: While removing a 1-mile gap in a berm/road ("no1Mi" vs. "base" scenarios, regarding the eastern 1 Mile Bridge along Tamiami Trail) will

clearly, intuitively, decrease flow from the adjacent source canal into NESRS marshes immediately downstream, the model quantified the spatial and temporal extent of this difference across multiple hydro-ecological variables:

- *velocity*: downstream of all culverts and bridges, both (base, no1Mi) scenarios had high surface water velocity pulses, in localized areas ca. hundreds of meters;
- *velocity & depth*: downstream of the 1 Mile Bridge area without the bridge gap, surface water depths and flow velocities were lower (than with bridge gap) for the first ~kilometer, with differences gradually decreasing to minimal with distance at 2-4 km downstream;
- *velocity & depth*: downstream areas west (and a small area east) of the 1 Mile Bridge area (in the without bridge gap scenario) had moderately greater depths and velocities across a broad region, likely offsetting the (without bridge gap) lower values downstream of the 1 Mile Bridge area;
- *phosphorous*: in all inflow areas, the 5-decade total-ecosystem phosphorous accumulation rates were $50\text{--}60 \text{ mg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ (near or above threshold) along the inflows, decreasing ~4 km down transect to slightly above the ambient atmospheric P deposition rate;
- *phosphorous*: downstream of the 1 Mile Bridge area without the bridge gap, P accumulation was significantly lower (than with the bridge gap), which was likely offset by North-South striations of culvert-derived positive and negative differences in western and eastern regions, with striations extending almost to the south domain boundary;
- *peat accretion*: downstream of the 1 Mile Bridge area without the bridge gap, peat accretion was significantly lower (than with the bridge gap), which was likely offset by (limited) North-South striations of culvert-derived positive and negative differences in western and eastern regions;
- *peat accretion*: in all areas, peat accretion was not strongly affected by the scenario changes.

Increased/Decreased P inflow concentrations: These scenarios had relatively minimal effect on most hydrologic variables. While the (model baseline) inflow P concentration of 10 ppb ($\text{ug}\cdot\text{l}^{-1}$) has been considered "protective" of the Everglades, 5 ppb inflows are closer to Everglades National Park ambient surface water marsh concentrations. Using that lower inflow concentration resulted in the entire NESRS domain having P accumulation rates less than the $50 \text{ mg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ threshold. In that scenario, most of the receiving marsh was closer to ambient atmospheric P accumulation rates.

In contrast, an inflow P concentration of 15 ppb resulted in significant increases in P accumulation rates, with almost a third of the NESRS domain having P accumulation rates above the threshold.

- *phosphorus*: downstream of all culverts and bridges, 5 ppb increases or decreases in inflow concentrations expanded or reduced, respectively, the North-South

extent of exceedances of the P accumulation rate, with difference bands extending ~4 km downstream of the inflows.

We demonstrated that this new ELM3nesrs_100 model application is a useful platform for testing a range of hypothetical scenarios in the NESRS, a marsh which is on the way to partial ecosystem recovery via improved flows across the Tamiami Trail berm/road. In particular, we will use the model in several FCE research applications, investigating process-rate dynamics of the model, extrapolating to the "real world" system across multiple decades. Periphyton, macrophytes, soils, and their interactive biogeochemical cycling will be model venues for improved understanding of the relationships between fast (e.g., velocity) and slow (e.g., soil) process dynamics that assemble and evolve Everglades ecosystems over decadal time scales.

1.8 Literature Cited

-- have not assembled references from the document citations, nor inserted some useful citations in the text. (8/31/26)

1.9 Appendix 1: Elevation development

Description of detailed development methods of the LiDAR and HAED elevation data, including elevation profiles, watershed cumulative flow paths, etc.

-- have not assembled this from existing development notes and map graphics. (8/31/26)

1.10 Appendix 2: Difference Map Summary Example

The table below is an extract from an MS Excel file, which was used in summarizing the broad spatial patterns of the quantitative difference map Performance Measure results.

This is simply an example (sched_no1Mi scenario vs. the sched_base scenario) of how we evaluate overall trends in a similar manner across the 9 Performance Measure variables, including an explanation of the significance of threshold vectors and color table patterns.

Results summaries for Difference Maps

-- **sched_no1Mi** scenario (vs. sched_base scenario)

The below quantitative pattern-comparisons of the future base scenario to the future alternative scenario refer to "significant-vector-area" and "observable-color-area". These are defined as:

-- **significant-vector area** == marsh area within a **vector-delineated threshold** for either the variable's value or for the variable's scenario-difference-value

-- **observable-color area** == marsh area values visible based on the map's color table for either the variable's value or for the variable's scenario-difference-value [See notation on each Difference Map, that **observable-color differences may show ecologically-insignificant differences**; but trends may be inferred]

Veloc	(difference statements all relative to sched_base) --- bottom line diffs no1Mi minus base: POS mean - significant-vector areas of negative differences (base-higher-velocities) downstream of 1 Mile bridge area (w/o bridge), and observable-color negative differences that extended to south domain boundary; in contrast, velocity differences were positive to west of 1 MileBridge area, with patches of significant-vector areas and observable color area extending to south domain boundary --- bottom line variable's values: POS mean - in both (base & no1Mi) scenarios, there were significant-vector areas of high (relative to other marsh) velocities in localized areas downstream of culvert and bridge inflows; these significant-vector values extended along N->S distance ca. several hundred meters, or more, depending on location and scenario
Depth	(difference statements all relative to sched_base) --- bottom line diffs no1Mi minus base: POS mean - significant-vector areas of negative differences (base-higher-depths) downstream of 1 Mile bridge area (w/o bridge), and observable-color negative differences that extended to south domain boundary; in contrast, depth differences were positive to west of 1 Mile Bridge area, with patches of significant-vector areas and observable color area extending to south domain boundary --- bottom line variable's values: POS mean - in both (base & no1Mi) scenarios, depths supported marsh health
HydPer	(difference statements all relative to sched_base)

--- **bottom line diffs no1Mi minus base:** POS mean - observable-color negative differences (base-higher-hydroperiod) downstream of 1 Mile bridge area (w/o bridge) that extended to south domain boundary; in contrast, hydroperiod differences were positive to west of 1 Mile Bridge area, with patches of significant-vector areas and observable color area extending to south domain boundary

--- **bottom line variable's values:** POS mean - in both (base & no1Mi) scenarios, hydroperiods supported marsh health

Cl sf conc (difference statements all relative to sched_base)

--- **bottom line diffs no1Mi minus base:** POS mean - observable-color negative differences (base-higher-Cl sf conc) downstream from 1 Mile bridge area (w/o bridge), that extended to south domain boundary; the region west of this 1 Mile Bridge area broadly had observable-color positive differences

--- **bottom line variable's values:** POS mean - surface water chloride concentration was used only (salinity not effecting this freshwater region) as a conservative tracer of flows from a source, using a constant concentration of 0.050 g/L in the S333 inflow source

P sf conc (difference statements all relative to sched_base)

--- **bottom line diffs no1Mi minus base:** POS mean - very subtle observable-color negative differences (base-higher-P sf conc) downstream from 1 Mile bridge area (w/o bridge), that extended to south domain boundary; the region west of this 1 Mile Bridge area broadly had almost no observable-color differences

--- **bottom line variable's values:** POS mean - surface water phosphorus concentration is not a very useful metric to evaluate eutrophication, at least compared to other model metrics; no marsh area had a concentration exceeding 10 ppb (0.010 mg/L) using a constant concentration of 0.010 mg/L in the S333 inflow source

P floc conc (difference statements all relative to sched_base)

--- **bottom line diffs no1Mi minus base:** POS mean - significant-vector area of negative differences (base-higher-P floc conc) in upper quarter of domain downstream from 1 Mile bridge area (w/o bridge), and observable-color negative differences that extended to south domain boundary; the region west of this 1 Mile Bridge area mostly had observable-color positive differences, but subtle N->S striation patterns of observable-color differences of alternating positive and negative values, almost all positive, with striation patterns extending several km to west; to east of 1 Mile bridge area, a limited area of positive observable-color difference

--- **bottom line variable's values:** POS mean - most of marsh area exceeded a 400 mg/kgOM threshold; that threshold is specific to total inorganic+organic mass of soil (mgP/kg soil), maintained here for consistency; P concentration relative to kg of organic matter is much higher in flocculent organic matter; regardless, while these values are reasonable approximations to observed values, they are likely overestimates, and relative differences among scenarios are most appropriate (as with all model scenario comparisons)

P soil conc (difference statements all relative to sched_base)

--- **bottom line diffs no1Mi minus base:** Simulation end - observable-color negative differences (base-higher-P soil conc) that extended to south domain boundary; the region west of this 1 Mile Bridge area broadly had observable-color positive differences; to east of 1Mi bridge location, a limited area of positive observable-color difference

--- **bottom line variable's values:** Simulation end - limited marsh area exceeding a 400 mg/kgSoil threshold (generally due to initial, antecedent, conditions)

P accum (difference statements all relative to sched_base)

--- **bottom line diffs no1Mi minus base:** POS rate - significant-vector area of negative differences (base-higher-P accumulation rate) in upper half of domain downstream from 1 Mi lebridge area (w/o bridge), and observable-color negative differences that extended to south domain boundary; the region west of this 1 Mile Bridge area mostly had observable-color positive differences, but N->S striation patterns of (large magnitude, but not quite significant-vector) observable-color differences of alternating positive and negative values, mostly positive, with striation patterns extending several km to west; to east of 1Mi bridge location, a broadly distributed positive observable-color difference, with a significant-vector (small) area

--- **bottom line diffs no1Mi minus base (summary):** POS rate - ecologically meaningful negative differences (base-higher-P accumulation rate) in P eutrophication in limited area downstream of the 1Mi bridge area (w/o bridge), which were likely offset by broad swaths, and difference-striations, of positive differences to the west -- striations associated with culverts

--- **bottom line variable's values:** POS rate - in both (base & no1Mi) scenarios, most of the marsh had P accumulation rates less than the 50 mg/m²/yr threshold; but exceedances broadly occurred in N->S patterns within a ~kilometer downstream of the culverts-bridges inflows (which came from S333 10 ppb TP concentration inflows into L-29 canal, exiting south via culverts-bridges)

Peat
accret

(difference statements all relative to sched_base)

--- **bottom line diffs no1Mi minus base:** POS rate - significant-vector area of negative difference (base-higher-peat accretion rate) in upper third of domain down from 1 Mile bridge area (w/o bridge), and observable-color negative diffs that extended almost to south domain boundary; the region west of this 1 Mile Bridge area had N->S striation patterns of observable-color diffs of alternating positive and negative diffs, mostly positive, with striation patterns extending several km to west; to east of 1 Mile bridge area, a broadly distributed positive observable-color difference with a significant-vector (small) area

--- **bottom line diffs no1Mi minus base (summary):** POS rate - while possibly not ecologically meaningful, the sched_no1Mi had less accretion downstream of 1 Mile bridge area (w/o bridge); N->S patterns of alternating positive and negative differences extended several km to west of that area -- striations associated with culverts

--- **bottom line variable's values:** POS rate - in both (base & no1Mi) scenarios, all marsh areas had positive, and not excessive (via eutrophication), accretion rates consistent with a healthy marsh

Overall

So, in this modeling context, the removal of the 1mile bridge had little marsh ecosystem benefit, except by reducing P accumulation downstream of the (removed) 1 Mile bridge, which may have some very localized marsh ecosystem benefit. This P accumulation (via loading) difference likely led to marginally lower (but healthy) peat accretion rates. The significant velocity decreases in that general area (down from the removed 1Mi bridge) may have influenced several other model-process variables, not explored here.