Chapter 11: Model Perturbation Experiments

11.1 Overview

At the request of the ELM Peer Review Panel, we *examined the ecological dynamics that were simulated by the Everglades Landscape Model (ELM) under a suite of extreme scenarios of altered phosphorus (P) loads and initial conditions*. For these "perturbation experiments", we evaluated a (100 km^2) subregional application during century-long simulations, and evaluated the entire (>10,000 km^2) Everglades regional landscape during simulations of two decades in duration. The century-scale simulations encompassed one simple spatial gradient, facilitating the interpretation of the non-linear ecosystem interactions through space and time. The regional simulations included not only those complex-system dynamics, but spanned a mosaic of ecosystems that were strongly influenced by managed flows of water and nutrients along multiple gradients.

There are two simple Performance Measures that are available for use in planning-applications of ELM v2.5/2.6: P accumulation in the ecosystem, and P concentration in surface waters (Chapter 8). These two Performance Measures, and particularly P accumulation, effectively integrate and summarize the multitude of ecosystem processes that describe the long term dynamics of Everglades P biogeochemistry. Both Performance Measures were used in assessing the results of the perturbation experiments, and should be considered to be the primary quantitative tools in this analysis.

The ***goal of the perturbation experiments was to provide another basis for better understanding the ELM capabilities in simulating P dynamics of the Everglades***. To meet that goal, it was necessary to consider more than the two application Performance Measures, and delve into the changes in the rates and storages of phosphorus (and carbon) under a range of extreme conditions. These whole- ecosystem evaluations of the 20-yr and 108-yr perturbation experiments yielded significant explanatory insights, and proved to be an invaluable tool for demonstrating the model capabilities. For these model perturbation experiments, which were driven by large ("unrealistic") extremes in environmental inputs, the *expectation was that the model responses should be consistent with expert scientific understanding of ecosystem dynamics*.

The post-processed, graphical results from the regional, 20-yr perturbation experiments were provided to the Peer Review Panel soon after their initial request in August 2006. Those results provided insight into the regional ELM capabilities, but (as with many experiments), the information also led to more detailed questions that were posed by the Review Panel. In general, *spatial heterogeneity of the regional landscape made it difficult to interpret a small subset of the results*, in the relative absence of (the user's) knowledge on other landscape characteristics such as the magnitude and direction of water/nutrient flows. In particular, the regional Everglades system is sharply demarcated by impounded hydrologic basins, with managed flows within and among basins that impose significant controls on ecosystem (incl. water, nutrients, plants, & soils) dynamics. These flow complexities, combined with spatial heterogeneity of habitats and of soil properties (such as bulk density), made the regional simulations far from idealized experiments in which all factors were directly controlled or otherwise factored into the results. We addressed specific questions regarding localized behavior of the regional application - after demonstrating the underlying ecosystem dynamics via the simpler spatial configuration of the century-scale perturbation experiments.

Compared to the regional perturbation experiments, the *century-scale simulations more directly provided insights into the ecosystem dynamics of the ELM* algorithms. Similar perturbations to this much simpler landscape demonstrated the cumulative, multi-decadal changes in principal ecosystem measures of eutrophication along simple gradients.

The ELM explicitly *considers (many of) the principal mechanisms responsible for ecosystem dynamics, and thus the direct and indirect interactions among model variables may lead to results that may initially be thought to be counter-intuitive*. There were a variety of dynamic behaviors found in the (two-decade and) century-scale simulations that effectively summarize some of the strengths of the ELM algorithms. Compared to a "nominal" scenario, doubling the load of P into the receiving "basin" led to a larger (>2x over nominal) increase in the accumulation of P within the basin's ecosystem. This was a result of a P-limited system that had high affinity for P, with accelerated growth (and P uptake) under increased loads, which in turn led to increased turnover and thus increased P accumulation in the long term soil storages. In another positive feedback mechanism, higher initial P concentrations in upstream soil storages led to increased decomposition (and P loss) rates within that local basin, again compared to the nominal conditions. Increased P losses from that basin led to decreased long term P accumulation locally. These upstream losses were reflected in higher P inputs to downstream receiving basins, and increased downstream P accumulation relative to the nominal case. Such cascading downstream effects are an important part of understanding spatial and temporal changes in Everglades P dynamics.

Not all of the details of these rate processes are completely understood under the full range of possible environmental drivers, but these rates are not the specific focus of model application. The simpler model application Performance Measures have been shown, in the Model Performance Chapter 6, and in the perturbation experiments, to be effectively simulated by the ELM. Relative comparisons of the ELM output for the P accumulation and surface water concentration Performance Measures appear to be well within the bounds of available knowledge on Everglades dynamics. Importantly, the process-based framework of this landscape model can also continue to serve as a tool to identify research needs, providing spatial and temporal extrapolations of advances in field research.

11.2 Background

During the August 1-2, 2006 Workshop I of the ELM Peer Review[1], the Review Panel requested that they be provided with simulation results under a variety of different phosphorus (P) loads and initial conditions. The basic intent of this request was to understand the range of model responses to significant changes in P loads or initial P conditions. Moreover, while a 2-decade (ELM v2.5 calibration/validation period) simulation represents a long time scale for most hydrologic and water quality processes, there are longer time scales of interest for some ecological processes involving soil and habitat characteristics. Thus, the Panel also expressed the desire to view the behavior of the ELM over the very long time scales of a century duration.

In addition to the nominal (i.e., historical) simulation, the Panel requested five simulations of varying P loads or initial conditions:

Initial P conditions	Phosphorus (P) Loading
Zero, or very-low	Nominal input concentrations
Double Nominal	Nominal input concentrations
Nominal	Zero P input concentrations
Nominal	Double P input concentrations
Nominal	Halve P input concentrations
Nominal	Nominal input concentrations

The ***goal of these "perturbation experiments" was to provide another basis for better understanding the ELM capabilities in simulating P dynamics of the Everglades***. For our initial response to the information needs of the Review Panel, we developed simulation perturbation experiments for the regional ELM application of 20 year duration (for direct comparison to the Chapter 6 Model Performance historical simulation), delivering model output summaries on August 23, 2006. Following the delivery of these results, the Panel continued to maintain an interest in viewing results for longer (century) time periods. Data constraints made this a significantly more involved effort, and discussions with the Panel led us to formulate such simulations for new subregional applications. Questions that the Panel had posed regarding the results of the 20-year perturbation runs were also considered in producing the century-scale perturbation experiments, which were posted on the ELM web site in draft form during the Developer response time period on November 15, 2006, and updated to this version (and posted) on November 22, 2006.

There are two simple Performance Measures that are available for use in planning-applications of ELM v2.5/2.6: P accumulation in the ecosystem, and P concentration in surface waters (Chapter 8). These two Performance Measures, and particularly P accumulation, effectively integrate and summarize the multitude of ecosystem processes that describe the long term dynamics of Everglades P biogeochemistry. Both Performance Measures were used in assessing the results of the perturbation experiments, and should be considered to be the primary quantitative tools in this analysis.

[1] ELM documentation and information on the Peer Review project are available at: http://my.sfwmd.gov/elm

The impetus for initial development of the century-scale, subregional applications was to respond to information needs from the panel, with the primary objective of documenting ELM responses to phosphorus perturbations over very long time scales. Beyond this primary objective, we viewed this as an opportunity to initiate development of some model applications at fine spatial grains and large time domains that could be used in a research framework (also a Peer Review Panel recommendation). Using a combination of observed and "synthetic" data, we developed "Ridge & Slough" applications of the ELM. These applications continued to use algorithms and parameters that were unchanged from ELM v2.5, temporally extrapolating the effects of long-term interactions between ecosystem processes and landscape patterns in the Everglades. In this first step, we used the model to synthesize some of the simple process interactions that lead to maintenance of an anisotropic pattern of habitats in the Everglades – a patterned habitat that has undergone significant degradation in response to decades of water management practices. A brief summary of those results were posted on the ELM web site (and are not discussed further in this Model Perturbation Experiments Chapter).

11.3 Data

The input data to these perturbation experiments took on a variety of forms, depending on the time and space scales of the application. Their simplest implementation involved the regional ELM within a 20-yr simulation time domain. Virtually all of the data used in those perturbation experiments are described in the Data Chapter 4 of the ELM v2.5 Documentation Report; the several modifications to data for perturbation experiments are summarized below. However, the century-scale simulations involved significantly more data preparation.

The Review Panel had expressed interest in viewing greater Everglades, regional simulations that spanned a century duration. This request involved significantly more data constraints than that of the shorter term (2 decade) perturbation experiments. The maximum length of time that regional models simulate hydrology in south Florida is across a 36 yr Period of Record (POR). The initial Panel request involved the perception that available climate and managed water control structure flow "drivers" of the ELM could be concatenated for a longer regional simulation to meet the perturbation experiment needs. However, a major constraint in generating regional ELM simulations across time periods longer than the available POR involves the managed flows among hydrologic basins. The available volumes of water at the ending time of a 36-yr period are different from those found at the initial time point. The concatenations of a 36-year period of input "forcing" data in a simulation of a century duration (or restarts of multiple simulations, with ending conditions being the initial conditions for another simulation) are significantly complicated by the often large mismatch between end-of-period stages in each basin and the subsequent restart/concatenation of managed (input data) flows that assume very different volumes of water to manage at the beginning of a period of record. Reconciling these managed flows with the available volumes would have required significant efforts to modify the flow and/or volume data, or would have required a new application of the SFWMM[2] for century long simulations using 36-yr concatenated

[2] South Florida Water Management Model. The SFWMM has made hydrologic predictions for managed flows under 36 yr future scenarios, assuming variations in future climate inputs will be similar to the

meteorological data. Neither effort would be considered useful for future model applications (beyond the experiment for ELM perturbations across century time scales). Due to such considerations, the creation of a century-scale simulation of the regional ELM was not considered feasible within the time constraints of the ELM Peer Review Project.

For the century-scale model experiments, some new subregional applications were created. Compared to the regional application, the subregional applications were significantly simpler due to the removal of water management considerations within the model domain. Moreover, the domain was selected such that it was within the interior region of a hydrologic basin, and thus further simplified the boundary conditions by obviating the need to consider levee boundaries. Another consideration was the potential application needs for century scale simulations: the domain was ultimately chosen to partially fulfill a significant research need, by investigating the fine scale, local ecosystem dynamics associated with water flows and depths within an anisotropic patterned mosaic of habitats in the central Everglades of Water Conservation Area 3A.

We created 1000 m, 500 m, 250 m, and 125 m applications of this subregional domain. For simplicity, and to focus on meeting the specific information needs of the Peer Review Panel for century-scale perturbation experiments, we summarize here only the 250 m grid subregional application as it was configured for the perturbation experiments.

11.3.1 Common data

11.3.1.1 20-yr simulations (regional)

With the exceptions (described in a later section) that were used to alter phosphorus loads or initial conditions for perturbations, the data used to initialize and drive the model for the 20-yr (1981-2000) regional simulations were identical to those documented in the ELM v2.5 Documentation Report.

11.3.1.2 108-yr simulations (subregional)

11.3.1.2.1 Domain

The domain was selected to encompass a subregion of central Water Conservation Area 3A, south of I-75 (Alligator Alley) and west of the Miami Canal. Figure 11.1 shows the location within the context of the larger region and other ELM subregional applications. The following are the bounding UTM (zone 17, NAD 1927) geographic coordinates of the ELMwca3RS250 (ELM Water Conservation Area Ridge & Slough), 250 m application:

northing:	2,888,989 m
southing:	2,877,989 m
easting:	537,211 m
westing:	526,211 m

For the model domain of this (and each of the other scales of the other ELMwca3RS applications), a bounding buffer of 2 grid cells was added outside of the active “on_map”

available 1965-2000 climate POR (for assessing relative comparisons among scenarios). Historical (observed) managed flows are only available for the entire region from 1981-2000 (and were used in ELM v2.5 calibration/validation described in the Model Performance Chapter 6).

area. The upper left corner of the active grid cells of this ELMwca3RS250 application (and all grid scale applications for this domain) is at 2,888,489 m northing, 526,711 m westing, which nests exactly within the regional ELM grid topology. The active grid cells have 40 rows (10 km) and 40 columns (10 km), while the entire domain is 44 rows x 44 columns.

11.3.1.2.2 Basins/Indicator Regions

The map of the Basins and Indicator Regions (Figure 11.1) defines the spatial distribution of hydrologic Basins and Indicator Regions (BIR). The largest spatial unit is Basin 0, the "basin" of the entire active grid cell domain. For the ELMwca3RS applications, the "basins" defined in this map are not distinct hydrologic units, but are defined merely for convenience to summarize dynamics along a gradient of 1 km grain across a 10 km distance.

11.3.1.2.3 Land surface elevation map

The map of the land surface elevation (Figure 11.3) for the ELMwca3RS250 perturbation experiments was generated by a series of coarse-scale neighborhood filters[3] on an original 125 m resolution land surface elevation map. That original (125 m resolution) elevation map (Figure 11.4) was generated with anisotropic parameters applied in a "regularized spline with tension" interpolation method (GRASS GIS v.surf.rst module). After filtering, the resulting 250 m elevation map used in the perturbation experiments (i.e., Figure 11.3) did not retain any of the fine scale "ridge & slough" topographic pattern, and instead only reflected the coarse scale regional topographic gradient. Note that, unlike the regional ELM v2.5, this ELMwca3RS elevation data was maintained in the NAVD 1988 vertical datum in which the surveyed point data were collected.

11.3.1.2.4 Soil and aquifer maps

The maps of soil total phosphorus concentration, bulk density, and organic bulk density were resampled data from the ELM v2.5 regional application (Data Chapter 4). The resampled data (originally at 1 km resolution) were smoothed at the 250 m grid resolution using a 3-cell neighborhood filter operation. (The soil phosphorus concentration map was modified for two of the perturbation runs, as described below).

The map of hydraulic conductivity was resampled data from the ELM v2.5 regional application (Data Chapter 4). The resampled data (at 1 km resolution) were smoothed at the 250 m grid resolution using a 3-cell neighborhood filter operation.

11.3.1.2.5 Habitat and initial macrophyte biomass maps

For the perturbation experiments, we set the landscape to a homogenous habitat type of "sawgrass plain" (habitat record #2 in the HabParms habitat-specific parameter database, Data Chapter 4). Finer scaled data on classified vegetation types are available, and were used in other applications of ELMwca3RS250. The initial macrophyte biomass was taken to be that of the "sawgrass plain" value used in the ELM v2.5 regional application (Data Chapter 4).

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[3] The neighborhood filter operations effectively removed fine-scaled directionality of the original 125 m topographic surface, such that multiple scales of applications of the ELMwca3RS could be compared without the influence of finer-scaled directional flows induced by a directional ridge & slough pattern.

11.3.1.2.6 Canal and controlled flows

For the perturbation experiments, we placed a (1.5 m deep by 20 m wide) canal running east-west within ~50 m of the northern limits of the active model domain, and ~1 km distant from the east and west edges of the active domain. Flows from a single water control "structure" were input to the canal, which had no levees and thus was a source of canal-to-marsh inflow along the northern domain boundary of the ELMwca3RS250 as implemented for the perturbation experiments. The daily flow data were derived from a 36 year simulation of the SFWMM: one-tenth of each daily outflow from a Stormwater Treatment Area basin (STA 5) was used as input to the ELMwca3RS250. That 36 yr POR of data was concatenated twice, to create a "synthetic" data set that spanned 108 yr.

Overland outflows from the ELMwca3RS250 were calculated internally using new source code for ELM v2.6: a maximum water depth parameter[4] contained in the "ModExperimParms_NOM" data file (see below) was checked during each hydrologic iteration, and a stage-based flux was calculated to reduce the water depth internal to the model towards that depth target. Such boundary condition outflows were allowed only in the easternmost 6 km of the 10 km length of the southern domain boundary, and the southernmost 2 km of the 10 km length of the eastern domain boundary (approximating the topographic outflow pathway).

11.3.1.2.7 Climate

The longest climate record available for spatially explicit, regional simulation in the greater Everglades is a 36-yr data set from 1965-2000[5]. As described in the Data Chapter 4, the climate data inputs to the ELM are rainfall and potential evapotranspiration (pET). For the subregional application, we desired to have simple point time series data that could be readily concatenated temporally, and spatially interpolated across the local domain. Thus, we ran the regional ELM v2.5 for the 1965-2000 POR, with daily point time series output of both rainfall and pET for two locations situated along the northern and the southern boundaries of the ELMwca3RS250 active domain[6]. The data in these two (rain and pET) 36 yr daily point time series data files were concatenated into 108 yr "synthetic" time series, then used as climate data input to the subregional application.

11.3.2 Perturbation data changes

11.3.2.1 20-yr simulations (regional)

For the 20-yr perturbation experiments of the regional application of the ELM, Table 11.1 describes the changes that were made to input data. No source code change (and re-compilation) of the model was needed for these data modifications.

It is important to recognize that the only regional simulation that represents historical "reality" is that of the nominal simulation labeled "perf2.5.2" (whose history-matching performance is described in the Model Performance Chapter 6 of the ELM v2.5

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[4] All perturbation runs maintained this maximum target depth at 60 cm.

[5] As of November 2006, a) a new rainfall data set has become provisionally available for the period 1914-2000; and b) a potential evapotranspiration data set is soon to be available for a similar time span. Neither data set has not been fully evaluated for quality assurance, and were not used in these simulations.

[6] Because there was trivial spatial variability in the climate data at the 10 km x 10 km scale of this domain, we simply chose a single point location for input data, and the ELM internal interpolation thus became a simple homogenous distribution of the data across the entire domain.

Documentation Report). Significant alterations to model inputs in the other simulations represent very large deviations from historical dynamics of the Everglades.

Table 11.1 Perturbation Runs 23-Aug-06

The "perturbation" runs are a series of greater Everglades regional simulations driven by many of the 1981-2000 observed input data, but with significant "perturbations" to the Everglades via altered phosphorus initial conditions or input loads. At the request of the ELM Peer Review Panel, these are newly provided with the objective of diagnosing or evaluating the long-term ELM response to such large deviations in environmental drivers.

The workbooks in this file (**see tabs below**) document the changes to input data that were needed to implement this series of simulations. The intent is to document only those changes; the original data and databases are fully documented in the ELM v2.5 Documentation Report (July 2006), which is found on the ELM web site.

Five perturbation runs were requested, as summarized here.

Run name	Initial P conditions	Phosphorus Loading
IColig_LoadHist	Extremely oligotrophic	Historical (1981-2000) input concentrations
IChist_Load0x	Historical (1981)	Zero P input concentrations
IChist_Load2x	Historical (1981)	Double P input concentrations (relative to historical)
IChist_Load0.5x	Historical (1981)	Halve P input concentrations (relative to historical)
IC2x_LoadHist	Double Historical	Historical (1981-2000) input concentrations
perf2.5.2	Historical (1981)	Historical (1981-2000) input concentrations

The "perf2.5.2" run is the historical simulation that was evaluated in the ELM v2.5 Documentation Report, Model Performance Chapter 6.

ELM web site:
http://my.sfwmd.gov/elm

Table 11.1 Perturbation Runs 23-Aug-06

Managed-flow P loads

A) Time-varying phosphorus (TP) concentration in domain-inflow water control structure flows

Changes to CanalData.struct_TP (data v2.2.3) (ELM v2.5 Documentation Report, July 2006), summarizing the changed concentrations for "perturbation" runs.
The two header rows are from the input data file(s). The "Simulation identity" field denotes the new simulation run's TP Load (Load_) identity
The "Load_hist" Simulation identity uses the unchanged (v2.2.3) data (used in ELM v2.5 documentation)

Simulation identity	year	mo	da	ACME12	G155	G200	G251	G310	L28WQ	S140in	S150in	S175	S18C	S332	S332D	S5A2SO1	S5A2SO2	S6in	S7in	S8in	S9
Load_hist	calib historical TP conc (ug/L TP) from a) Guy Germain, processed daily flow->conc; (see struct_TP.calib.v2.2.xls for details)																				
Load_hist			81-00_Mean:	58.8	121.4	46.0	21.0	40.1	71.1	67.4	66.1	4.6	8.7	8.5	5.2	169.7	169.7	126.3	91.5	102.8	19.1
Load_hist			81-00_Minimum:	50.0	20.0	5.0	6.0	17.7	13.0	4.0	8.0	4.0	1.0	1.0	0.3	4.0	4.0	19.0	10.0	14.2	3.0
Load_hist			81-00_Maximum:	348.0	514.0	423.0	64.0	111.0	666.0	688.0	679.0	15.0	59.0	57.0	15.0	581.0	581.0	872.0	845.2	933.0	172.0

Simulation identity	year	mo	da	ACME12	G155	G200	G251	G310	L28WQ	S140in	S150in	S175	S18C	S332	S332D	S5A2SO1	S5A2SO2	S6in	S7in	S8in	S9
Load_0.5x	calib HALVE the historical TP conc (0.5 * conc, ug/L TP) from Guy Germain, processed daily flow->conc; (see struct_TP.calib.v2.2.xls for details of orig, un-halved data)																				
Load_0.5x			81-00_Mean:	29.4	60.7	23.0	10.5	0.488747	35.5	33.7	33.0	2.3	4.3	4.3	2.6	84.8	84.8	63.1	45.8	51.4	9.6
Load_0.5x			81-00_Minimum:	25.0	10.0	2.5	3.0	0	6.5	2.0	4.0	2.0	0.5	0.5	0.2	2.0	2.0	9.5	5.0	7.1	1.5
Load_0.5x			81-00_Maximum:	174.0	257.0	211.5	32.0	55.5	333.0	344.0	339.5	7.5	29.5	28.5	7.5	290.5	290.5	436.0	422.6	466.5	86.0

Simulation identity	year	mo	da	ACME12	G155	G200	G251	G310	L28WQ	S140in	S150in	S175	S18C	S332	S332D	S5A2SO1	S5A2SO2	S6in	S7in	S8in	S9
Load_2.0x	calib DOUBLE the historical TP conc (2.0 * conc, ug/L TP) from Guy Germain, processed daily flow->conc; (see struct_TP.calib.v2.2.xls for details of orig, un-doubled data)																				
Load_2.0x			81-00_Mean:	117.6	242.8	92.1	42.1	2.0	142.2	134.9	132.1	9.3	17.4	17.1	10.3	339.4	339.4	252.6	183.1	205.7	38.2
Load_2.0x			81-00_Minimum:	100.0	40.0	10.0	12.0	0.0	26.0	8.0	16.0	8.0	2.0	2.0	0.6	8.0	8.0	38.0	20.0	28.4	6.0
Load_2.0x			81-00_Maximum:	696.0	1028.0	846.0	128.0	222.0	1332.0	1376.0	1358.0	30.0	118.0	114.0	30.0	1162.0	1162.0	1744.0	1690.4	1866.0	344.0

B) Constant (non-zero) phosphorus (TP) concentration in domain-inflow water control structure flows

Changes to CanalData.struct (data v2.5.3) (ELM v2.5 Documentation Report, July 2006), summarizing the changed concentrations for "perturbation" runs.
Three domain-inflow structures do not have time-series of observed data, and thus a constant concentration was applied to those inflows.

Name	Load_hist TP (ug/L)	Load_0.5x TP (ug/L)	Load_2.0x TP (ug/L)
NSIMP2	38	19	76
NSIMP3	38	19	76
S332B	7	3.5	14

C) Constant (all-zero) phosphorus (TP) concentration in domain-inflow water control structure flows

Changes to CanalData.struct (data v2.5.3) (ELM v2.5 Documentation Report, July 2006), summarizing the changed concentrations for "perturbation" runs.

For the Load_0.0x perturbation run, ALL domain-inflow structures had a constant 0.0 ug/L concentration applied to those inflows.
A new CanalData.struct_TP time series file is not needed (the string "tser" in CanalData.struct is replaced w/ the constant 0.0 ug/L)

Table 11.1 Perturbation Runs
Initial P Conditions

23-Aug-06

Soil phosphorus concentration, 0-30 cm depth.

The Initial Condition map used in the historical "IC_hist" simulation identity (ELM v2.5 Documentation Report, July 2006) was changed for the two Initial Condition perturbation "Simulation identities" as follows:

Simulation identity	soilTP map operation	Minimum cell value (mg P / kg soil)	Maximum cell value (mg P / kg soil)
IC_hist	Spatially distributed, 1981_estimate (no change)	70	300
IC_olig	Spatially constant, 10 mg P / kg soil	10	10
IC_2x	Spatially distributed, 2.0 * 1981_estimate	140	600

Note that because soil organic bulk density and bulk density are spatially distributed, and vary spatially by more 5x and more than 10x, respectively, the total mass of phosphorus is still spatially distributed, despite a constant concentration in the "IC_olig" simulation identity.

Table 11.1 Perturbation Runs 23-Aug-06

Initial P Conditions, Atmospheric P loads

Subset of GlobalParms_v2.5.xls (data v2.5.1) dbase (ELM v2.5 Documentation Report, July 2006), including only changes for "perturbation" runs.
"Parameter name", "Units", "Default Value", and "Brief documentation" fields unchanged from the v2.5.1 dbase (used in ELM v2.5 documentation).

The "Simulation identity" field denotes the new simulation run's TP Load (Load_) identity
The "diff?" field shows the calculation of ("Value Used" - "Default Value")/"Default Value" * 100

Global parameters for input to ELM

Simulation identity	Parameter name	Value Used	Units	Default Value	diff?	Brief documentation
Load_0.0x	GP_TP_IN_RAIN=	0	mg/L	0.02	-100%	***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)
Load_0.5x	GP_TP_IN_RAIN=	0.01	mg/L	0.02	-50%	***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)
Load_2.0x	GP_TP_IN_RAIN=	0.04	mg/L	0.02	100%	***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)

11.3.2.2 108-yr simulations (subregional)

For the 108-yr perturbation experiments of the subregional application of the ELMwca3RS250, Table 11.2 describes the changes that were made to input data. No source code change (and re-compilation) of the model was needed among perturbation experiments, but some source code utilities required modification to implement the project for these century runs, as described in the next section.

It is important to recognize that the objective of these century long perturbation runs is to evaluate the algorithm/data behavior of ELM v2.5. The “synthetic” nature of much of the data does not allow inferences of historical dynamics within the geographic locale of this model application. This application is, specifically, to be used for model experiments only (at least at this stage).

Table 11.2 Century-Scale Perturbation Runs

13-Nov-06

The century-scale "perturbation" runs are a series of Everglades WCA-3A subregional simulations driven by "synthetic" input data that are based on historical observations, but with significant "perturbations" to the Everglades via altered phosphorus initial conditions or input loads. At the request of the ELM Peer Review Panel, these are newly provided with the objective of diagnosing or evaluating the century-scale ELM response to such large deviations in environmental drivers.

The workbooks in this file (**see tabs below**) document the changes to input data that were needed to implement this series of simulations. The intent is to document only those changes; the original data and databases are fully documented in the ELM v2.5 Documentation Report (July 2006), which is found on the ELM web site.

Five perturbation runs were made, as summarized here.

Run name	Initial P conditions	Phosphorus Loading
IColig_LoadNom	Extremely oligotrophic	Nominal (1965-2072) input concentrations
ICnom_Load0x	Historical (ca. 1981)	Zero all P input concentrations
ICnom_Load2x	Historical (ca. 1981)	Double all P input conc. (re. nominal inflows)
ICnom_ LoadOL10x	Historical (ca. 1981)	10x increase in overland inflow P input conc. (re. nominal inflows); nominal rainfall P
IC600grad_ LoadNom	Double Max of Regional Historical; apply local gradient	Nominal (1965-2072) input concentrations
nominal	Historical (ca. 1981)	Nominal (1965-2072) input concentrations

The "nominal" run is the base simulation of the subregional ELM2.6wca3RS250 project, using synthetic input data for century-scale simulation. All of these century-scale simulations are considered "synthetic" rather than "historical", as they use input data that have been extrapolated in various ways to allow long-term model "experiments" that demonstrate the capabilities of the ELM v2.5 algorithms and parameters.

ELM web site:
http://my.sfwmd.gov/elm

Table 11.2 Century-Scale Perturbation Runs Initial P Conditions

13-Nov-06

Soil phosphorus concentration, 0-30 cm depth.

The Initial Condition map used in the nominal "IC_nom" simulation identity used a local window of the regional ELM data (ELM v2.5 Documentation Report, July 2006); for the two Initial Condition perturbation "Simulation identities", changes were made as follows:

Simulation identity	soilTP map operation	Minimum cell value (mg P / kg soil)	Maximum cell value (mg P / kg soil)
IC_nom	Spatially distributed, 1981_estimate (local domain)	234	247
IC_olig	Spatially constant, 10 mg P / kg soil	10	10
IC_600grad	Spatially distributed, steep gradient down from 2.0 * Max_regional_1981	150	600

"IC_600grad" doubles the 1981 regional maximum estimate (300 x 2 = 600) in 160 cells of a 1 km swath along inflow border, with steep north-south synthetic gradient

Note that because soil organic bulk density and bulk density are spatially distributed, the total mass of P is still spatially distributed, despite a constant concentration in the "IC_olig" simulation identity.

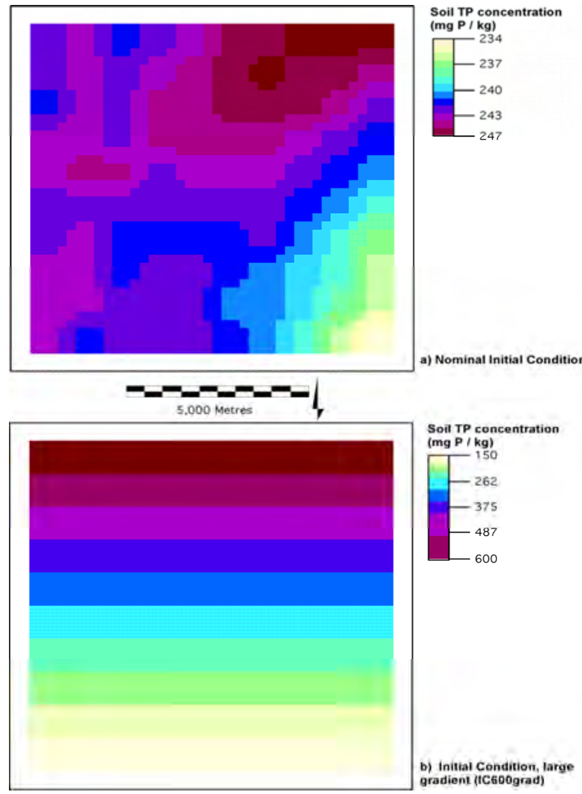

Table 11.2 Century-Scale Perturbation Runs

13-Nov-06

Overland-inflow P loads

Constant phosphorus (TP) concentration in domain-inflow water control structure flows

Changes to "CanalData.struct", summarizing the changed (constant) concentrations for "perturbation" runs.

Name	Load_nom TP (ug/L)	Load_0x TP (ug/L)	Load_2x TP (ug/L)	Load_OL10x TP (ug/L)
North_in	10	0	20	100

The constant TP concentration was applied to all inflow volumes through the "structure" named "North_in".
Those structure flows were input to an un-leveed, east-to-west, canal along the northern domain boundary.
The chloride tracer concentration was modified in the same ratios, but the tracer results are not provided (due to lack of time).

Table 11.2 Century-Scale Perturbation Runs 13-Nov-06

Atmospheric P loads

Subset of GlobalParms_v2.5.xls (data v2.5.1) dbase (ELM v2.5 Documentation Report, July 2006), including only changes for "perturbation" runs.
"Parameter name", "Units", "Default Value", and "Brief documentation" fields unchanged from the v2.5.1 dbase (used in ELM v2.5 documentation).

The "Simulation identity" field denotes the new simulation run's TP Load (Load_) identity
The "diff?" field shows the calculation of ("Value Used" - "Default Value")/"Default Value" * 100

Global parameters for input to ELM

Simulation identity	Parameter name	Value Used	Units	Default Value	diff?	Brief documentation
nominal	GP_TP_IN_RAIN=	0.02	mg/L	0.02		***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)
Load_0.0x	GP_TP_IN_RAIN=	0	mg/L	0.02	-100%	***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)
Load_2x	GP_TP_IN_RAIN=	0.04	mg/L	0.02	100%	***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)
Load_OL10x	GP_TP_IN_RAIN=	0.02	mg/L	0.02		***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)

In order to better isolate the potential affects of very large P loading associated with overland inflows, the atmospheric P loading was kept at nominal conditions in the "Load_OL10x" simulation identity.

Dispersion parameter: a coding error was found in ELM v2.5, such that the Anti-Numerical Dispersion (AND) algorithm does not automatically scale the dispersion to maintain (approximately) the same dispersion among model application grid sizes (as intended - ELMv2.5 documentation). The source code will be corrected. But because of the error, the term dispersion "reference length" is not truly applicable to the parameter's use in ELM v2.5. While the encoded AND algorithm indeed modifies the extent of the numerical dispersion based an application's grid scale, the error is such that the regional ELM v2.5's "reference length" to grid size ratio needs to be matched at another grid scale (to approximately match dispersion among applications).

Thus, the dispersion "reference length" must be manually changed for each grid: for all of these 250m grid applications, the parameter was set to 1/2 of the grid size (250km-grid, GP_dispLenRef=125), to "match" dispersion in the 1000m grid applications that used a 500m dispersion "reference length" (regional 1km-grid ELMv2.5, GP_dispLenRef=500). See Chapter text for dispersive flux output data for different dispersion "reference lengths" in this 250m grid application.

11.4 Source code

11.4.1 20-yr simulations (regional)

No source code change of the model (ELM v2.5) was needed for these simulations.

11.4.2 108-yr simulations (subregional)

Because of the necessity to modify some source code, we will refer to the century simulations as using an "alpha-release" of ELM v2.6 (v2.6a). A formal (fully documented) release of ELM v2.6[7] will be made during the 2006 Peer Review of ELM. The following source code was added/modified in order to implement the century-scale simulations. Beyond these additions to overland and groundwater grid cell fluxes for synthetic perturbation experiments, the algorithms in ELM v2.6 are the same as those in ELM v2.5. Thus, the ELM v2.6 code changes did not affect the results of a "standard" (non-experimental) run of the ELM (i.e., if the new [optional] data files described below do not exist in the "Data" directory of a model application, the outputs of an ELM v2.6 application are identical to those described in the ELM v2.5 documentation Chapter 6 Model Performance[8]).

- added code to "GenericDriver.c" to check for the existence of (optional) input data files, which then establishes a) whether to use individual-point time series for rainfall and potential evapotranspiration inputs (intended primarily for subregional applications), and b) whether the new stage-based synthetic boundary condition (fixed parameter) data are used to drive model experiments
- added code to "UnitMod.c" to a) read a new (optional) parameter file named "ModExperimParms_NOM" that is used in model experiments such as the century-scale perturbation runs, and b) call (existing) code in "Serial.c" to spatially interpolate point data across the model domain, "on-the-fly" (for the daily time series of atmospheric input data).
- added code to "Fluxes.c" to accommodate "synthetic", calculated boundary stages for use in the grid cell overland/groundwater fluxes, as opposed to existing use of a daily time series of spatially explicit (map) data for external stages in those routines.
- added code to "WatMgmt.c" that better organizes several distinct input data methods into separate functions, that are called only if needed (i.e., increased the modularity of a segment of code for boundary condition inputs).

11.5 Results

11.5.1 108-yr simulations (subregional)

Because of its spatial simplicity, it is most informative to present the results of the subregional, century-scale perturbation experiments prior to discussing the complexities

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7 This release is anticipated to be indexed as ELM v2.6.0 or 2.6.1.
8 See Appendix A, however, for description of a source code error found in ELM v2.5 that will need correction in the formal release of ELM v2.6.

of the managed regional system (simulated in the 20-yr perturbation experiments). For the century-scale subregional application, phosphorus was input into the model domain via the input water control structure, which flowed directly into the canal along the (higher elevation) northern periphery of the model domain, and (depending on local stage differences) then flowed into the receiving marsh of Basin/Indicator (hereafter, Basin) 1. With the downslope topographic gradient in the north-to-south[9] direction, flows are induced downslope to the Basins 2 – 9 that are numbered sequentially from north to south (depicted in Figure 11.2).

11.5.1.1 Total P budgets

Relative to that of living plants and (ground and surface) water, storages of P in the soil strongly dominated the total mass storage in all Basins (Figure 11.5). Moreover, Figure 11.5 shows that long term (century) changes in P storages along a gradient (induced by upstream inputs) were dominated by changes in the soils[10]. These are fundamental characteristics of an accreting wetland, as the soils represent a long term "integrator" of the interactions among the physics, chemistry, and biology over such long time scales.

The model perturbation experiments exhibited some output characteristics that were common to most scenarios. The following are summaries of output data that were aggregated (as part of the total inflows or outflows) within the budget summaries:

- P inflow was the sum of atmospheric, overland, and groundwater inputs to each basin. ***P inflow from atmospheric deposition was homogenous among all Basins*** in all of the simulations, averaging 25.0 mg m^{-2} yr^{-1} in each Basin in all but the ICnom_Load0x and ICnom_Load2x perturbations, for which all basins received 0.0 or 50.0 mg m^{-2} yr^{-1}, respectively. (Note that we kept atmospheric P inputs at the nominal levels for the ICnom_LoadOL10x perturbation, in order to better isolate the effects of overland flow inputs from atmospheric inputs).
- ***The nominal scenario of P overland inflow into the northern receiving region*** (i.e., introduced into the domain) averaged (Basin 1, 19.0 mg m^{-2} yr^{-1}) somewhat ***less than that of atmospheric deposition*** in that basin. This overland inflow load (averaged over a 1-km path length) is approximately half of that which appears likely to lead to rapid (<< 1 decade), observable impacts to Everglades communities (40 mg m^{-2} yr^{-1} above atmospheric loads, references in Model Application Chapter 8, p. 8-8).
- ***Groundwater flows of P were generally minor*** in most Basins and perturbations (for this specific Everglades subregion), never exceeding 1 mg m^{-2} yr^{-1}, except in Basins 1 & 2 under the ICnom_LoadOL10x perturbation (outflow from Basin 1 = inflow to Basin 2 = 2.5 mg m^{-2} yr^{-1}, compared to 69.7 mg m^{-2} yr^{-1} overland P inflow to Basin 2).

[9] More accurately, the directionality of the topographic gradient is roughly 340 degrees to roughly 155 degrees on the compass.
[10] During every simulation of ELM, a variety of (spatially explicit time series of) phosphorus budgets are output: a) total P mass, b) total P mass per unit area, c) P mass (per unit area) associated with "dead" (soil-related) storage, d) P mass (per unit area) associated with living plants, and e) P mass (per unit area) associated with water. For specific variables output in each budget, see ELM v2.5 Documentation Report, User's Guide Chapter 10, p. 10-13.

Figure 11.6 presents the 108-yr mean (total) P accumulation, P inflow, and P outflow within each of the 9 gradient Basins for each of the perturbation experiments. (Note that Basin 10 is not included; located along three downstream sides of the domain, Basin 10 encompasses any potential boundary flow effects). These results include the total mass of all (live, dead-soil, and water-borne) phosphorus storages.

In Basin 0, which is the entire 100 km^2 active domain, P accumulation was equivalent among scenarios that had nominal P loading, irrespective of the initial soil phosphorus concentration. *Due to spatial averaging, P accumulation was ~150% of the nominal scenario (averaged across the entire domain) with a tenfold (10x) increase in P load in (only) overland inflows* into the upstream end of the system. *Doubling the total load* (via both atmospheric and overland inflows) almost exactly *doubled the domain-wide P accumulation* in Basin 0 (from 25.4 to 50.9 mg m^{-2} y^{-1}). This Basin 0 had a very slightly negative P accumulation in the scenario with no (0.0) external P loads.

The upstream receiving area, Basin 1, had inflow loads that were equivalent among scenarios with nominal P loading, irrespective of the initial soil phosphorus biomass. In the scenario with significantly *elevated initial soil TP concentration (IC600grad_LoadNom), P accumulation was reduced* relative to the other nominal-load scenarios: while Basin 1 inflows were equivalent among those scenarios, the scenario with ~2.5x higher initial P storage in the soil had P outflows that were approximately 150% of those in the nominal scenario. As outlined below (in the soil budget analysis), long term *decomposition losses of P were greatly increased in this highly eutrophic soil* (with P concentration of 600 mg kg^{-1} in the upper 30 cm of the vertical profile), relative to the oligotrophic soils of the nominal initial condition scenarios. (Phosphorus is a limiting nutrient to the implicit microbial driver of this decomposition process). Appendix 11.1 contains time series plots of porewater P concentrations under the different scenarios, and indicates extremely high porewater concentrations in this eutrophic soil after multiple decades. This positive feedback (of increased decomposition with increased available P) may be somewhat under constrained in the simulations, but still reflect the appropriate spatial and temporal trends (in this component of the model output that is not being considered as an application Performance Measure).

When all (atmospheric and overland) P inflows were 200% (ICnom_Load2x) of the nominal scenario, the receiving Basin 1 had a P accumulation rate that was 209% of the nominal value. This (relatively subtle) *non-linear response is demonstrative of the non-linear integration of ecosystem processes in ELM* algorithms. Increasing surface water column inflow concentrations from 10 to 20 ug l^{-1} (and thus doubling the load) led to rapid uptake of the additional phosphorus in this severely P-limited ecosystem. In a positive feedback mechanism, P uptake by biota became accelerated as the biomass of that living storage increased, increasing the turnover of the biological communities. With increased turnover of (carbon and) phosphorus, the increased biological uptake of P under increasing eutrophy was reflected in increased soil accumulation rates – the ultimate integrator of long term P dynamics in this wetland system. The extent to which this acceleration occurs in other local ecosystems distributed throughout the Everglades region (i.e., as seen in the regional ELM application, discussed in a later section) is highly dependent on the physical, chemical, and biological interactions in this spatially heterogeneous, complex system of managed flows amongst hydrologic units that are often sharply bounded.

Compared to the nominal scenario, a 10x increase in (only) the overland inflow P loads resulted in a very large increase (4.9x) in P accumulation in the receiving Basin 1. (The total inflow load in the ICnom_LoadOL10x scenario was 4.9x that of the nominal simulation, due to the atmospheric load contribution). The *accumulation rate of >140 mg m^{-2} y^{-1} P in this scenario is highly indicative of eutrophy, and the >60 mg m^{-2} y^{-1} P accumulation rate in the ICnom_Load2x scenario is indicative of probable/possible eutrophic* ecosystem responses (see Model Application Chapter 8).

It was evident (i.e., Figure 11.6) that the receiving Basin 1 was the subregion that was most strongly affected by changes in loads and/or initial conditions among the perturbation scenarios (due to basin configurations): overland P loads from outside of the model domain were introduced only into this Basin, which also had the largest relative difference in initial soil TP concentrations for the perturbation scenario of increased initial storages. *Perturbations that altered outflows from Basin 1 had cascading (and attenuating) effects downstream through Basins 2 – 9*. A primary example of these spatial interactions was demonstrated in the IC600grad_LoadNom scenario. With increased (relative to nominal) P outflow from that basin, the downstream basin(s) received larger P loads than in the nominal scenario. The P inflow to Basin 2 in the IC600grad_LoadNom scenario was 123% of that in the nominal scenario (without increases in external load), resulting in a relative P accumulation that was 109% of that in the nominal scenario.

11.5.1.2 Soil ("dead") P budgets

Soils dominate the long term P storages, as previously indicated. Moreover, the rates of change in soil P (and carbon) storage are important biogeochemical "drivers" in the Everglades, and may also serve as useful ecological "indicators" of the eutrophication status of the area. While (the desire for simplicity dictates that) we do not plan on using such rates as Performance Measures for model application, their analysis is useful in order to gain insights into the different responses of the total P budgets among perturbation experiments.

Figure 11.7 presents the 108-yr mean *soil-specific* P accumulation, inflow (sorption gains, inputs from mortality of periphyton and macrophytes, inputs from water column settling), and outflow (decomposition, desorption) within each of the 9 gradient Basins for each of the perturbation experiments. *In general, the trends among perturbations seen in the overall (total) budgets (Figure 11.6) were reflected in the soil budgets*. One general difference between these budgets was most apparent in the accumulation rates with no external P loads (ICnom_Load0x). In this perturbation of severe oligotrophy, the P accumulation rate to the soil was 11-12 mg m^{-2} yr^{-1} within the basins. This net gain to the soil was equivalent to the total losses from the macrophyte community (in a separate output budget). Appendix 11.1 of this document shows the magnitude of the macrophyte (carbon) decline from initial conditions in this, and to a lesser extent, other perturbation(s). The simulated decline from the initial estimate of macrophyte biomass led to the observed net gain of P in the soil among all perturbations, which occurred in conjunction with continual (input and output) turnover of (macrophyte and periphyton) live plants. This sensitivity to initial macrophyte biomass was not reflected in the total P accumulation rate (Figure 11.6), which is one of the two existing Performance Measures for model applications.

Another principal difference that was apparent between the soil and the overall (total) P budgets was the *accelerated turnover of soils under high-load conditions*, relative to the total system P input-outputs. Increasing the overland inflow P loads by an order of magnitude (ICnom_LoadOL10x) increased both the inputs[11] and outputs of the overall (total) P budget by approximately 5x in the receiving Basin 1, relative to the nominal perturbation. For the soil P budget, the 10x increase in overland P inputs to Basin 1 led to a 9x increase in P inputs to the soil and a 15x increase in outputs from the soil, relative to the oligotrophic nominal perturbation. This acceleration of soil P turnover was driven largely by decomposition (P loss) processes (Figure 11.8), which are P-limited (via implicit microbial limitation). Plant (macrophyte and periphyton) turnover was also increased under these increased P loads and higher P availability, leading to higher turnover and thus accelerated input to the soil P storage. While these rate processes are not specific Performance Measures for model application, their responses to the large perturbations were indicative of the mechanisms underlying the complex system dynamics of the Everglades wetlands.

11.5.1.3 Integrated ecosystem variables

The preceding discussion of average century-long P accumulation provides a relatively simple summary of complex-system P dynamics in a subregion of the Everglades. Underlying those dynamics are the interactions among principal ecosystem variables under changing environmental conditions. The current section on integrated ecosystem variables provides a somewhat cursory overview of some of these ecosystem dynamics across a landscape gradient. A more comprehensive model synthesis of the Everglades is beyond the scope of this Model Perturbation Chapter's goals: as discussed in the Model Application Chapter 8, a Model Synthesis Chapter is planned, to provide a model perspective of the causal mechanisms behind pattern changes within the greater Everglades landscape.

Phosphorus accumulation in the ecosystem (discussed in the previous section) is one of the two Performance Measures to be used in applications of ELM v2.5/2.6. Phosphorus concentration in the surface water is the second (current-) application Performance Measure. Because the "real" and the simulated ecosystem assimilates water column phosphorus at extremely rapid rates, this water column metric is not as sensitive of a eutrophication indicator as that which considers total P accumulation within the ecosystem (see Chapter 8 for a literature overview).

Nevertheless, over decadal time scales, and particularly at century time scales, water column phosphorus concentrations become reflective of the "underlying" ecosystem eutrophication status. This was readily apparent in the century-long time series of surface water concentrations under the suite of perturbation experiments (Figure 11.9a). For the nominal scenario, the 10-yr mean surface water P concentration was similar between the

[11] As previously indicated, the atmospheric P load was maintained at the nominal rate in this ICnom_LoadOL10x perturbation run, thus the total input was not increased by 10x due to the significant contribution of atmospheric deposition under these scenarios.

initial decade (7 ug l^{-1}) and the final decade (8 ug l^{-1}) in the upstream receiving Basin 1. In scenarios with (above-nominal) increases in external P loads from overland inflows, the receiving Basin 1 had surface water P concentrations that were higher than the nominal scenario. The magnitude of this difference evolved (increased) with time, as the ecosystem's plants and soils became increasingly eutrophic in status. Increasing the overland-inflow concentration by an order of magnitude (in ICnom_LoadOL10x, from 10 to 100 ug l^{-1}) led to an initial, relatively small increase in surface water concentration relative to nominal conditions: the mean surface water P concentration during the first decade of that scenario was 17 ug l^{-1} (with a maximum monthly mean of 40 ug l^{-1}). As indicated earlier, these "low" concentrations, relative to the concentrations in the inflows, are consistent with field observations of the P-limited ecosystem's assimilative rates and capacity: the water column does not fully reflect the immediate effects of eutrophication. As Basin 1 continued to assimilate P across multiple decades, the mean surface water P concentration became 44 ug l^{-1} during the final decade of the century-long simulation (with a maximum monthly concentration of 90 ug l^{-1}).

Surface water P concentration in the basin farthest downstream (Basin 9) was generally similar in all scenarios, except for that which had doubled atmospheric (and overland, into Basin 1 only) loads. In the nominal scenario, the 10-yr mean concentration in Basin 9 during both the initial and the final decade was 5 ug l^{-1}. With doubled loads, the mean concentrations were 8 and 9 ug l^{-1} during the initial and final decades, respectively. Due to rapid ecosystem assimilation in upstream basins, this increase was attributable to atmospheric load increases alone (rather than upstream inflow loads). While these water column concentrations are quite low (with recent laboratory detection limits having been 4 ug l^{-1}), the differences among scenarios are indicative of the model sensitivity in discerning such relatively subtle differences. (Note, however, that the P accumulation Performance Measure may provide more definitive comparisons between these nominal and perturbation scenarios).

Initializing a perturbation scenario with highly eutrophic soil P concentrations also led to a long term trajectory of increased surface water P concentration. In Basin 1, initialized with the highest values along a gradient in the IC600grad_LoadNom scenario, surface water phosphorus concentrations increased significantly with time, albeit not to levels attained under the highest external loads. As shown in the previous section, soil decomposition was elevated over nominal rates in this scenario, leading to higher plant productivity and more rapid P cycling, which was ultimately reflected in the whole ecosystem that includes the surface water components. Subjected to relatively low (10 ug l^{-1}) external loads, soil P losses via decomposition were reflected in long term declines in soil P concentration (Figure 11.9b). In general, the temporal trends in soil P concentrations within the various perturbation scenarios were inherent in the soil-dominated P budgets discussed in the previous section.

While potentially outside of the scope of the perturbation experiments which focus on P dynamics, soil (carbon) accretion rates are useful indicators of wetland status over long time scales. Soil accretion rates tend to increase with higher production and turnover of plants, which are stimulated by increased P availability, and dependent on water depths. In another feedback mechanism described earlier, an increase in P also can increase the loss of soil via decomposition, which is also highly dependent on water levels (and the concomitant extent of soil oxygenation). The relative contribution of these positive and negative feedbacks under changing environments reflects a delicate balance that is captured in the current ELM: Figure 11.9c shows the generally increasing rates of soil (carbon, with fixed bulk density) accumulation under scenarios that were associated with higher P availability. The balance that results between plant turnover and soil decomposition at higher and lower elevations becomes an important hydrologic consideration in wetland maintenance and restoration. Preliminary results of century-scale simulations (at multiple spatial scales) indicate that the ELM was capable of simulating the strongly differential soil accumulation rates between long-hydroperiod sloughs and adjacent short-hydroperiod ridges, with interactive ecosystem processes that served to maintain the anisotropic pattern of the ridge and slough habitats of the Everglades[12].

11.6 Response to Review Panel questions

11.6.1 20-yr simulations (regional)

The Review Panel posed specific questions concerning the 20-yr regional perturbation experiments, which were the only perturbation scenarios that were available for review at the time. Overall, we anticipate that the *results and interpretation of the simpler, subregional simulations (above) will address most of the uncertainties/concerns that were expressed by the Review Panel*. In particular, the non-linear ecosystem processes captured by the ELM are more easily understood in that simpler subregional domain, without most of the complexities of spatial heterogeneity in managed flows and antecedent conditions within the Everglades landscape mosaic. In this section, we provide further information to clarify the dynamics found within specific Basins and Indicator Regions that are distributed through the model domain of the regional Everglades.

11.6.1.1 Spatial configurations and flows

For summarizing ELM application Performance Measures, we defined a set of hierarchical subregions within the regional ELM domain. Hydrologic Basins (Figure 11.10a) were designated as the large-scale spatial units. These Basins aggregated the results of a large number of model grid cells and canals (if present), within areas that were usually, but not necessarily, impounded by levees. Nested within each separate Basin were (usually) a number of Indicator Regions (Figure 11.10b), each of which by definition consisted of (an equal number or) fewer model grid cells relative to the "parent" hydrologic Basin. Thus, in this hierarchical framework, Basins aggregated all model cells and canals within the defining polygon, which includes any "child" Indicator Region in an explicitly hierarchical topology.

The spatial topology of Indicator Regions in the landscape was developed using best professional judgment, in conjunction with analyses of prior model outputs. In general, the rationale was to capture many of the ecological gradients associated with existing and future (Comprehensive Everglades Restoration Plan) flows of water and nutrients. IN

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[12] See Nov 3, 2006 status report of the century-scale simulations, posted in the Implementation: v2.5 subtab of http://my.sfwmd.gov/elm .

this process, a number of Indicator Regions were delineated (in a GIS) in series along pathways of flow downstream of P inflow locations, such as the existing flow gradient in northern WCA-2A (BIRs 36-38, 40), and the anticipated future flow gradient in northeastern WCA-3A (BIRs 41-44). Schematics of these generalized flow paths were provided in the Data Chapter 4 (Figure 4-19).

11.6.1.2 Results, in response to Panel questions

Nov 22, 2006: This section may be considered incomplete; we desire to be "succinctly comprehensive" in response to Review Panel concerns. We will revisit this section for potential revision on Nov 27, if that is acceptable to the Review Panel.

All (raw numerical and graphically-postprocessed) results of the 20-yr regional perturbation experiments were posted on the ELM web site, as described in Appendix 11.2 of this document. The "Quick-Look" section of the html-interface to those results provided representative example results for distinguishing gradients and localized subregions, for both the P budget (histograms) and integrated ecosystem variables (time series). We do not attempt here to fully describe the regional and subregional phosphorus dynamics, which is outside of the scope of the goals of these perturbation experiments. (The goal was to provide another basis for *better understanding the ELM capabilities* in simulating P dynamics of the Everglades, but not necessarily summarize the full complexity of system-wide Everglades dynamics). A Model Synthesis Chapter will be formulated in the future, to provide a model perspective of the causal mechanisms behind pattern changes within the greater Everglades landscape.

The specific questions posed by the Review Panel were detailed in an October 30, 2006 document (by C. Cerco), which was posted on the ELM web site. Each of the questions showed significant insight into the interpretation of the regional ELM results, and we made significant efforts to formulate comprehensive, quantitative responses. Towards this end, we concluded that an unambiguous approach would involve demonstrating the same dynamics within the simple, controlled spatial framework of the subregional application. Thus, we used the subregional application to summarize the causal mechanisms behind the model behaviors (as presented earlier), and below outline our responses to the questions (which contained supporting comments within the Panel's document).

1. Why does phosphorus accumulate in basins 15, 17, and 24 when initial conditions are doubled? Why do these basins demonstrate different behavior than other basins e.g. 19,20, and 21?

   Response outline: a) see causal mechanism description for subregional application, describing the acceleration in plant turnover and P uptake with higher P loads in eutrophic-tending system; b) see below descriptions of "basins", regarding the widely varying heterogeneity of flow sources, soils, and habitats.

2. Why is the change [in] accumulation rate not proportional to change in loading rate in basins 15, 36, and 52?

   Response outline: see causal mechanism description for subregional application, describing the non-linear dynamics of increasing/decreasing eutrophication.

3. Why is phosphorus accumulation [intended meaning appeared to be, “the phosphorus porewater concentration-increase”] in basins 15 and 36 porewater accelerated when initial conditions were doubled?

   Response outline: see causal mechanism description for subregional application, describing the non-linear decomposition response to P availability.

Basin/Indicator (BIR) Region descriptions (see Figure 11.10):

“Basin 15” is a large (447 km^2) Indicator Region, which was to some extent an artifact of partitioning a large hydrologic Basin (number 3, WCA-3A). Encompassing most of the region north of the (east-west) highway named “Alligator Alley”, it has no direct inflows from water control structures or canals, and instead is downstream of smaller Indicator Regions which directly receive external flows of often very high P concentrations. Along its western portion, it overlaps an area of high soil bulk density. Historical soil P concentrations ranged widely within the area, from oligotrophic to moderately high and high levels. Sawgrass is a dominant habitat type.

“Basin 17” is a large (568 km^2) Indicator Region in central WCA-3A. South of “Alligator Alley” and west of the “Miami Canal”, it directly receives inflows of canal waters that often have relatively high concentrations of P, although the sources of those flows are not external to the Everglades-proper. It is also downstream of an Indicator Region (BIR 52) that had inflows of very high concentrations of P, (and incidentally, receives flows from BIR 15). Along its western portion, it overlaps a small area of high soil bulk density. Sawgrass is a dominant habitat type.

“Basin 19” is an Indicator Region of moderate size (139 km^2) in northern Everglades National Park. The area has direct inflows from water control structures that generally have low concentrations of P. It is in an area with short hydroperiods, and high soil bulk density. The area is dominated by the relatively sparse densities of sawgrass marl prairie habitat.

“Basins 20 and 21” are contiguous, large (455 and 167 km^2, respectively) Indicator Regions that together comprise most of “Shark Slough” in northern Everglades National Park. The area has direct inflows from water control structures that generally have low concentrations of P. This peat based slough has low soil bulk density, in habitats dominated by sawgrass.

“Basin 24” is a large (341 km^2) Indicator Region in southern Everglades National Park. The area has no direct managed water inflows (other than overland marsh flows), and includes estuarine intertidal boundary flows. A significant portion of the area has high soil bulk densities. Habitats are heterogeneous, ranging from estuarine mangroves to freshwater wet prairies and sawgrass marl prairies.

“Basins 36” is a small (25 km^2) Indicator Region in northern WCA-2A. This area directly receives high P concentration inflows from water control structures. With low (peat-based) soil bulk densities, the area had the highest known historical soil concentrations in the Everglades. The habitat was dominated by sawgrass, but also (switched to) cattail in some model scenarios.

“Basins 52” is a small (14 km^2) Indicator Region in western WCA-3A. This area directly receives high P concentration inflows from a managed canal outflow. With moderate soil bulk densities, the area had the high historical soil concentrations. The habitat was dominated by sawgrass, but also (switched to) cattail in some model scenarios.

11.7 Figures

Figures 11.1 through 11.10 follow.

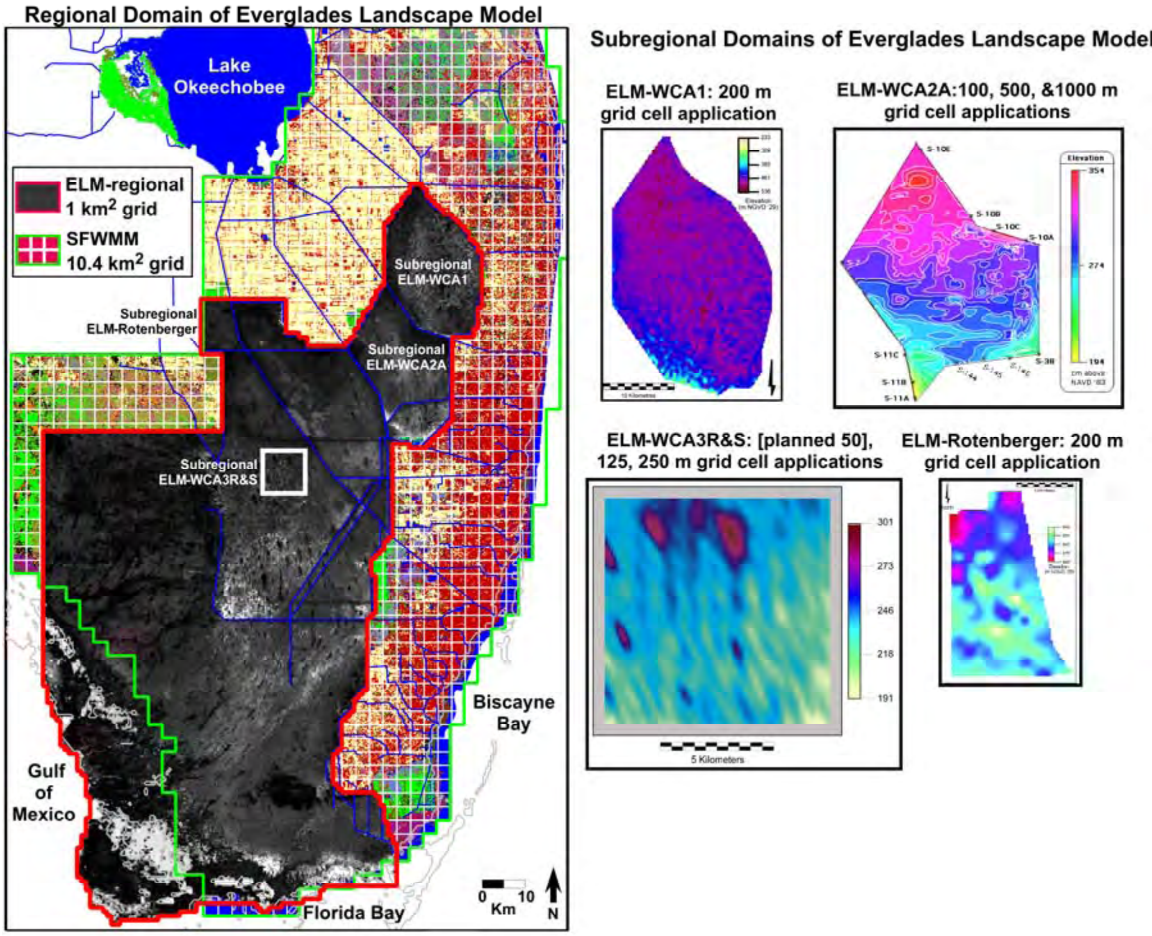


Figure 11.1. Location and scales of ELM regional and subregional applications. The ELMwca3RS domain has 1000, 500, 250, and 125 m applications.

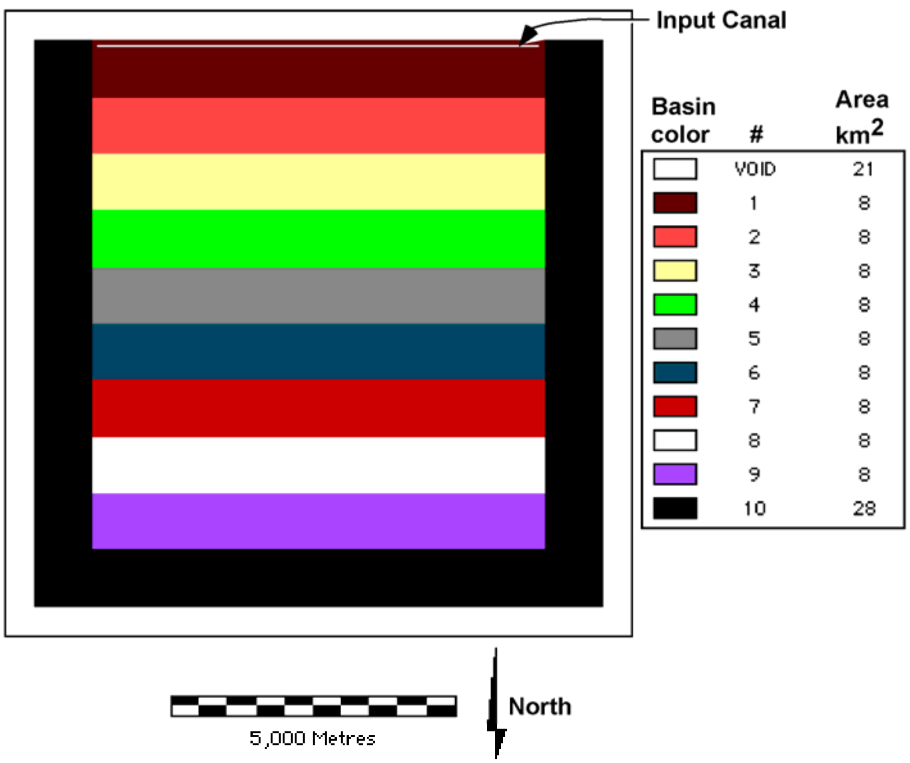


Figure 11.2. The basins used to summarize the ELMwca3RS250 output. Flow is completely unconstrained among all basins (and thus are not separate hydrologic units). Basin "0" is the sum of all basins in the active (non-void) model domain. Note that the square model grid cells are 250 meters on a side, while each basin is 1 km in the north-south dimension.

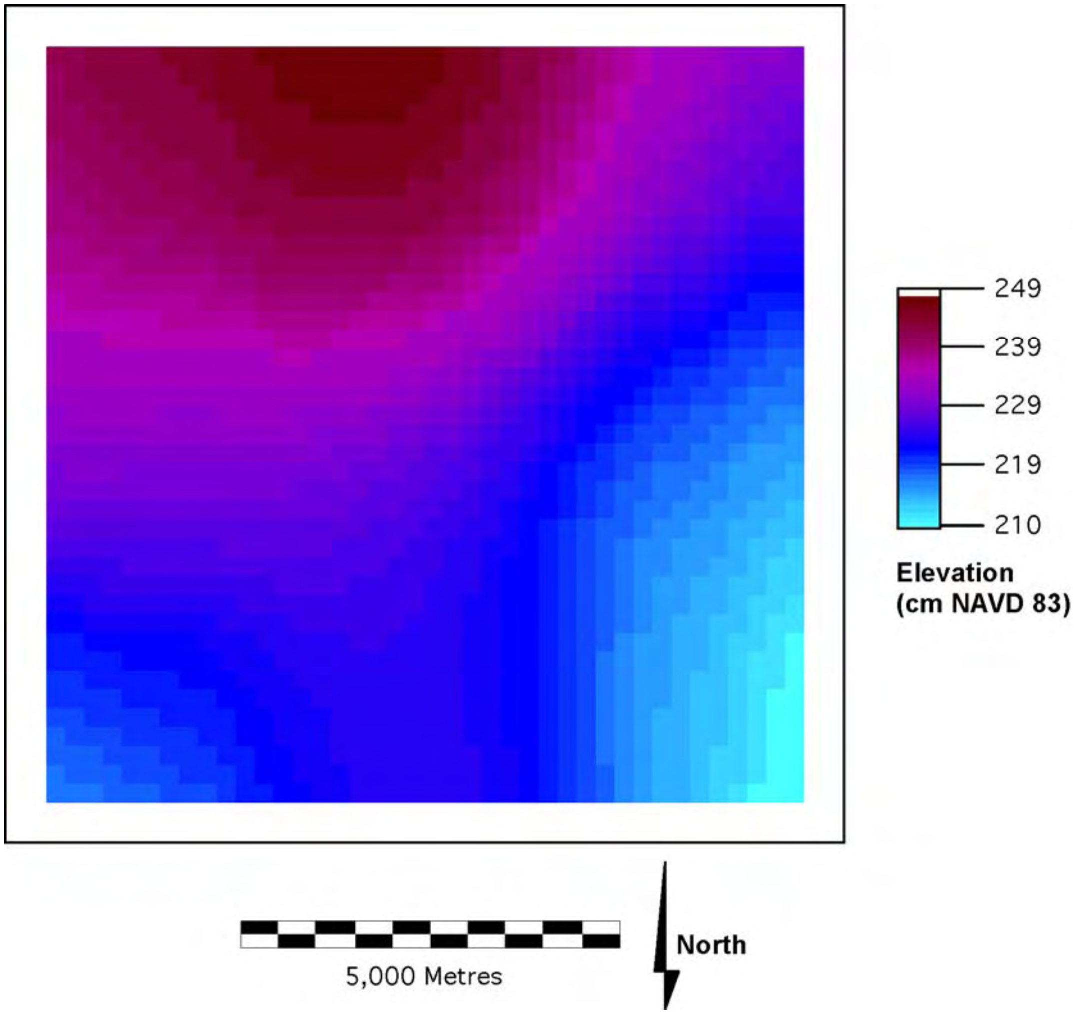


Figure 11.3. Land surface elevation of the ELMwca3RS250 application as implemented for the perturbation experiments. (This elevation surface is a smoothed representation of the finer scaled topographic features in another, original elevation map. Simulations of fine scale ridge and slough ecosystem dynamics utilized the original, unsmoothed map of elevation).

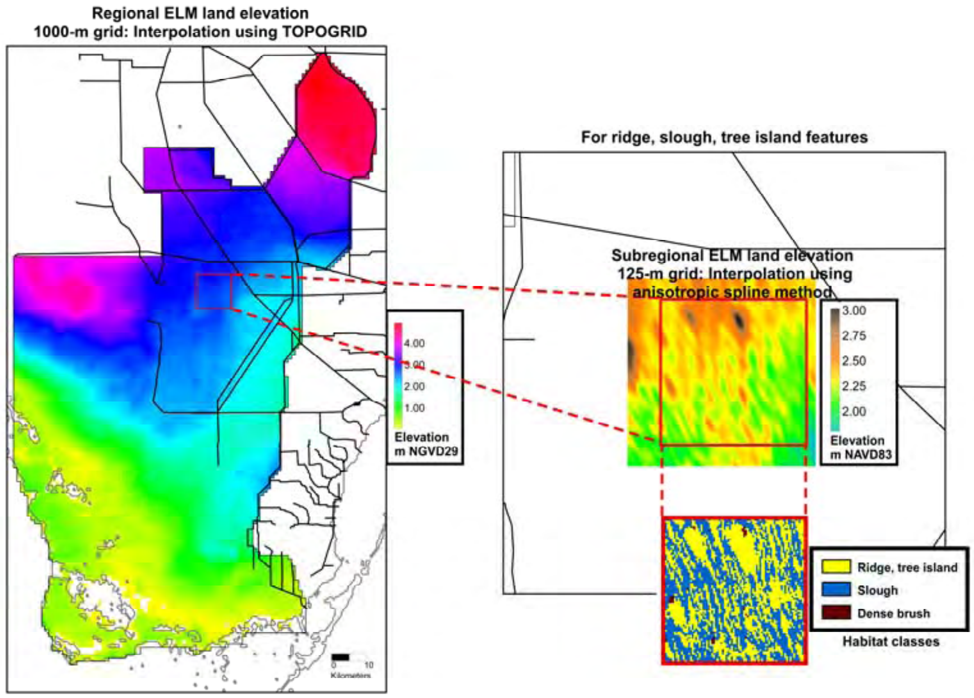
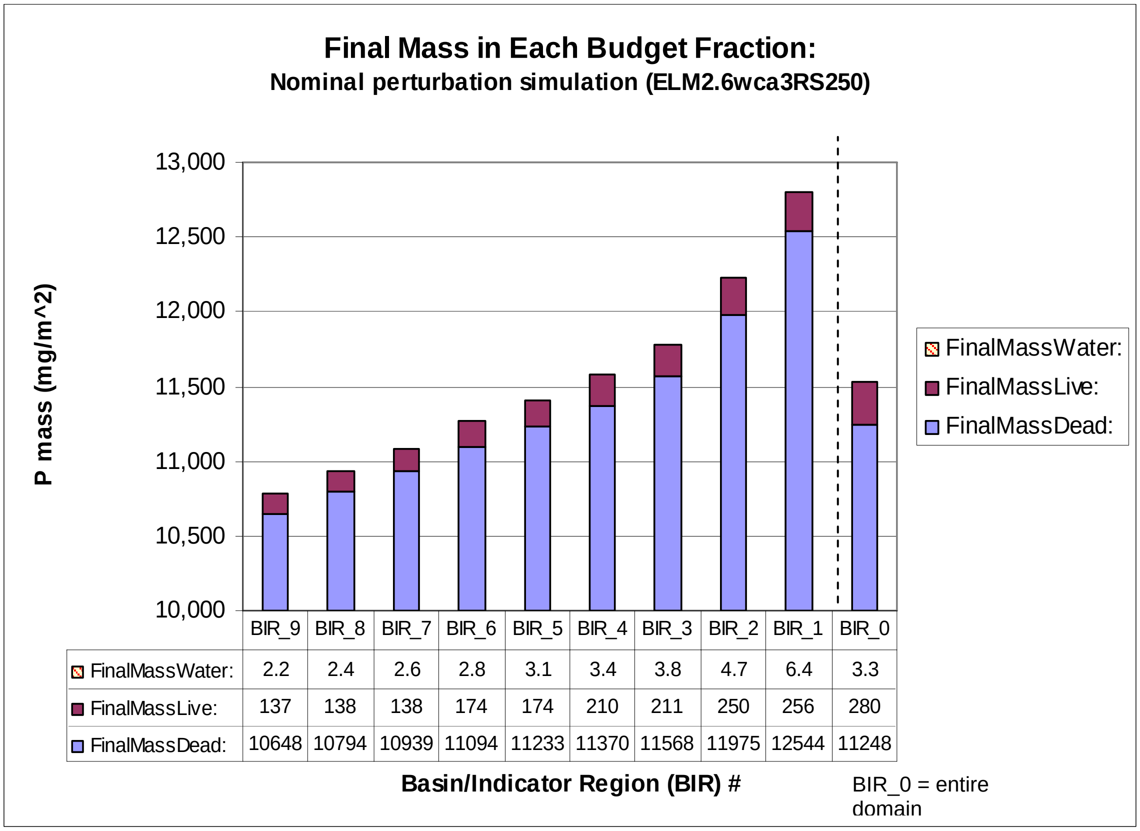


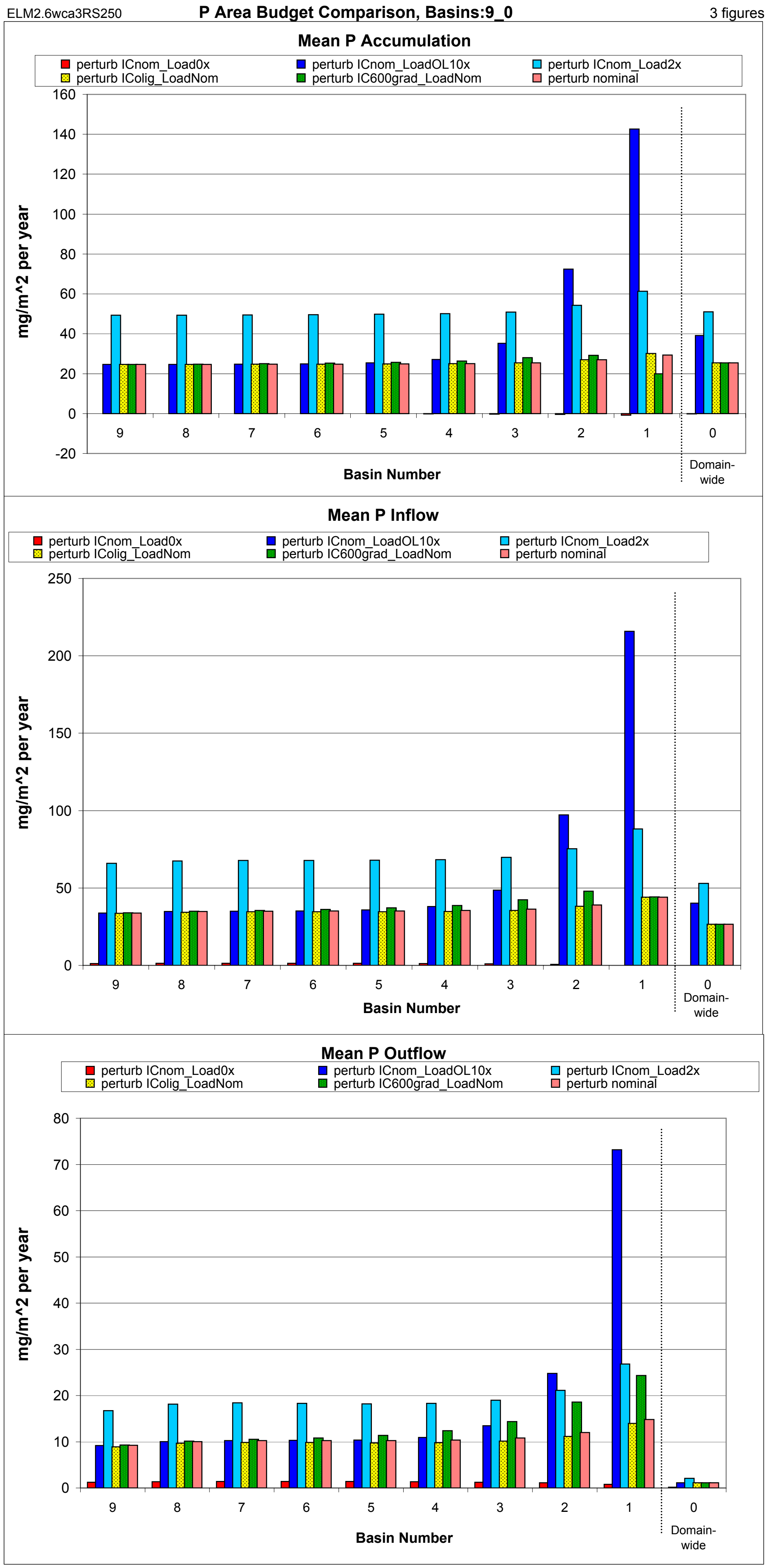
Figure 11.4. Land surface elevation and habitat distributions used in the ELMwca3RS125 application to investigate ecosystem processes and landscape patterns; these data were not directly used in the perturbation experiments. The regional ELM elevation data are shown for relative comparisons of the topographic patterns only.

Figure 11.5. Phosphorus (P) mass in each Basin/Indicator Region (BIR, hereafter referred to simply as Basins) at the end of the 108 yr, nominal simulation of the perturbation experiments. The "MassDead" fraction of the total mass in any BIR includes organic soil P, organic floc (surficial soil) P, and inorganic P sorbed to soils. The "MassLive" fraction includes P in tissues of all live periphyton and all live macrophytes. The "MassWater" includes P in the surface water, unsaturated water, and saturated water storages.



	BIR_9	BIR_8	BIR_7	BIR_6	BIR_5	BIR_4	BIR_3	BIR_2	BIR_1	BIR_0
FinalMassWater:	2.2	2.4	2.6	2.8	3.1	3.4	3.8	4.7	6.4	3.3
FinalMassLive:	137	138	138	174	174	210	211	250	256	280
FinalMassDead:	10648	10794	10939	11094	11233	11370	11568	11975	12544	11248

Figure 11.6. Phosphorus budget flows for gradient Basins/Indicator Regions. The six scenarios of the century scale perturbation experiments are defined in the Data descriptions in the main text.



"Managed" inflow Run	Basin 1
Load0x	0
Load10x	190
Load2x	38
LoadNom	19

Figure 11.7. Phosphorus flows in the soil ("dead") fraction of the total P budget, for gradient Basins/Indicator Regions. The six scenarios of the century scale perturbation experiments are defined in the Data description in the main text.

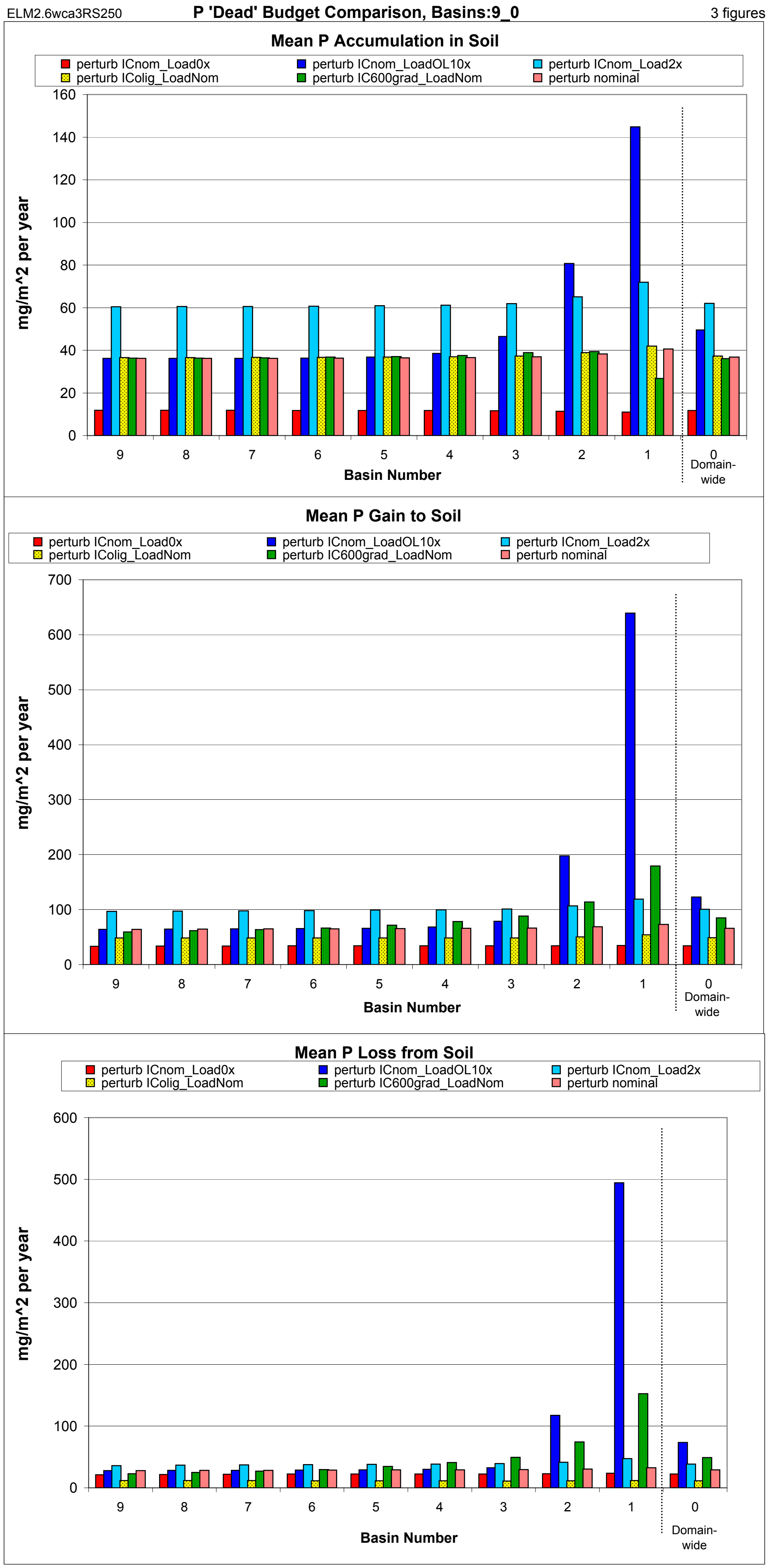


Figure 11.8. Phosphorus (P) mass loss due to soil decomposition in each Basin for each 108-yr perturbation experiment.

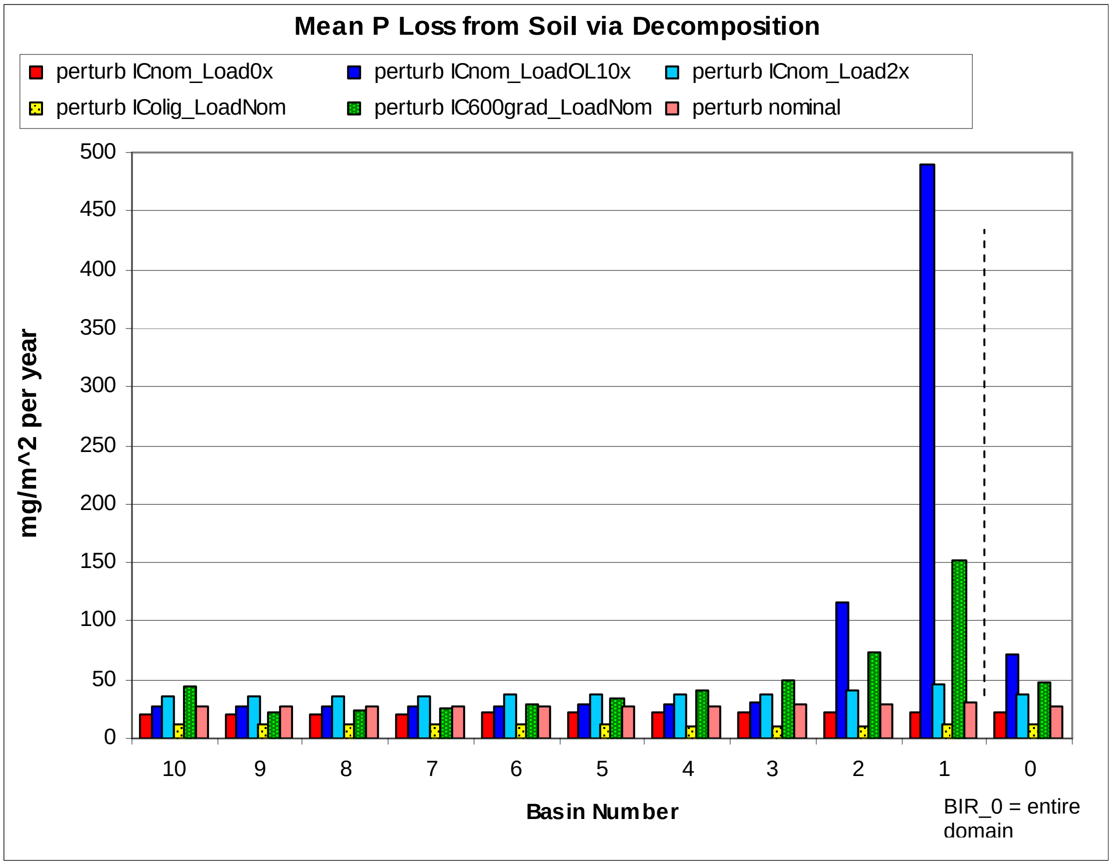


Figure 11.9a Surface water TP concentration in selected Basins along gradient for each 108-yr perturbation experiment.

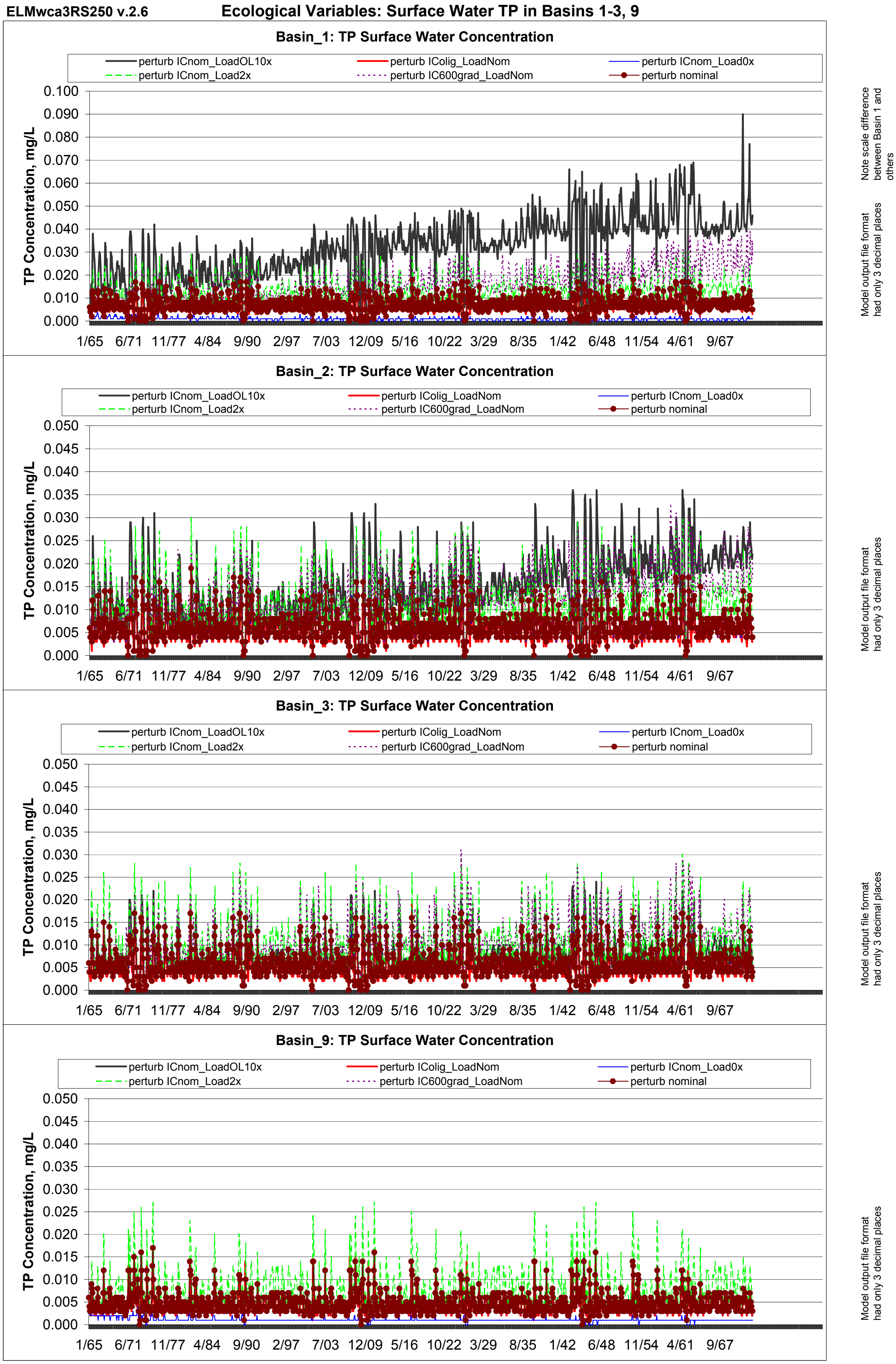


Figure 11.9b Soil TP concentration in selected Basins along gradient for each 108-yr perturbation experiment.

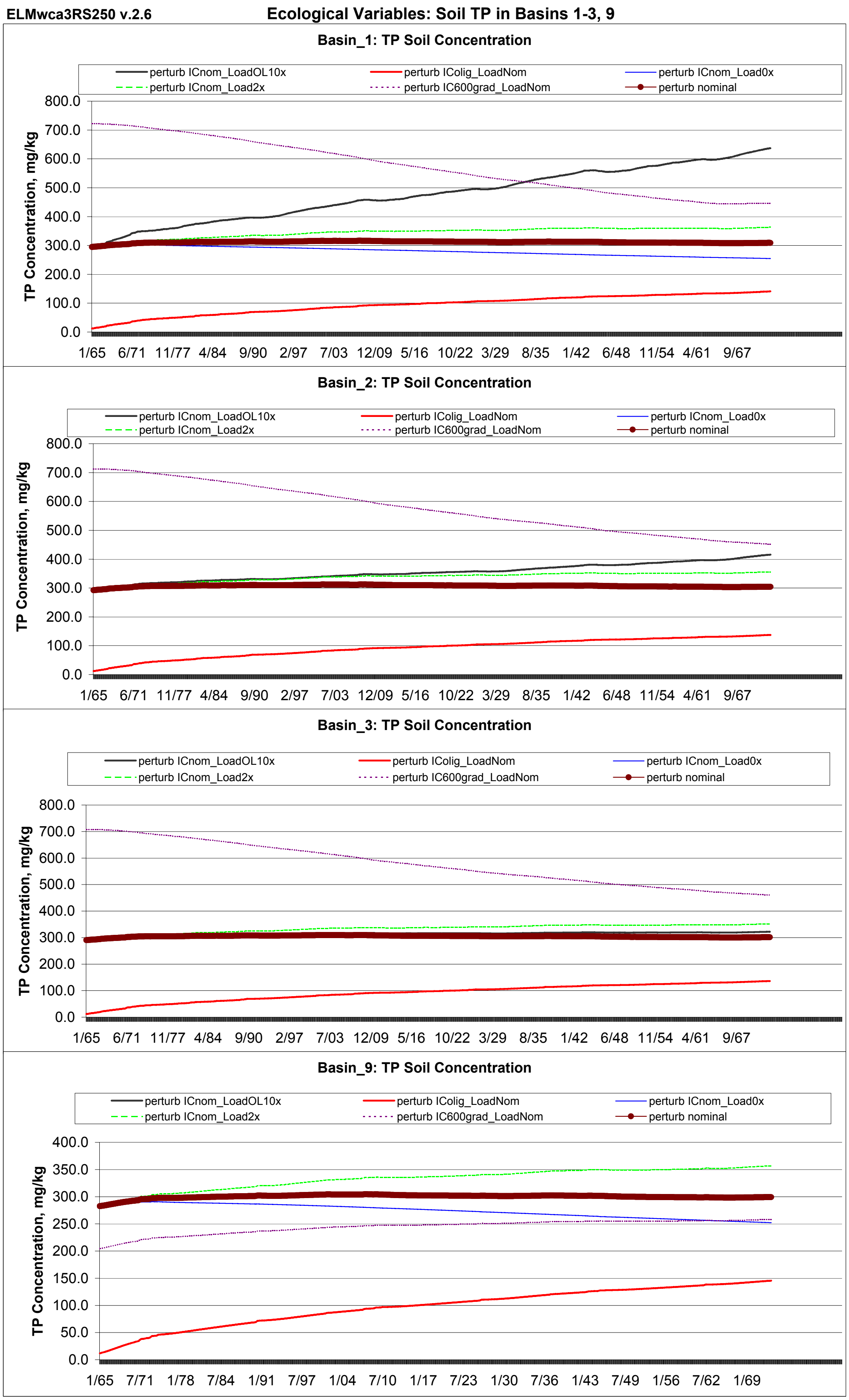


Figure 11.9c Soil elevation in selected Basins along gradient for each 108-yr perturbation experiment. (Datum is NAVD88).

ELMwca3RS250 v.2.6 **Ecological Variables: Elevation in Basins 1-3, 9**

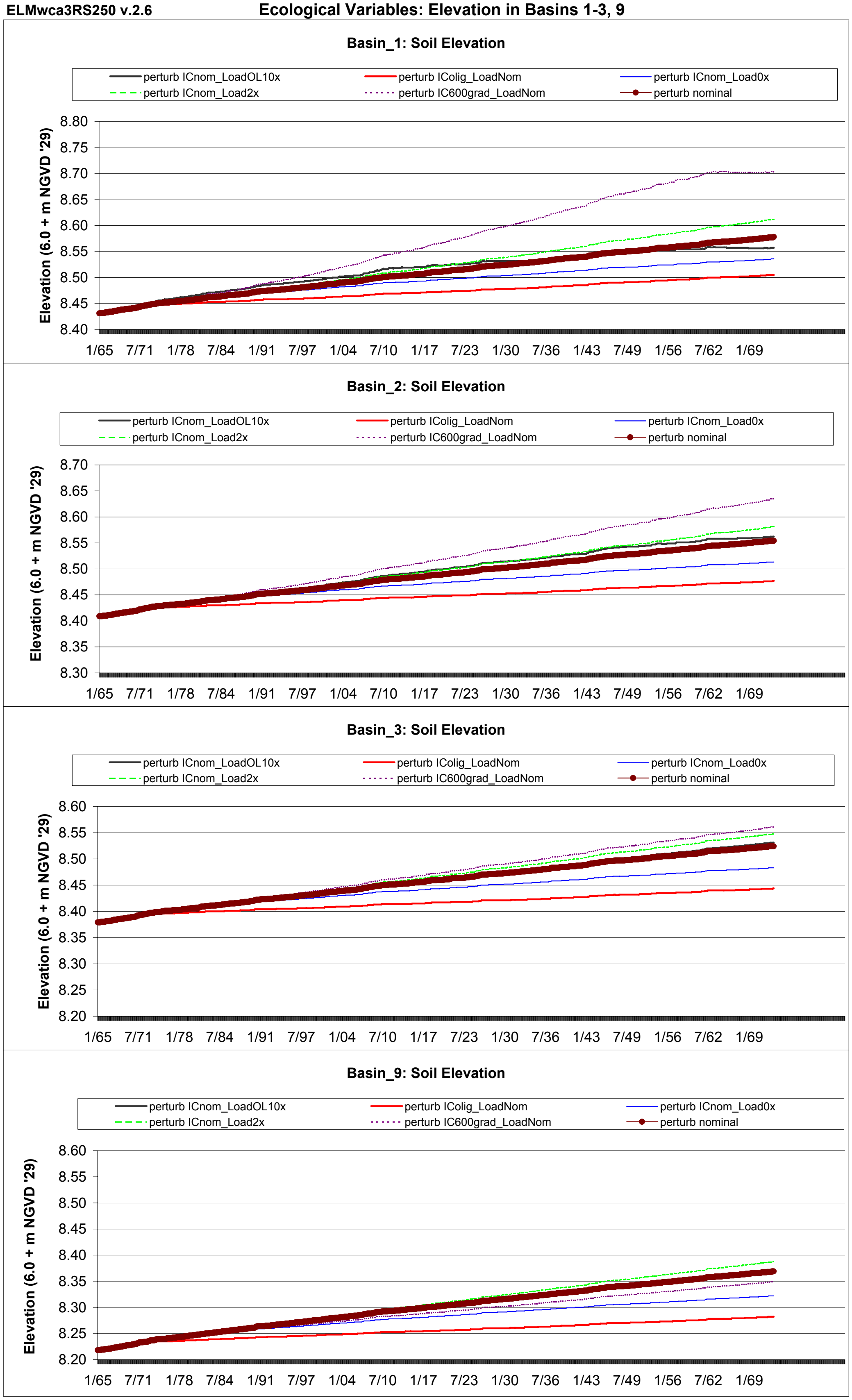
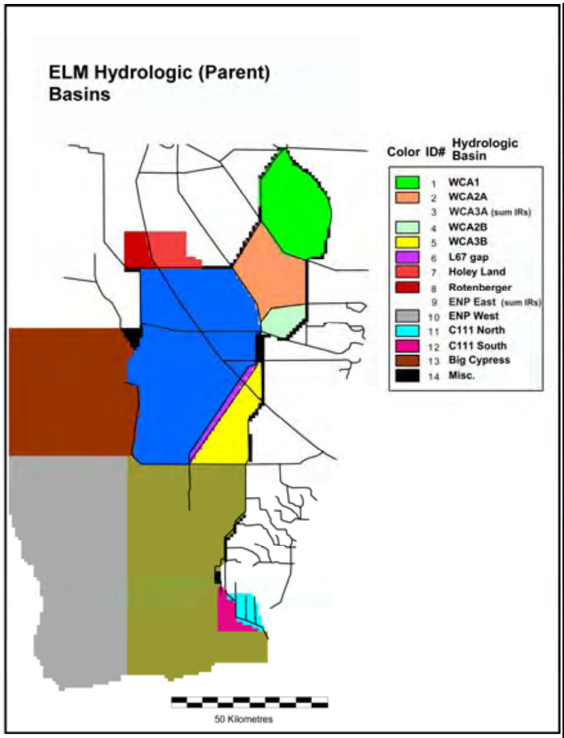
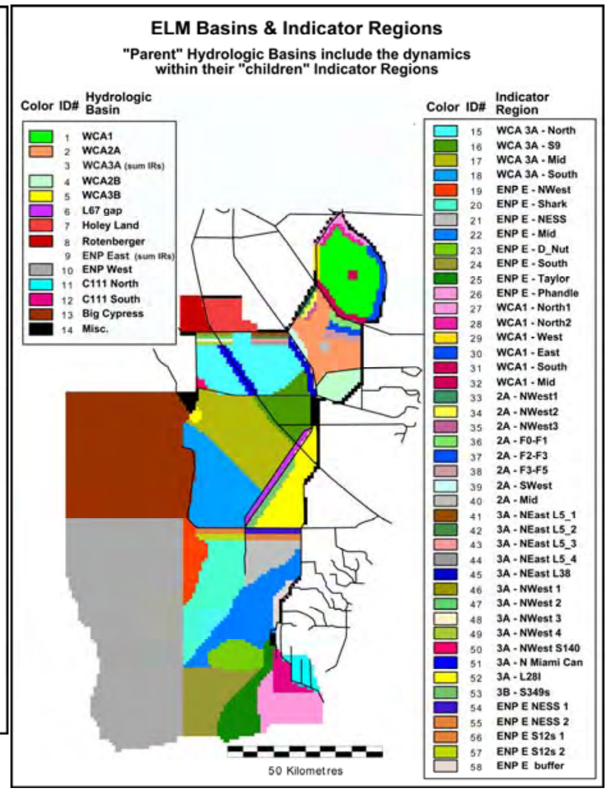


Figure 11.10. Spatial aggregation of multiple model grid cells into Basins and Indicator Regions (BIRs). All model output within "parent" Basins include output of any Indicator Region nested within its local domain. Note that some Basins (such as WCA3A) are entirely derived from individual Indicator Regions. Other Basins (such as WCA1) contain many grid cells that are only considered as an output component of the entire Basin.

a) Hydrologic Basins in regional ELM.



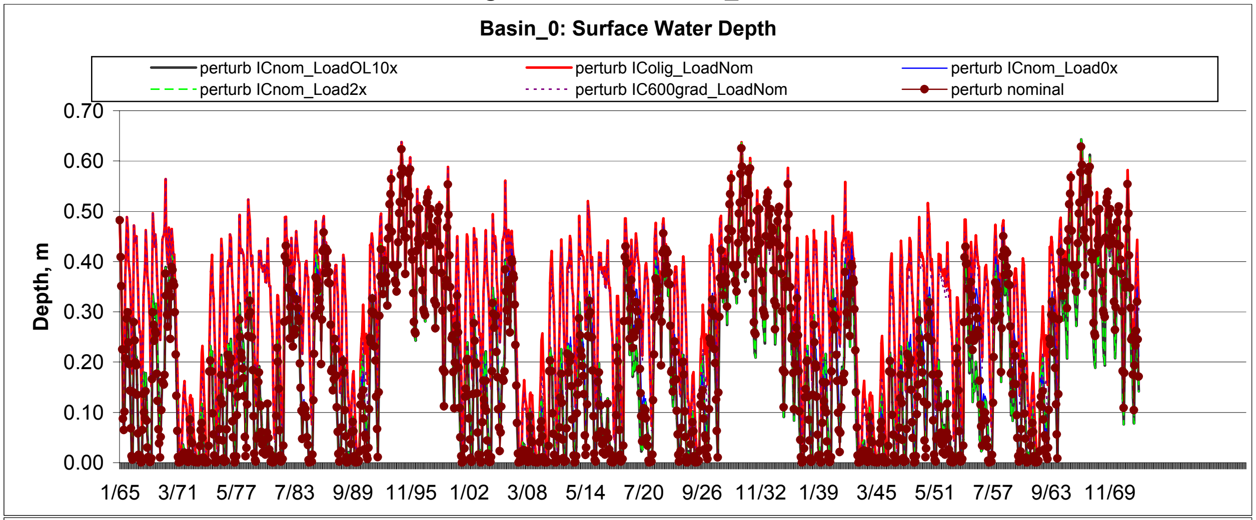
b) Indicator Regions in regional ELM.

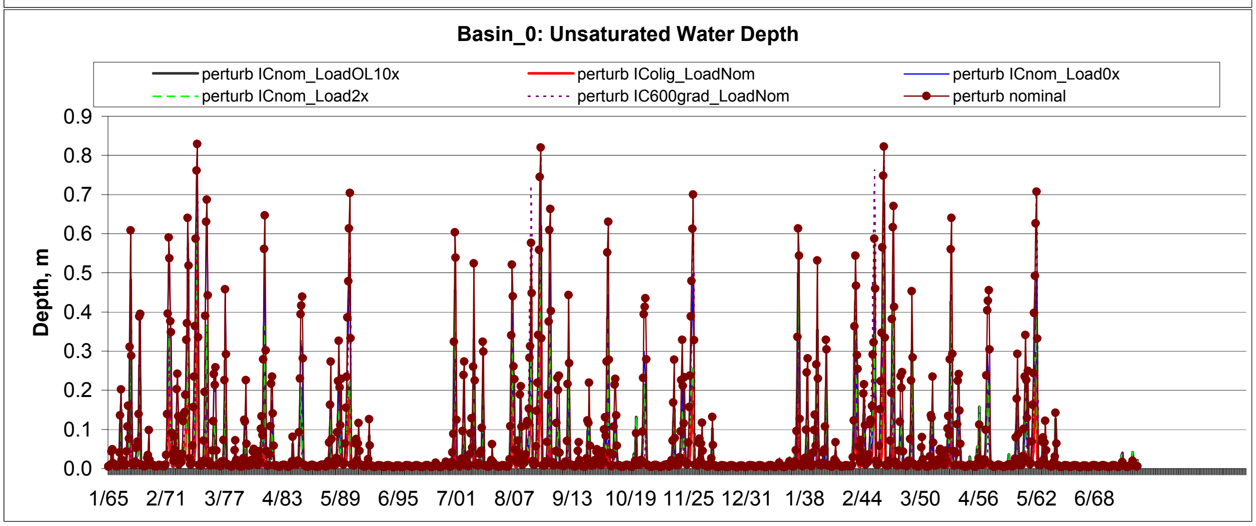


11.8 Appendix 11.1 All results, subregional 108-yr

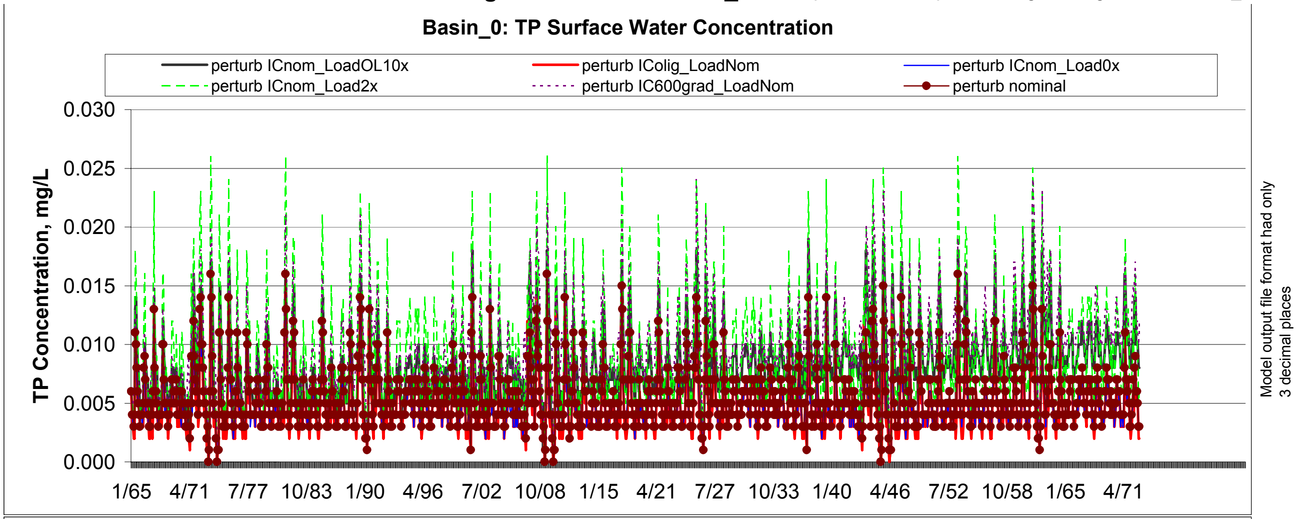
All 108-yr time series outputs for nine ecological variables in the whole-domain (Basin 0) and gradient Basins 1 – 9, for the ELMwca3RS250 project simulations under six scenarios of phosphorus perturbations. See text for the descriptions of the model configuration and phosphorus perturbation experiments.

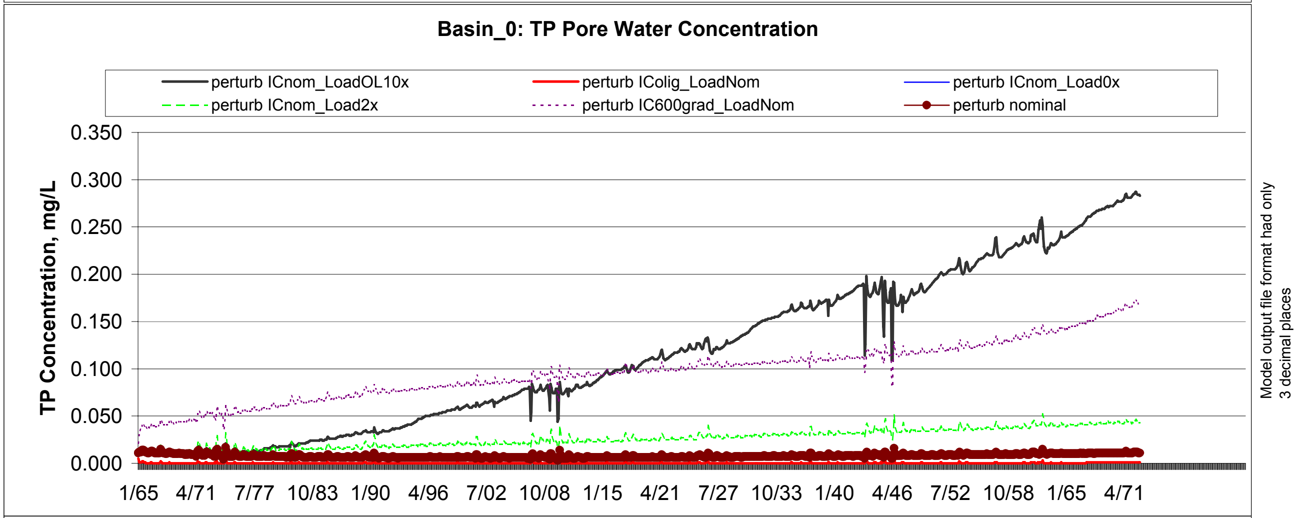
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_0** **(entire Domain)** 4 Pages, 9 Figures Basin_0

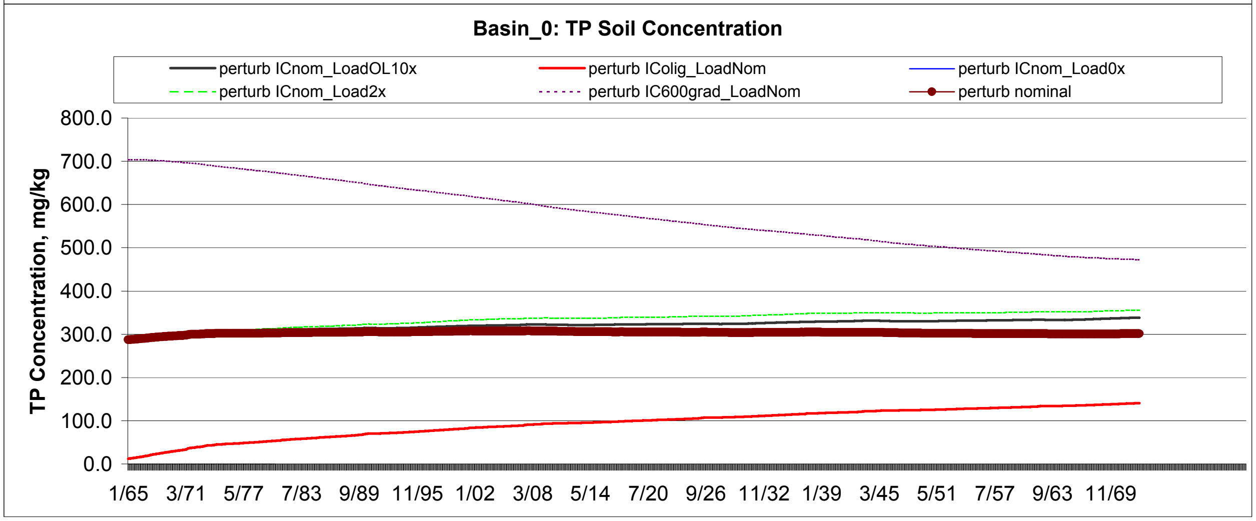




ELMwca3RS250 v.2.6 **Ecological Variables:Basin_0** **(entire Domain)** 4 Pages, 9 Figures Basin_0

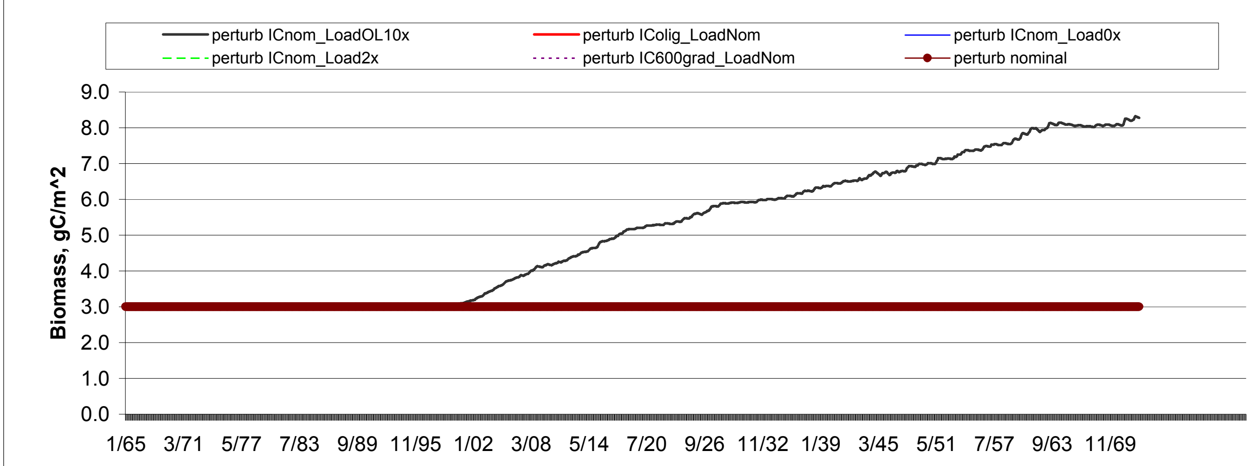




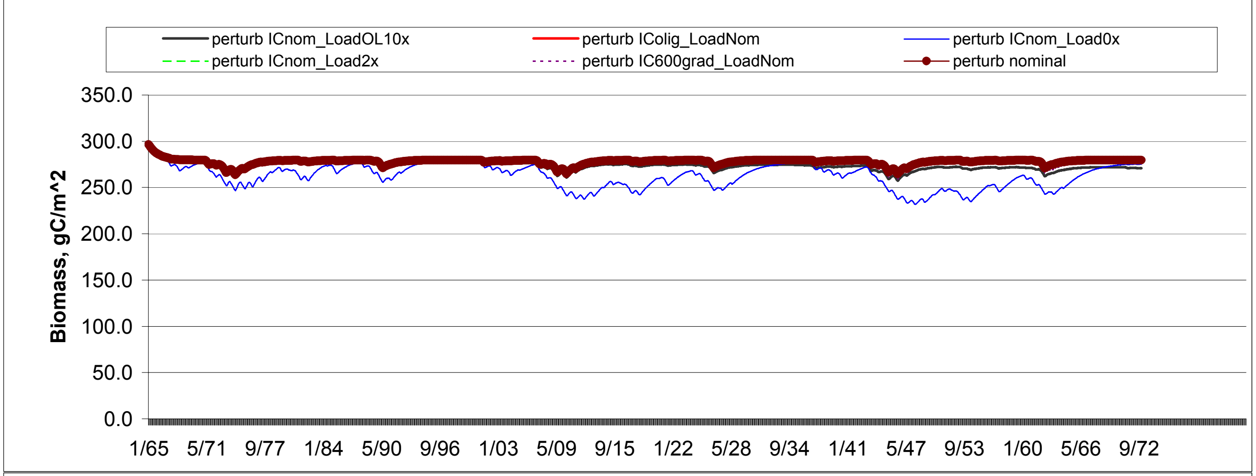


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_0** **(entire Domain)** 4 Pages, 9 Figures Basin_0

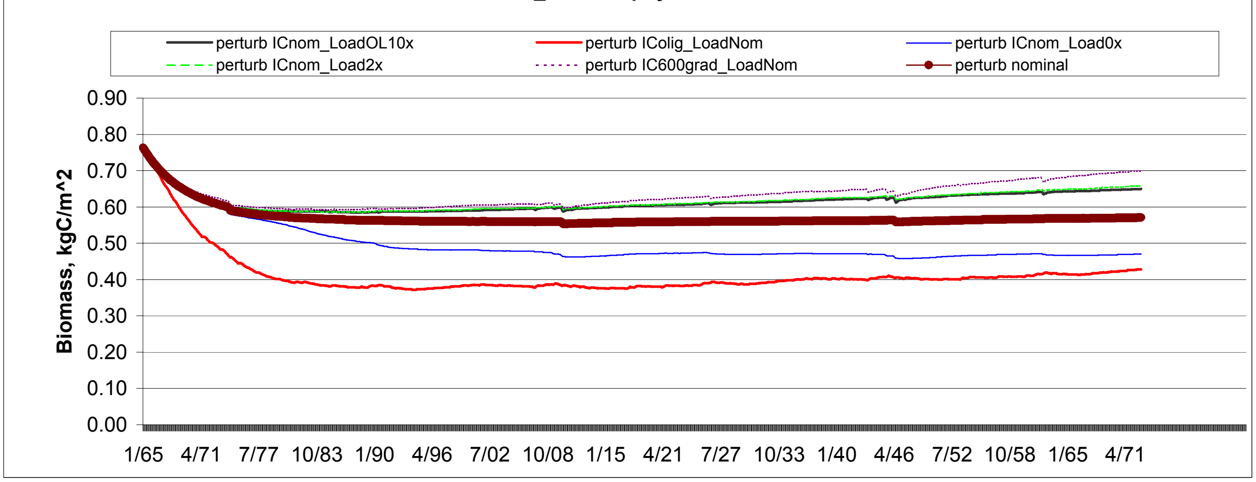
Basin_0: Eutrophic Periphyton Biomass



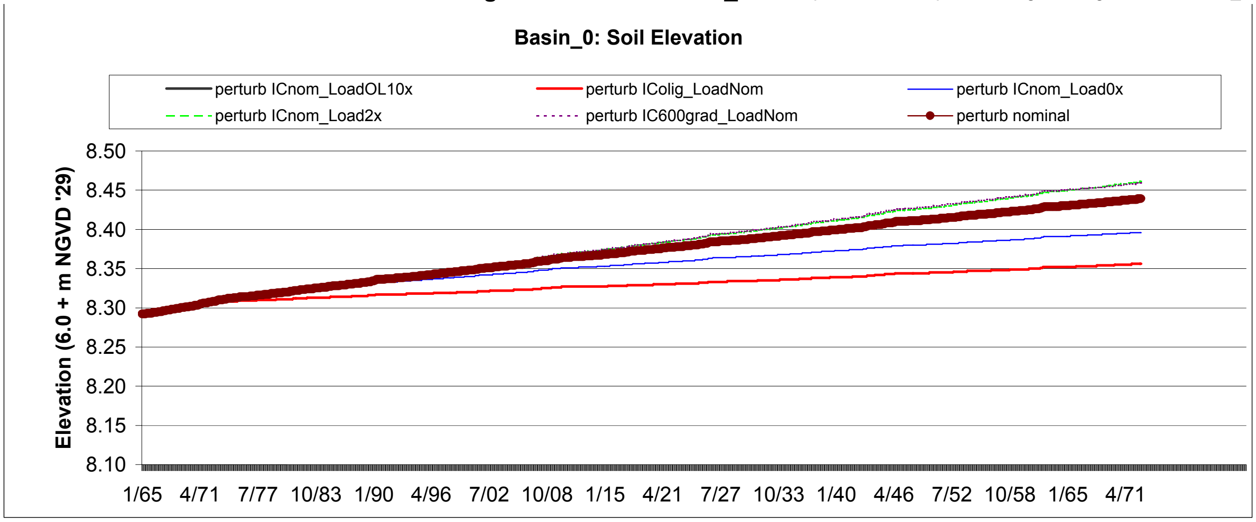
Basin_0: Oligotrophic Periphyton Biomass



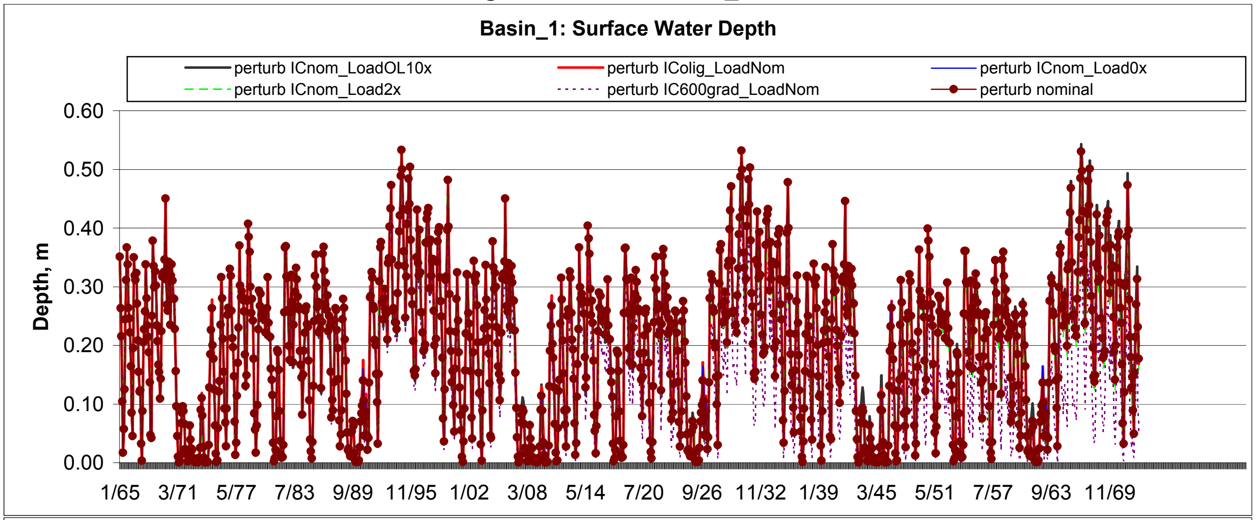
Basin_0: Macrophyte Biomass

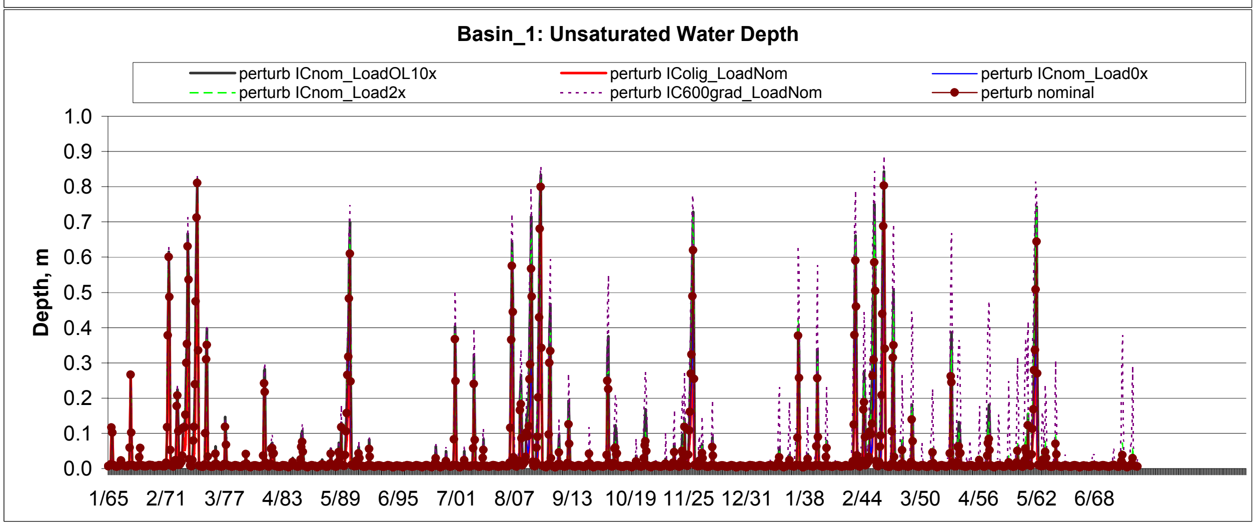


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_0** (entire Domain) 4 Pages, 9 Figures Basin_0



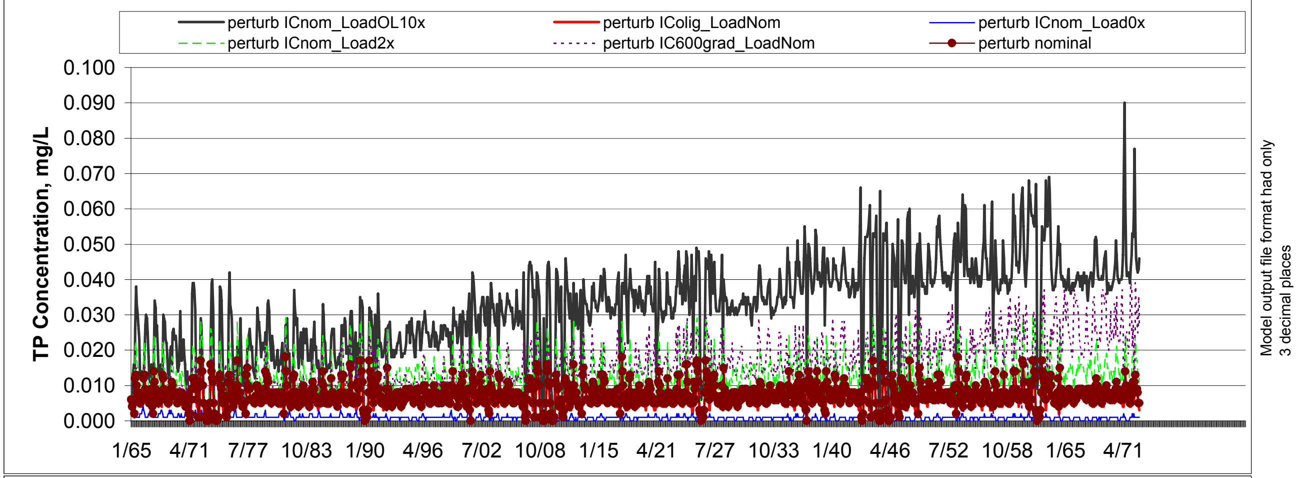
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_1** 4 Pages, 9 Figures Basin_1



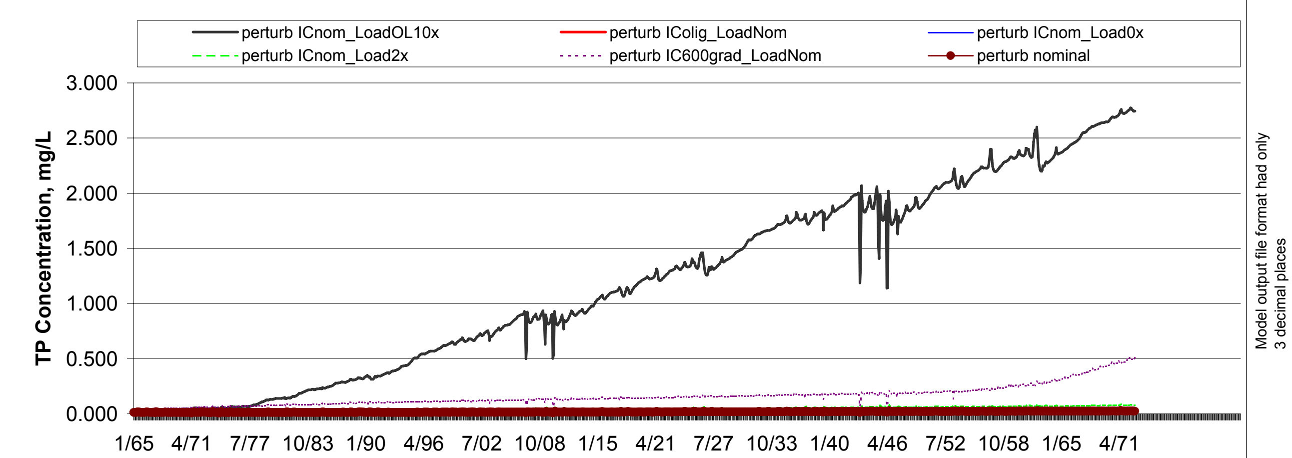


ELMwca3RS250 v.2.6 | **Ecological Variables:Basin_1** | 4 Pages, 9 Figures | Basin_1

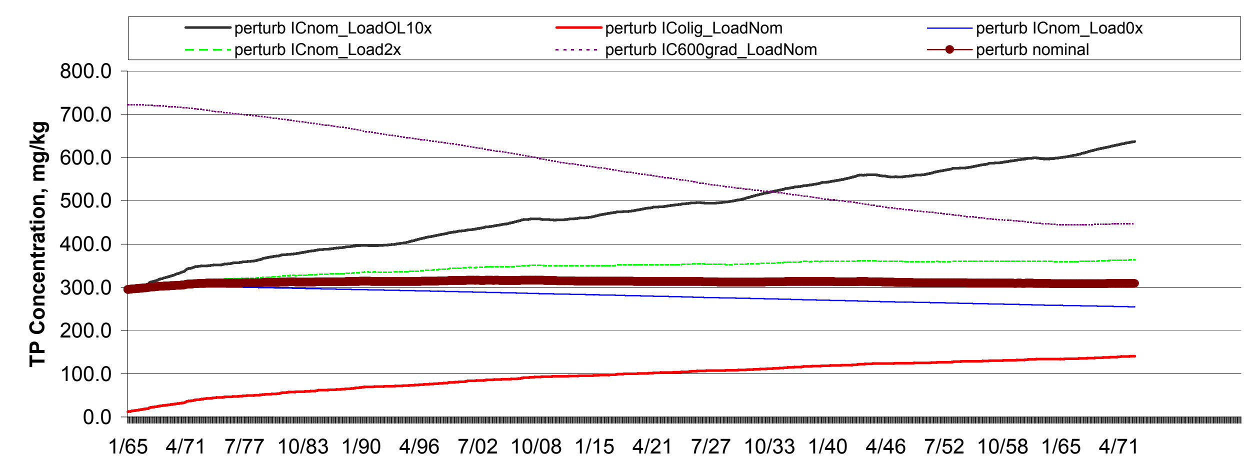
Basin_1: TP Surface Water Concentration



Basin_1: TP Pore Water Concentration

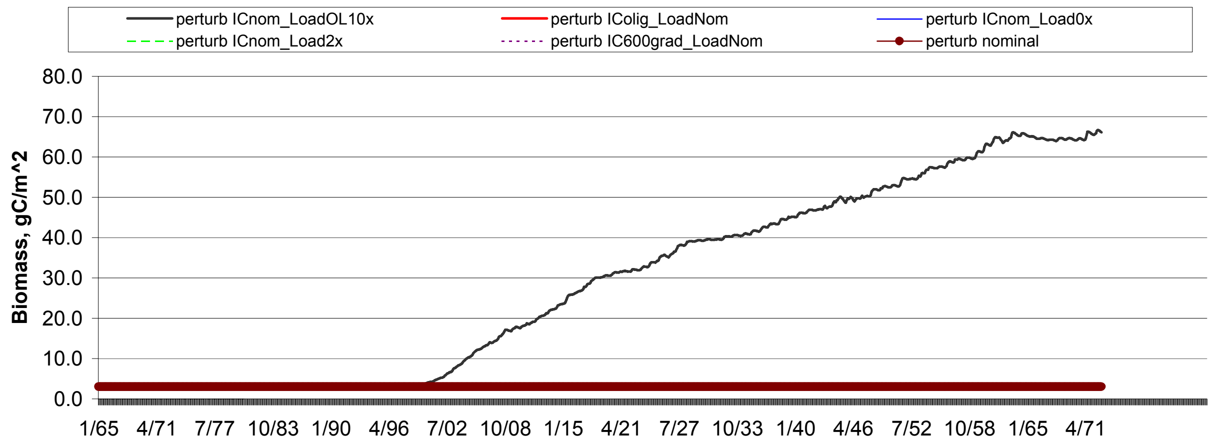


Basin_1: TP Soil Concentration

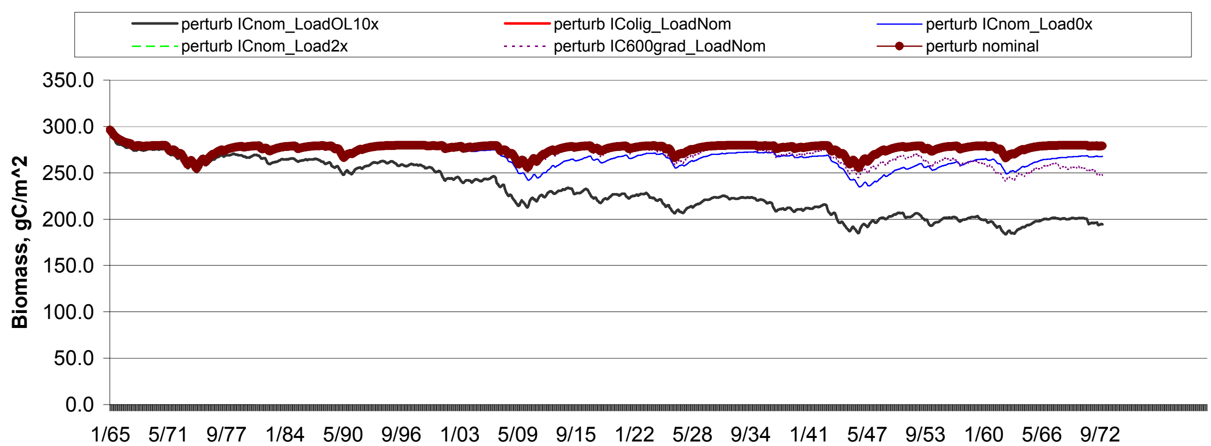


ELMwca3RS250 v.2.6 | **Ecological Variables:Basin_1** | 4 Pages, 9 Figures | Basin_1

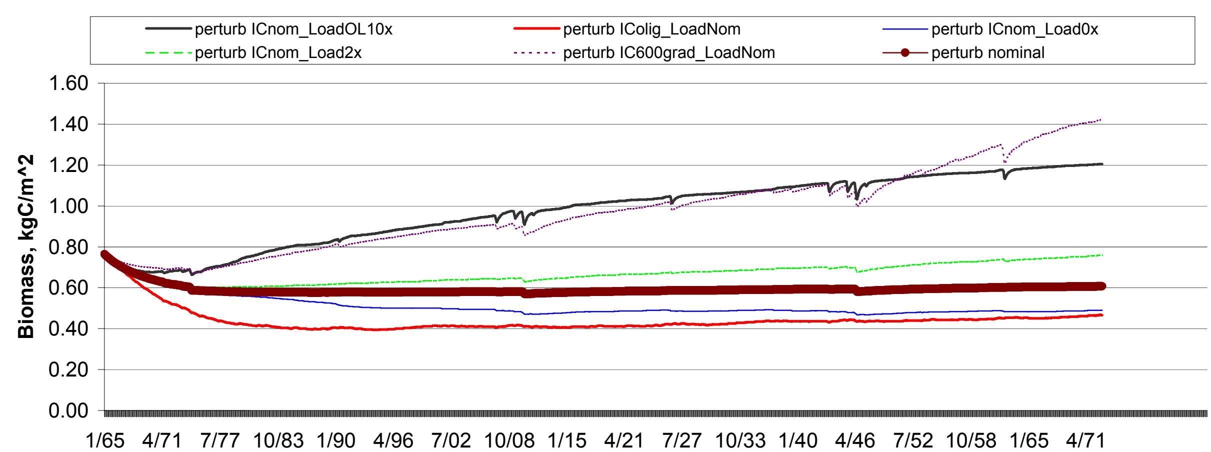
Basin_1: Eutrophic Periphyton Biomass



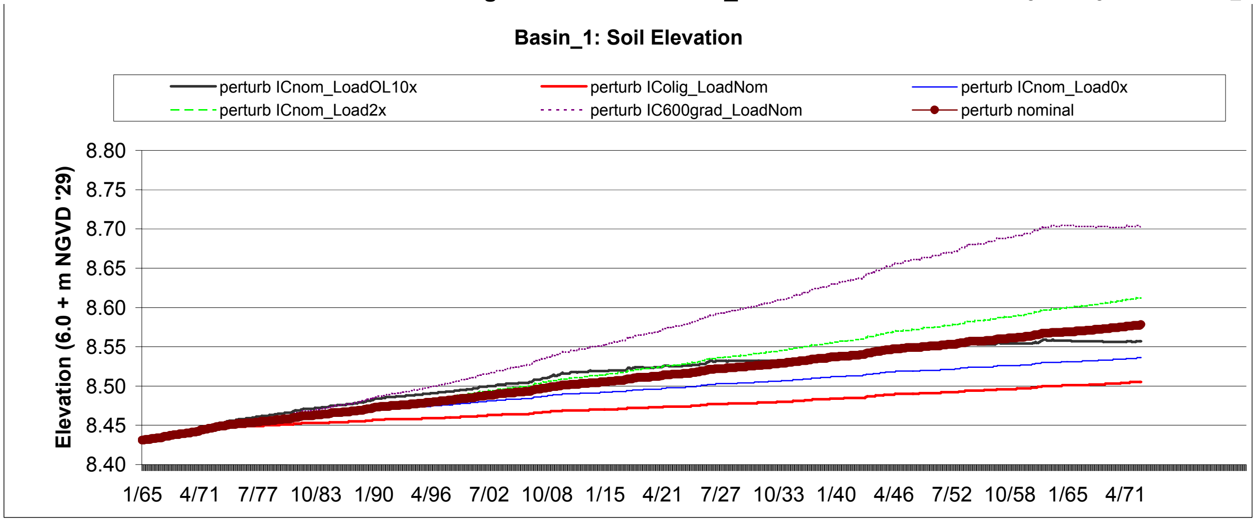
Basin_1: Oligotrophic Periphyton Biomass



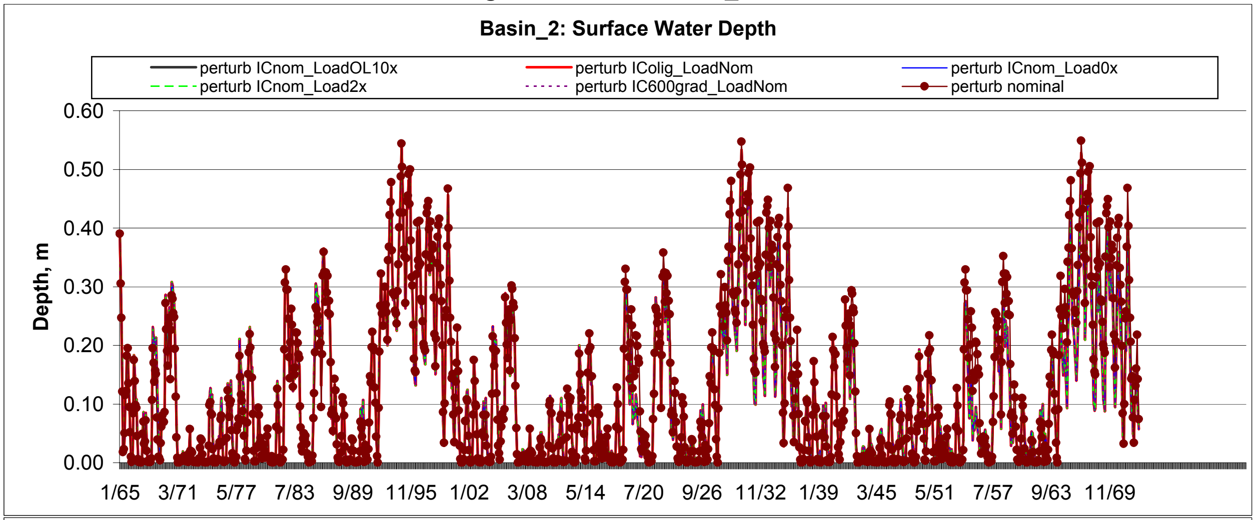
Basin_1: Macrophyte Biomass

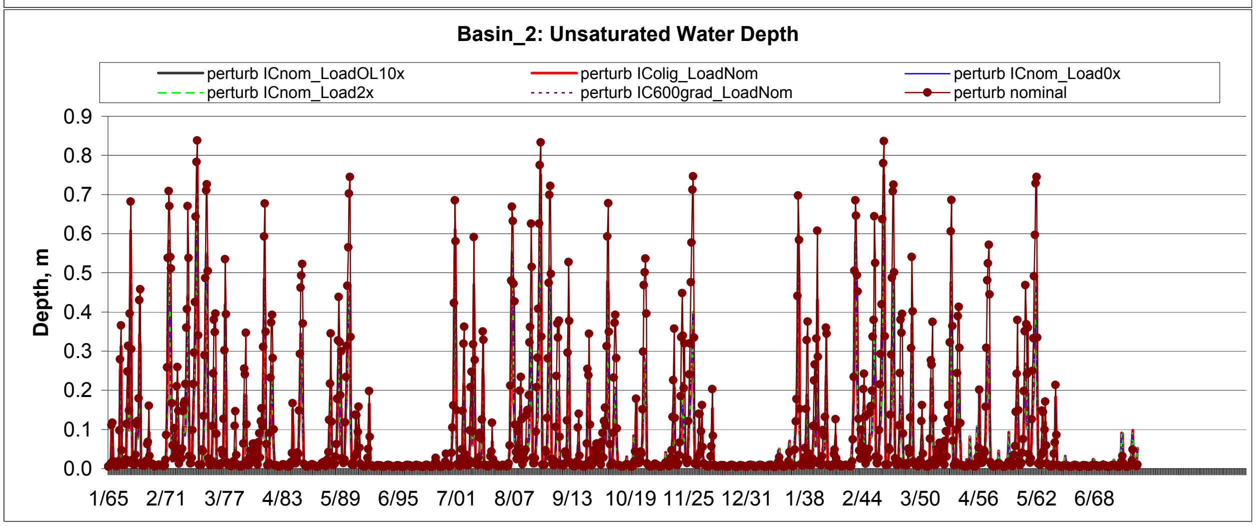


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_1** 4 Pages, 9 Figures Basin_1



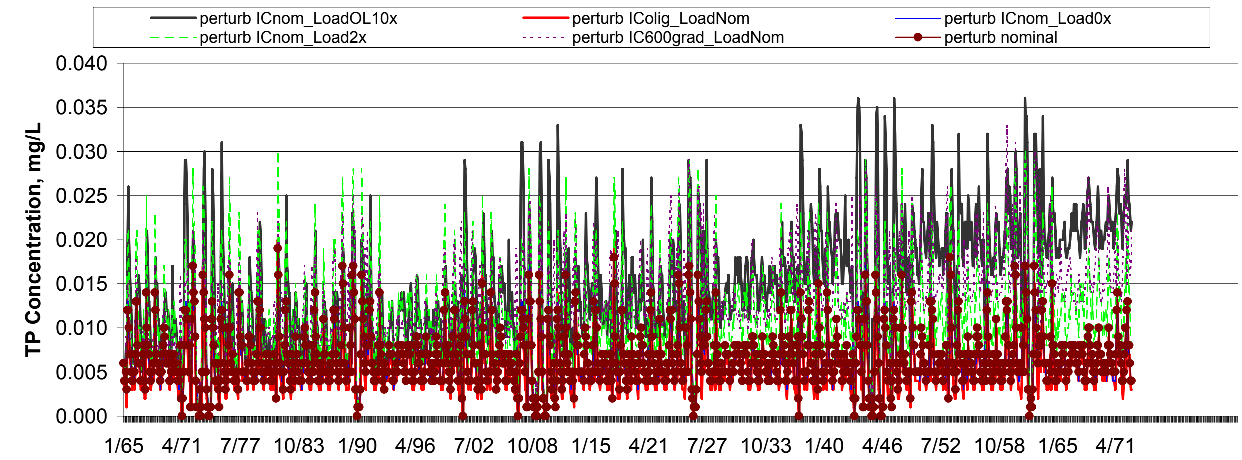
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_2** 4 Pages, 9 Figures Basin_2





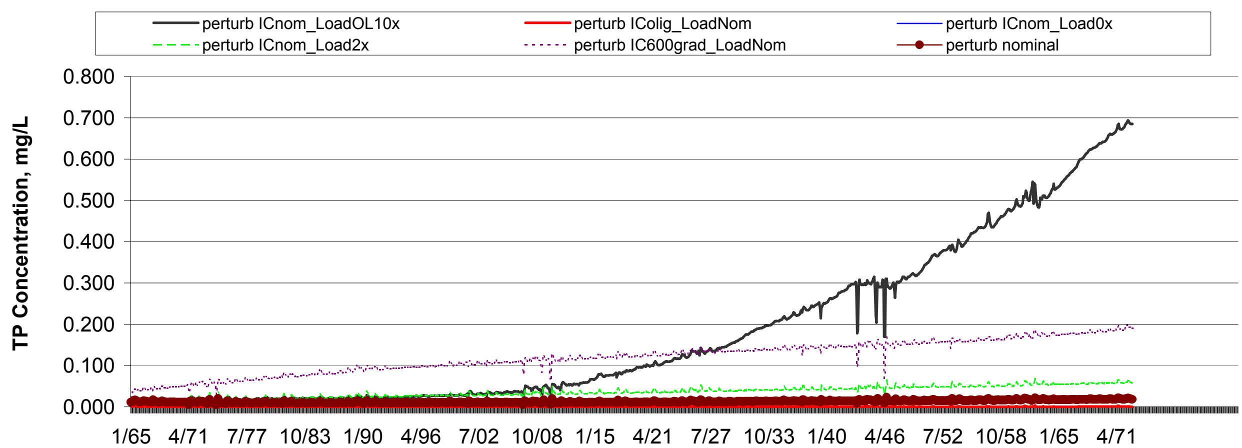
Ecological Variables:Basin_2

Basin_2: TP Surface Water Concentration



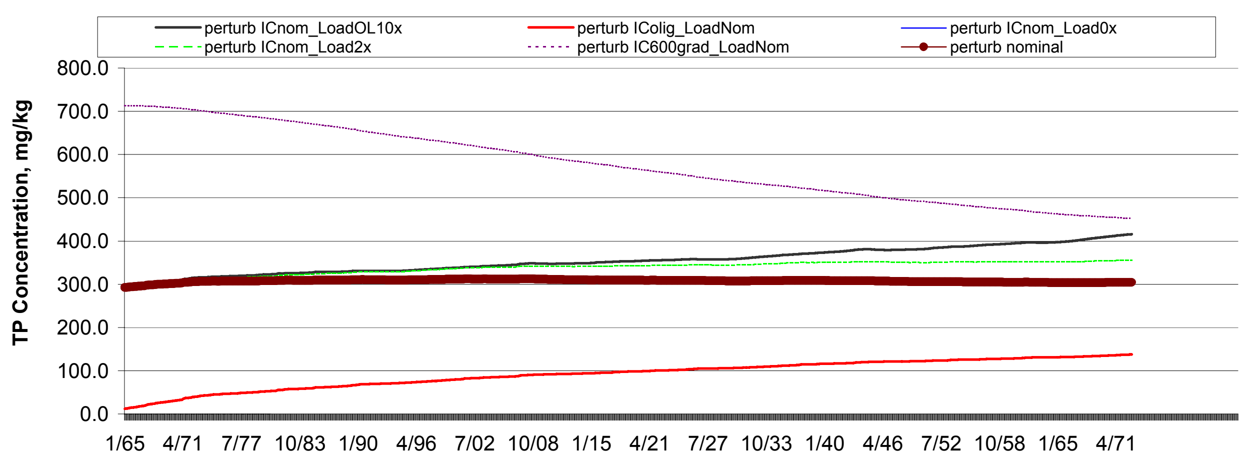
Model output file format had only 3 decimal places

Basin_2: TP Pore Water Concentration

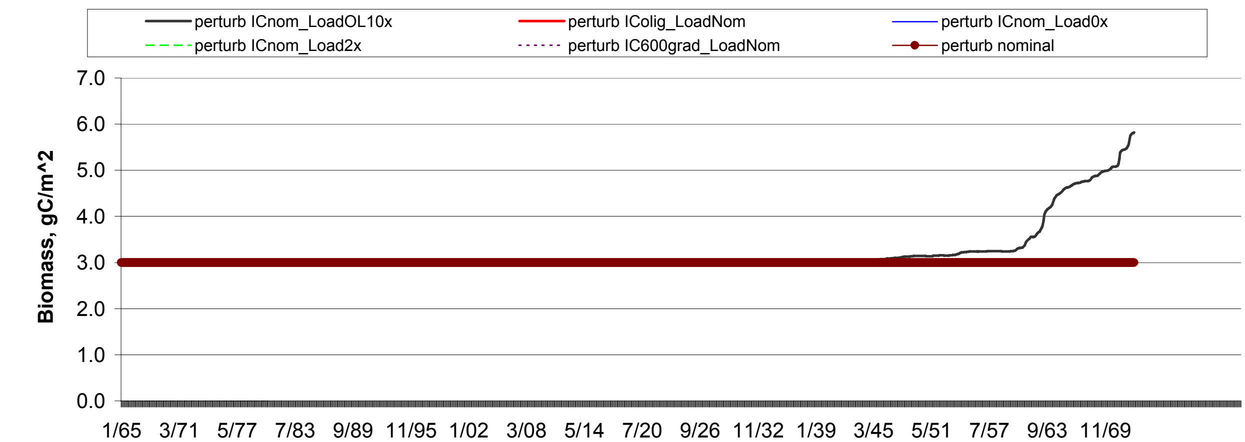


Model output file format had only 3 decimal places

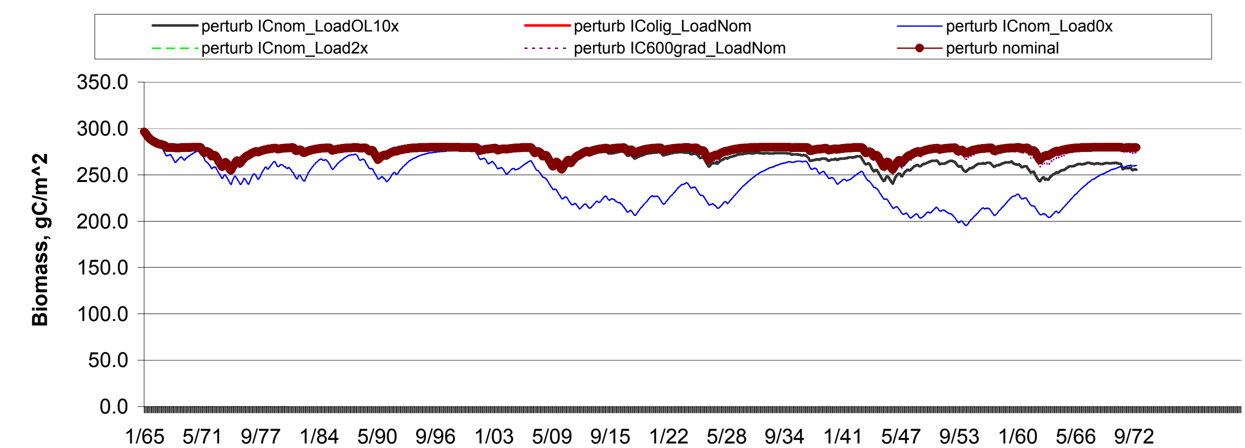
Basin_2: TP Soil Concentration



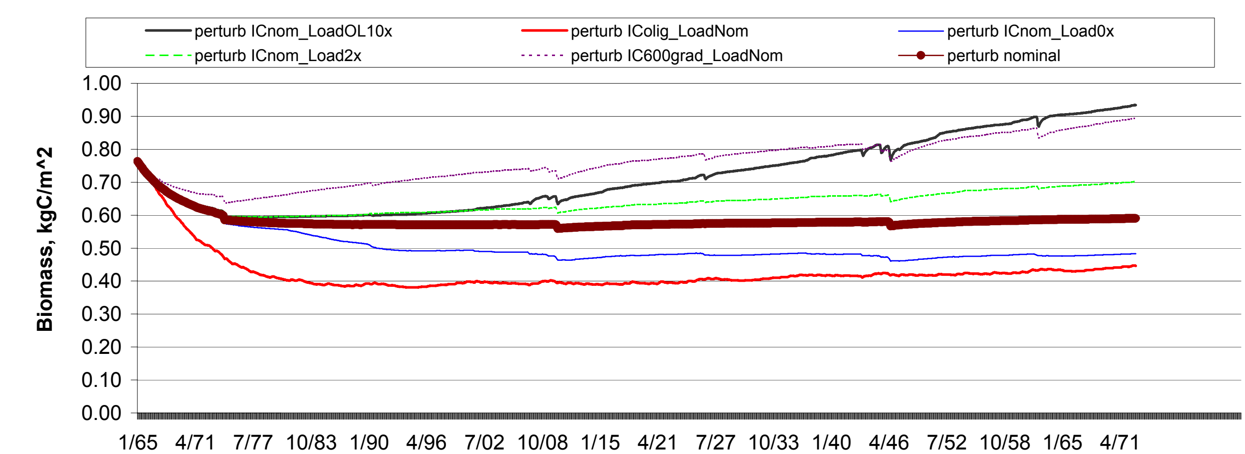
Basin_2: Eutrophic Periphyton Biomass



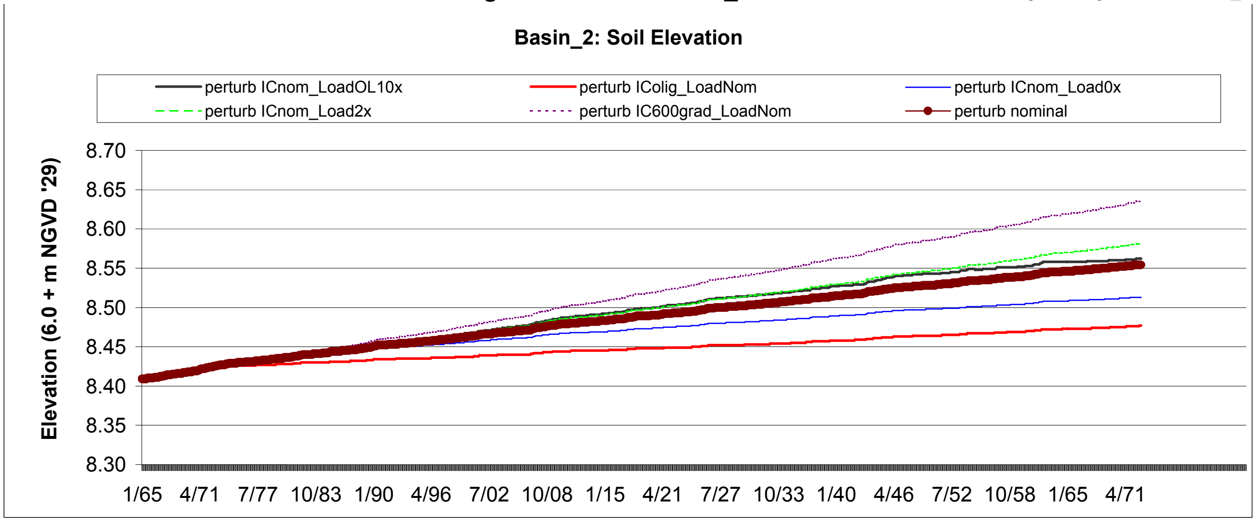
Basin_2: Oligotrophic Periphyton Biomass



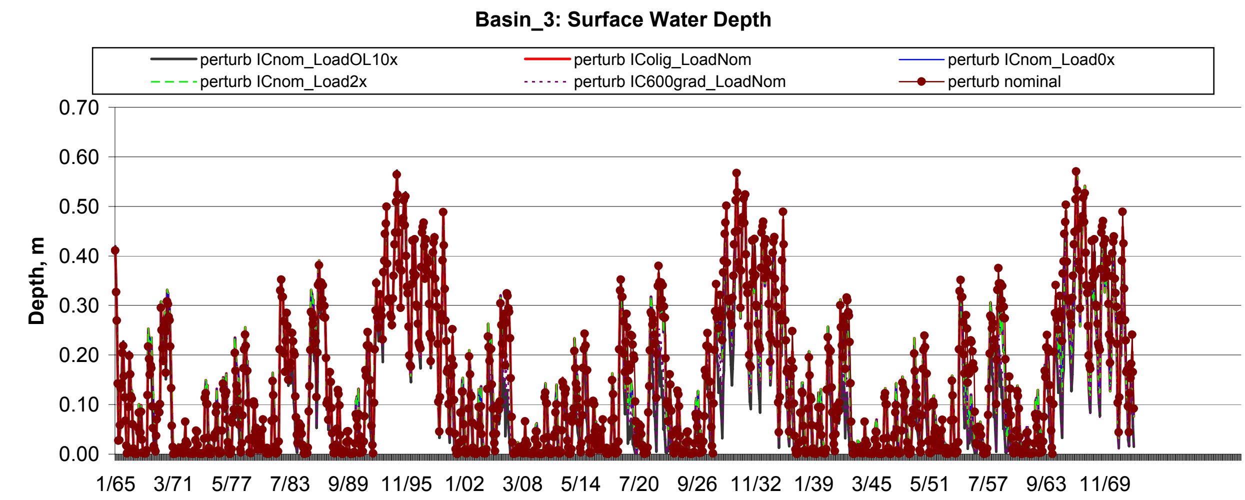
Basin_2: Macrophyte Biomass

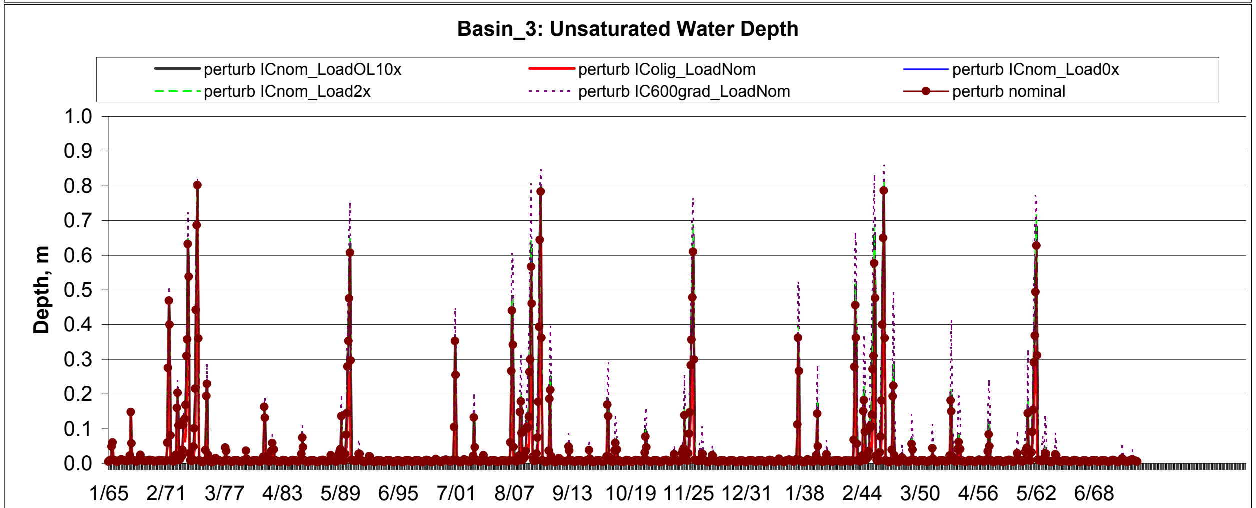


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_2** 4 Pages, 9 Figures Basin_2



ELMwca3RS250 v.2.6 **Ecological Variables:Basin_3** 4 Pages, 9 Figures Basin_3



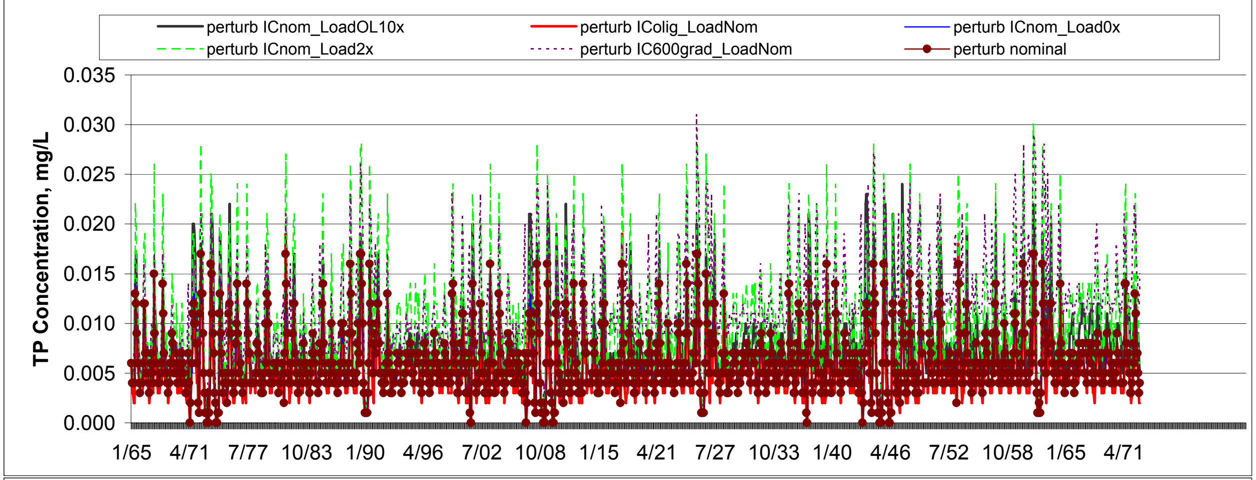


ELMwca3RS250 v.2.6

Ecological Variables:Basin_3

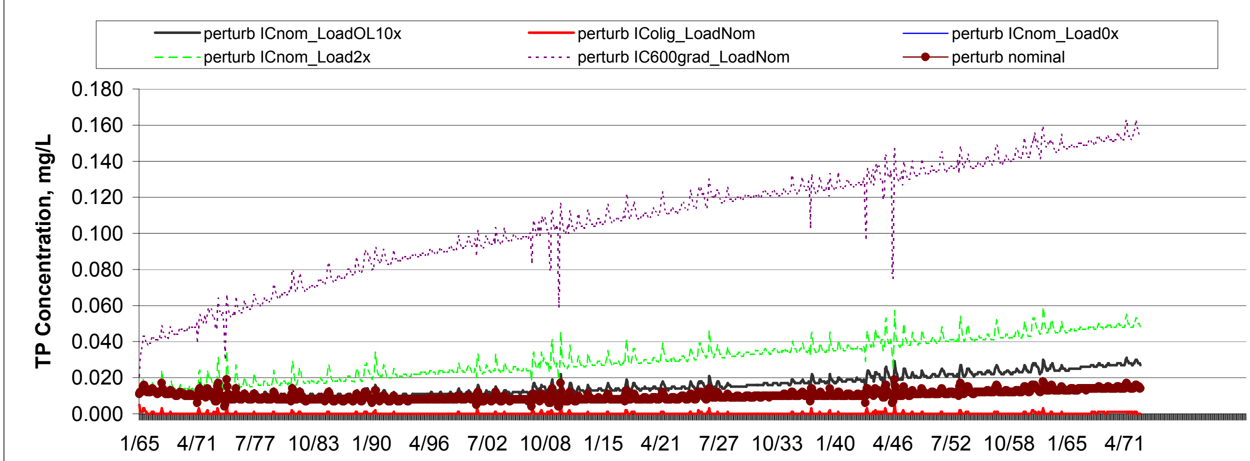
4 Pages, 9 Figures Basin_3

Basin_3: TP Surface Water Concentration



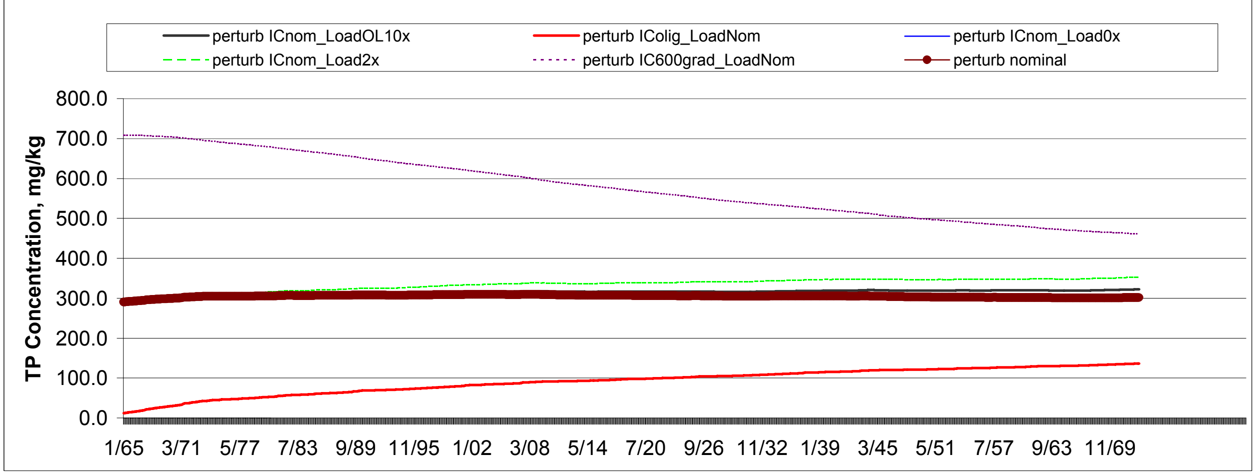
Model output file format had only 3 decimal places

Basin_3: TP Pore Water Concentration

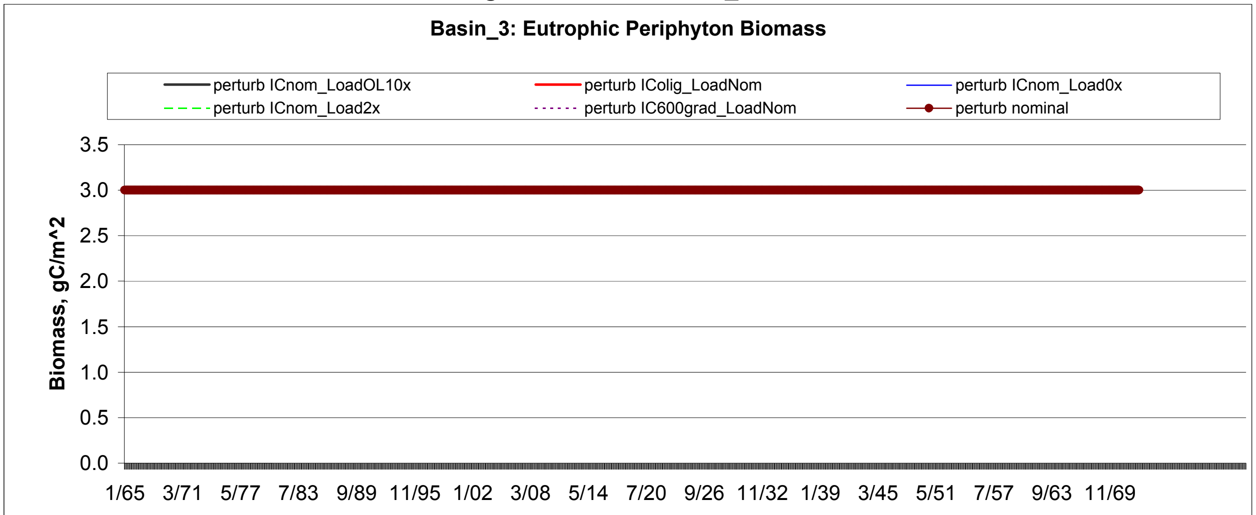


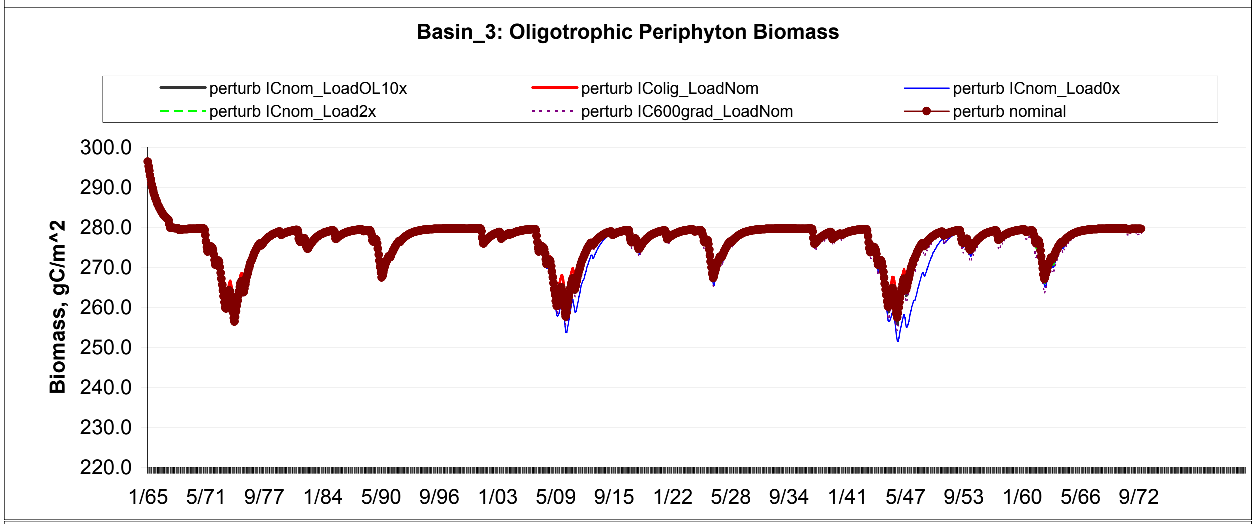
Model output file format had only 3 decimal places

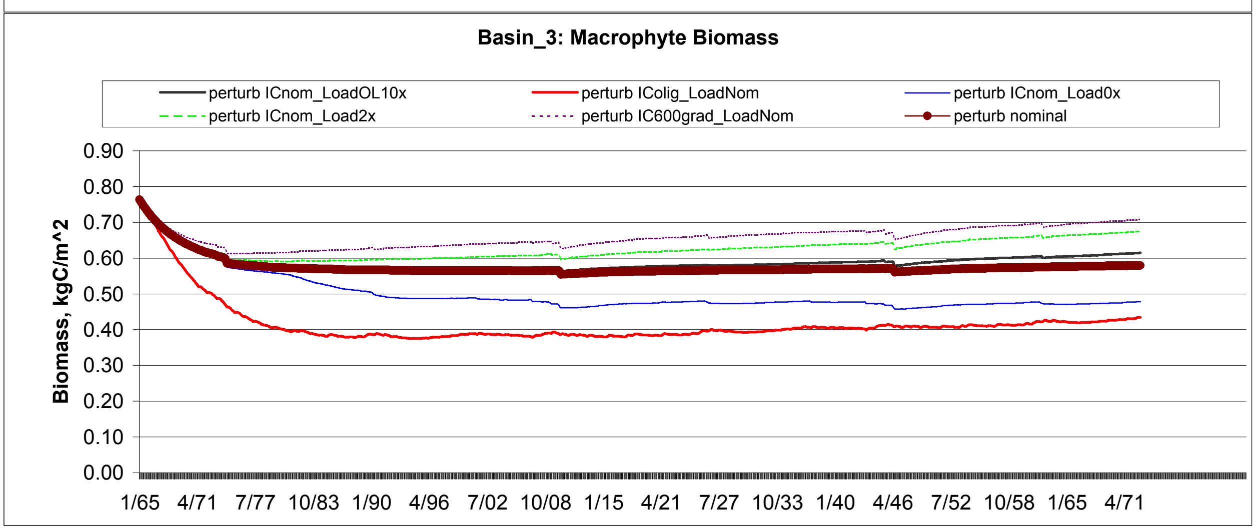
Basin_3: TP Soil Concentration



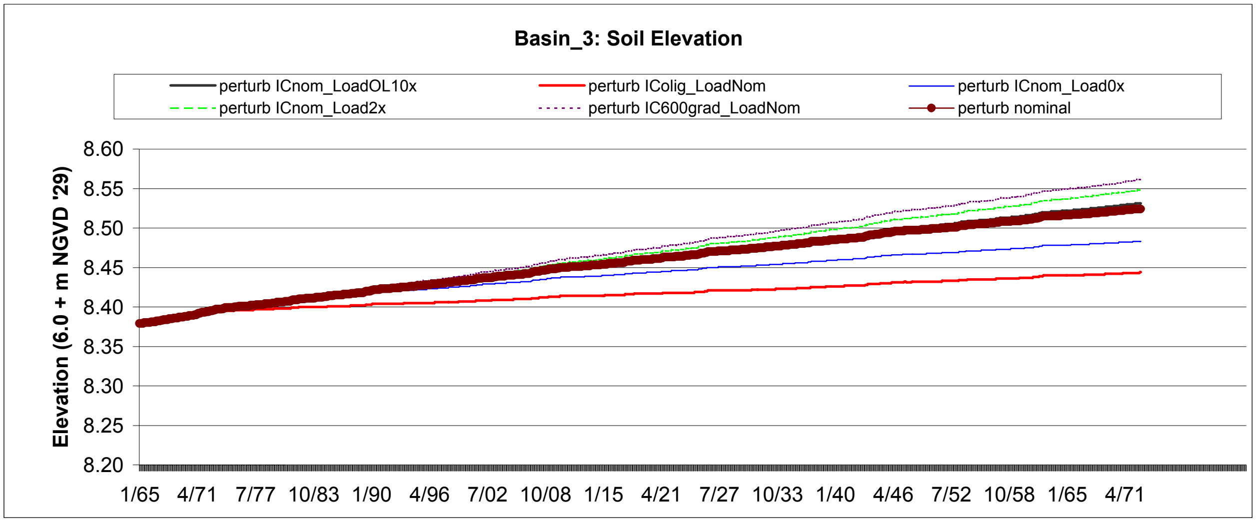
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_3** 4 Pages, 9 Figures Basin_3



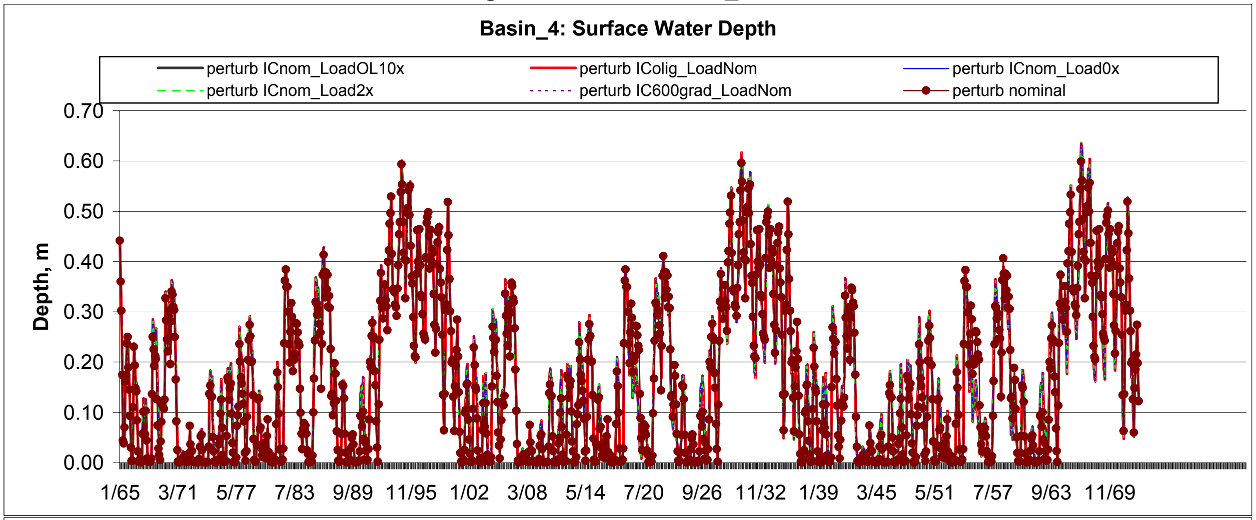


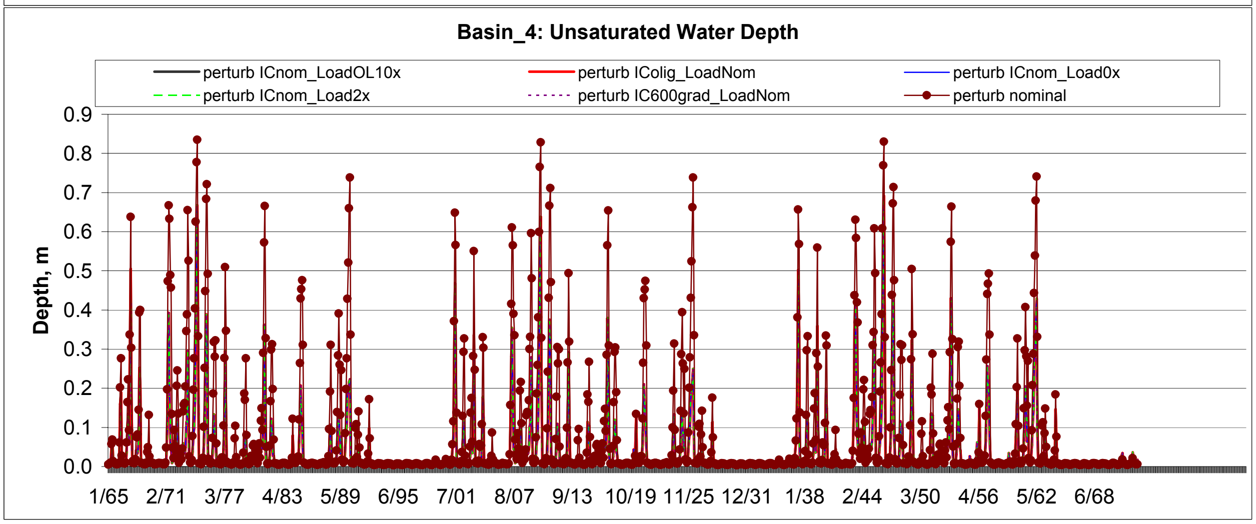


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_3** 4 Pages, 9 Figures Basin_3



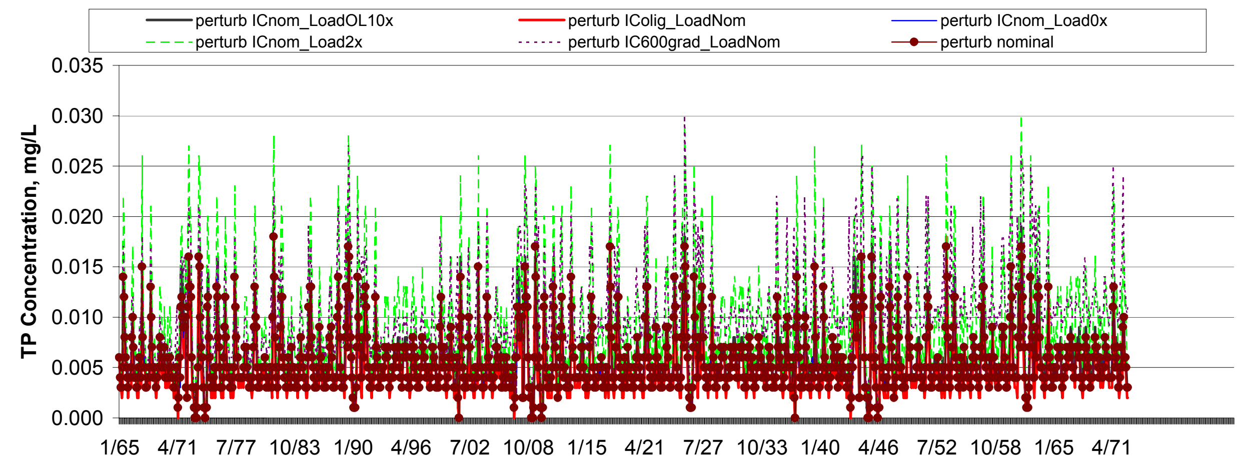
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_4** 4 Pages, 9 Figures Basin_4





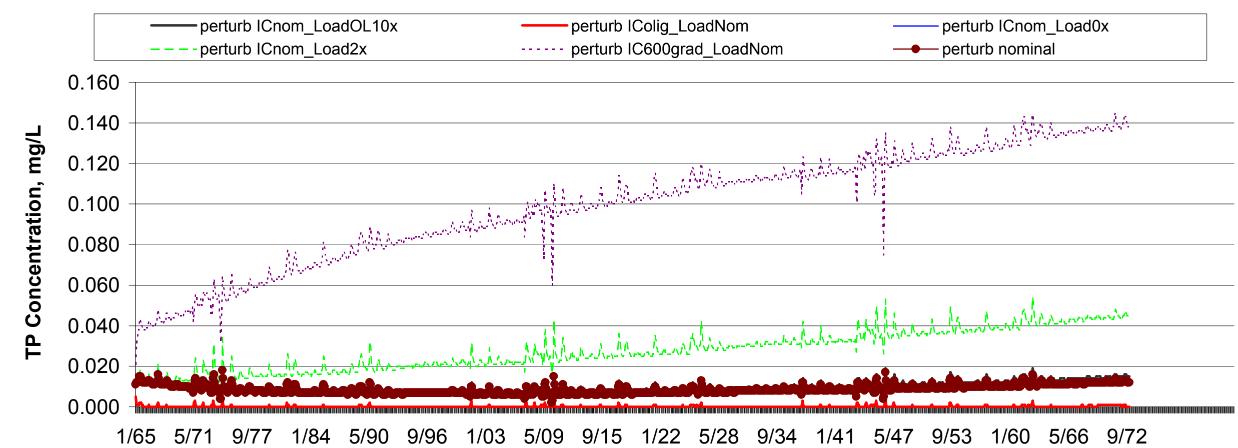
ELMwca3RS250 v.2.6 | **Ecological Variables:Basin_4** | 4 Pages, 9 Figures | Basin_4

Basin_4: TP Surface Water Concentration



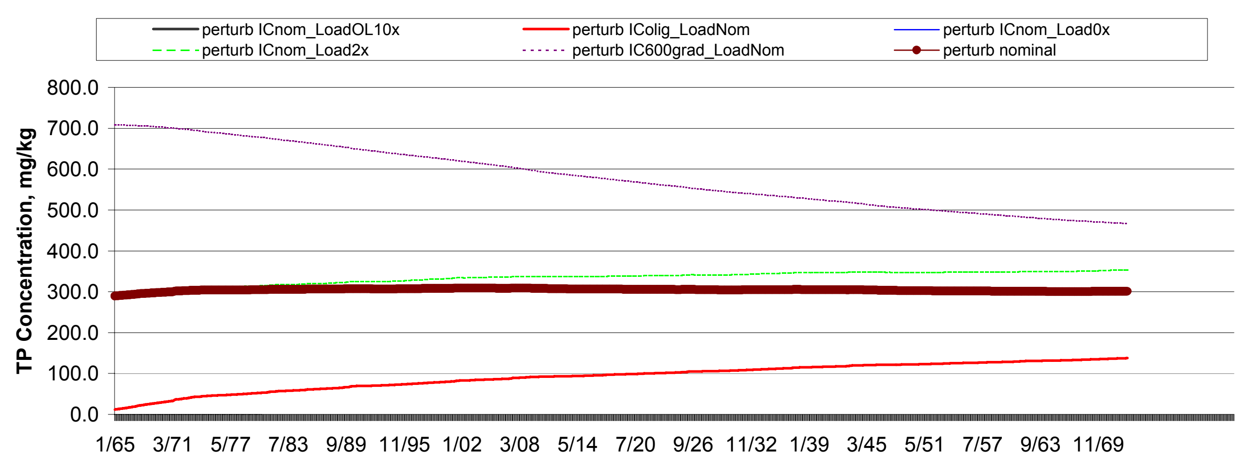
Model output file format had only 3 decimal places

Basin_4: TP Pore Water Concentration

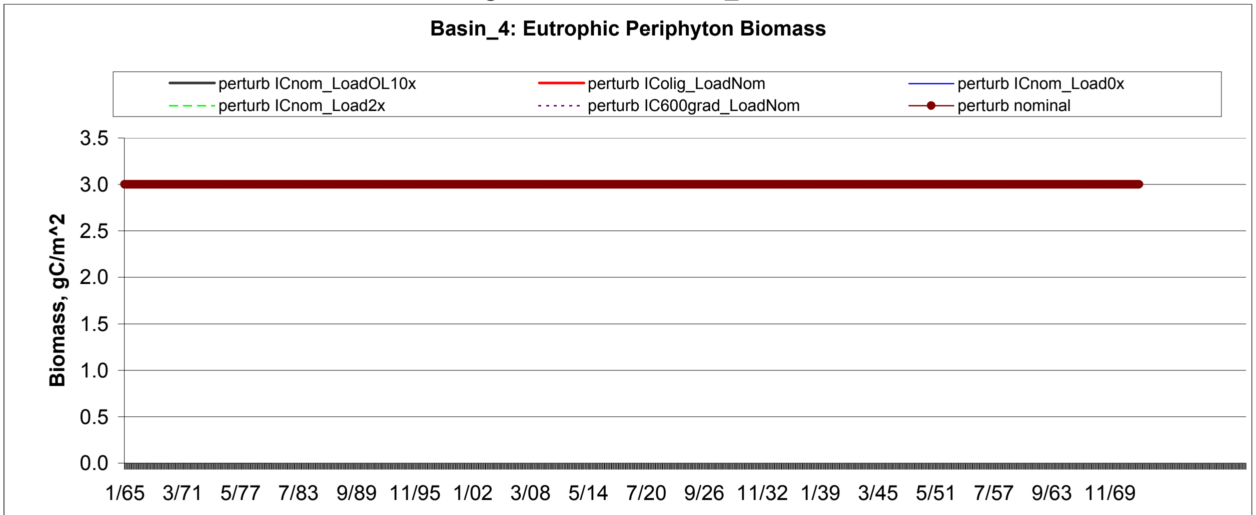


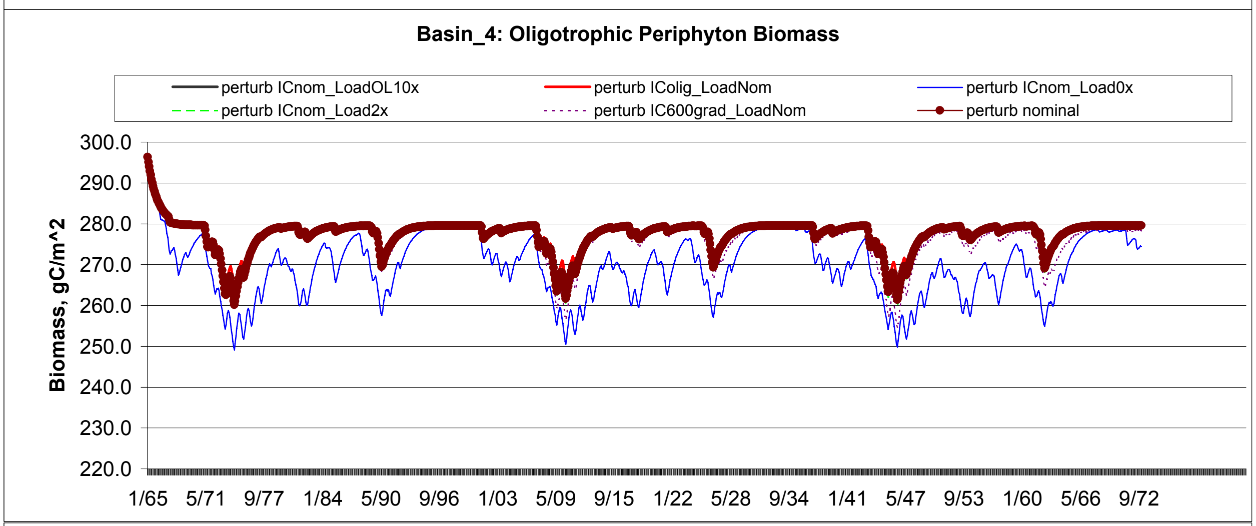
Model output file format had only 3 decimal places

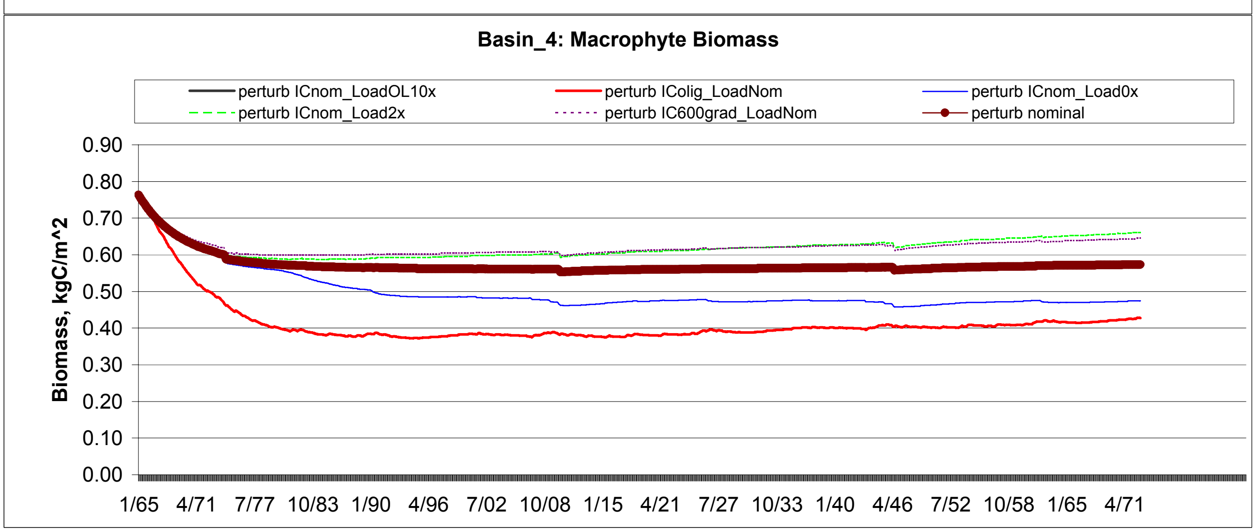
Basin_4: TP Soil Concentration



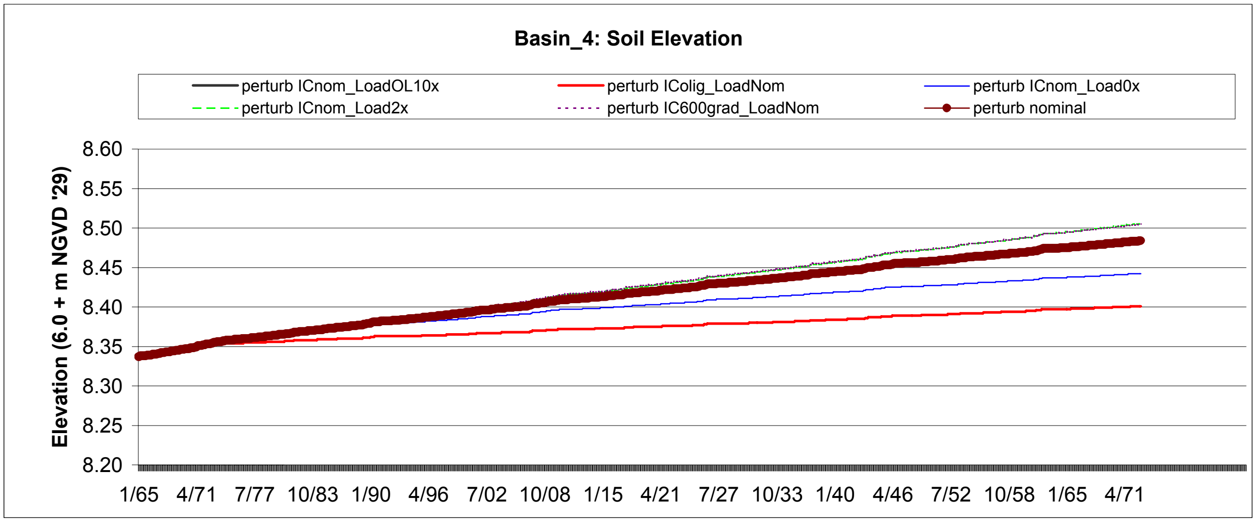
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_4** 4 Pages, 9 Figures Basin_4



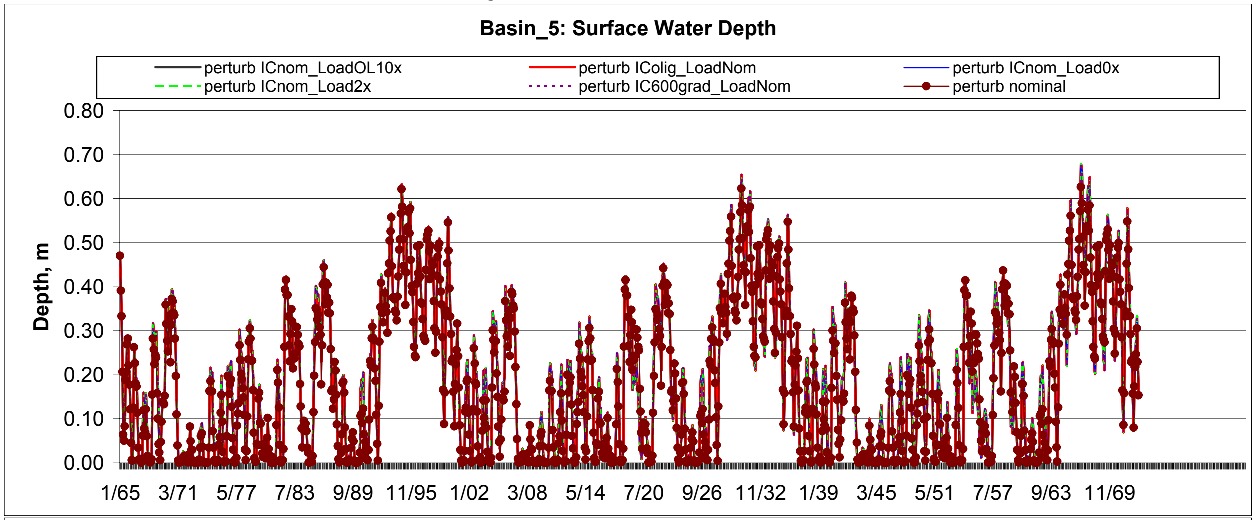


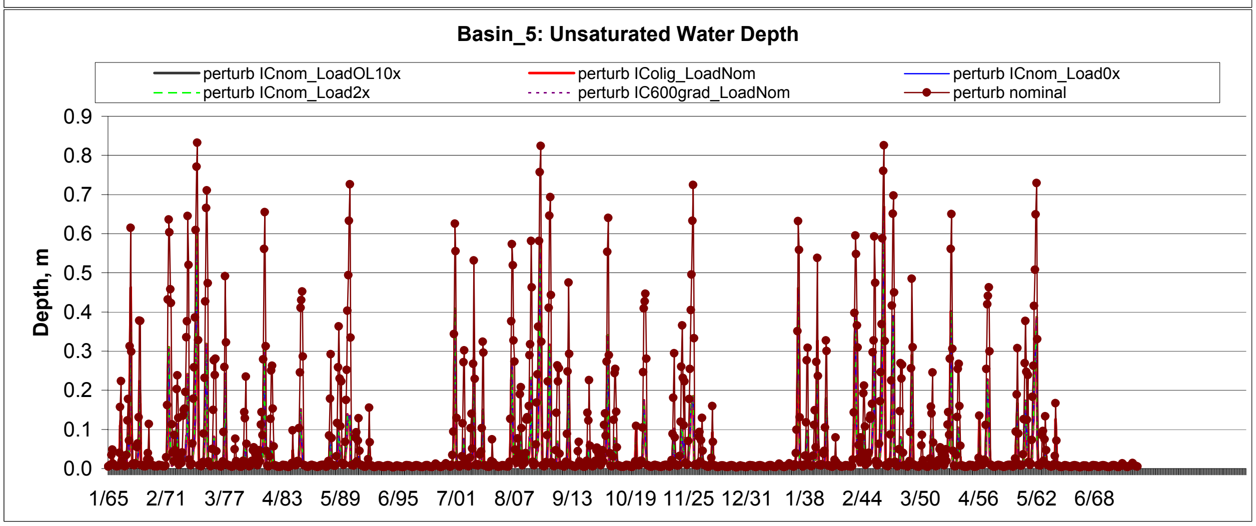


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_4** 4 Pages, 9 Figures Basin_4



ELMwca3RS250 v.2.6 **Ecological Variables:Basin_5** 4 Pages, 9 Figures Basin_5



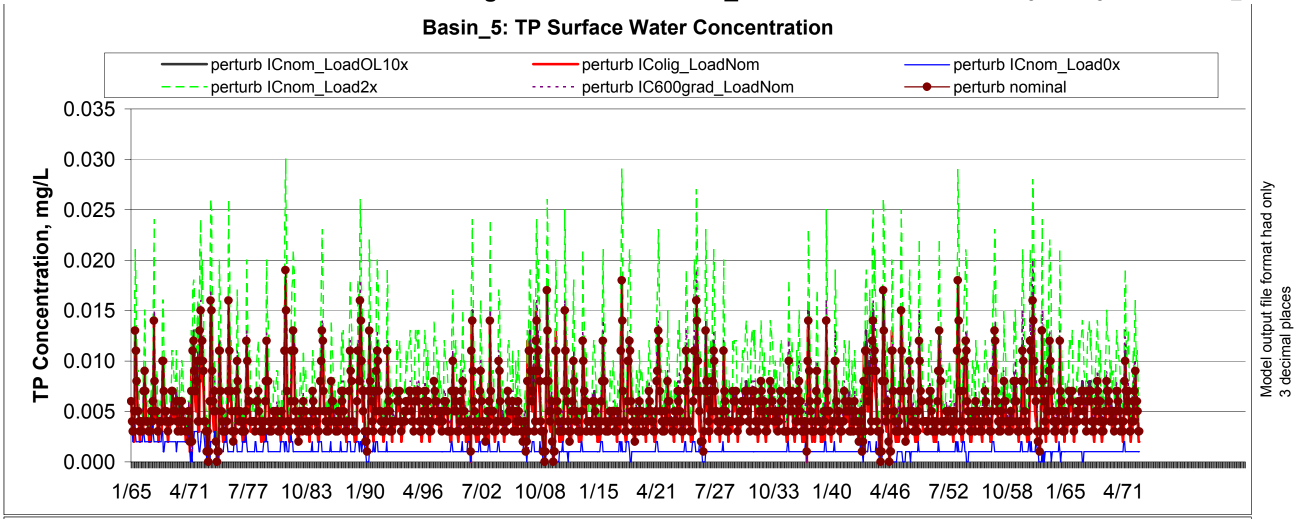


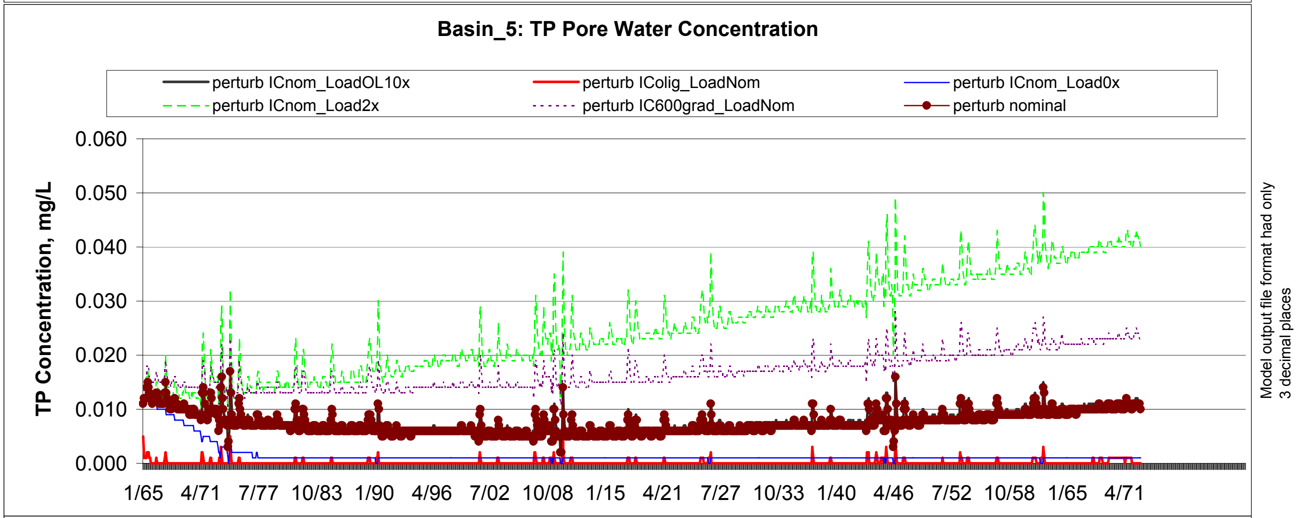
ELMwca3RS250 v.2.6

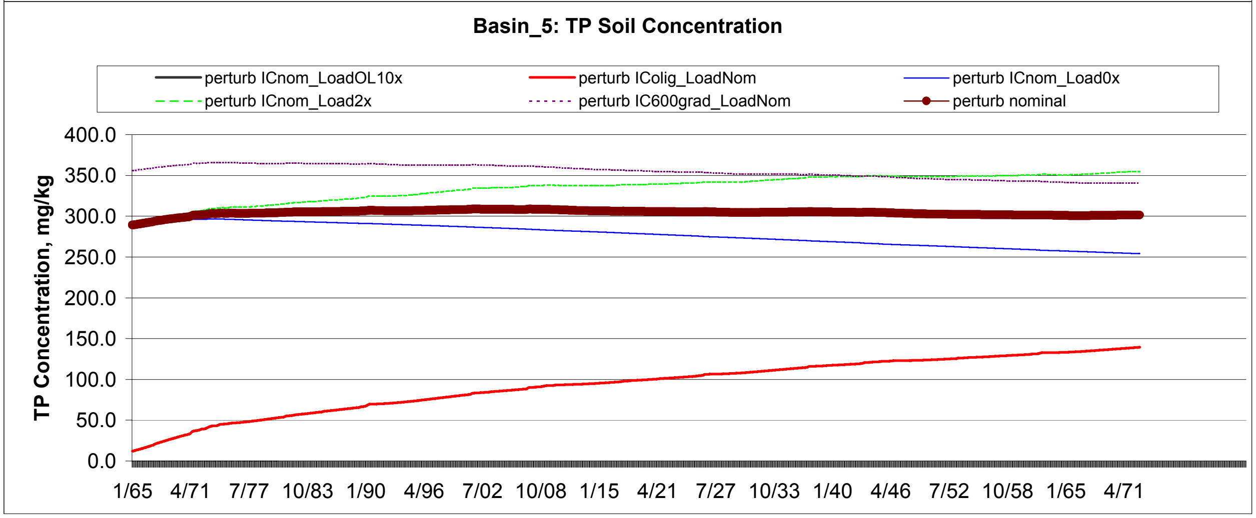
Ecological Variables:Basin_5

4 Pages, 9 Figures

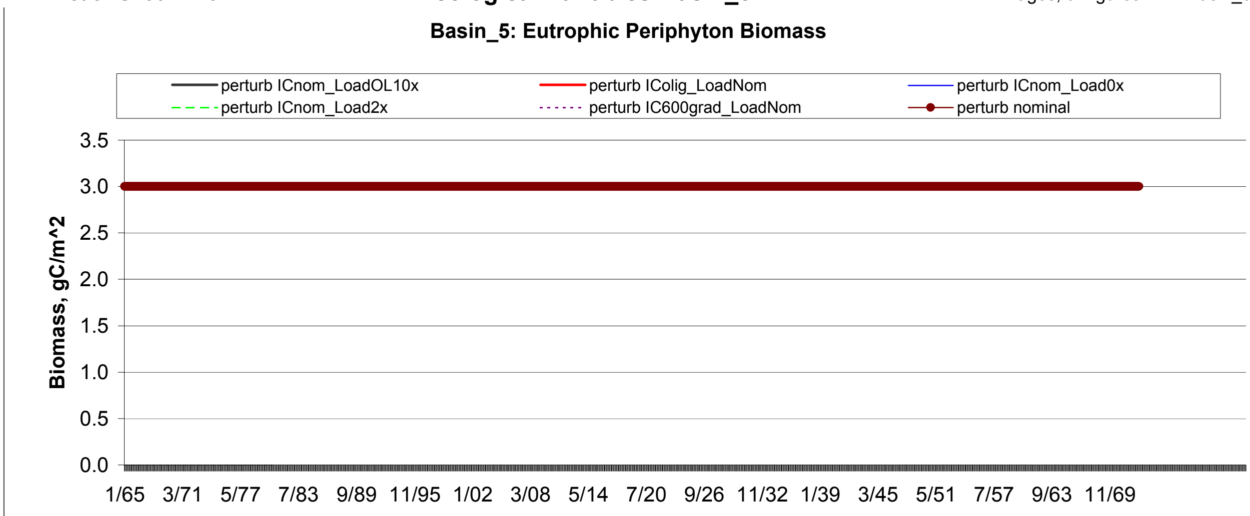
Basin_5

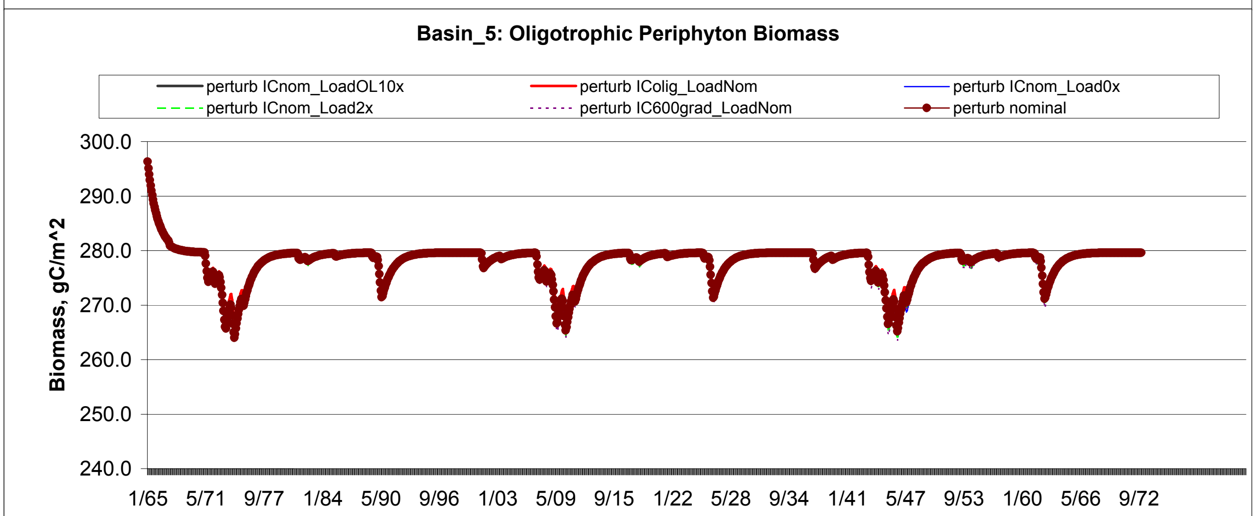


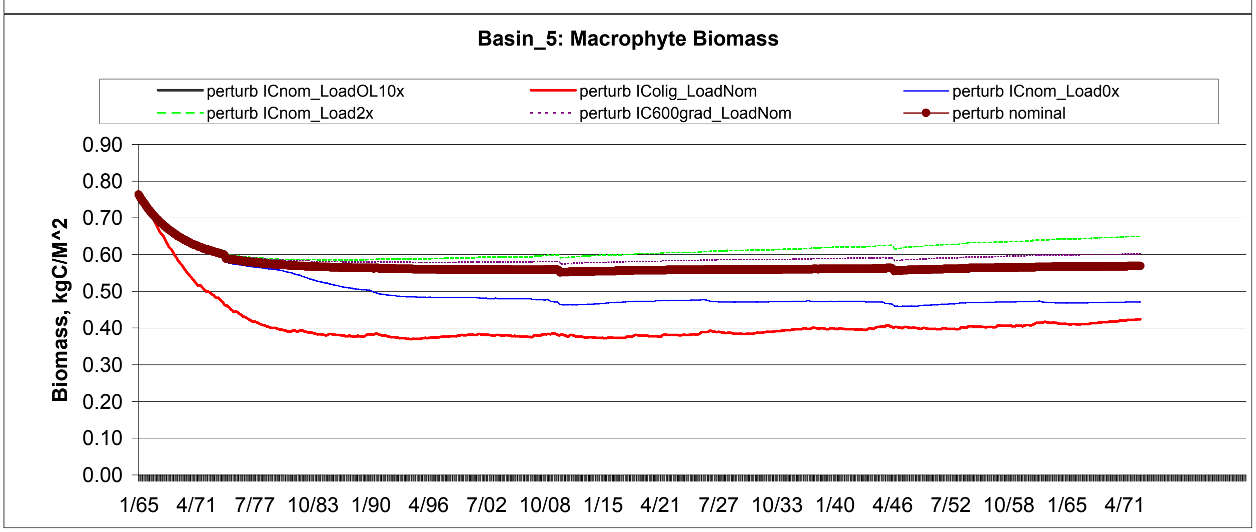




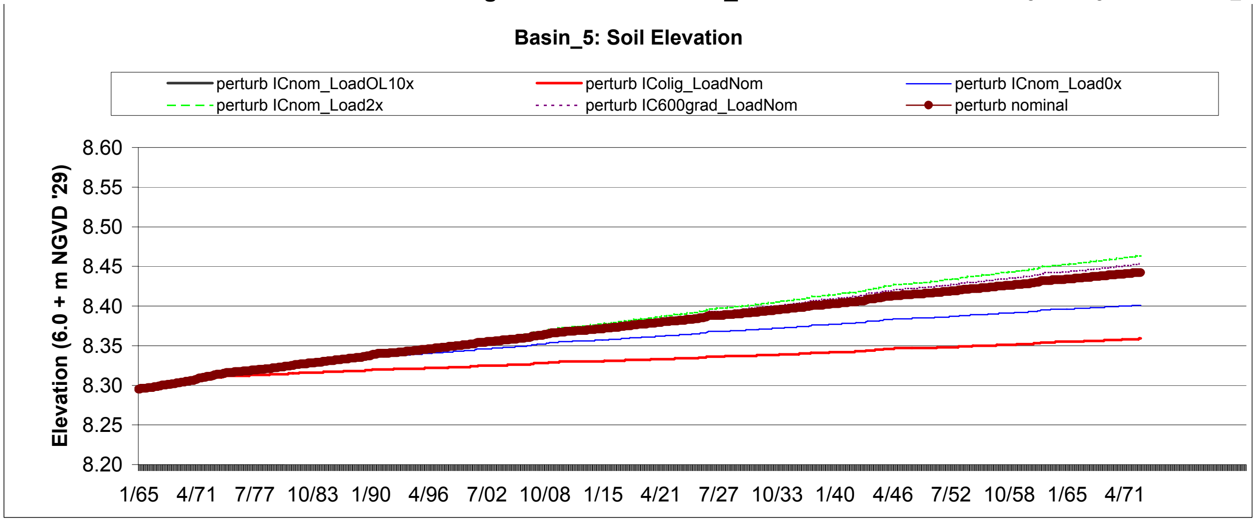
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_5** 4 Pages, 9 Figures Basin_5







ELMwca3RS250 v.2.6 **Ecological Variables:Basin_5** 4 Pages, 9 Figures Basin_5



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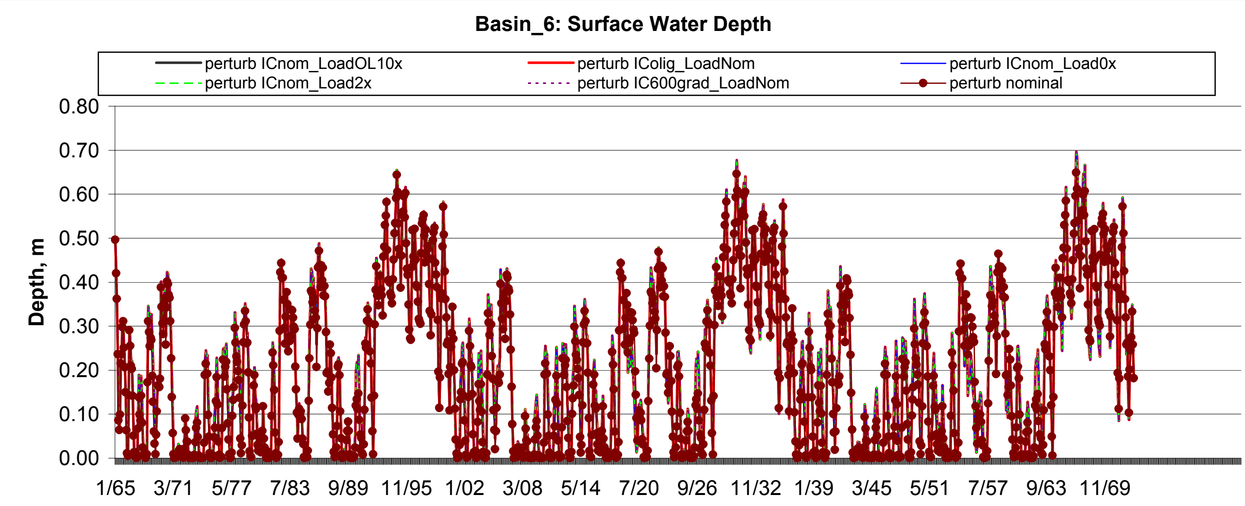
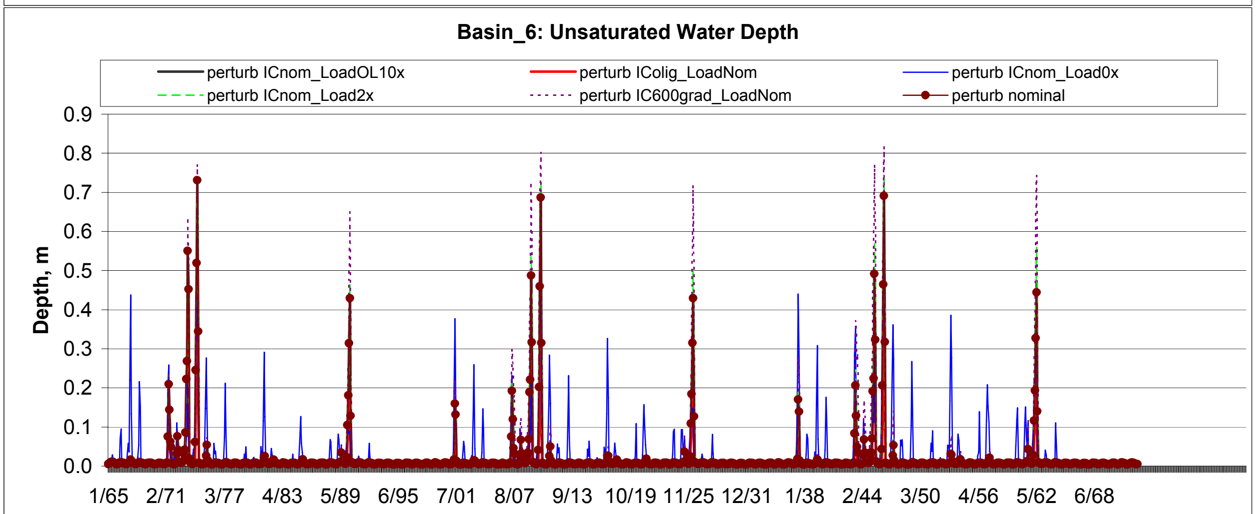
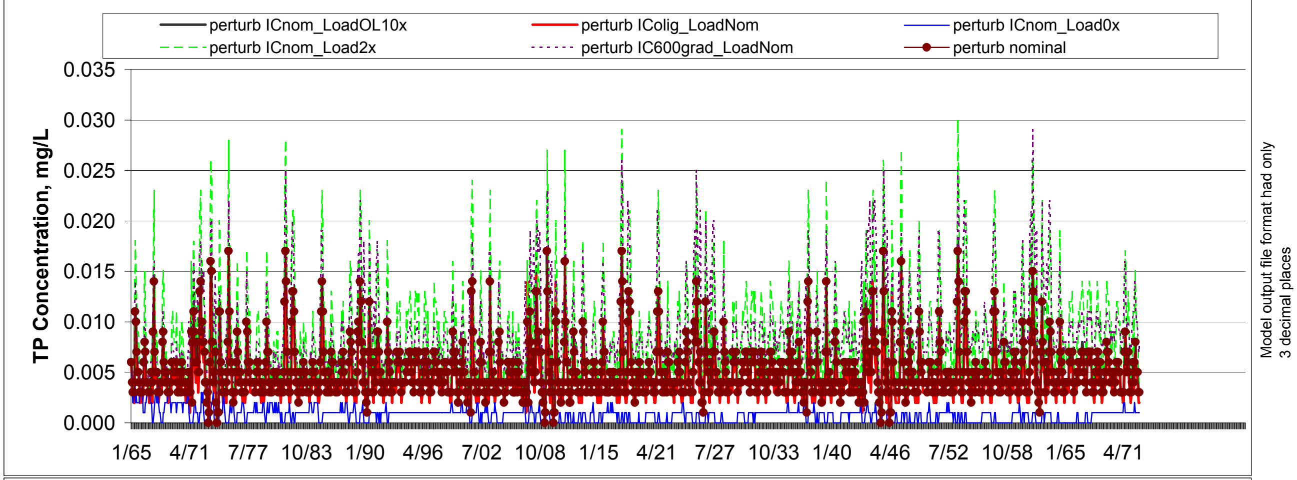


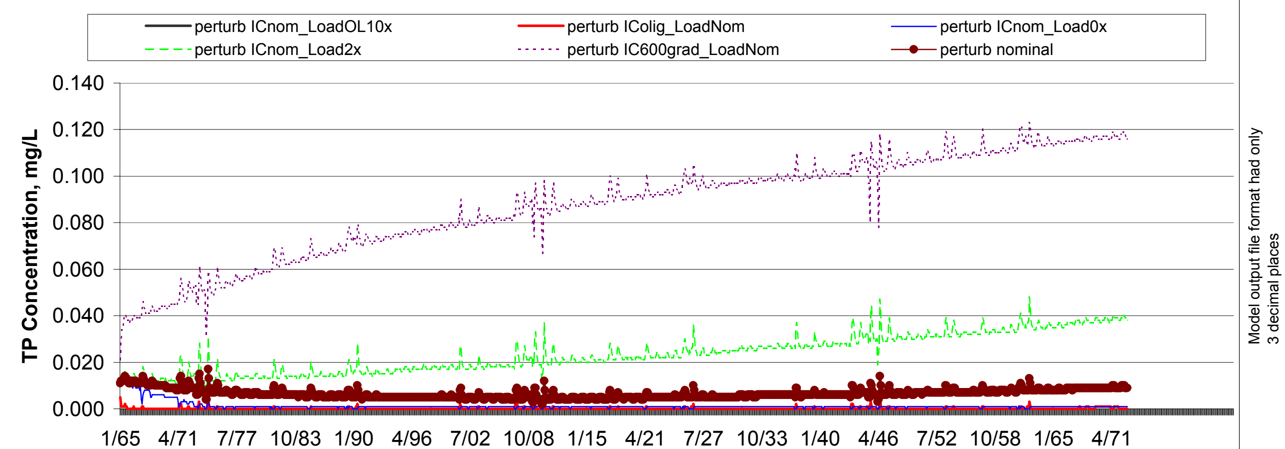


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_6** 4 Pages, 9 Figures Basin_6

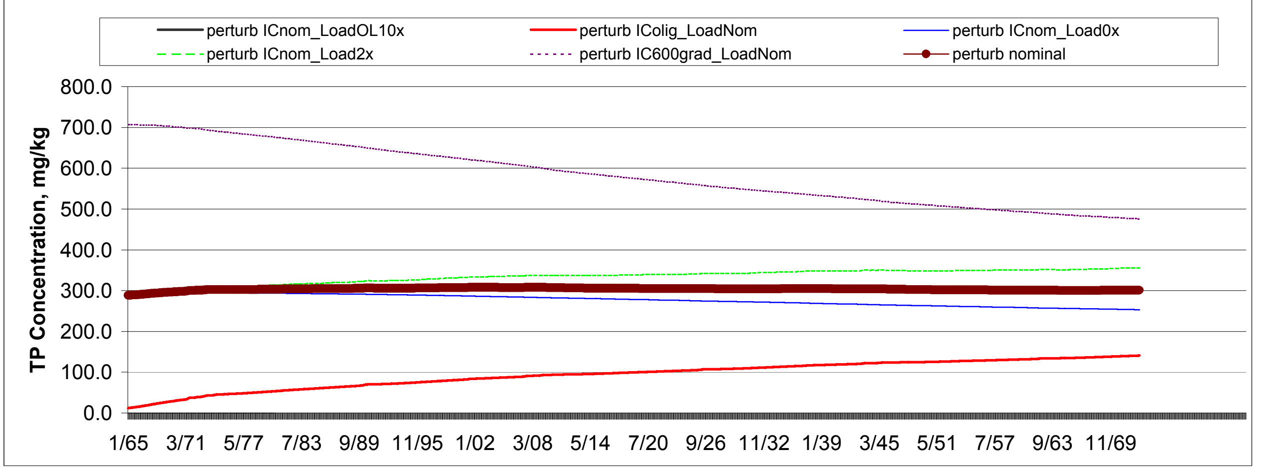
Basin_6: TP Surface Water Concentration



Basin_6: TP Pore Water Concentration

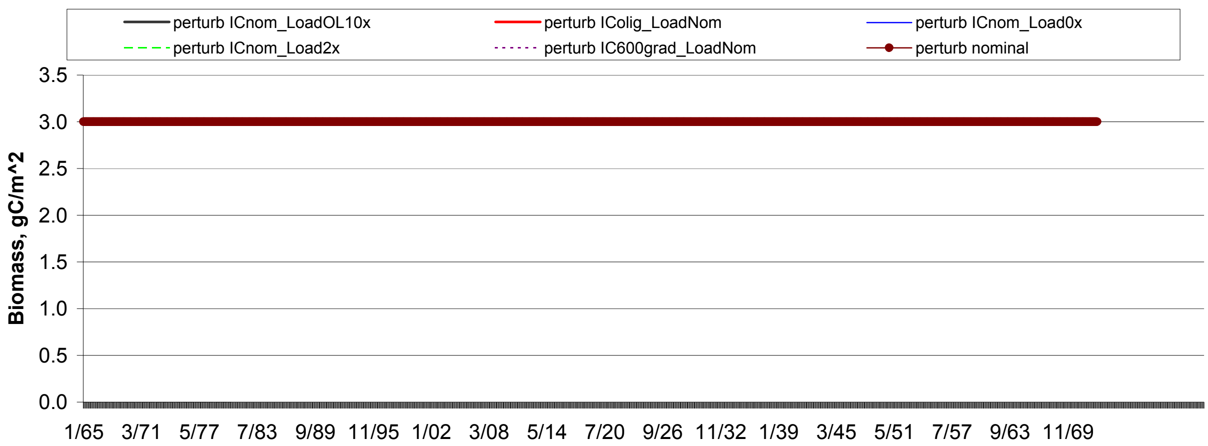


Basin_6: TP Soil Concentration

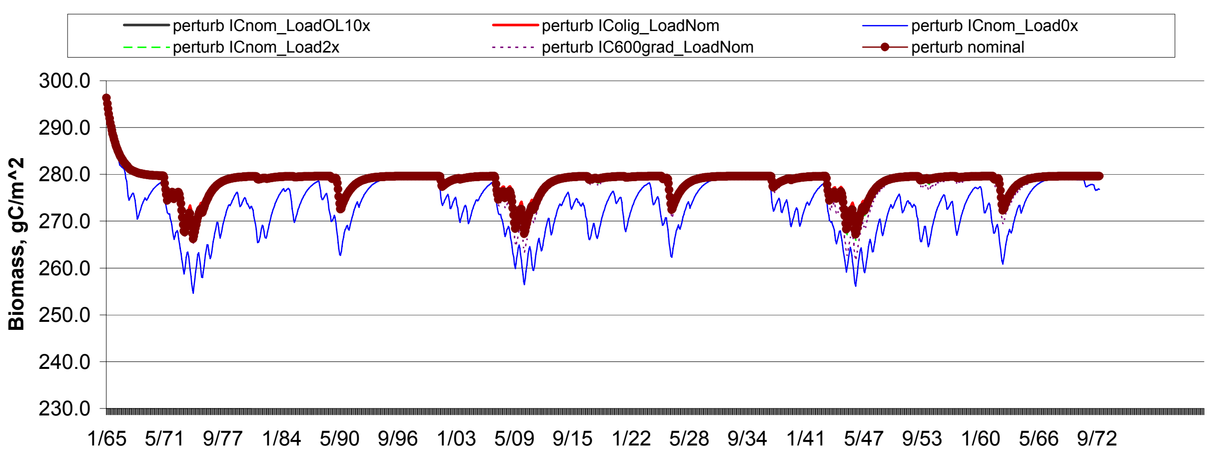


ELMwca3RS250 v.2.6 | **Ecological Variables:Basin_6** | 4 Pages, 9 Figures | Basin_6

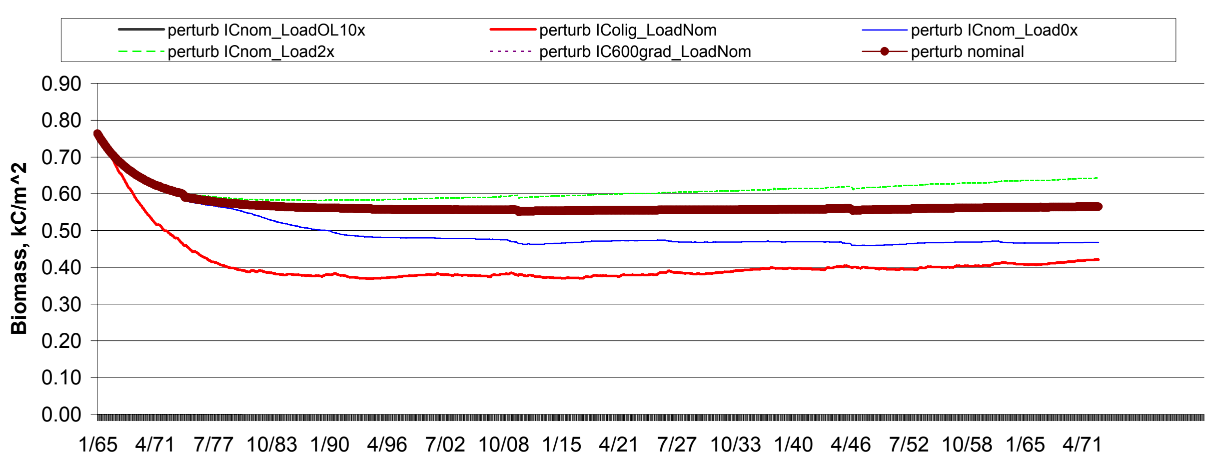
Basin_6: Eutrophic Periphyton Biomass

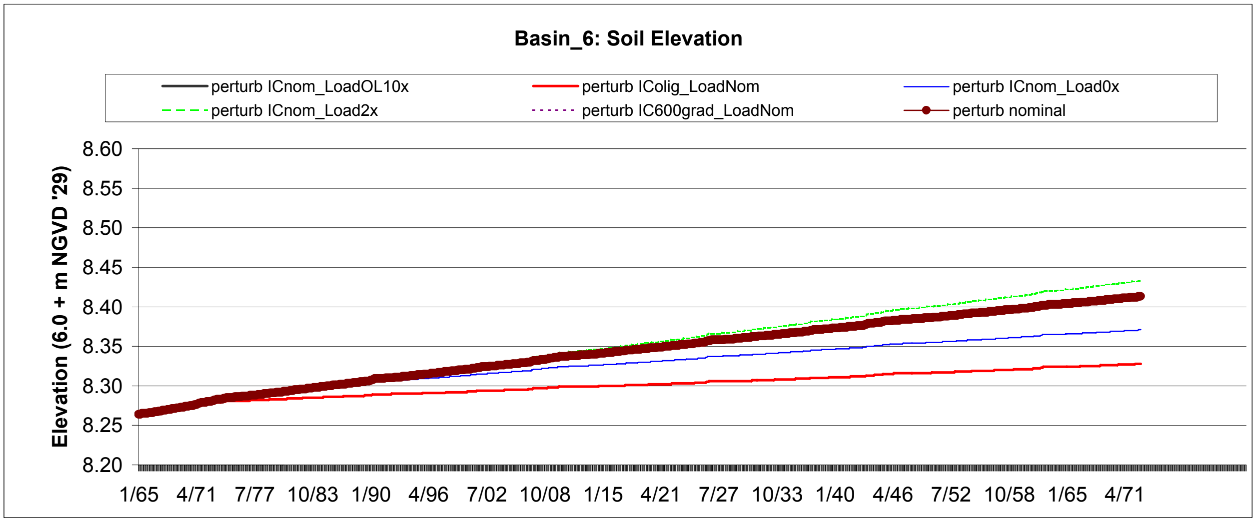


Basin_6: Oligotrophic Periphyton Biomass

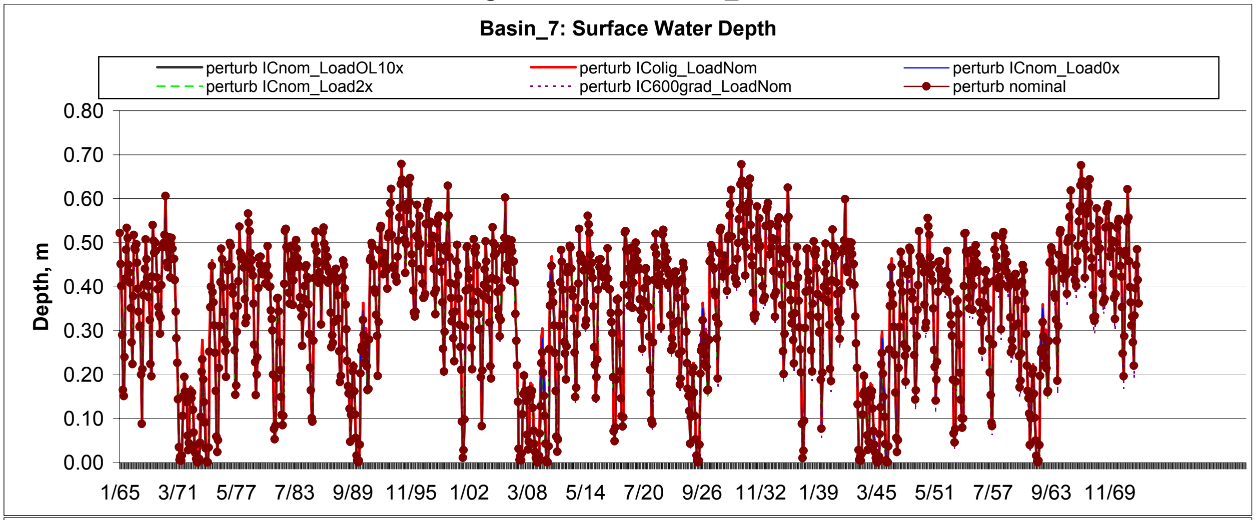


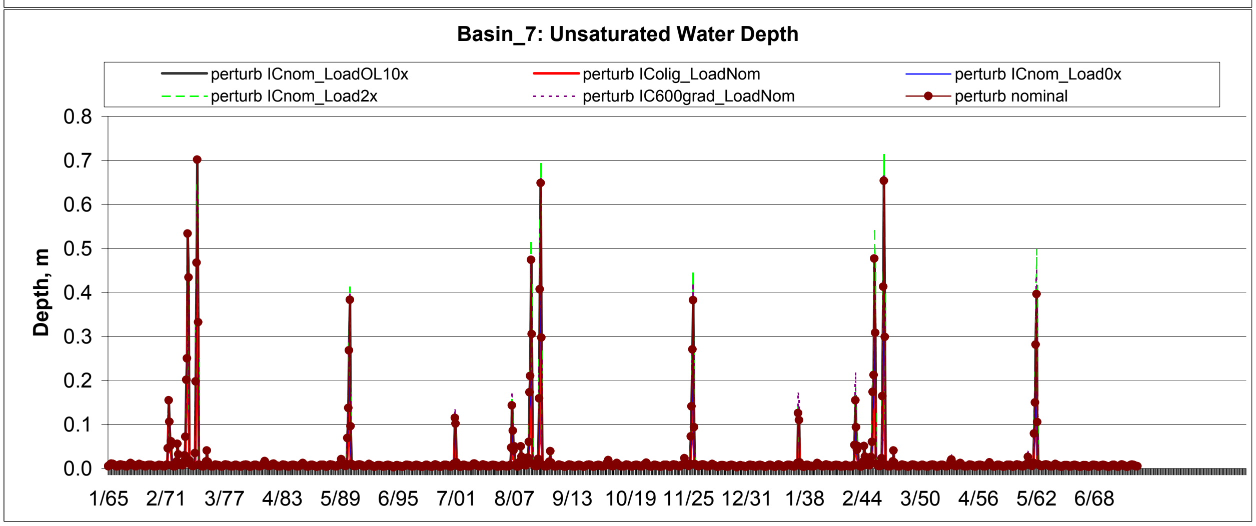
Basin_6: Macrophyte Biomass



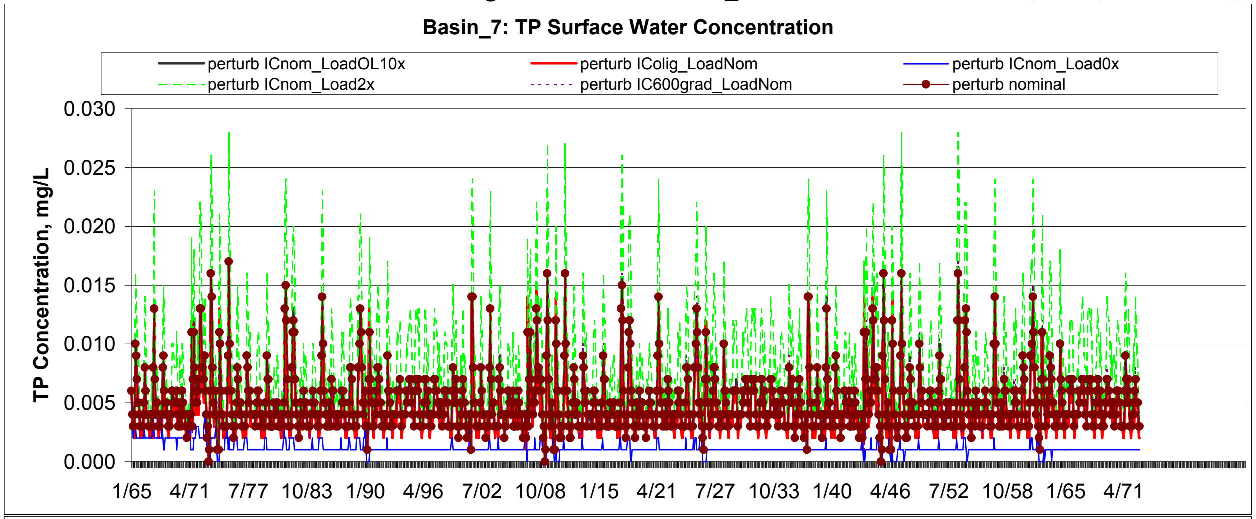

Basin_6: Soil Elevation
perturb ICnom_LoadOL10x
perturb ICnom_Load2x
perturb ICdensvig_LoadNom
perturb IC600grad_LoadNom
perturb ICnom_Load0x
perturb nominal
Elevation (6.0 + m NGVD '29)
8.60
8.55
8.50
8.45
8.40
8.35
8.30
8.25
8.20
1/65
4/71
7/77
10/83
1/90
4/96
7/02
10/08
1/15
4/21
7/27
10/33
1/40
4/46
7/52
10/58
1/65
4/71

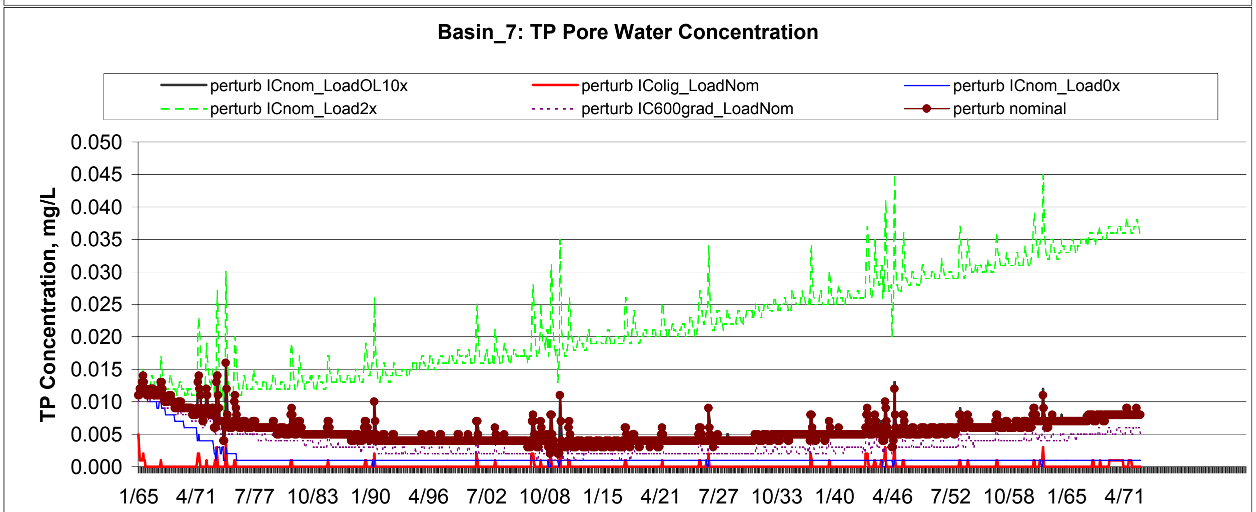
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_7** 4 Pages, 9 Figures Basin_7

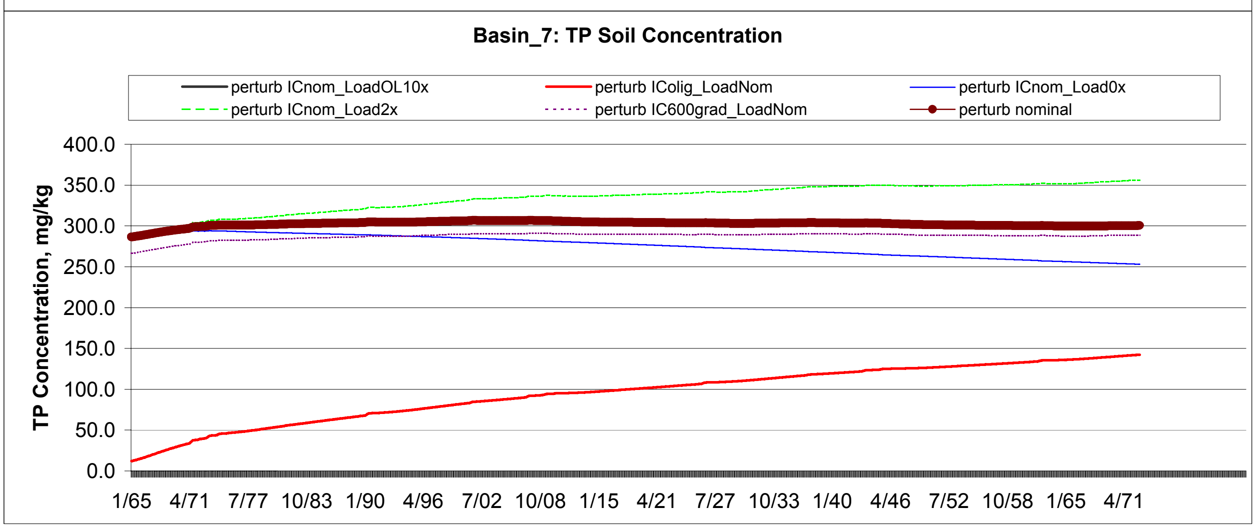




ELMwca3RS250 v.2.6 **Ecological Variables:Basin_7** 4 Pages, 9 Figures Basin_7

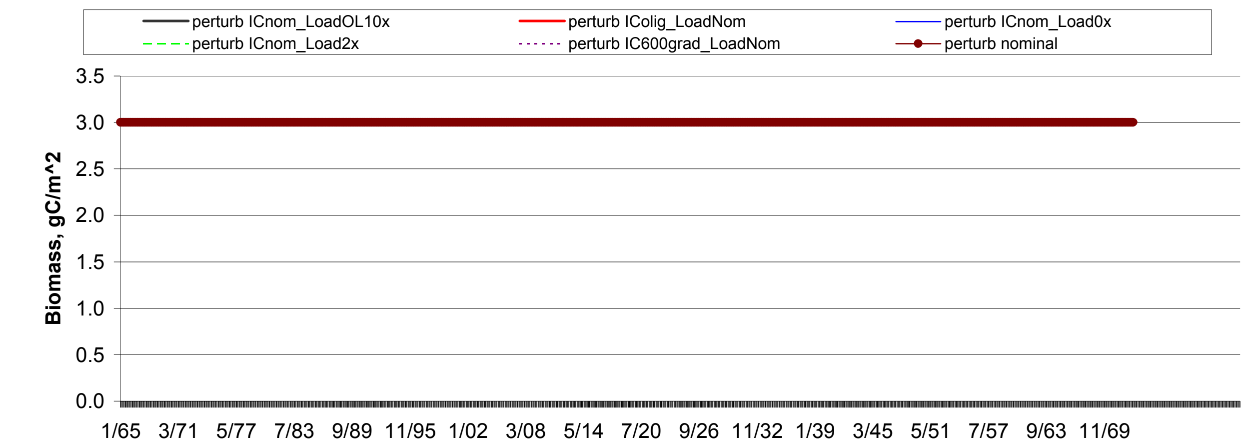




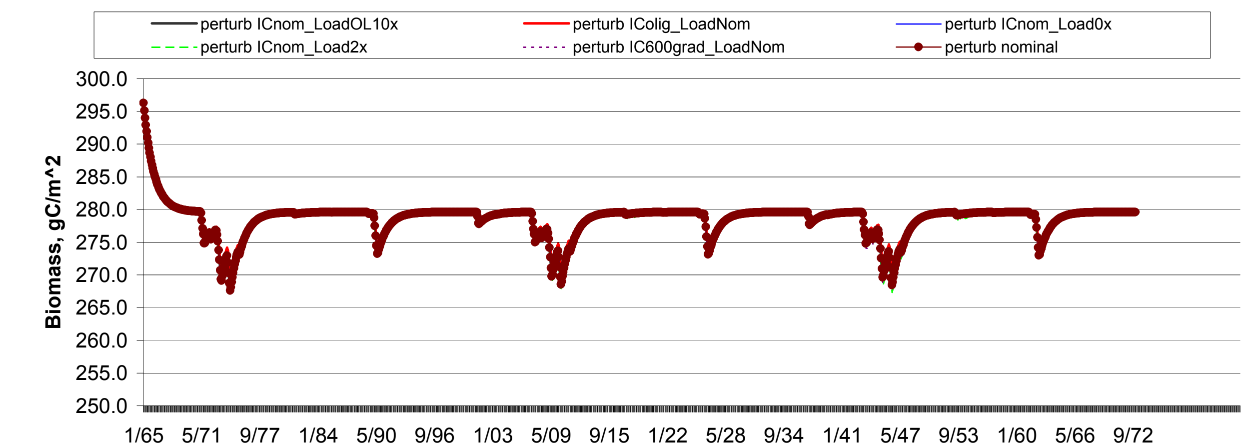


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_7** 4 Pages, 9 Figures Basin_7

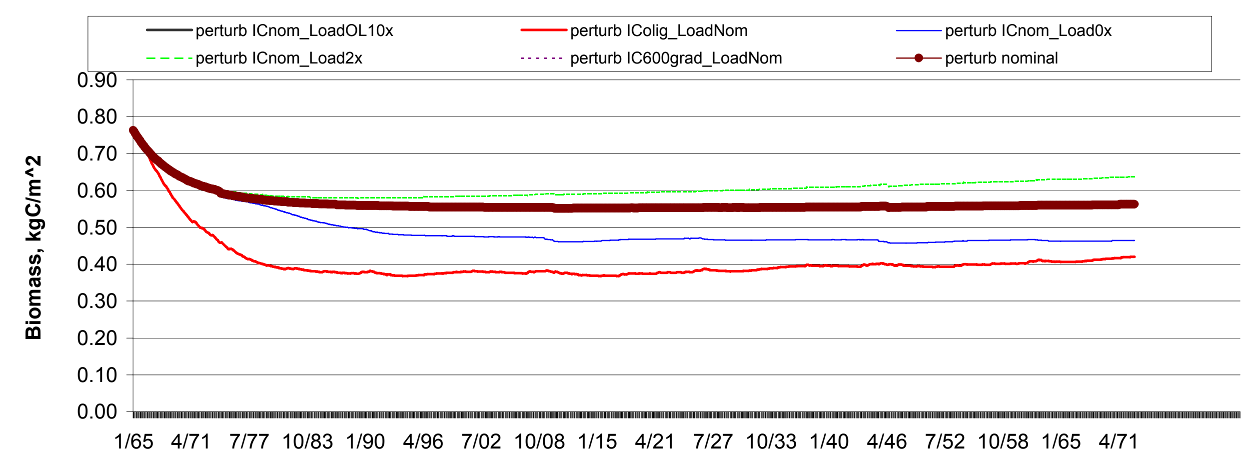
Basin_7: Eutrophic Periphyton Biomass



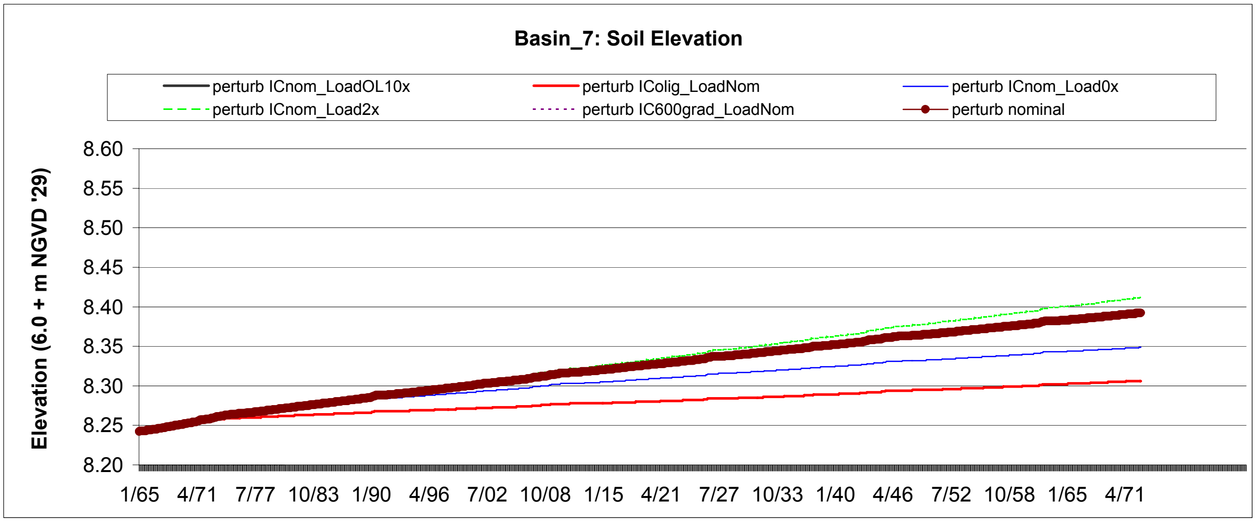
Basin_7: Oligotrophic Periphyton Biomass



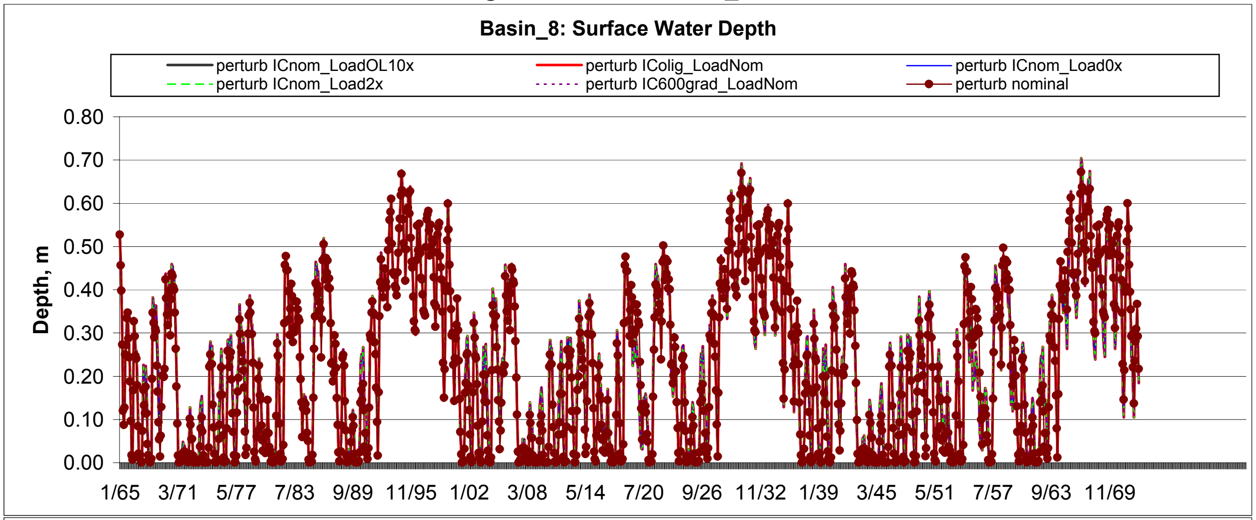
Basin_7: Macrophyte Biomass

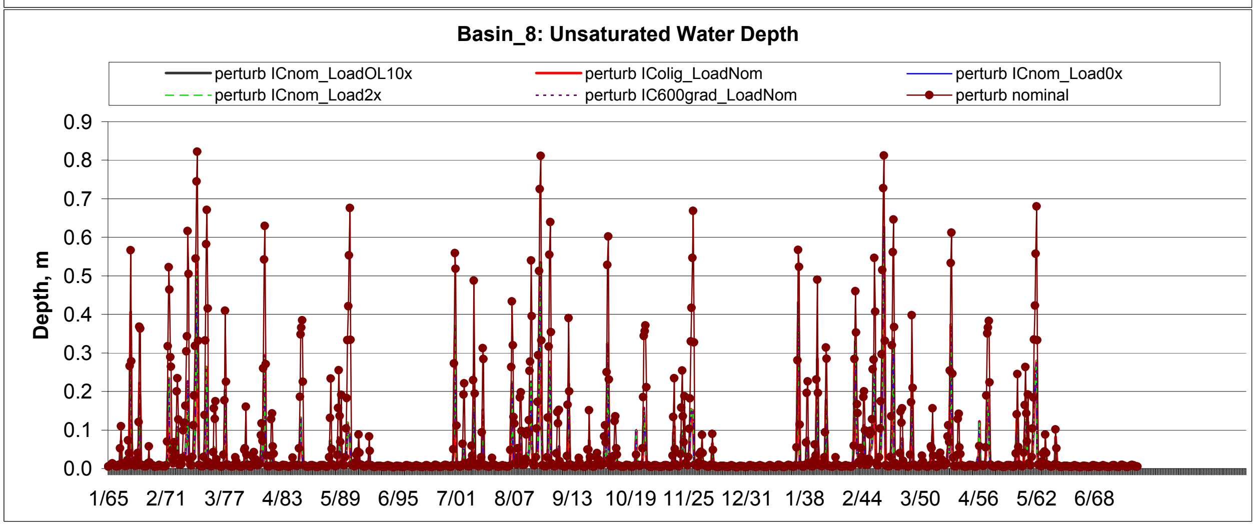


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_7** 4 Pages, 9 Figures Basin_7

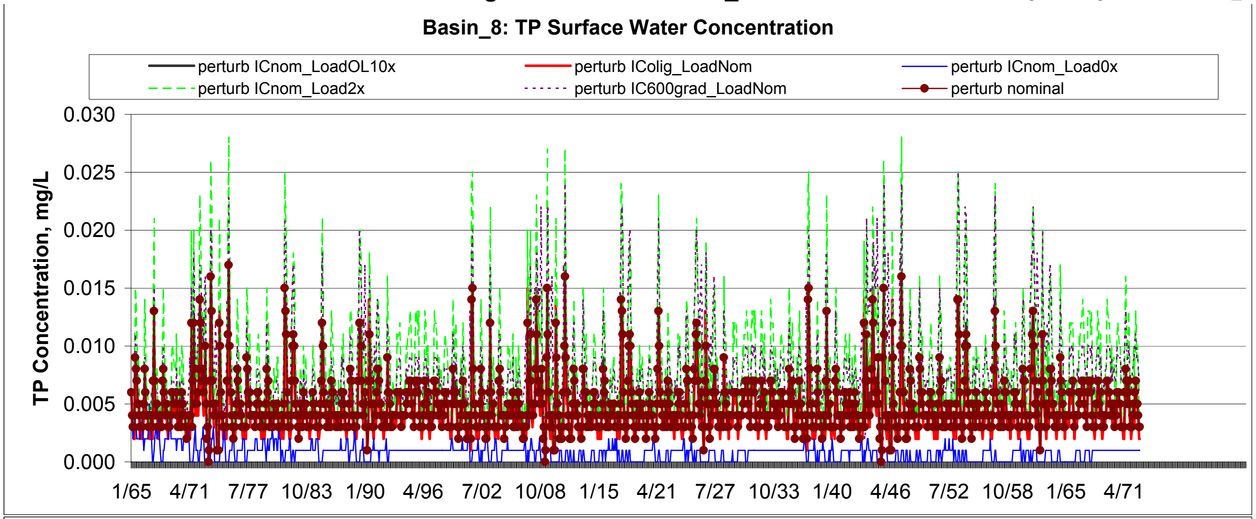


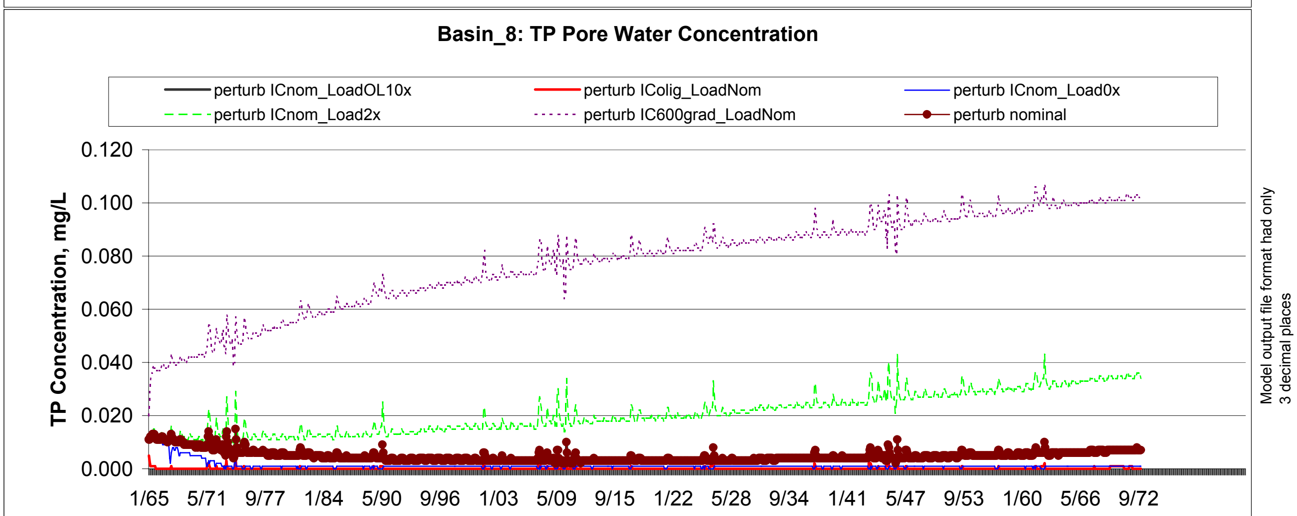
ELMwca3RS250 v.2.6 **Ecological Variables:Basin_8** 4 Pages, 9 Figures Basin_8

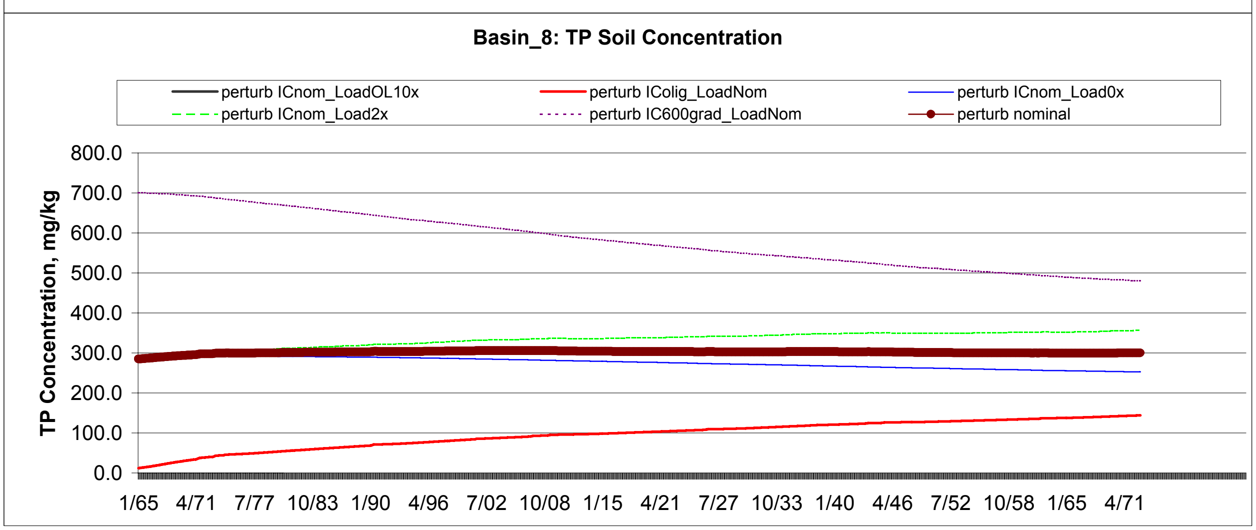




ELMwca3RS250 v.2.6 **Ecological Variables:Basin_8** 4 Pages, 9 Figures Basin_8

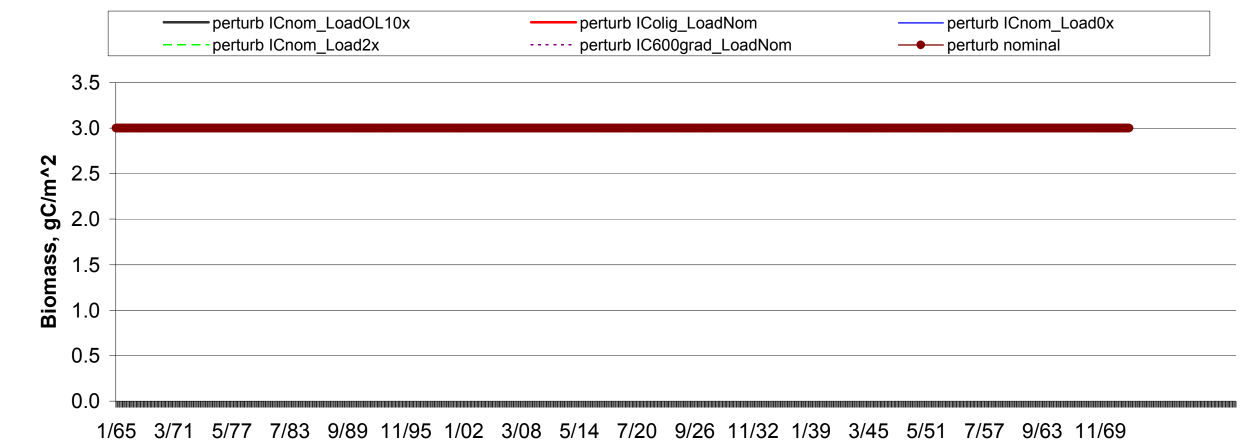




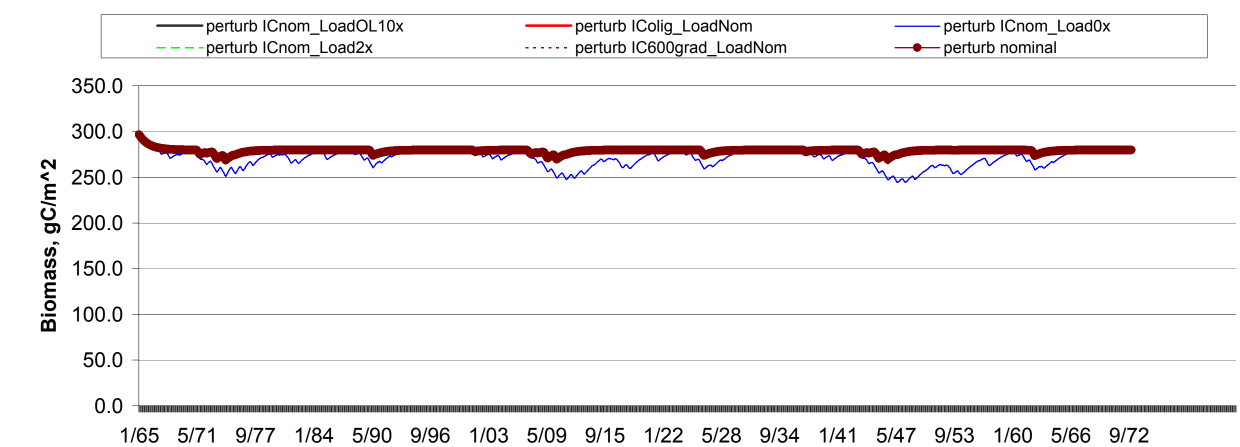


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_8** 4 Pages, 9 Figures Basin_8

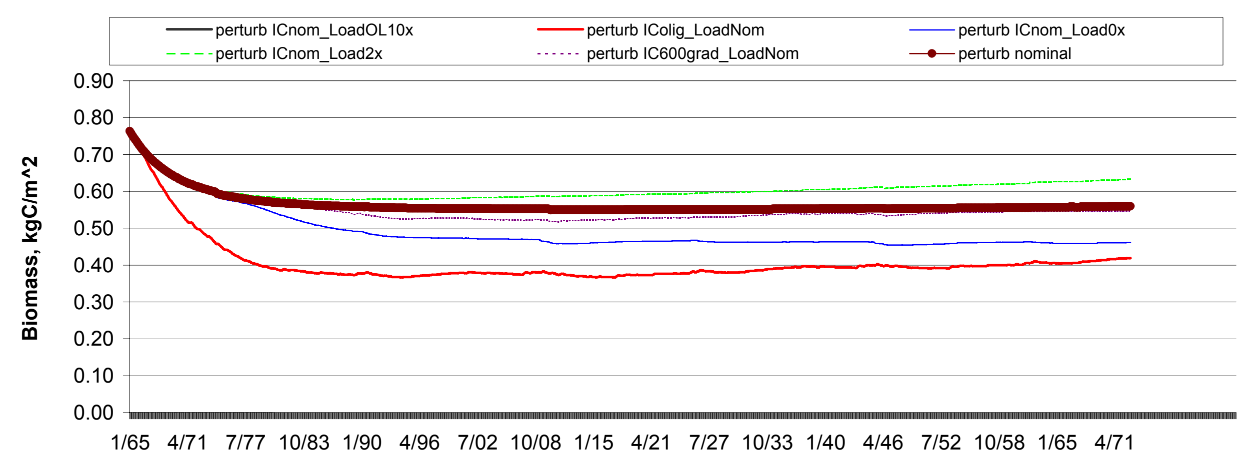
Basin_8: Eutrophic Periphyton Biomass



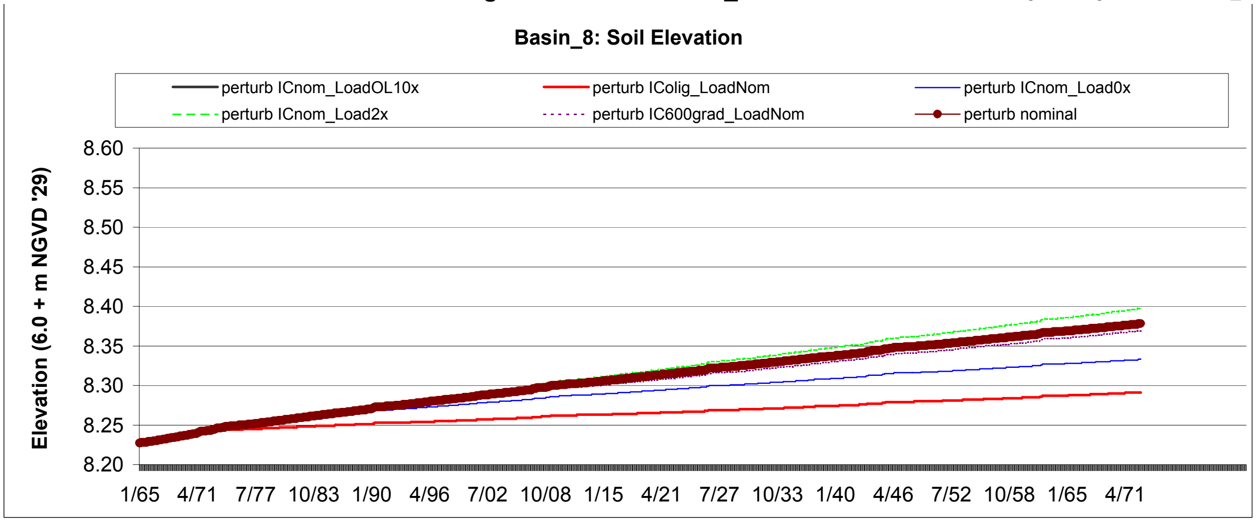
Basin_8: Oligotrophic Periphyton Biomass



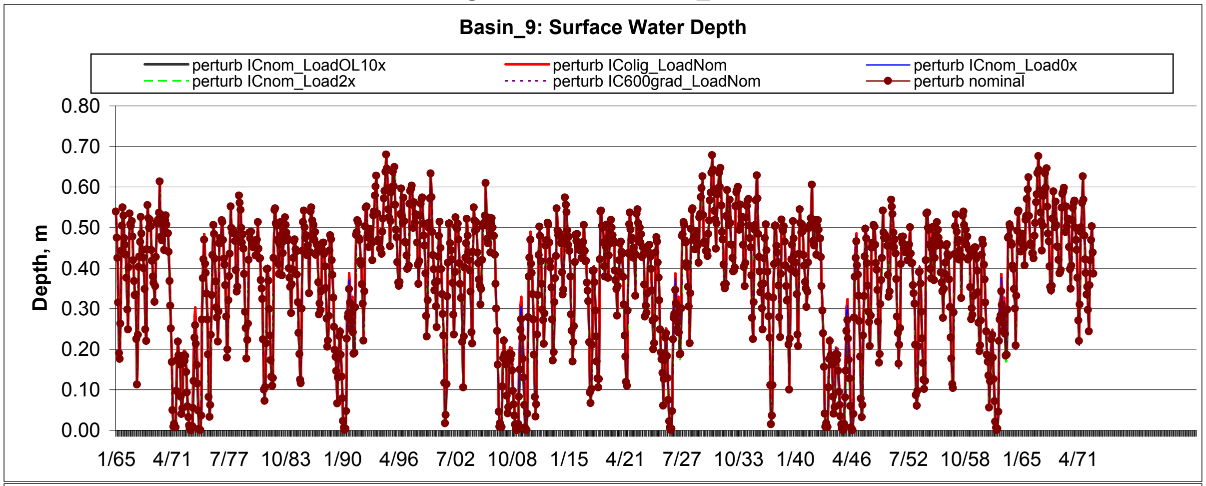
Basin_8: Macrophyte Biomass

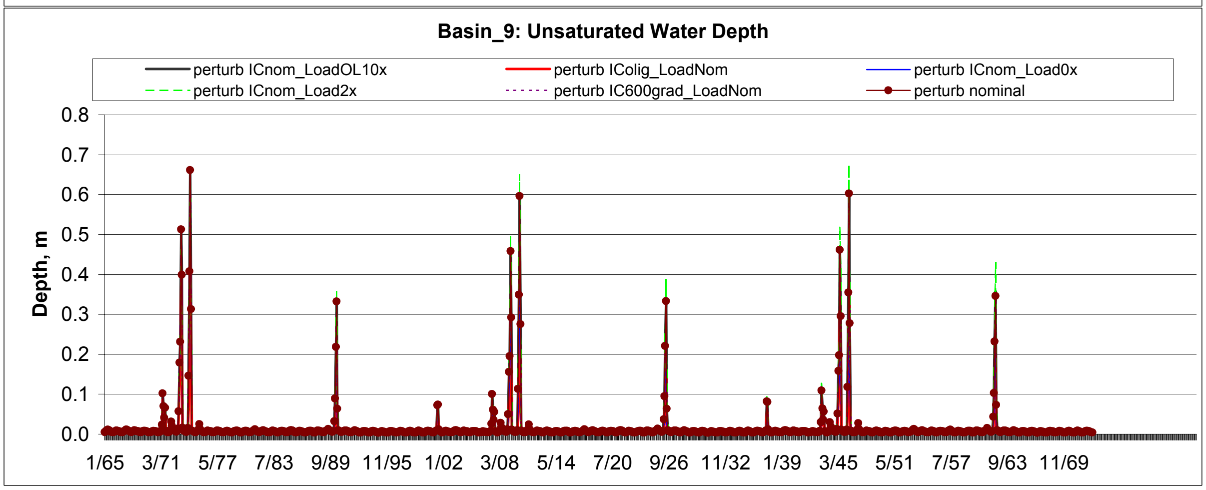


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_8** 4 Pages, 9 Figures Basin_8

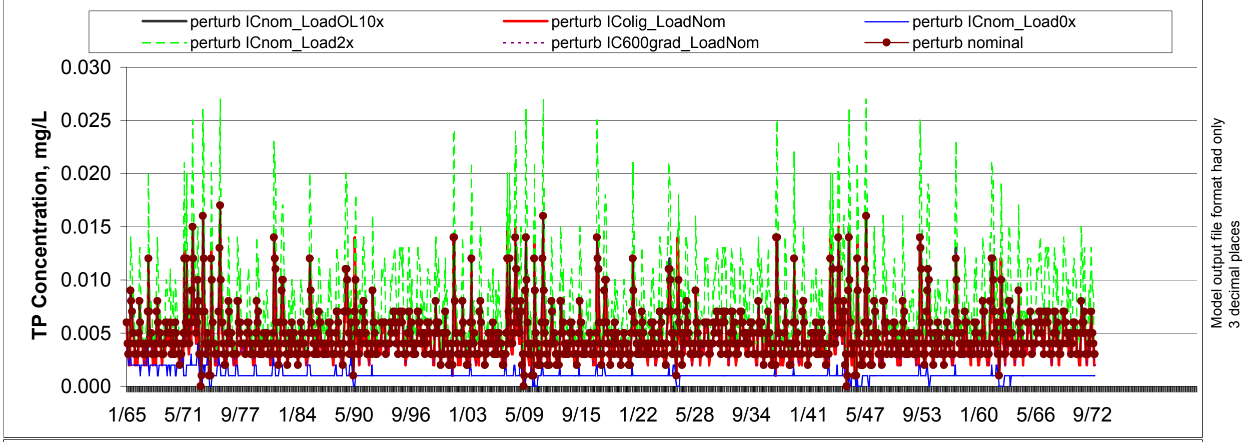


ELMwca3RS250 v.2.6 **Ecological Variables:Basin_9** 4 Pages, 9 Figures Basin_9

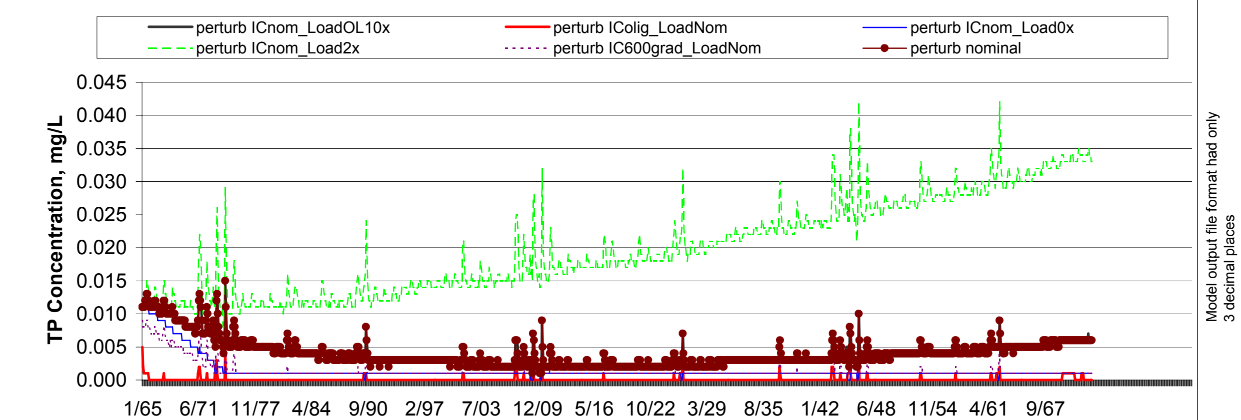




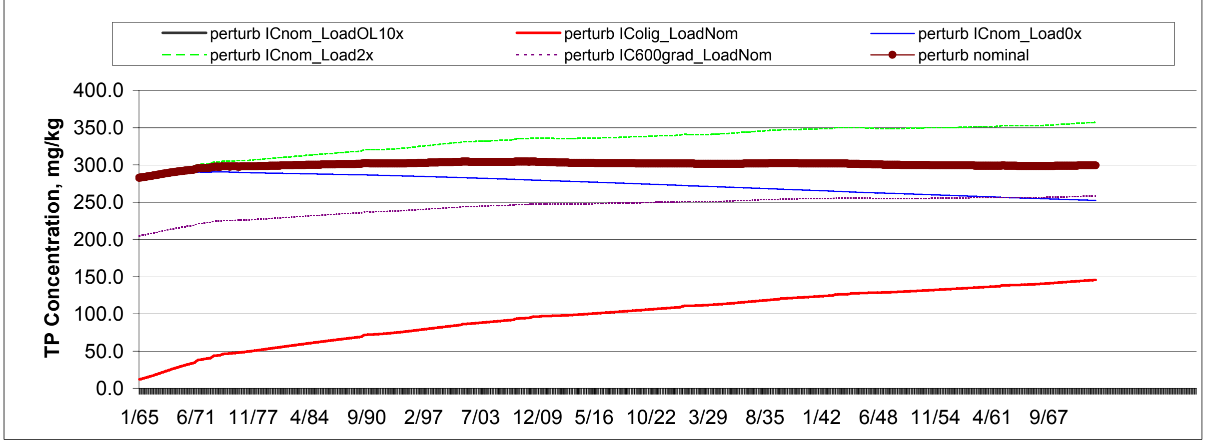
Basin_9: TP Surface Water Concentration



Basin_9: TP Pore Water Concentration



Basin_9: TP Soil Concentration

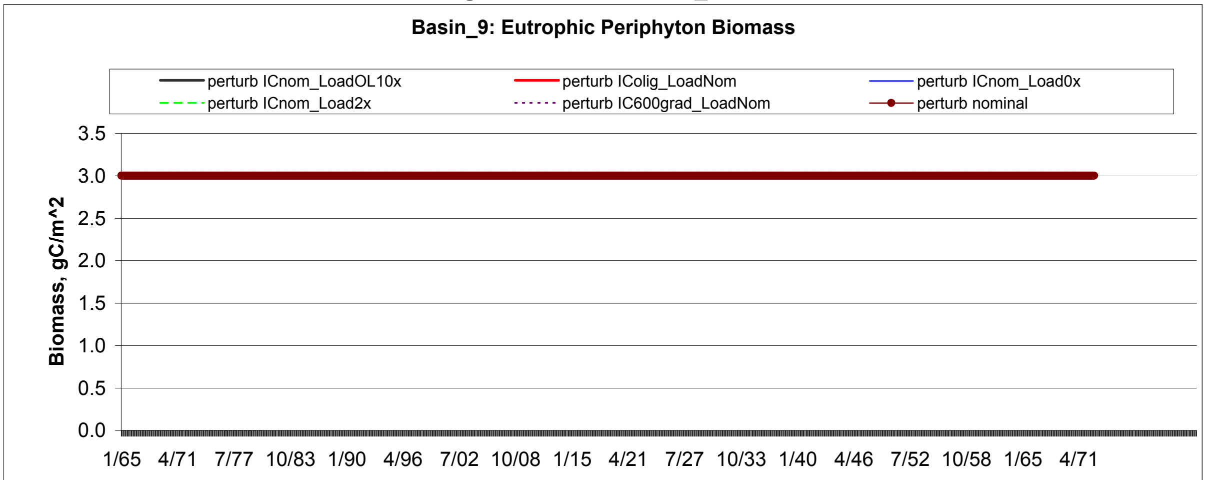


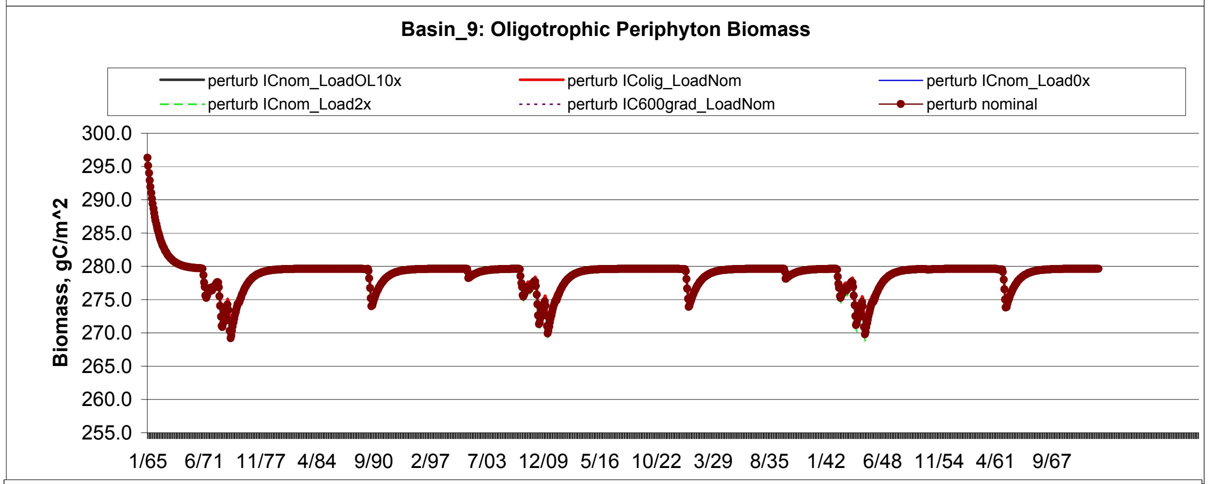
ELMwca3RS250 v.2.6

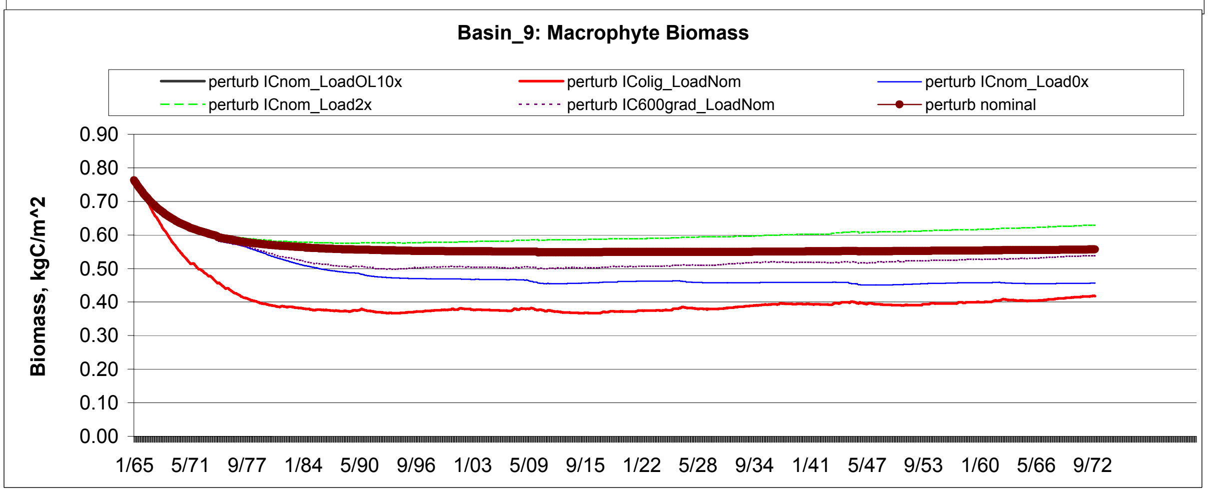
Ecological Variables:Basin_9

4 Pages, 9 Figures

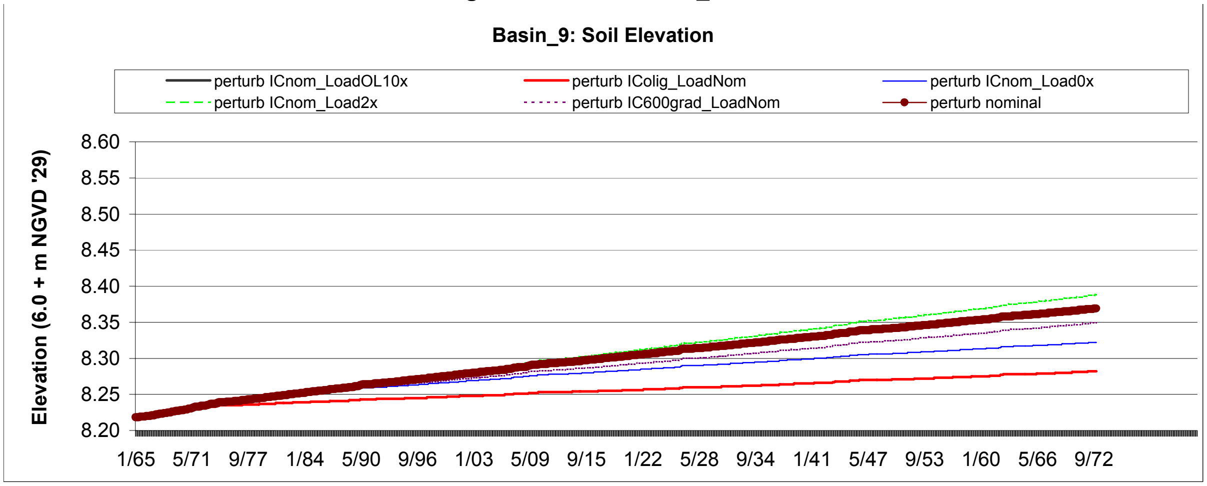
Basin_9







ELMwca3RS250 v.2.6 **Ecological Variables:Basin_9** 4 Pages, 9 Figures Basin_9



11.9 Appendix 11.2 All results, regional 20-yr

All 20-yr P budget summaries, and all time series outputs for nine ecological variables, in the whole-domain (Basin 0) and Basin/Indicator Regions 1 – 58, for the ELM regional project simulations under six scenarios of phosphorus perturbations. See text for the descriptions of the model configuration and phosphorus perturbation experiments.

NOTE: this (large) Appendix is provided as a separate download from the ELM web site. Because of the spatial complexity of the 58 Basins/Indicator Regions (B/IRs) distributed throughout the greater Everglades region, the results are organized within an html-interface containing these output. Using this interface, the user can point&click on individual B/IRs to view output for that specific region.

For all Perturbation Experiment documents (and model output), see the ELM web site, http://my.sfwmd.gov/elm , in the "Implementation: v2.5" sub-tab (Perturbation Experiments heading).