The Everglades Landscape Model: Multiscale Sensitivity Analysis

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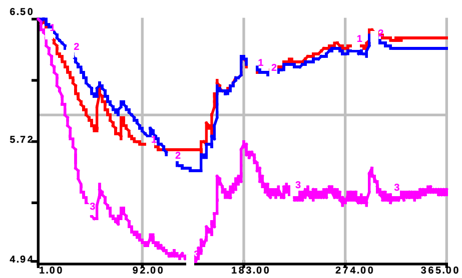

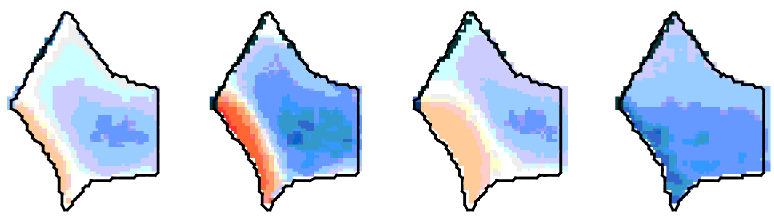

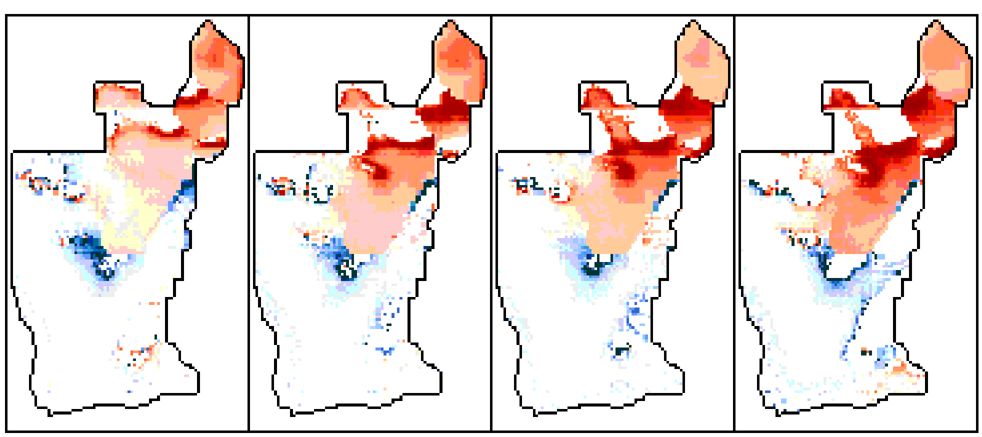

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Executive Summary

The Everglades Landscape Model (ELM) incorporates several fundamental submodels that affect water, nutrients and plant biomass in the model landscape, with each model operating at different spatial scales. The unit model is at the ecosystem level and simulates primarily the “vertical” dynamics of nutrient cycling, evapotranspiration, plant growth, etc. within an homogeneous ecosystem represented by one raster cell in the gridded model area. This model is replicated in the ~10,000 cells that comprise the heterogeneous landscape of the spatial model at the landscape scale, which simulates the cell-to-cell horizontal fluxes of nutrients, water and fire in response to simulated conditions in neighboring cells of the model landscape. A third fundamental model within the ELM is that of canals, levees and control structures. Canals and associated levees are represented by a set of vector objects that interact with a defined set of raster landscape cells at a fast rate over long distances. Finally, the habitat switching model of ELM defines the changing of habitats according to successional rules. Because this switching among sets of habitats effectively switches among sets of model parameters that are varied in the sensitivity analysis, the analyses here implicitly include the changing of habitat types with their different parameter sets.

The influence of landscape habitat heterogeneity on model behavior is accommodated by varying the parameter sets associated with the unit model, a process determined by a landscape cell's habitat type. Differences in habitat type (which also changes over long time scales) may alter ecosystem dynamics, which in turn may change the horizontal flux of water and nutrients across the landscape. There are a very large number of combinations of parameters in this complex model (approximately 80 parameters) over a heterogeneous landscape (6 fundamental habitats, with more when using mixtures of fundamental habitats). The explicit testing of the full spatial model sensitivity to varying multiple parameters at a time is prohibitive both from a computational perspective and from a conceptual viewpoint. Indirect interactions at the ecosystem level coupled with significant spatial heterogeneity and pattern-effects on the processes makes the interpretation of massive series of output with multiple combinations of parameter changes and habitat heterogeneity difficult at best. The results would likely be open to a variety of interpretations. Thus, we sought to discern the basic model behavior at different levels of model scale, using results from the ecosystem level to aid in directing analyses at two landscape scales of different complexity and areal extent.

We partitioned the sensitivity analyses into a set that parallels the model structure. We varied habitat specific parameters at the unit ecosystem model level in order to determine which parameters had the most significant influence on model dynamics at the scale of an homogeneous ecosystem within one model cell. The important state variables for the model objectives were: water stage, nutrient concentrations in interstitial sediment water and in ponded surface water, organic matter deposited in the sediments, and the biomass of macrophytes and periphyton. Parameter changes that resulted in non-trivial changes to these variables' model behavior at the unit model level were identified for further analysis at the scale of the landscape. Moreover, variables that flux spatially (horizontally), and variables that have significant influence on such fluxes, are "landscape driver" variables and have the potential to alter the landscape pattern: the most important of these are water levels, nutrient concentrations and macrophyte biomass. Particular attention was paid to parameters that changed these driving variables.

For the bulk of the analyses of ecological sensitivity at the spatially explicit scale, we rescaled a subregion of the ELM. The Conservation Area Landscape Model (CALM) is a spatial ecological model of WCA2A at a higher spatial resolution than the ELM (1,734 0.25km^2 cells vs 10,264 1.0 km^2 ELM cells). The CALM contains a unit model identical to the ELM and has the same forcing functions where appropriate, e.g., structure inflows and precipitation registered at one station . This model contains borrow canals along its interior periphery, with historical data input through S10 structures and outflows through the S11 (and several other) structures according to the drydown management schedule. Due to the significantly higher quality/quantity of data for WCA2A (and faster runtime), the CALM is being used as the test platform for debugging and calibrating much of the ecological (including hydrologic) components of the larger ELM.

After determining the influence of various parameter changes at the scale of the spatially explicit CALM, we analyzed the full ELM that contains the full canal/levee vector network and more vegetation types. Whereas the CALM has a relatively simple canal configuration, the ELM contains the complex canal/levee network, with structure flows that are determined by either historical data or management rules (all database driven instead of hard coded). For these analyses, we focused on the hydrologic component of the ELM, determining the model behavior under varying water/nutrient inflows (through the S-5 through S-8 structures), alteration in flow rates through structures, and Manning's roughness coefficient.

Some of the parameters that we found to be most influential on model dynamics in terms of water and nutrient levels and plant biomass have relatively high uncertainty and low measurement quality. The plant nutrient requirements (expressed as coefficients in Michaelis-Menton kinetics) and the maximum rate of net primary production of macrophytes were two biological processes which are uncertain, but which have significant influence on landscape-level changes in both nutrient levels and plant biomass. The initial concentration of PO_4 sorbed to organic sediments was a potentially important factor in determining the nutrient levels in the landscape and subsequent plant production. The macrophyte maximum Leaf Area Index (linked to changing plant biomass) had broad effects, altering transpiration and thus water levels, ultimately altering plant production levels in the landscape. The influence of changing the Manning's roughness coefficient had the potential to alter water levels in certain regions, but small changes in parameters that determine evaporative water losses (evaporation and transpiration) resulted in more significant landscape level changes in water supply.

The unit model, and its spatial articulation in the CALM and ELM, proved to be operationally robust to varying parameters within ranges that are feasible within the Everglades landscape. The model has constraints such that even unrealistic combinations of ecological parameters or forcing functions result in model dynamics that are within reason in that they stay within ranges that are potentially observable . Water supply via the canal network can significantly alter both the water and nutrient regime of the more northern Everglades, and further evaluation is one of the scenarios that we are currently performing.

Introduction

We have developed the Everglades Landscape Model (ELM) in a hierarchical fashion, with a unit model at the ecosystem level that is coupled to spatial model drivers to flux water and dissolved nutrients through canal vectors and raster cells in a landscape whose pattern may vary over time. The unit model is replicated in each grid cell of the landscape and incorporates the fundamental hydrologic and ecological processes that dictate much of the model behavior. With approximately 80 parameters input to the model, the user needs to understand the relative influence of parameter variations on the model results. The parameters range from rate coefficients to nutrient stoichiometric ratios and initial conditions. Some parameters are known with relatively high accuracy, while others are poorly understood and are the subject of further research. To understand how changes to forcing functions and the parameter uncertainties may affect the ELM dynamics and its interpretation, we performed a suite of sensitivity analyses on the ELM.

We approached the task of evaluating the model sensitivity and communicating those results in a stepwise, hierarchical fashion in keeping with the model structure. The unit model primarily involves "vertical", or non-spatial, processes such as plant growth, nutrient cycling, evapotranspiration, etc. Water and nutrients flux in the horizontal dimension, altering the ambient conditions in the model landscape cells, potentially altering the ecosystem processes in the cells and the pattern of the cells in the landscape. Thus, the unit model develops potential water and nutrient flux conditions, which are propagated to neighboring cells. Variables that flux spatially (horizontally), and variables that have significant influence on such fluxes, are “landscape driver” variables and have the potential to alter the landscape pattern: the most important of these are water levels, nutrient concentrations and macrophyte biomass[1]. Particular attention was paid to parameters that had a significant influence on these driving variables. Parameters that create significant changes in these variables at the ecosystem scale are those that require further analysis in the spatial context. Whereas the unit model domain and spatial model domain are tightly coupled in the total model results, not all parameters have significant (large) effects on key landscape driving variables, and we can effectively partition the model into two entities: one responsible for the vertical transport, the other - for the horizontal one, and perform sensitivity analysis for both of them. If a parameter has little effect on landscape drivers at the ecosystem level, then it may have a similarly small effect at the scale of the landscape.

However, this partitioning is not definitive, and currently involves a certain level of subjectiveness on the part of the modeler performing the analyses. Due to the required isolation of the unit model and its unique set of forcing functions, a number of landscape driver variables may not be significantly influenced by parameters that are related to the external conditions dictated by the model forcing functions (such as Manning’s roughness or concentrations of nutrients fluxing with water). Thus, these generalizations do not imply that small changes do not propagate and increase across space with varying habitats and altered parameters. This partitioning of models of varying scale and complexity provides a mechanism for better understanding the relative importance of different ecosystem processes on the dynamics of the localized ecosystem and on the pattern of the landscape. The partitioning of the spatial model into ecosystem process sensitivity and landscape process sensitivity is intended to more effectively understand the nature of the sensitive parameters and the scale at which they operate most strongly.

Methods

In the multi-tiered approach, we incorporated changes in single parameters at a time for both the unit model and the spatial models. At the first level, we analyzed the unit model sensitivity to parameter variations for one habitat type. Restricting this process to one habitat maintained the output to an extent that is manageable, while still exercising the model within a range of behaviors. This provided insight into some of the most significant parameters that modified the landscape drivers of water, nutrients and macrophytes. We then analyzed the sensitivity of two spatial models of increasing areal extent and complexity to parameters identified as moderately sensitive at the first level of scale, while also analyzing model forcing functions and other parameters that were not necessarily identified at the unit model level, but which are specific for the spatial level of resolution.

For the bulk of the analyses of ecological sensitivity at the spatially explicit scale, we rescaled a subregion of the ELM. The Conservation Area Landscape Model (CALM) is a spatial ecological model of WCA2A at a higher spatial resolution than the ELM (1,734 $0.25 km^2$ cells vs 10,264 $1.0\ km^2$ ELM cells, Figure 1). The CALM contains a unit model identical to the ELM and has the same forcing functions where appropriate, e.g., structure inflows and precipitation at one station. Due to the significantly higher quality/quantity of data for WCA2A (and faster runtime), the CALM is being used as the test platform for debugging and calibrating much of the ecological (including hydrologic) components of the larger ELM.

After determining the influence of various parameter changes at the scale of the spatially explicit CALM, we analyzed the full ELM that contains the extensive canal/levee vector network and more vegetation types. Whereas the CALM has a relatively simple canal configuration, the ELM contains the complex canal/levee network, with structure flows that are determined by either historical data or management rules (all database driven instead of hard coded). For these analyses, we focused on the hydrologic component of the ELM, determining the model behavior under varying water/nutrient inflows (through the S-5 through

S-8 structures), alteration in flow rates through structures, and Manning's roughness coefficient.

Ecosystem process sensitivity

These tests of the model sensitivity were made for the sawgrass marsh habitat in order to analyze the model response to a broad range of conditions for a particular habitat. Parameter documentation is provided in Tables 1-7, containing descriptions of how the parameters are used in the model. The unit model runs were all made with the same external forcing functions, with total water head external to the model cell varying from a maximum of 50 cm above the sediment during the wet season to 0 cm depth during the spring dry season. Nutrient concentrations in this external water volume (potential loadings if internal-external head differences result in water inflow) were set at a constant value equal to the initial conditions of the model cell (a parameter that is included in the sensitivity analyses). Rainfall (year 1983) was not varied among runs. In all unit and spatial model runs, the time step of the model (dt) was fixed at 0.5 d. The model was normally run for one year, with the exception of the set of runs when all parameters were varied together in a four year evaluation of the unit model under extreme parameter combinations. Two sets of parameter changes were used.

1) Change one parameter per run
    a) within measured ranges where data measurements are available and of good quality (data grade 1-2 of 5 in GEM_dbase).
    b) within ±10% variation for parameters for which a potential range of measurements is unknown but which either are data of good quality or whose range may be relatively tightly constrained, i.e., temperature optima for maximum production (data grade 3 of 5 in GEM_dbase).
    c) within ±50% (or more) variation about model's estimated (currently used) value, where the data are "first order" approximations, based on data from studies not directly comparable to Everglades habitats (data grade 4-5 of 5 in GEM_dbase).
2) Change all parameters per run
    a) using the parameter database above, test model behavior with all parameters at their lowest value, and all parameters at their highest value (resulting in some unrealistic combinations)

Output from sensitivity runs includes:
    a) Output from sensitivity runs using Stella were put into a spreadsheet (included as a "binary appendix") that contains the values of the parameters and the output for all model runs. Tables 1-7 are written descriptions of each of the parameters as they are used in the unit model. The best parameter estimates were used in

the nominal runs, and the state variable responses at the end of one-year model runs using low and high parameter values were compared to those nominal runs. These comparisons are presented in a series of bar graphs for each of 7 important state variables (Figures UBar1&2 through UBar13&14), indicating (a) the percent change in the model parameters from the nominal values and (b) the corresponding percent change in the state variables compared to the areal extent and complexity of the ELM is increased over the CALM, with a total of 11 habitat types (most recent data are from 1973, Figure 3). The full canal network (Figure 4) and WCA regulation schedules is operative using the iterative relaxation procedure used in the SFWMM. Structure flows among canal reaches and model cells are calculated using a simple weir equation, but historical data (year 1983) are used for water and nutrient inflows from the S-5, 6, 7, and 8 structures.

1) CALM parameter changes

   a) We ran the full ecosystem level unit model within the CALM, evaluating the hydrologic sensitivity to variations in the Manning's roughness coefficient and evapotranspiration parameters. We chose other ecological parameters to which the landscape driver variables were most sensitive, and further evaluated the model sensitivity to their changes in the spatially explicit CALM.

2) ELM parameter changes

   a) For the ELM analysis, we focused on the hydrologic variables in the large, heterogeneous landscape containing the canal network. We varied the total pumped inflows into the ELM, along with modifying individual structure operations. Finally, the base flow coefficient (see footnote 2), was modified within a large range, further evaluating its effect on water levels in the more complex landscape of the ELM.

3) Output

   a) Using the CALM, we focused on the spatial sensitivity of surface water depth, PO4 in sediment water, and macrophyte biomass in response to varying parameters identified at the unit model level. In order to effectively visualize the pattern of change in the landscape, the display uses a time series of maps for each variable, with color gradients that display the percent differences between each of two runs with changed parameters and the baseline run (using the best parameter estimate). Examples of four snapshots for each one-year series of model runs are provided in this written report, but the full series of weekly or monthly animation files are available as a "binary appendix" to this report.

   b) Using the ELM, we then analyzed the effects of altering some of the forcing functions and several attributes of the canal network. In addition to using the spatial animation representation for evaluating sensitivity, we calculated two norms to account for the overall sensitivity of the model to changes in parameters and forcing functions. The first norm was calculated as the mean state variable VAR value over the whole area over the time interval considered:

$$N_1(T)=\sum_{t<T}\sum_{i\ ON\_MAP} VAR_i(t)\ /\ TOT\_CELLS\ /\ T\ ,$$

where TOT_CELLS is the total number of cells in the model area; *T* is the time interval over which the norm is calculated.

The second norm defines the maximal total state variable value attained during the time interval considered:

$$N_2(T) = \max_{t<T}\sum_{i\ ON\_MAP} VAR_i(t) / TOT\_CELLS\,.$$

While the first norm presented the integral of *SURFACE WATER* levels over area and time and therefore described the sensitivity of the model on the average, the second norm traced the maximal values of the *SURFACE WATER* attained and thus characterized the extremes in the model behavior. As with the CALM results, we then present snapshots of animations of the differences among model runs.

Results

4 year response: Multiple parameter change

The four year sensitivity series where all parameters were either high or low at the unit model level indicated that the system processes and constraints encoded into the ELM are robust to even unrealistic combinations of parameters. All of the variables were within reasonable (potentially observable in field measurements) ranges of values, regardless of the extreme parameter sets. For the high-value parameter set (run #3), nutrients (Figure U5b) increase steadily because water levels are soon drawn below the sediment elevation (Figure U5c), allowing relatively high, constant rates of decomposition. The peat depth decreased approximately 30 cm after 4 years in this extreme case (Figure U5a), remineralizing inorganic nutrients and stimulating macrophyte growth, with the latter biomass decreasing in its rate of growth toward the end of the simulation run (Figure U5a). The extreme of all parameters at low values showed comparatively little change in most variables.

We now present the sensitivity results on a state variable by state variable basis, focusing primarily on results that varied substantially among model runs.

Water levels: unit model and CALM

Hydrology drives the wetland system, and the total water level is an important landscape driver. Water fluxes vertically and horizontally, carrying nutrients. Vegetation responds to water availability (or excess), and directly influences its quantity via the Manning's roughness coefficient and the combined effect on transpiration of the maximum Leaf Area

Index (maxLAI) and canopy conductance parameters. The actual Manning's n and LAI (as opposed to the fixed parameter on which they are based) change dynamically as a function of the vegetation biomass.

At the unit model level, changes to the Manning's n and the macrophyte maxLAI had the most significant effect on the water levels (Figures U1c, U3c, and UBar 14). However, the flow into/out of the unit model was dependent on the forced external conditions, and as such those fluxes and resulting water levels did not necessarily represent the situation encountered in a model landscape with multiple cells. As Figure C3a indicates, changes in the roughness coefficient influence modeled water levels in different areas of the landscape, but not to the extent that changes in the maxLAI affected transpiration and thus water losses (Figure C1a).

The available nutrients (initial PO_4 sorbed to sediments and in the water column) had little to no effect on water levels at the unit model level, primarily due to the forcing functions supplying PO_4 to the system and not limiting macrophyte growth. However, the plants were generally nutrient limited in the CALM, and changes in initial sorbed nutrient concentrations resulted in altered plant biomass (see below); with lower initial nutrient levels, less plant biomass accumulated. Whereas decreased plant biomass would tend to provide less surface roughness and increase flow in the landscape, it also decreases the total LAI. The latter appears to be a predominant process, as the water levels were generally higher with the lower nutrients and lower macrophyte biomass and LAI (Figures C4a-c).

The region in the middle of the WCA tends to be somewhat drier than other regions, and many of the relative changes in these simulation runs showed the sensitivity of that area to a variety of parameter changes. A pattern that appears through many of these spatial map comparisons of variables that flux in the landscape involves the borrow canals along the periphery and inflows into and out of these borrow canals and adjacent cells. The monitoring station that is approximately in the middle of WCA2 (S-2A17) is used in the model to trigger the regulatory structures to open and close. When water levels are high (e.g., Figure U1a, Week 24 on left), the S-11 structures are open, and drain water from the WCA. The influence of the borrow canal on draining the region is evident in the drawdown of water height along the border of the southwest portion. Conversely, when there is little water in the WCA and the structures are closed, there is a temporary increase in water levels along that border. These influences of inflows to the northeast and outflows primarily to the southwest affect many of the landscape patterns seen in these results, and should be kept in mind during the analysis. The influence of the canal network on the larger ELM is presented next.

Water levels: ELM

Sensitivity to Input Scenarios

Figure E1 presents the effect of varying water input into the area through the pumping structures S 5, 6, 7 and 8. This forcing function is one of the two major sources of water in the model area, the other one is precipitation. The Figure shows that there was a regular pattern of increase in the amount of surface water in the model area as a result of increased pumping from the outside. Under zero pumping there was a pattern of water accumulation in the landscape as modified by the canals and levees, but with no additional transport of incoming water through the canals. By the end of the (1983, wet) simulation year the amount of water remained higher than the initial conditions, (set for dry conditions) which means that they have to be modified for further runs or the model should go through a period of adjustment. In all other scenarios there were progressively larger accumulations of water in the area as pumping increased.

The other norm shows that the relationship between the amount of pumping and the maximal water levels in the area was approximately linear (Figure E2). There was only a slight difference in the incline of the graph when the input was increased versus the decreased inputs.

The sensitivity of the spatial distribution is presented in Figure E3. It turns out that under the canal/levee operation schedules currently implemented in the model there was not much effect of water input variations on the areas outside of the managed area. Much of the water that was pumped into the canals was then further channeled out of the model area. There were significant changes in the Water Conservation Areas that receive the pumping, but the management rules that we are currently operating are such that there was relatively little influence elsewhere. We are seeking better control operation criteria in calibrating the management portion of the model. . Finally, this figure reiterates the result observed when looking at the norms - the model is more sensitive to increases in water input, than to reductions.

Sensitivity of the canal network can be viewed in Figure E4, which shows variations of stages in the ELM segments of the Hillsboro and North New River canals (11 and 12), the two most directly affected by the external pumping. With no pumping the stages in both canals oscillated around 4m, equilibrating with the water levels in the adjacent cells. The stages reacted immediately to input, when high loads of water are received from the pumps and it sometimes took several days to accommodate all the water received and transfer it to the neighboring cells. Under nominal conditions the stages can reach the maximums of more than 8m, however usually they did not exceed 6m. Increased input further raised the stages to above 10m and higher. Other model runs with decreased time step in the hydrologic module showed that these unrealistic stages result from the discretization assumed in the model. Effectively that means that with elevated inflows the model has to be run with a smaller time step to allow the canals to equilibrate with the cells rapidly enough and avoid such high mounting of water in the canals. Running the same model with a time step of 0.1 (instead of 0.5 used currently) decreased stages to reasonable levels (5-6m).

We also looked at the operation of several structures to see how they were influenced by variations in the water input (Figure E5). With zero pumped inflow two of the chosen structures were inoperative, which is probably natural, when the canal stages are only tracing the background water levels in the adjacent cells. There was a small, insignificant flow in the S11 structure (S11C=ELM 113) when it was accommodating only the precipitated water held by the levees. The S10 structure (S10C = ELM 103) came into play only for increased water input. The larger the input, the earlier this structure came into operation, remaining open for the rest of the season. In the S11 structure graphed (ELM 113), the length of the active period gradually increased with the rise in the water input. Already under nominal conditions it operated over most of the year. Structure S34 (ELM 34) connects two major canal segments that effectively transfer water out of the area, therefore it's operation seemed to be quite chaotic, actually following the scenario of water input in the pumping structures.

Sensitivity to Flow Rate Parameters

The Base Flow Rate factor (BFR) is used in the model to modify the overland flow. Effectively it multiplies the inverse of the Manning's roughness coefficient. In the nominal run BFR = 1.

In Figure E6A,B the deviations of the *SURFACE WATER* variable are animated for two model runs: one with increased BFR=10 and BFR=2, the other for BFR=1/10 and BFR=1/2. Reducing Base Flow Rate decreased the horizontal fluxes among cells and between cells and canals. Therefore the areas that nominally were loosing water via overland flow, are going to be preserving that water, and vice versa.

Figure E6 indicates how complicated the hydrology of the area is, with the flows being affected by variations in habitat types, the canal network and the elevation gradient. In some particular regions the dynamics may seem counterintuitive if we are considering only one of these factors. On the whole we may see that by increasing the base flow rate, water was transported down to the lower elevation areas more efficiently (which results in the predominantly blue color in those areas). On the contrary, decreasing BFR left larger areas with less surface water. However in many cases interaction with canals, that flux large amounts of water over long distances fairly rapidly, and with varying habitats, which differ in the rates of evapotranspiration, make this relationship obviously non-linear and not single-valued.

Looking at the animation results, it is quite difficult to understand what pattern governs the relationship between overall model hydrology and the BFR coefficient. The reason for that becomes clear when displaying the two chosen norms. In Figure E7 the N1 norm is displayed, presenting an obvious increase in the total surface water over the area when the BFR is increased (BFR=2). This is probably because at higher flux rates more water was removed from the canals and less flushed through the canal network and discharged out of the model area. However if BFR is further increase (BFR=10), that trend was reversed and again the area started to accumulate less water. This is especially clear from the dynamics of the N2 norm (Figure E8). It shows that there is an maximum somewhere between 2<BFR<10 and that with higher flow rates the amount of overland water decreased. This is probably because such high flow rates not only efficiently move water from the canals and flood the area, but also flush the water from land further downhill to the boundaries of the western area, that drain to the ocean. Somewhere in between there is a value which is high enough to absorb most of the water from the canals, yet not high enough to move the water over the long way to the ocean in the west.

The stages responded quite reasonably to variations of BFR (Figure E9). At increased flow rates the stages decreased dramatically because water in the canals quickly equilibrated with the adjacent cells. This could be another option to deal with extremes of increased inflow, if necessary. Instead of decreasing the time step (as discussed above), we could increase the BFR. If that affects other processes or areas in the model and we cannot use this option, the model allows a larger range of interaction between the canals and cells, so that the canals are equilibrated with several cells on one or both sides, which effectively results in a local increase of the BFR coefficient.

The response of structures to variations in BFR is quite different. As seen in Figure E10, there was very little sensitivity in Structure S11 (S11C=ELM 113). However Structure S10 (S10C=ELM103)and especially S34 responded quite readily. The reaction of S34 is easily understood. It is a structure linking two canals (N12 and N20) and with higher alterations of the donor canal stage (N12) induced by decreased BFR, the flux through the structure increases. At higher BFR values and hence lower canal stages, the flux also falls. Behavior of S10 (ELM103) is less clear and again demonstrates the complexity of the system modelled.

Sensitivity to Structures

The last series of experiments involved removing certain structures from the model. We have switched off two of the most active structures, S5 and S7, to see how far their effect propagates over the landscape (Figure E11). It turned out that the effect of S5 is mostly confined to the area that it directly drains to, which is the WCA1, as well as the adjacent WCA2. In a way this could be expected from analyzing the operation schedule of this structure which allows water to flow from that area (ELM 101, 102, 103). As seen from Figure E5 these structures become active only in the second part of the year. Under nominal conditions most of inflow pumped through Structure S5 is accommodated by WCA1 and WCA2 and stored or evapotranspired there. On the contrary, removal of Structure S7 has more widespread effect, which is again defined by the structure of the canal/levee network and by the way other structures operate.

PO_4 in sediment water

In the model, macrophytes take up nutrients dissolved in the sediment water, with PO_4 being the nutrient on which we focused for analysis of the model sensitivity. Nutrients may flux horizontally among cells and vertically, and are taken up by macrophytes and remineralized at rates dictated by current environmental conditions (e.g., water levels, temperature, etc.). This state variable (and PO_4 in surface water), which fluxes across the landscape and directly impacts the vegetation communities, is a central landscape driving variable. Due to diffusion and advective downflow of surface water into the sediments (following evapotranspiration), the nutrients in the surface and sediment water generally reflect similar patterns of concentrations.

At a lower maximum rate of net primary production, less PO_4 was removed by plant uptake from the sediment water, as indicated at the unit model level (Figure UBar1, U2b), and as shown in the relatively uniform pattern of lower nutrient concentrations over the landscape (Figure C2b). Varying the initial concentration sorbed to sediments had dramatic effects on PO_4 in sediment water at the unit model level, and likewise showed up significantly at the spatial model level (Figure C4b, note scale = ±500%). Similarly, modification of the nutrient requirements of the plants had analogous effects on nutrient stocks at the unit model level (Figure UBar1) and the spatial model (Figure C5b).

Parts of WCA2A, mostly in the middle-southeast region, had very low model concentrations of PO_4 in the sediment water, and the relative sensitivity animation snapshots reflected the influence of concentrations that are near zero (or effectively at the lab instrument detection limit). Thus, some of the comparisons that indicated apparently large differences between runs in that region appear to be due to model nutrient concentrations that increased from very low concentrations by even relatively small absolute amounts. This behavior of the model output near the minimal concentrations is reflected mostly in the middle-southeast region of the WCA2A, where both lower and higher water levels at week 36 due to higher and lower LAI, respectively (Figure C1a) increased nutrient concentrations from very low values by an apparently large proportion.

Macrophyte biomass

Macrophyte growth responds directly to water levels and nutrients, both of which flux over the landscape and are altered via vertical flows at the unit model level. Because macrophytes can significantly alter transpiration rates, overland flow, and nutrient availability, another landscape driver is the macrophyte state variable (actually two in the ELM, but combined here into total biomass). Macrophyte growth is constrained from its maximum rate (a habitat specific parameter in the sensitivity analysis) by control functions based on available light, temperature, nutrients, water availability/excess, and salinity stress. The nutrient requirements are expressed using Michaelis Menton uptake kinetics (with a Ks parameter in the sensitivity analysis). The actual leaf area index of a plant community is a function of the variable biomass of plants relative to the maxLAI parameter (in the sensitivity analysis).

Macrophytes responded to the increased maxLAI parameter as the hydrologic response of the unit model and CALM varied. When the water was drawn below the root zone in the unit model (Figure U1c), the macrophyte production was curtailed by varying degrees (Figure U1a). However, as the water levels generally rose back into the root zone with the wet season, macrophyte biomass under high LAI conditions surpassed those obtained with lower LAIs. The production control function responded to higher PO_4 in the sediment water, most likely due to higher decomposition in aerobic sediments without overlying water in the case of the higher LAI. A different, but hydrologic related, response occurred at the spatial model scale, where changes also were due to altered water levels. Here, sawgrass growth along some of the periphery of WCA2A had been constrained somewhat by higher depths along the borrow canals; a higher LAI reduced the water levels throughout the WCA (Figure C1a), and subsequently allowed somewhat higher growth of the sawgrass just in those regions.

Macrophyte biomass was strongly influenced by variations in its maximum specific rate of net production at both the unit model and CALM scales (Figures U2a and C2c). Initial concentrations of PO4 sorbed to sediments were also strongly linked to annual growth of macrophytes (Figures U4a and C4c). In these cases, the changes in macrophyte growth were relatively homogeneous throughout the landscape.

PO_4 sorbed to sediments

The PO_4 sorbed to the organic sediments serves as a source or sink for PO_4 in the sediment water and plant uptake. It has a direct influence on the concentration of PO_4 in the sediment (and thus surface) water, but does not flux vertically or horizontally. In the absence of changes in uptake/mineralization, the PO4 in sediment water equilibrates to that sorbed to sediments.

For most of the sensitivity scenarios, the PO4 sorbed to sediments served as a source of nutrients and declined slightly in absolute value (e.g., on the order of 5 to 1 mgPO4/kgDOM). With a high LAI, the decline in concentration was lower (Figure U1b) than simulations with lower LAI due to the decreased water presence leading to more decomposition and remineralization of nutrients in the water column. Similarly, with higher rates of net production and greater uptake by plants, the phosphorus pool sorbed to sediments was depleted to a larger extent (Figure U2b).

Periphyton biomass

Periphyton respond to water availability and nutrients in the surface water, with senescence and mortality in dry periods. Most of the dynamics of the periphyton were responses to water presence/absence, which in these sensitivity scenarios was generally most controlling and modified periphyton biomass due to increased mortality with desiccation. PO_4 was not severely limiting under these conditions of parameter sets, as indicated by the comparatively small response to varying the initial PO4 sorbed to sediments (Figures UBar9, U4a).

Deposited Organic Matter

The depth of the organic material in the sediments may vary with deposition and decomposition of plant organic matter. In the ELM, we defined an “active” zone of deposited organic matter (a parameter that is on the order of 1 m), within which may be nutrient concentrations different from the remainder of the sediment-water column. Decomposition and nutrient sorption occur within this active zone. Decomposition depends on water availability, the level of anoxia, temperature, and available nutrients and carbon substrate.

Due to relatively slow rates of deposition and decomposition of the organic material, very small absolute changes occur in the depth of this sediment zone. Accretion occurs during prolonged inundation, but reduced water levels due to increased LAI (Figure 1c, run 3) promotes oxidation and a lowering of the rate of accretion (Figure U1a, run 3). The very small rates of accretion increased during higher macrophyte production (and mortality). Increased nutrients in the sediment water may increase the decomposition and lower the DOM depth to a significant degree (Figure U4a).

Discussion

In order to best understand the dynamics of a model of this complexity, a hierarchical approach to manipulating and analyzing the model components appears necessary. We feel that this multiscale, multiple model approach was indeed useful in understanding the level at which different processes are critical to model dynamics. As the comparison of the influence of Manning's n for the different models indicated, the complexity induced by the full ELM heterogeneous landscape and canal vector network would have made fine-scale interpretation of changes in roughness coefficient somewhat difficult. With this approach, we may interpret how the parameters operate, in direct and indirect effects, at the simpler model scales. Subsequent analysis at the more complex levels is then facilitated.

The multi-tiered analysis provided insight into the unit model dynamics and their spatial propagation using a realistic range of parameter values. The model is reasonably robust to expected variations in these parameters. However, the results indicated several parameters that are poorly known, but which significantly influence the landscape driving variables. These poorly quantified parameters include, but are not limited to, a) the distribution of nutrients sorbed to the soils throughout the Everglades, b) the nutrient requirements of different plant species, and c) the plants' dynamic leaf area index (linked directly to changes in biomass density of plants).

Perhaps most importantly, these analyses led to refinements in different model components, and should continue to do so. In particular, we are further evaluating some of the operating criteria for the water control structures in the ELM. Analyzing each model component, we are developing a model system that should be understandable, and modifiable, by District staff and other interested parties.

List of Tables

Tables 1-7 are the written descriptions of the habitat-specific parameters as they are used in the ELM. These tables were extracted from some of the descriptive records of the ELM database of habitat-specific parameters.

Tables 1-7: Parameter descriptions

2

3

4

5

6

7

List of Figures

Maps

Unit model: Bar Figures, all habitat specific parameters

Caption for all bar figures. There are seven sets of two figures for seven of the more important state variables (or combinations of state variables such as total water head). Each figure has a set of low and a set of high parameter changes and subsequent model results. High/low parameter changes are indicated in the percent relative to the nominal run that uses the best estimate, and resulting model output is shown as the percent (high/low) difference relative to the nominal run. The model result is that of the end-of-year value of the state variable. Time series graphs are provided below for selected sensitivity results.

Unit model: Line Figures, selected parameters

Caption for all line figures. For selected parameters that had significant effect on the model results, the 1 y time series of model variable output are shown for the model run with the low parameter value (line 1), the nominal value (line 2), and the high parameter value (line 3). All time series graphs (and parameter changes) correspond to the end-of-year bar charts above. The units of the state variables are below.

Model variable	**Description**	**Units**
mac_tot_biom	Total macrophyte biomass	kg C • m^{-2}
algae	Total algal (periphyton) biomass	g C • m^{-2}
DOM_activeZ	Depth of organic sediments, in defined active zone	m
PO4_sedwt_concACT_mg	PO4 in interstitial water of the active sediment zone	mg PO4 • L^{-1}
PO4SorbConc	PO4 sorbed to active zone sediments	g PO4 • (kg DOM)$^{-1}$
PO4_sfwt_conc_mg	PO4 in surface water	mg PO4 • L^{-1}
hyd_tot_wt_head	Total water head, measured from MSL	m (note that unit model initial sed. elevation = 6.0m)

U1a-c: Model responses to varying maxLAI
U2a-c: Model responses to varying max rate of net production
U3a-c: Model responses to varying Manning's roughness coefficient
U4a-c: Model responses to varying the initial PO4 sorbed to sediments
U5a-c: Four-year model responses to varying all parms simultaneously

Spatial model: CALM

Caption for all CALM animations . As done at the unit model level, the best parameter estimates were used in the nominal runs, and the state variable responses at the end of one-year model runs using low and high parameter values were compared to those nominal runs. These comparisons are presented in a series of landscape snapshots for each of three important landscape driver variables. The snapshots show the change in the state variable relative to the nominal run, with the left column of snapshots representing the change in the state variable when the parameter was decreased, and the right side representative of changes due to increases in the parameter. Whereas white represents no change from the nominal run, a blue pixel is an increased value (in percent) of the state variable due to the parameter change, and red represents a decrease in the state variable compared to that of the nominal run. *Note: due to software problems, the gradations in the Color Bar do not exactly duplicate the range of colors in the animation snapshots. The colors in the snapshots range from dark blue, softening to light blue to green and* *light green with gradual fading to white; after the white space near zero difference, the color smoothly ranges from light yellow to red/orange to red and dark red.*

C1a-c: Model responses to varying maxLAI

C2a-c: Model responses to varying max rate of net production

C3a-c: Model responses to varying Manning's roughness coefficient

C4a-c: Model responses to varying the initial PO4 sorbed to sediments

C5a-c: Model responses to varying the Michaelis-Menton Ks

Spatial model: ELM

Caption for all ELM animations . See the caption for the CALM animations that explain the interpretation of the snapshots of comparative animations.

E1: Variations in norm N_1 in response to varying pumping from S5 - S8

E2: Variations in norm N_2 in response to varying pumping from S5 - S8

E3: Spatial model responses to varying pumping from S5 - S8

E4: Variations of stages in canals N11 and 12 in response to varying pumping from S5 - S8

E5: Variations of flow through structures S10, S11 and S34 in response to varying pumping from S5 - S8

E6A,B: Spatial model responses to varying flow rate (Manning's n)

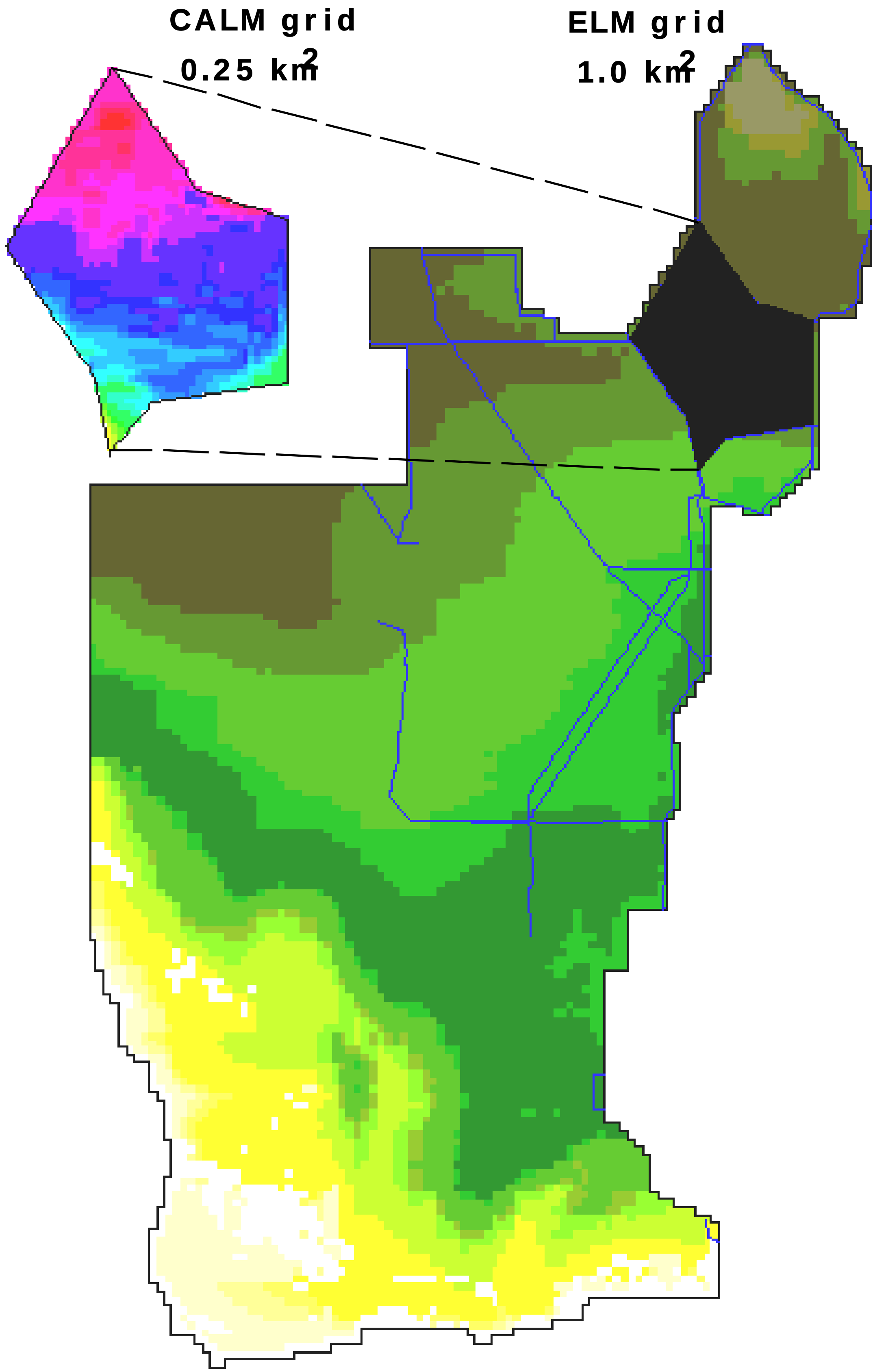
E7: Variations in norm N_1 in response to varying flow rate (Manning's n)

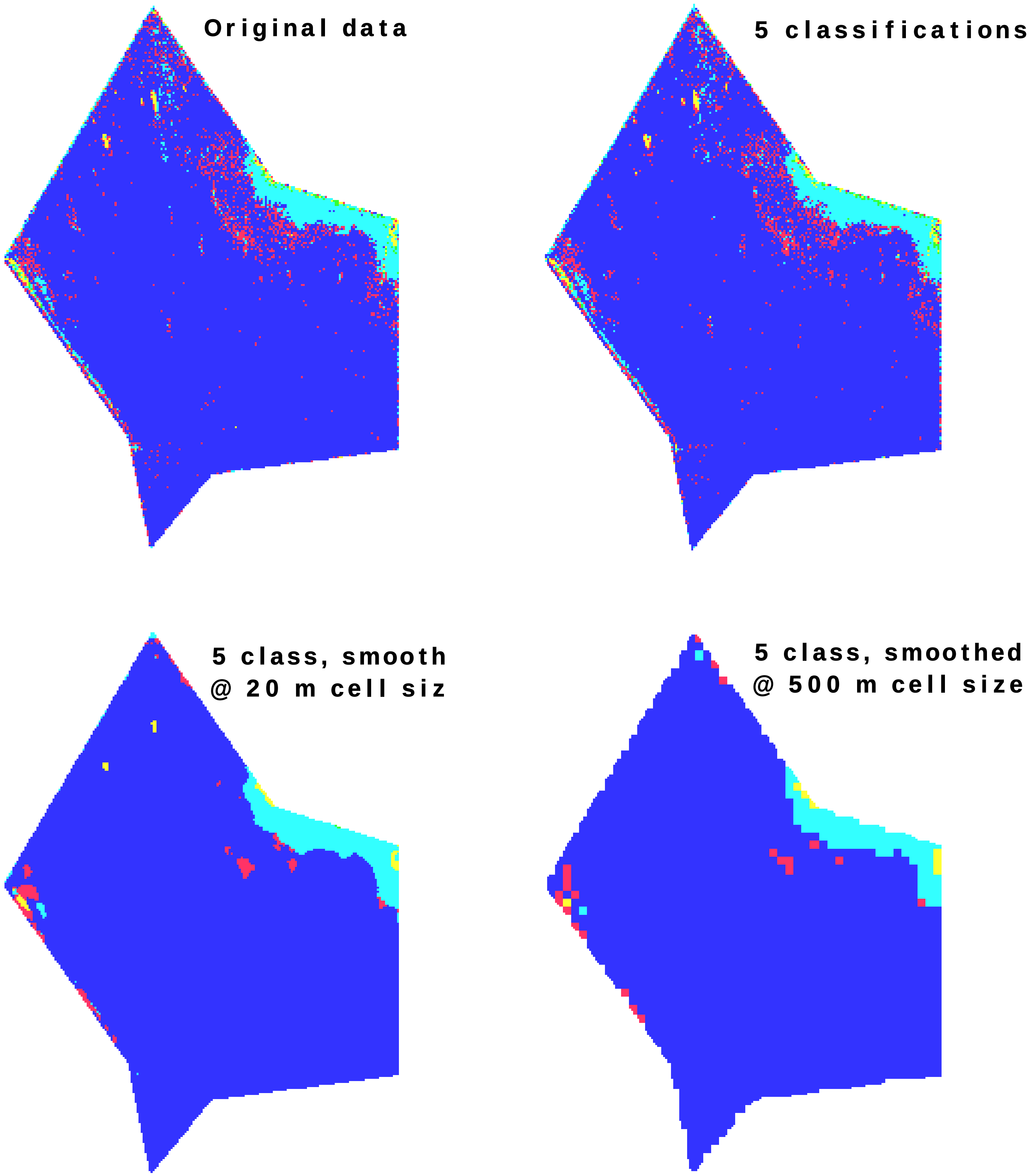
E8: Variations in norm N_2 in response to varying flow rate (Manning's n)

E9: Variations of stages in canals N11 and 12 in response to varying flow rate (Manning's n)

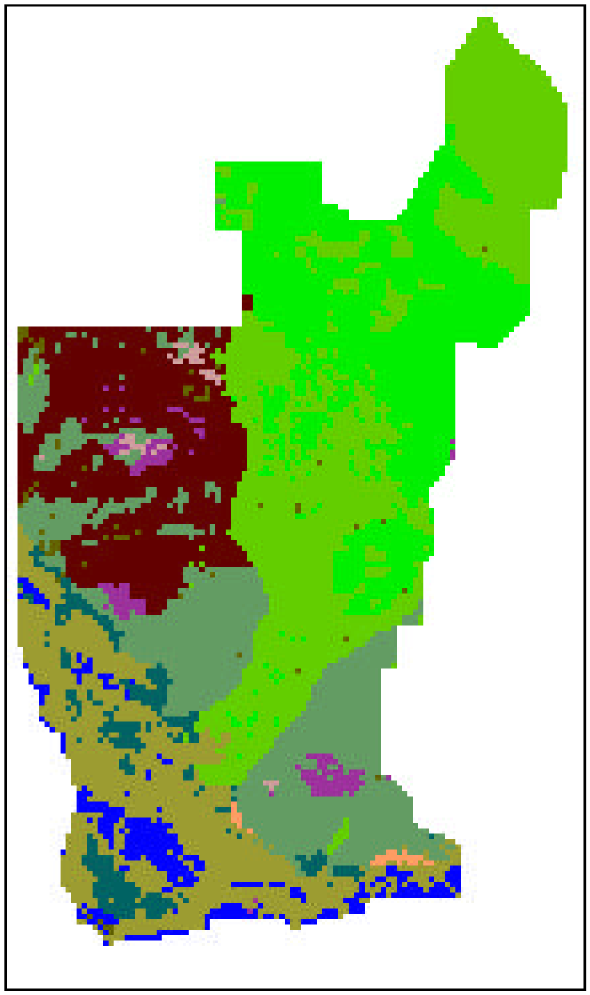
E10: Variations of flow through structures S10, S11 and S34 in response to varying flow rate (Manning's n)

E11: Model response to removal of structures.

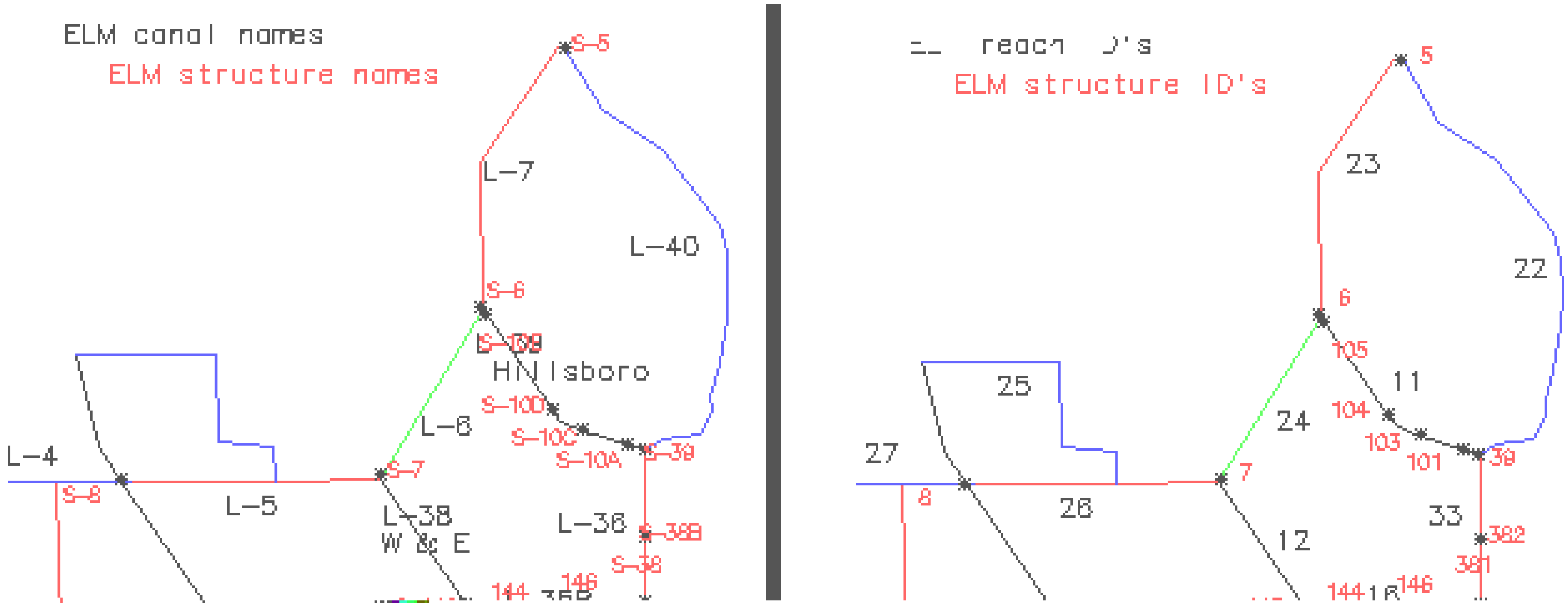

CALM grid
0.25 km2
ELM grid
1.0 km2


Original data
5 classifications
5 class, smooth
@ 20 m cell siz
5 class, smoothed
@ 500 m cell size

ELM Habitats: 1973



VOID	(9608)	
1	(366)	Open water (was void)
2	(2111)	Sawgrass
3	(2562)	Fresh Marsh
4	(1709)	Wet Prairies
5	(1412)	Scrub Cypress
6	(43)	Cypress Domes and
7	(157)	Pinelands
8	(1453)	Mangroves
9	(28)	Scrub Mangrove
10	(354)	Salt Marsh
11	(69)	Hardwoods


ELM canal names
ELM structure names
S-5
L-7
L-40
S-6
Hillsboro
S-10D
L-6
S-10C
S-10A
S-39
L-4
S-8
L-5
S-7
L-38
W & E
L-36
S-38B
S-38
144
146
ELM structure ID's
5
23
22
6
105
11
25
24
104
103
101
39
27
7
8
26
33
382
12
381
144
146

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity
Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

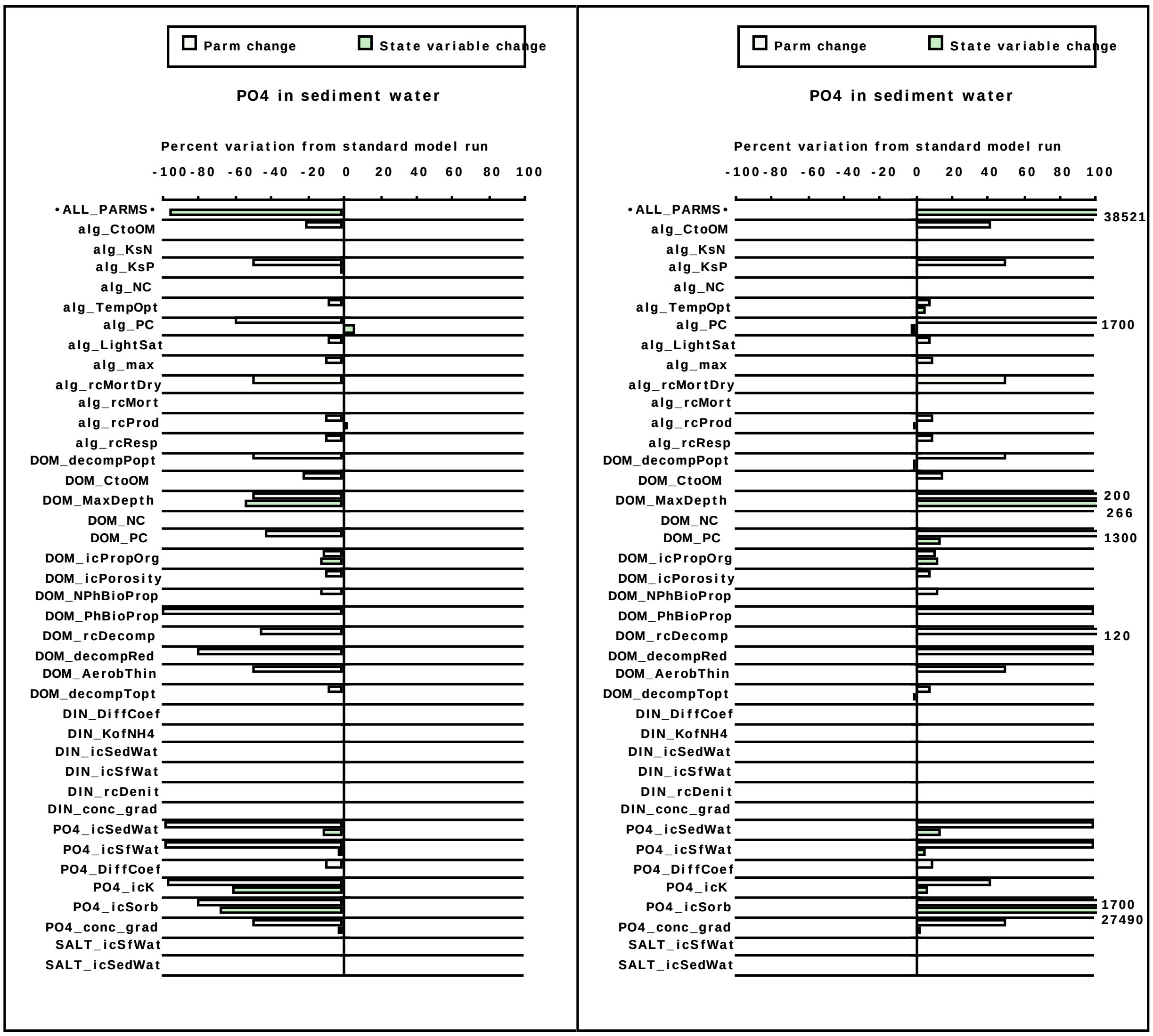


Figure UBar

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity
Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

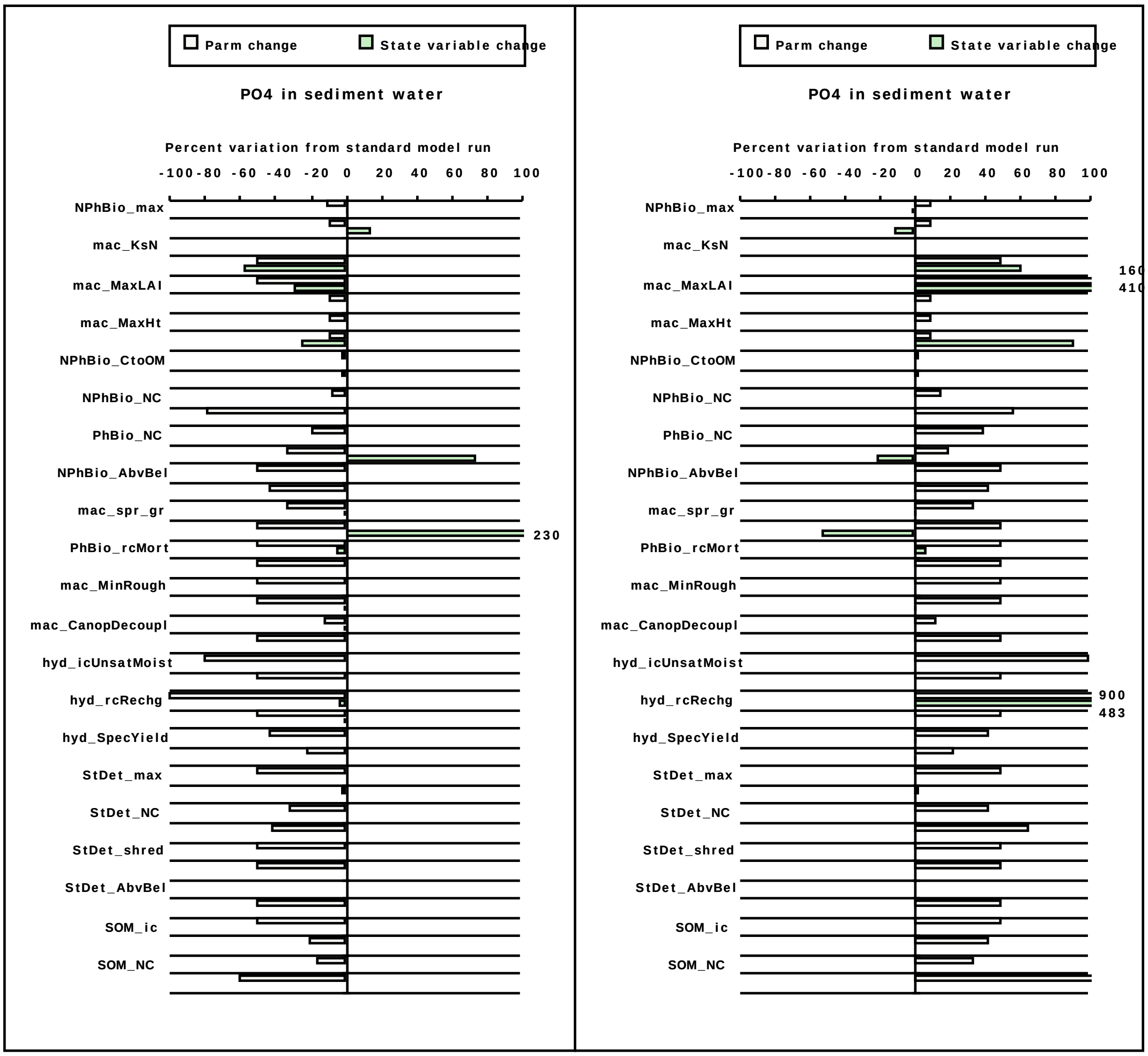


Figure UBar

Single parameter change to low value (except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity
Sawgrass marsh

Single parameter change to high value (except "ALL_PARMS", where all parms high)

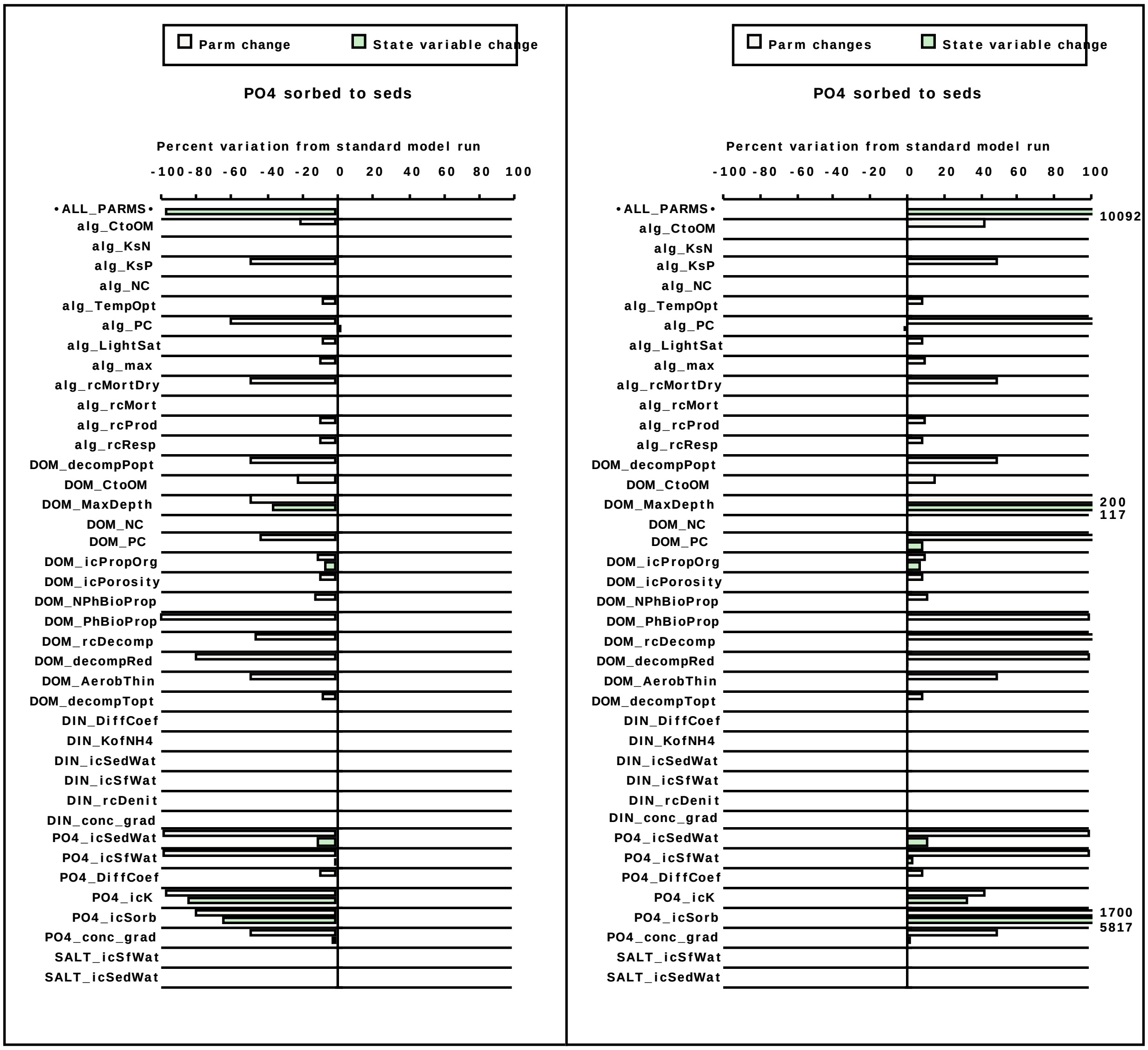


Figure UBar

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity

Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

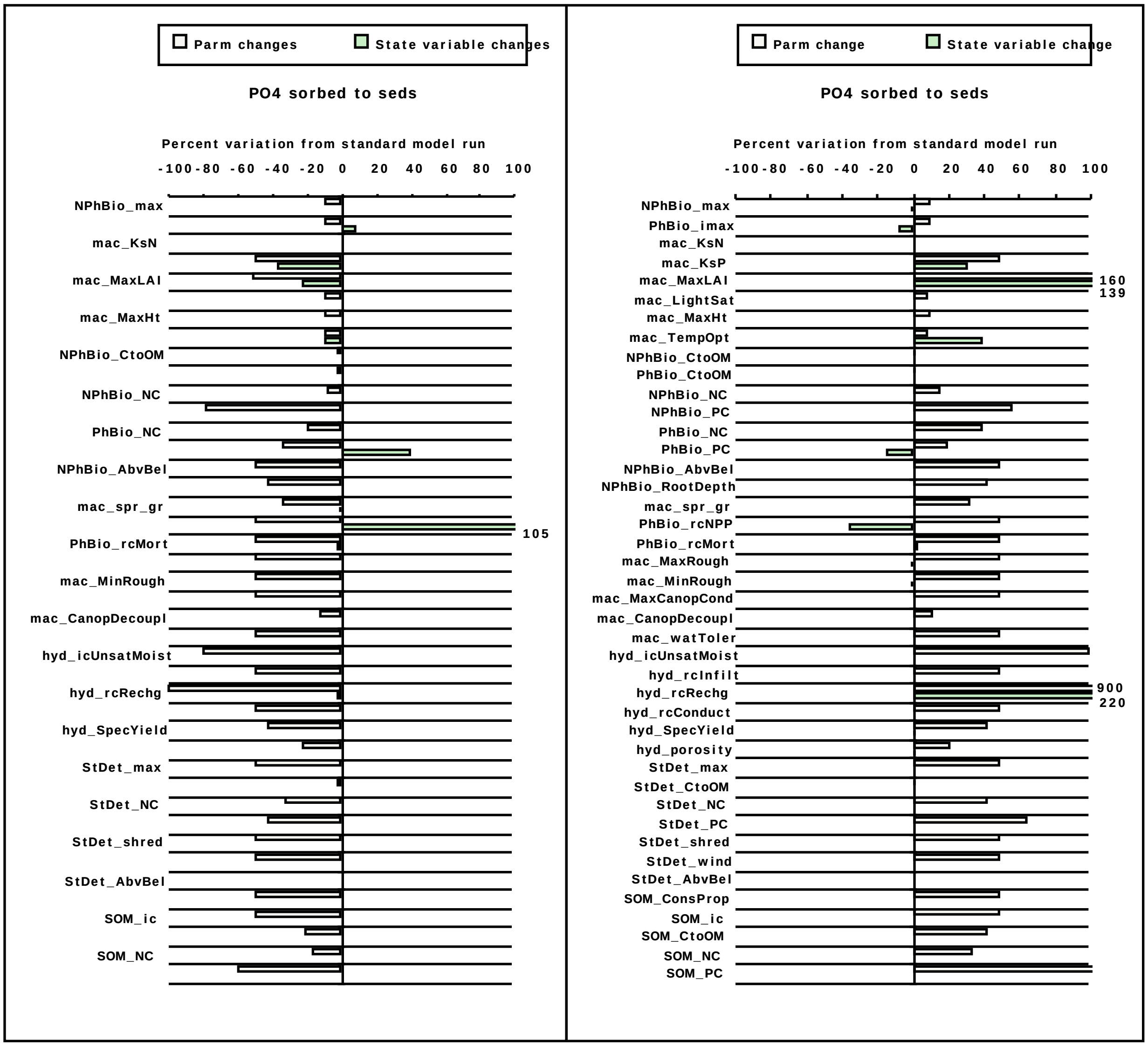
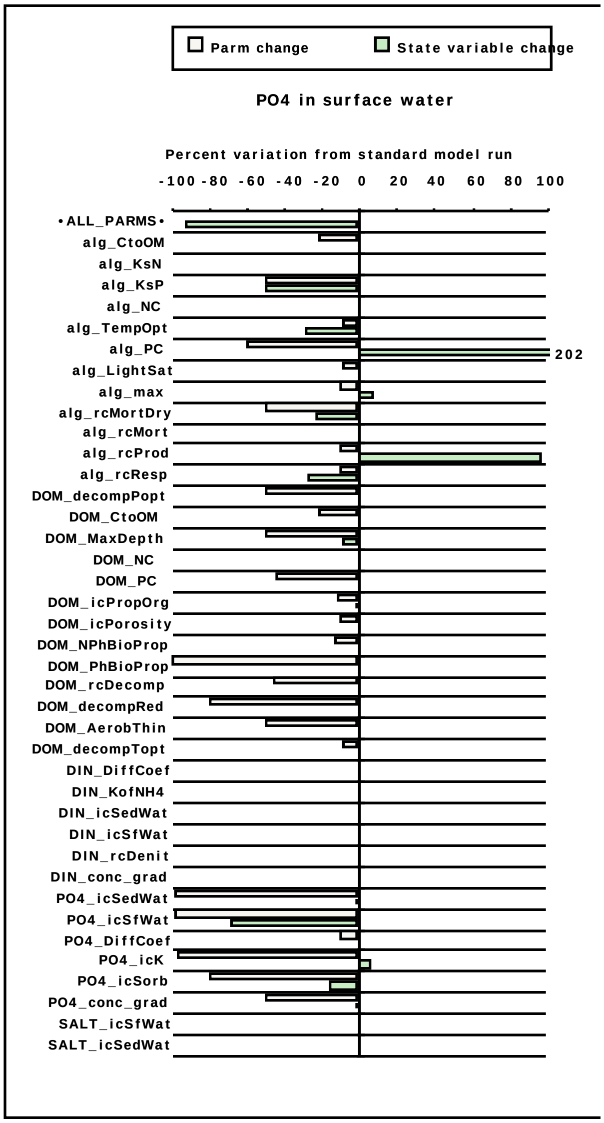


Figure UBar


Parm change
State variable change
PO4 in surface water
Percent variation from standard model run
-100 -80 -60 -40 -20 0 20 40 60 80 100
• ALL_PARMS •
alg_CtoOM
alg_KsN
alg_KsP
alg_NC
alg_TempOpt
alg_PC
202
alg_LightSat
alg_max
alg_rcMortDry
alg_rcMort
alg_rcProd
alg_rcResp
DOM_decompPopt
DOM_CtoOM
DOM_MaxDepth
DOM_NC
DOM_PC
DOM_icPropOrg
DOM_icPorosity
DOM_NPhBioProp
DOM_PhBioProp
DOM_rcDecomp
DOM_decompRed
DOM_AerobThin
DOM_decompTopt
DIN_DiffCoef
DIN_KofNH4
DIN_icSedWat
DIN_icSfWat
DIN_rcDenit
DIN_conc_grad
PO4_icSedWat
PO4_icSfWat
PO4_DiffCoef
PO4_icK
PO4_icSorb
PO4_conc_grad
SALT_icSfWat
SALT_icSedWat

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity
Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

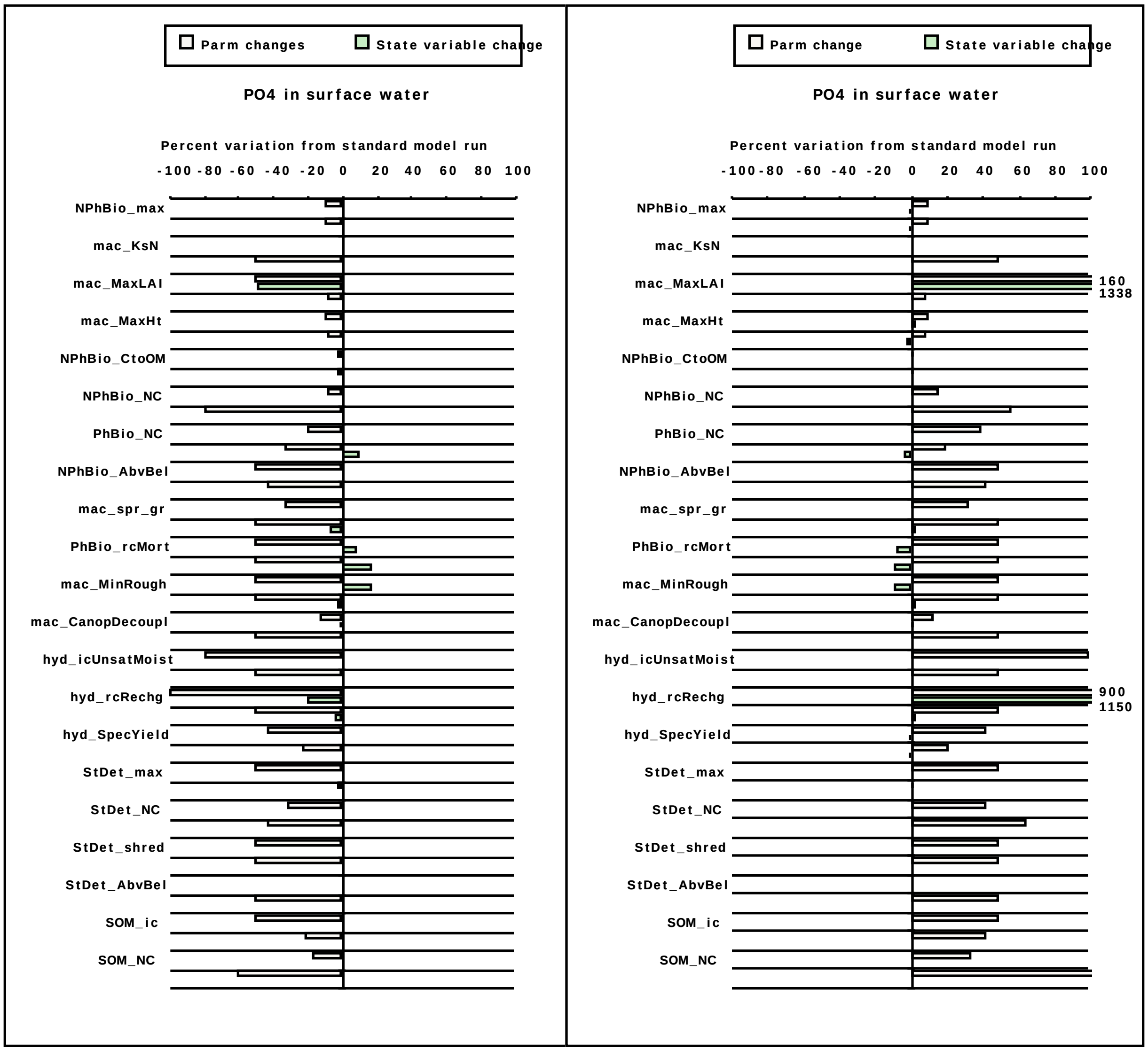


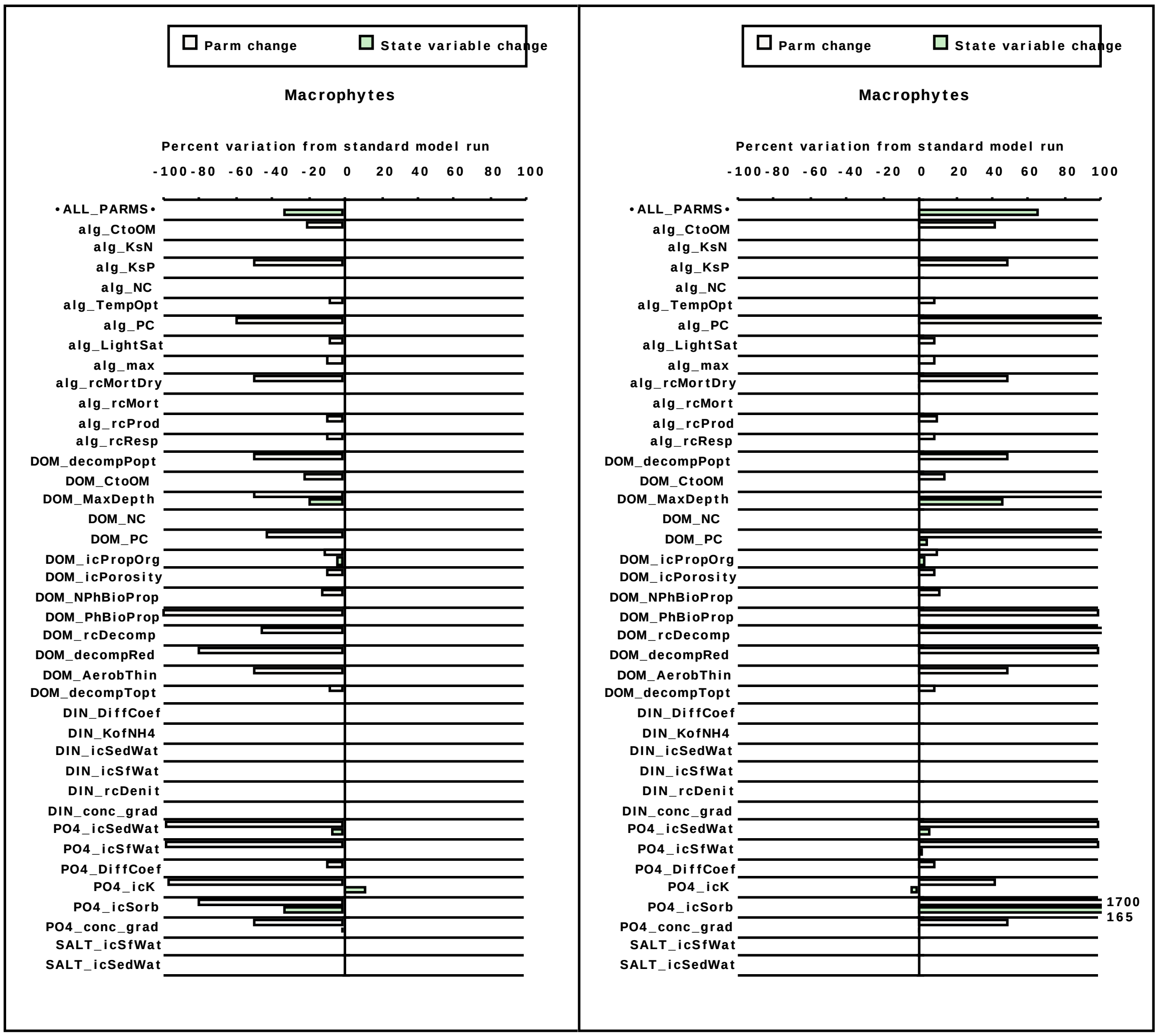
Figure UBar

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity

Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)



Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity

Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

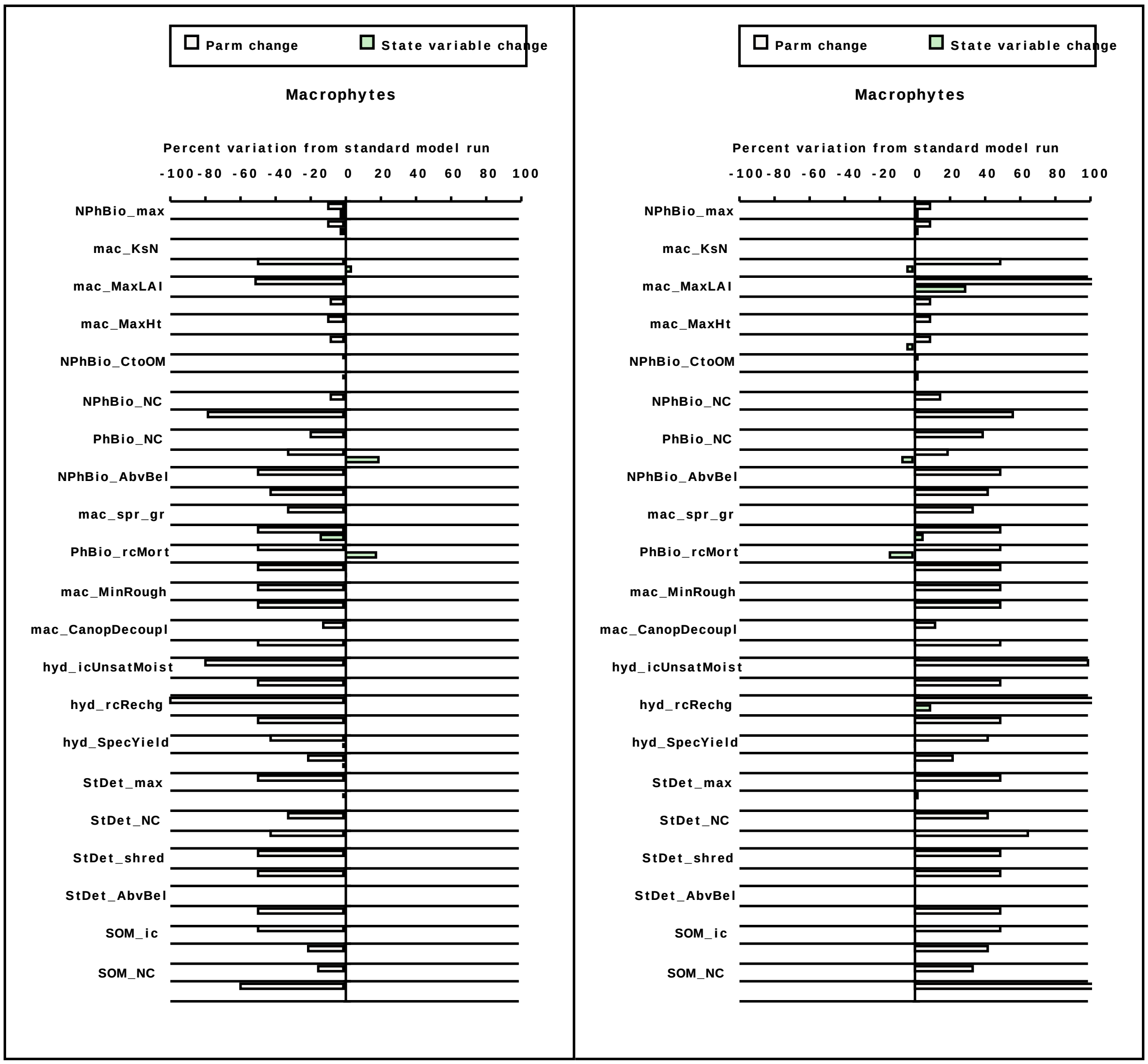


Figure UBar

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity

Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

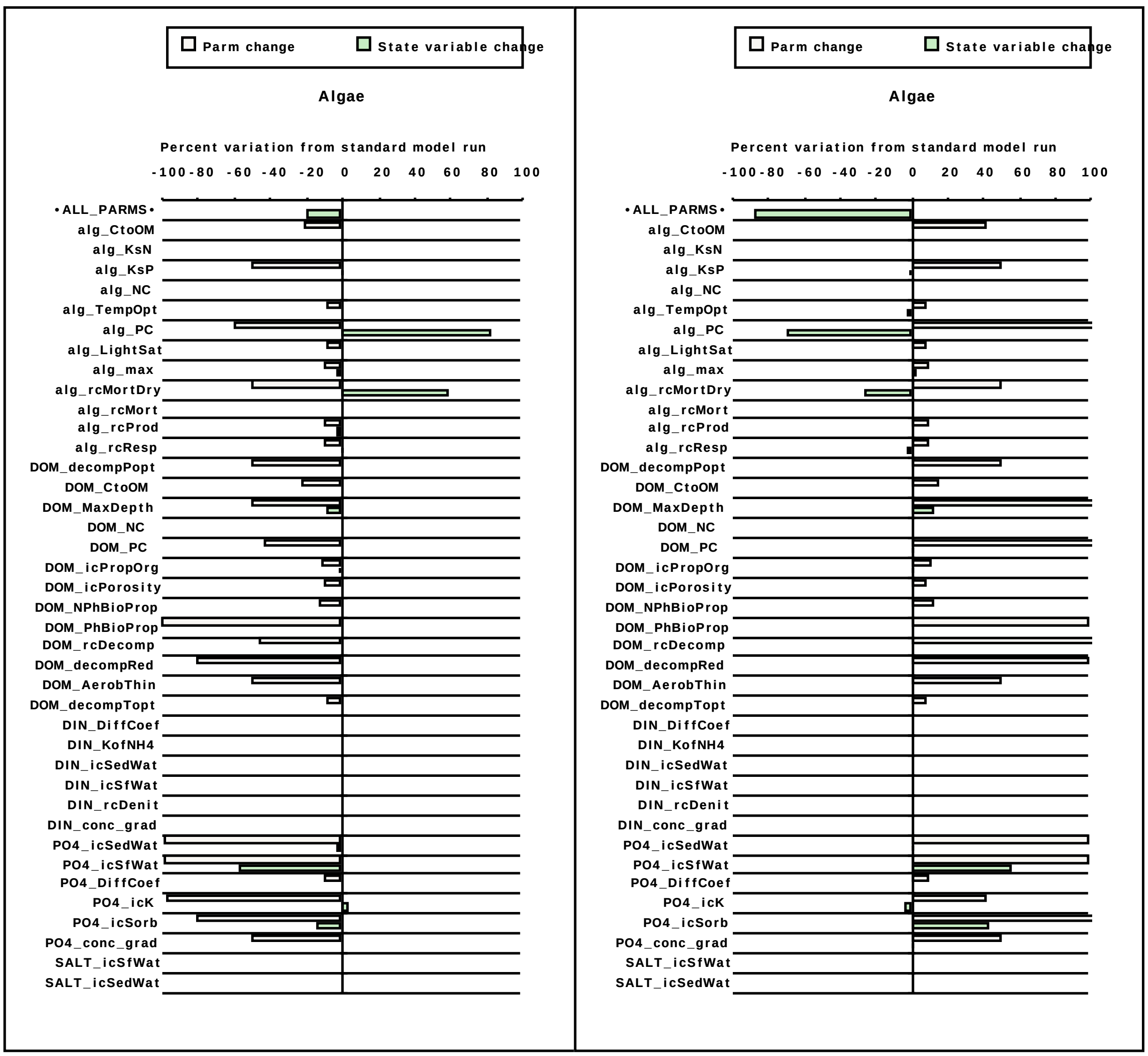


Figure UBar

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity
Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

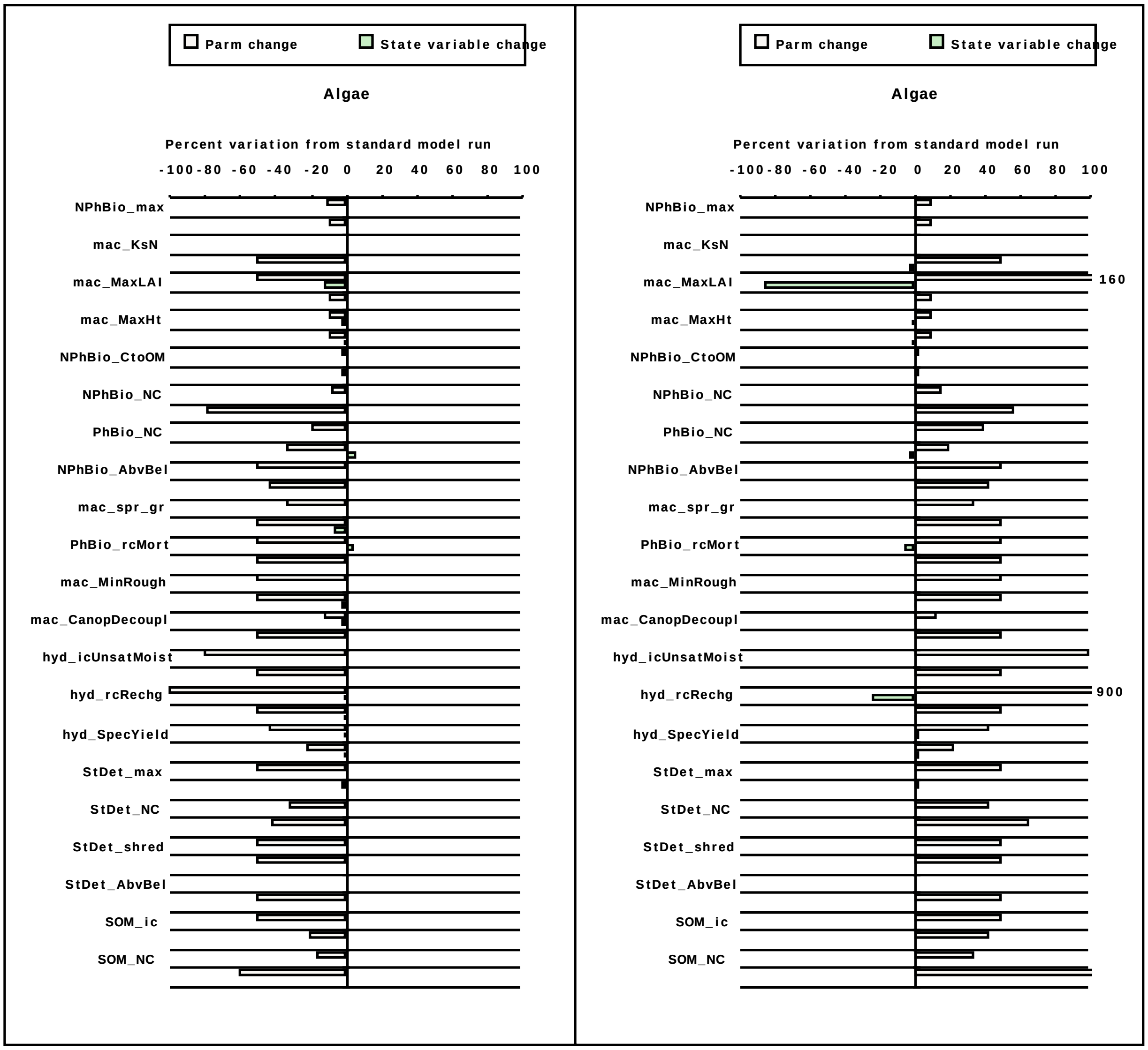
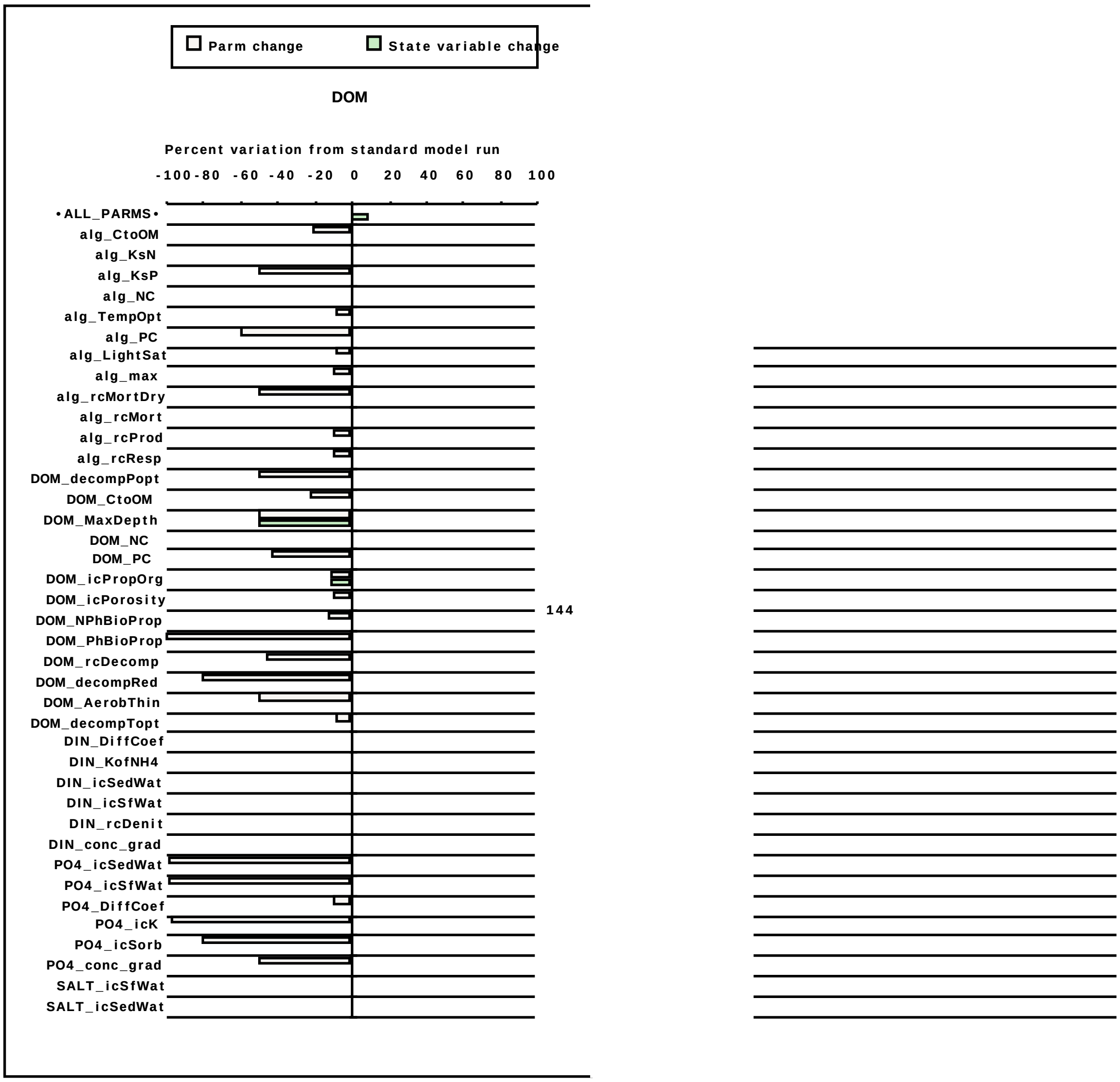


Figure UBar


Parm change
State variable change
DOM
Percent variation from standard model run
-100 -80 -60 -40 -20 0 20 40 60 80 100
•ALL_PARMS•
alg_CtoOM
alg_KsN
alg_KsP
alg_NC
alg_TempOpt
alg_PC
alg_LightSat
alg_max
alg_rcMortDry
alg_rcMort
alg_rcProd
alg_rcResp
DOM_decompPopt
DOM_CtoOM
DOM_MaxDepth
DOM_NC
DOM_PC
DOM_icPropOrg
DOM_icPorosity
DOM_NPhBioProp
DOM_PhBioProp
DOM_rcDecomp
DOM_decompRed
DOM_AerobThin
DOM_decompTopt
DIN_DiffCoef
DIN_KofNH4
DIN_icSedWat
DIN_icSfWat
DIN_rcDenit
DIN_conc_grad
PO4_icSedWat
PO4_icSfWat
PO4_DiffCoef
PO4_icK
PO4_icSorb
PO4_conc_grad
SALT_icSfWat
SALT_icSedWat
144

Single parameter change to
low value
(except "ALL_PARMS", where all parms low)

Unit model (GEM) sensitivity

Sawgrass marsh

Single parameter change to
high value
(except "ALL_PARMS", where all parms high)

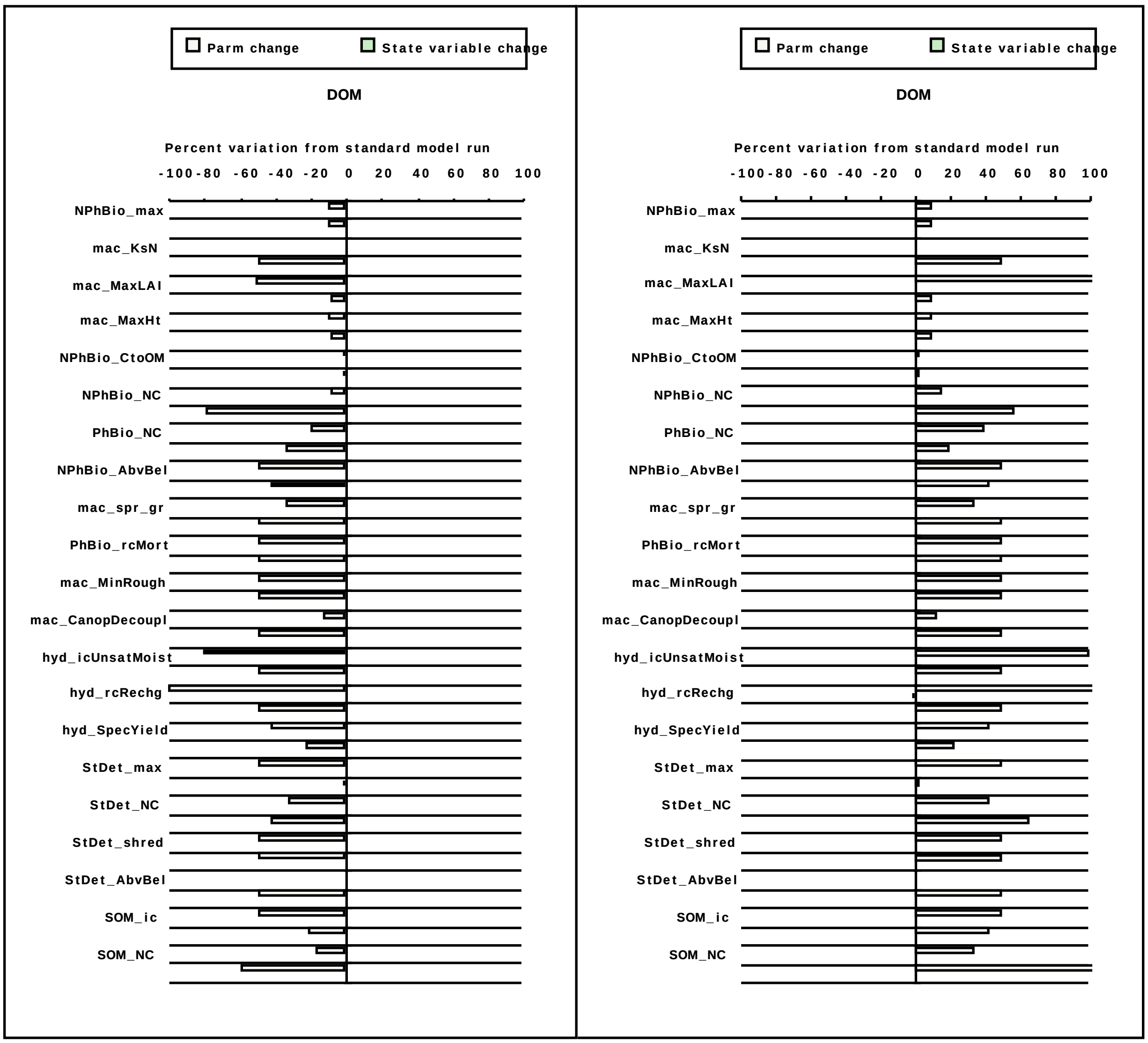
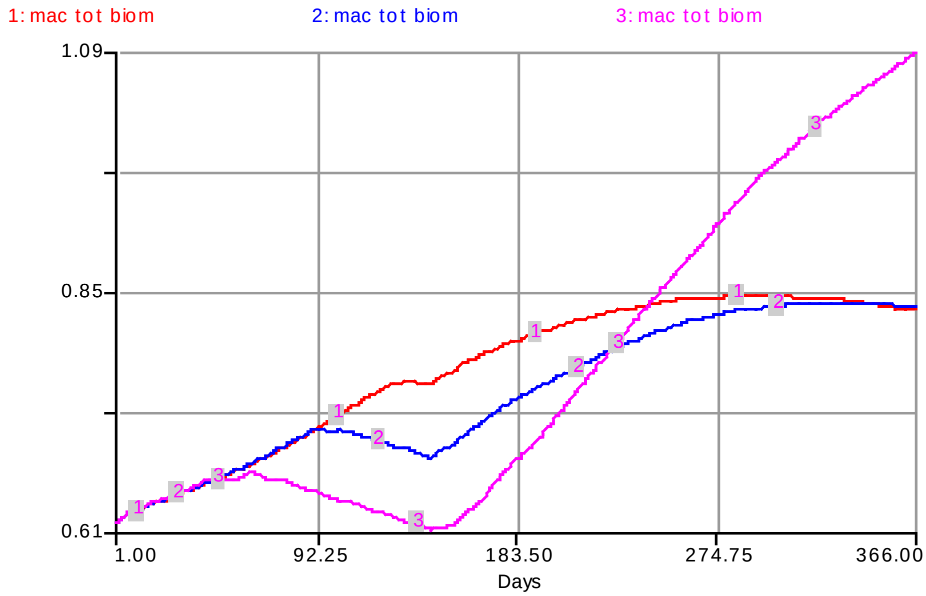
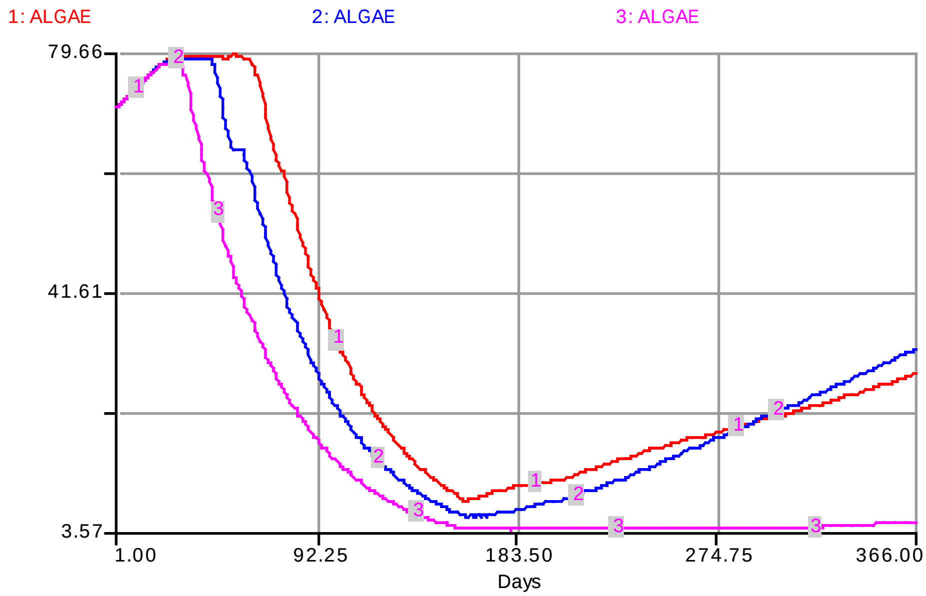


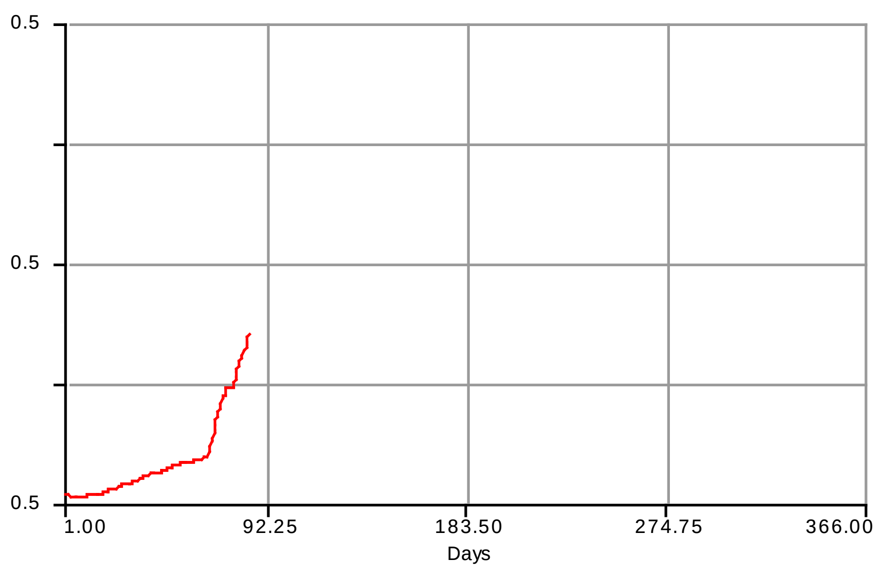
Figure UBar



1: mac tot biom
2: mac tot biom
3: mac tot biom
1.09
0.85
0.61
1.00
92.25
183.50
274.75
366.00
Days



1: ALGAE
2: ALGAE
3: ALGAE
79.66
41.61
3.57
1.00
92.25
183.50
274.75
366.00
Days



0.5
0.5
0.5
1.00
92.25
183.50
274.75
366.00
Days

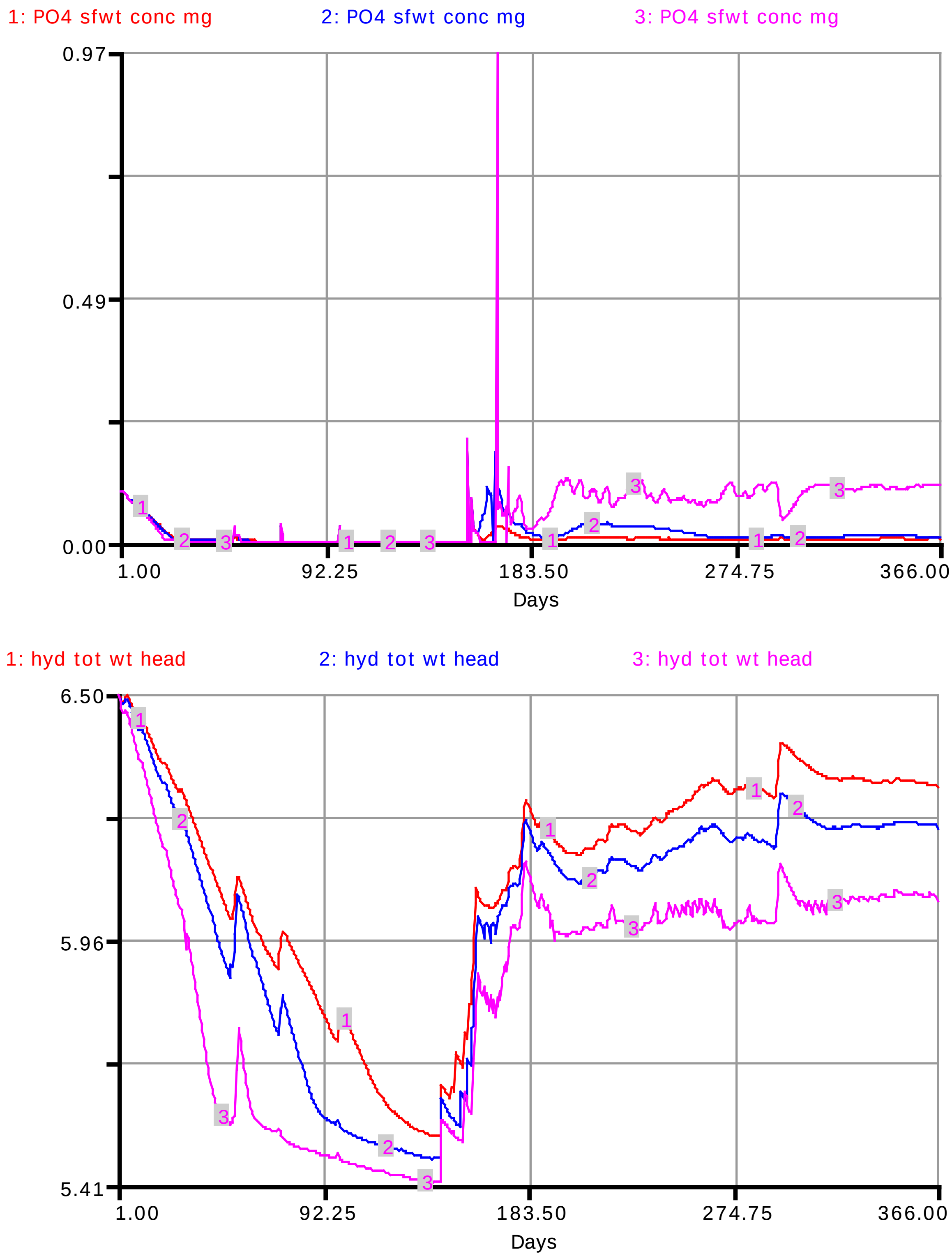


Figure U1c. Response to varying macrophyte maximum LAI.

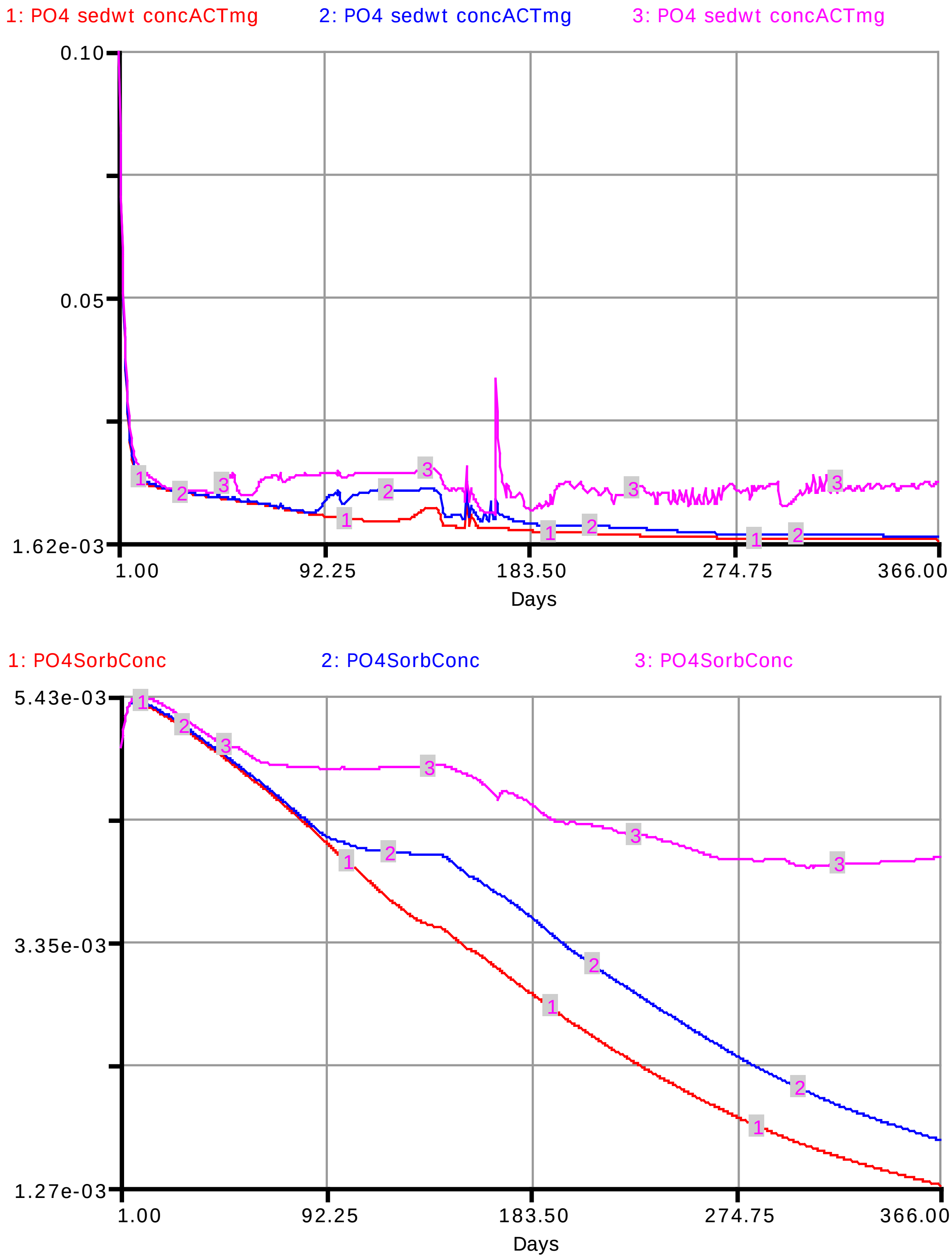


Figure U1b. Response to varying macrophyte maximum LAI.

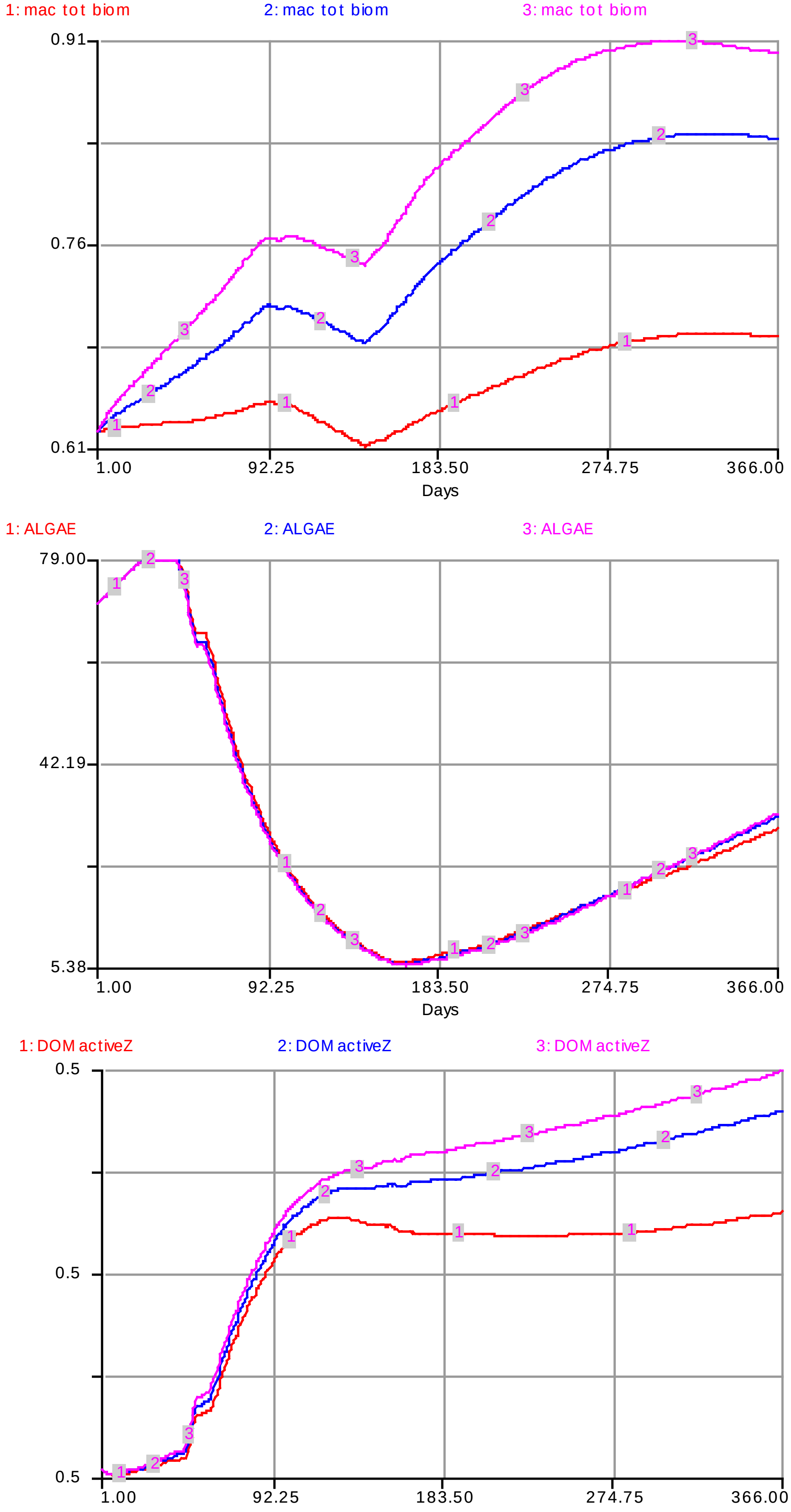


Figure U2a. Response to varying macrophyte maximum rate of net production.

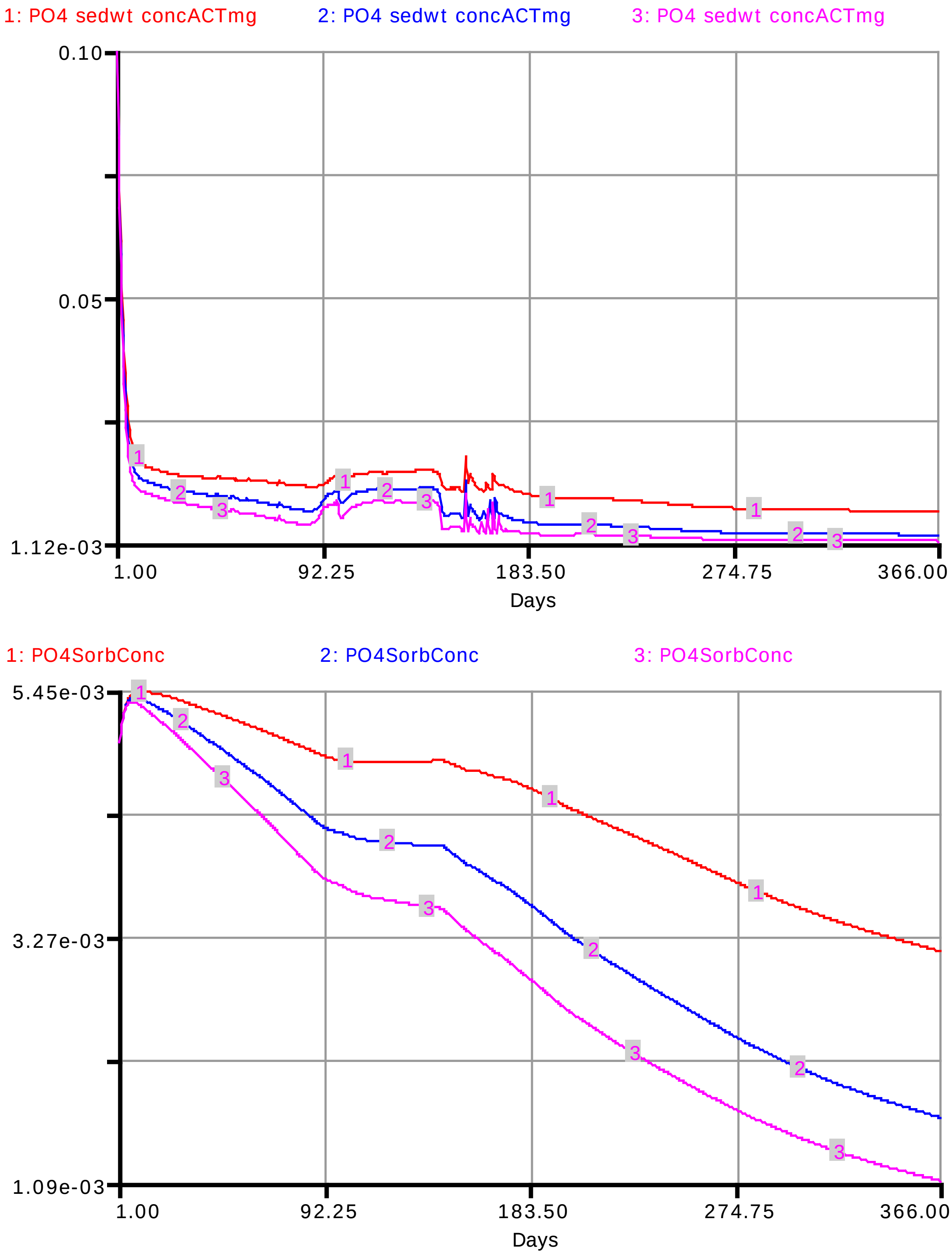
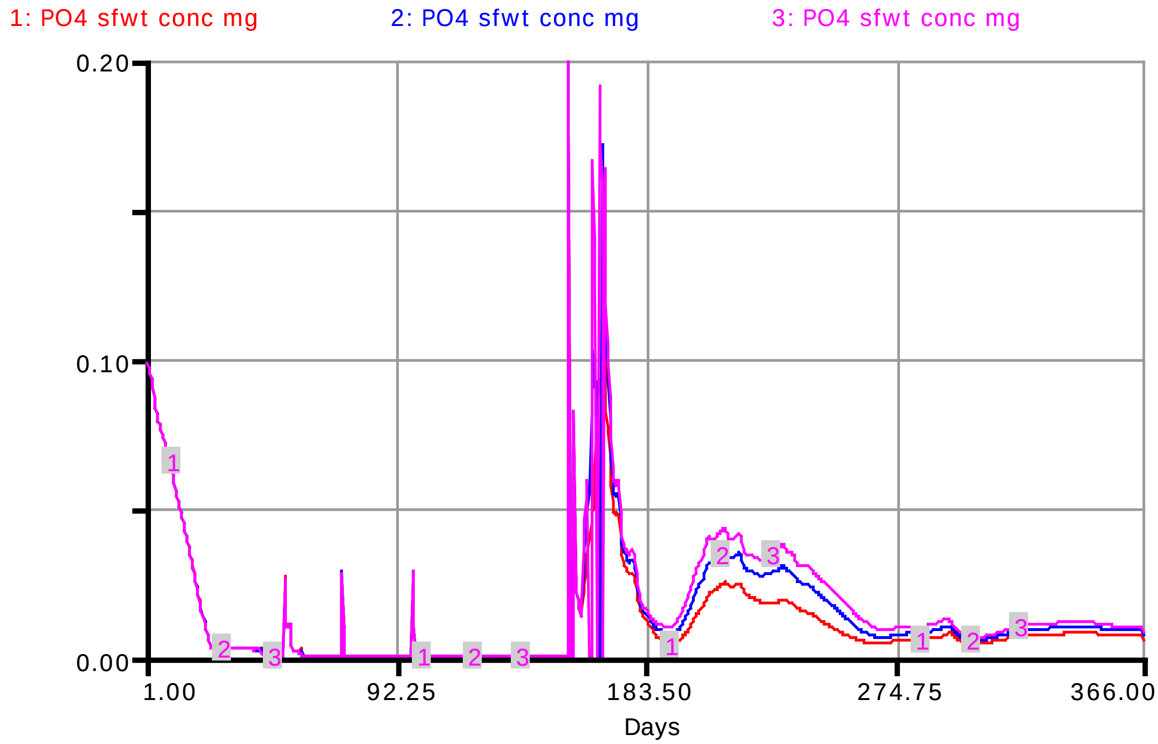


Figure U2b. Response to varying macrophyte maximum rate of net production.



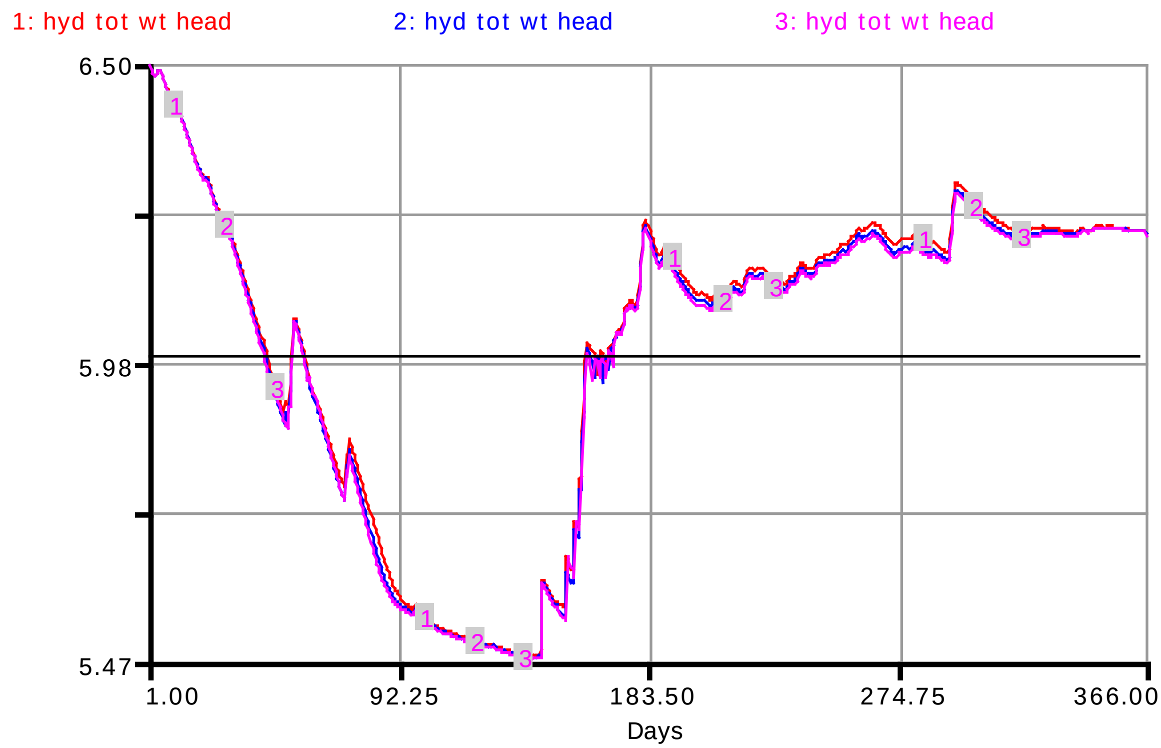


Figure U2c. Response to varying macrophyte maximum rate of net production.

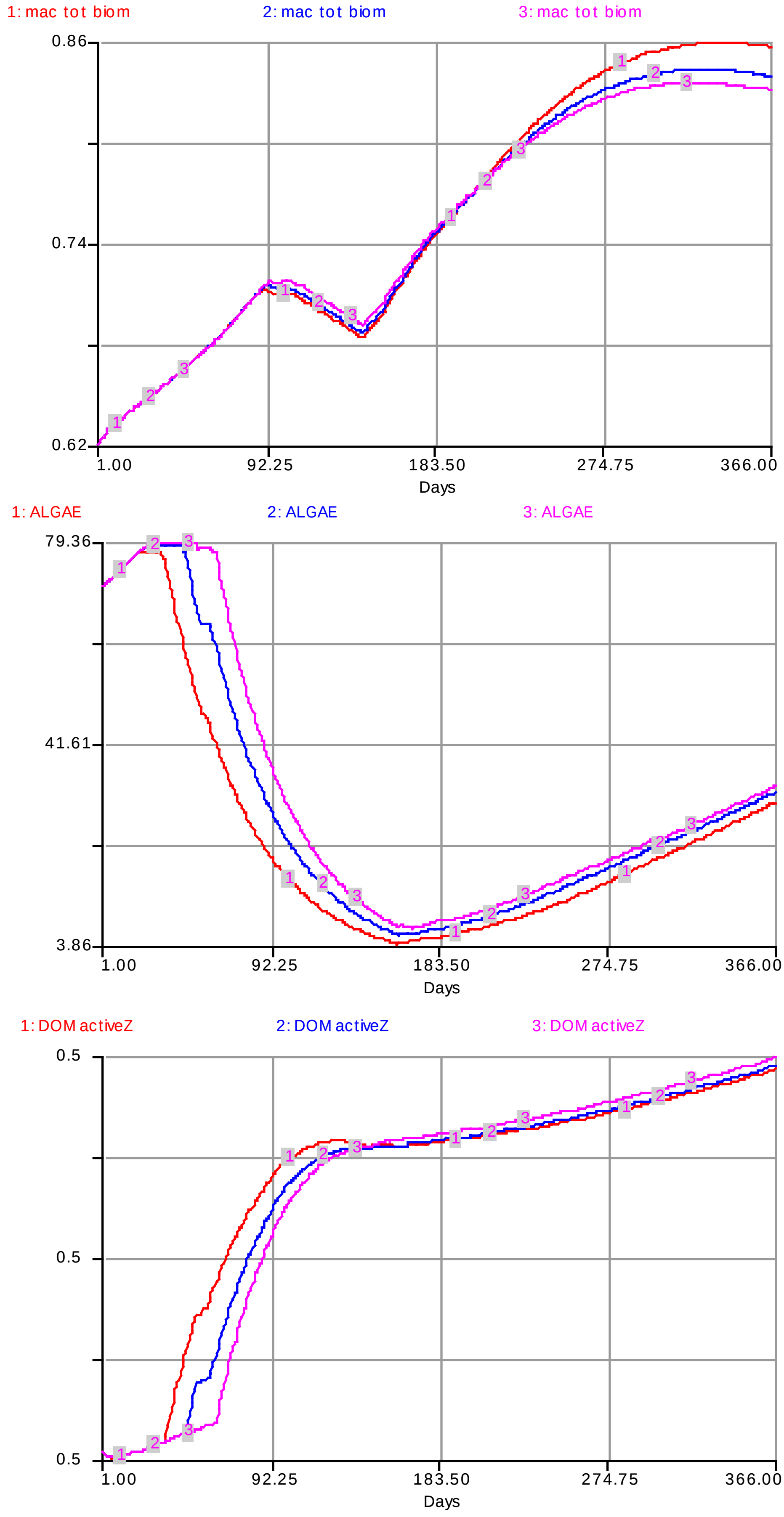


Figure U3a. Response to varying Manning's roughness coefficient.

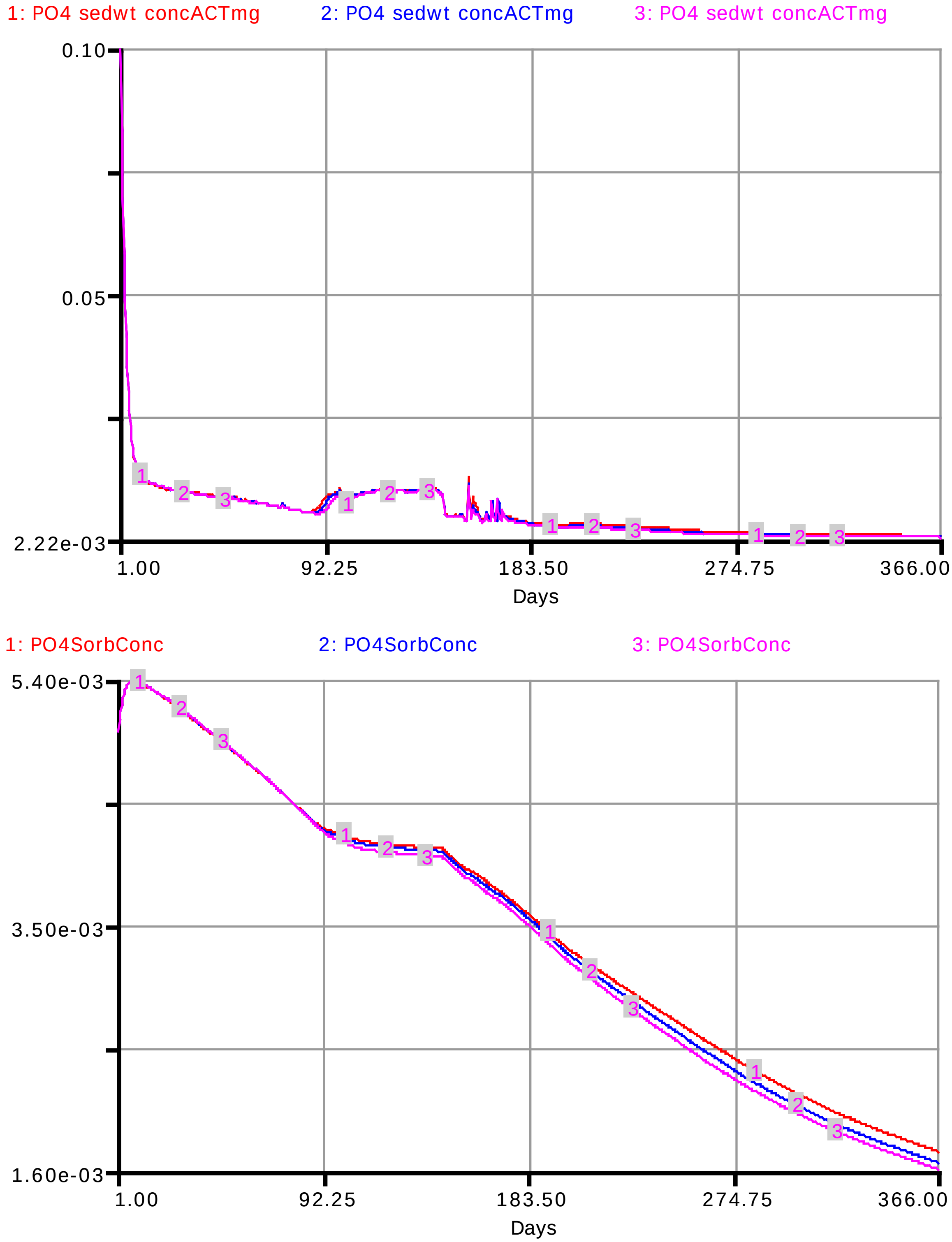


Figure U3b. Response to varying Manning's roughness coefficient.

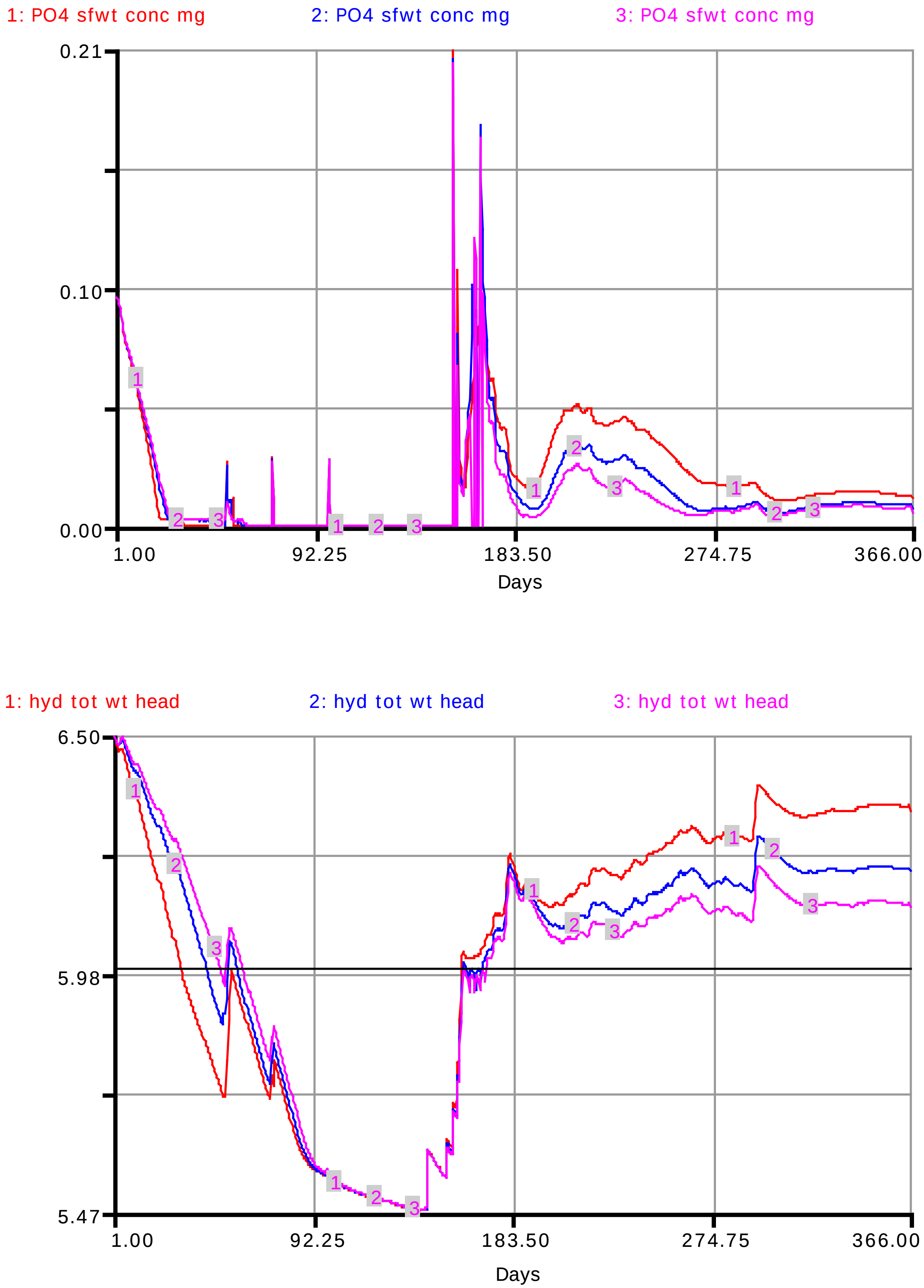
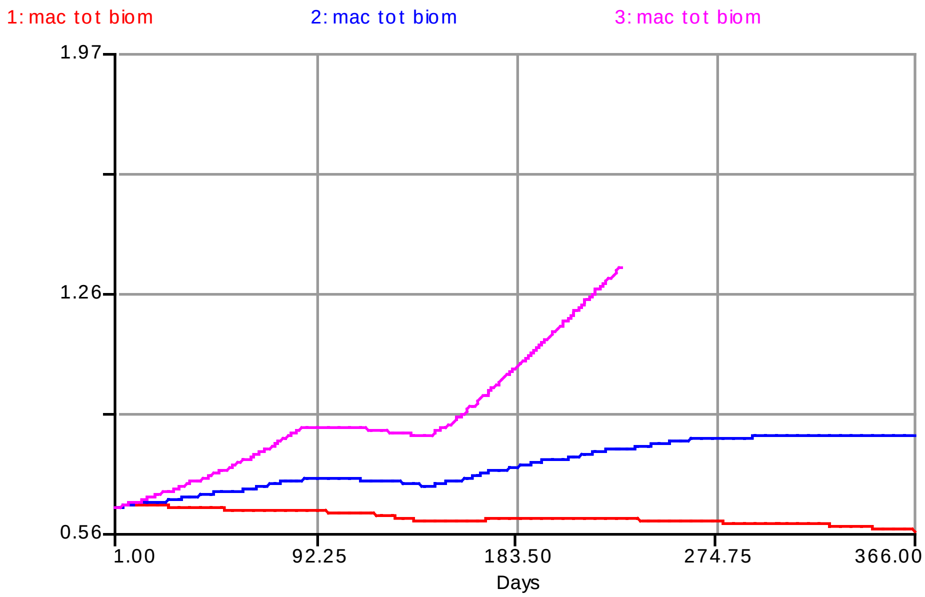


Figure U3c. Response to varying Manning's roughness coefficient.



1: mac tot biom
2: mac tot biom
3: mac tot biom
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1.26
0.56
1.00
92.25
183.50
274.75
366.00
Days

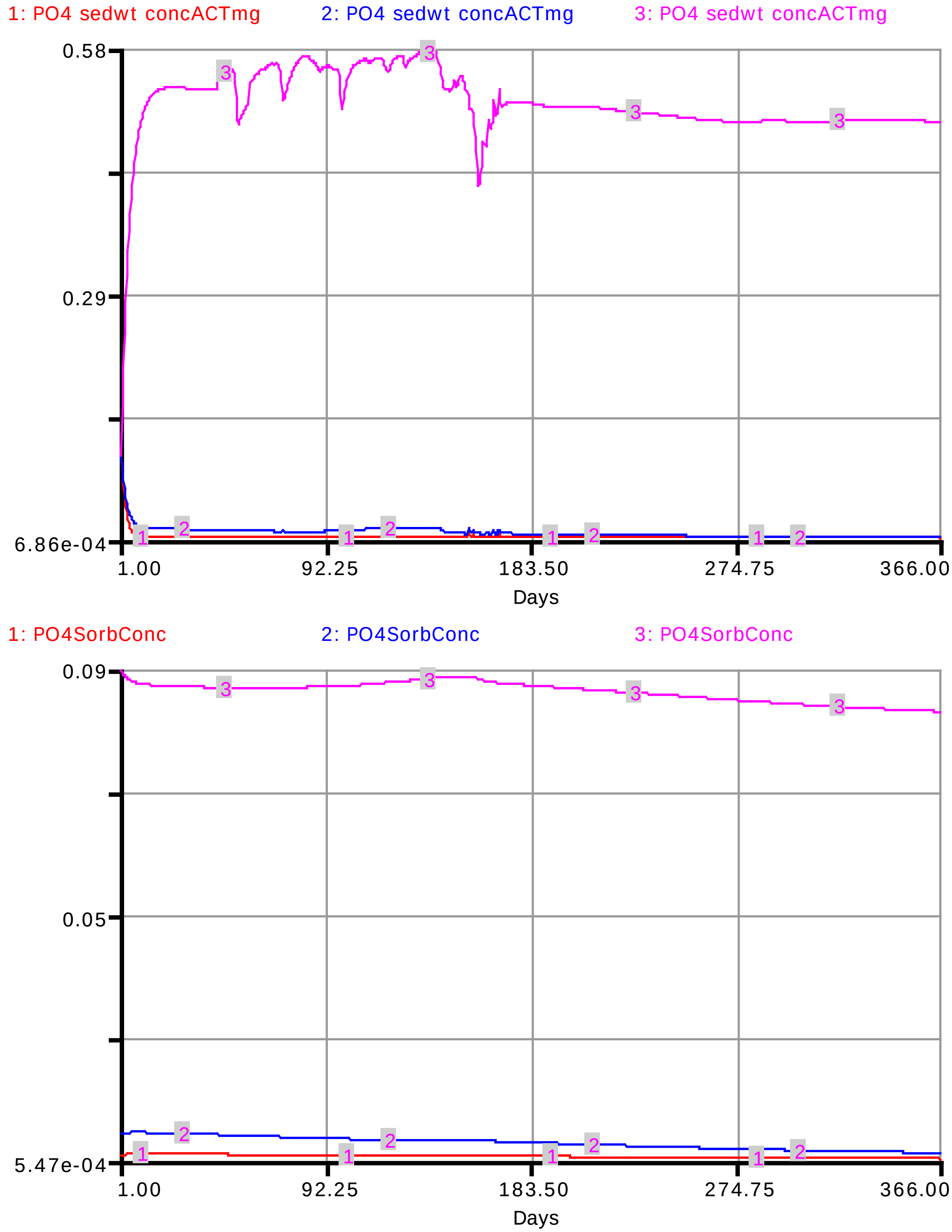


Figure U4b. Response to varying the initial concentration of PO4 sorbed to sediments.

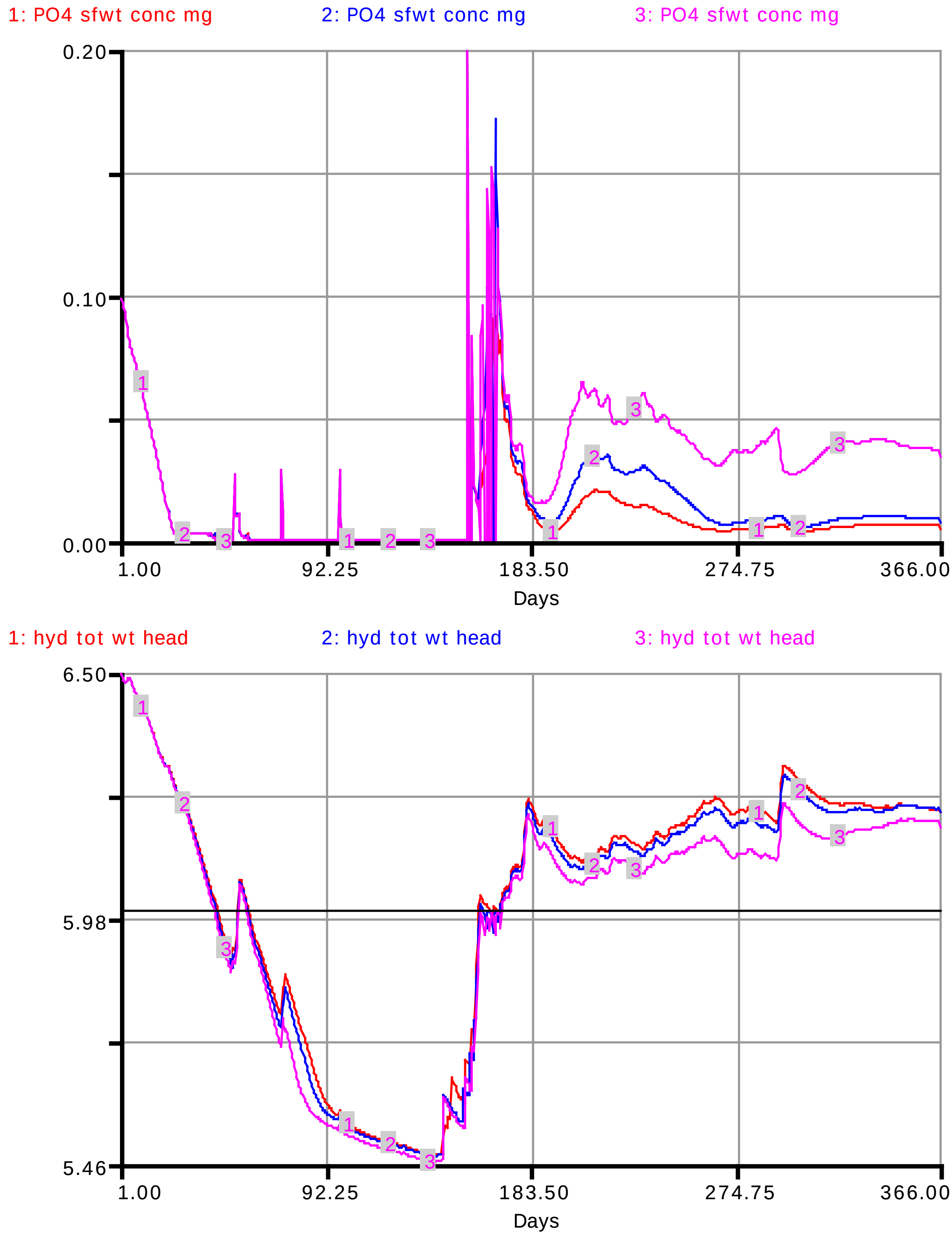


Figure U4c. Response to varying the initial concentration of PO4 sorbed to sediments.

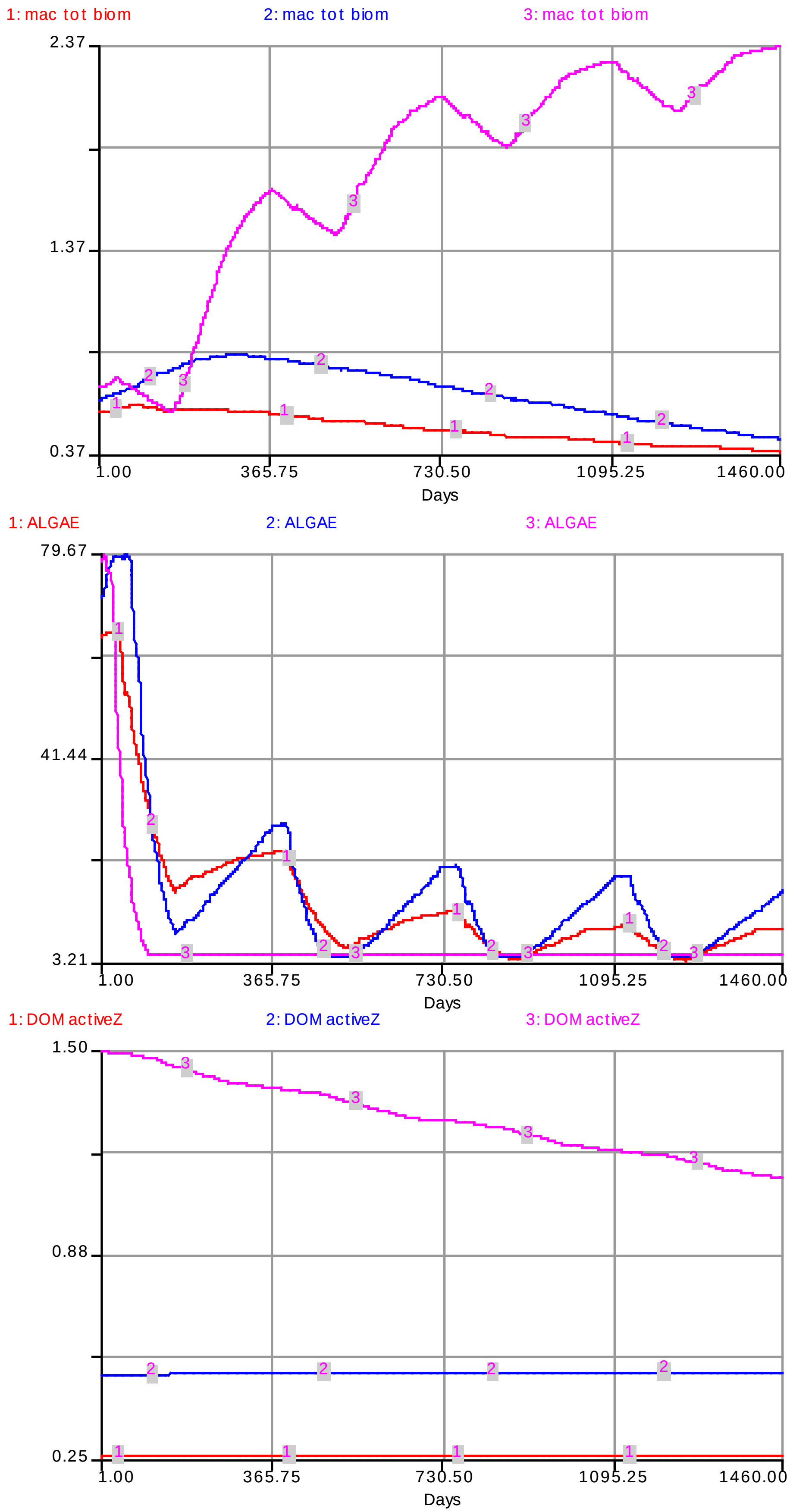
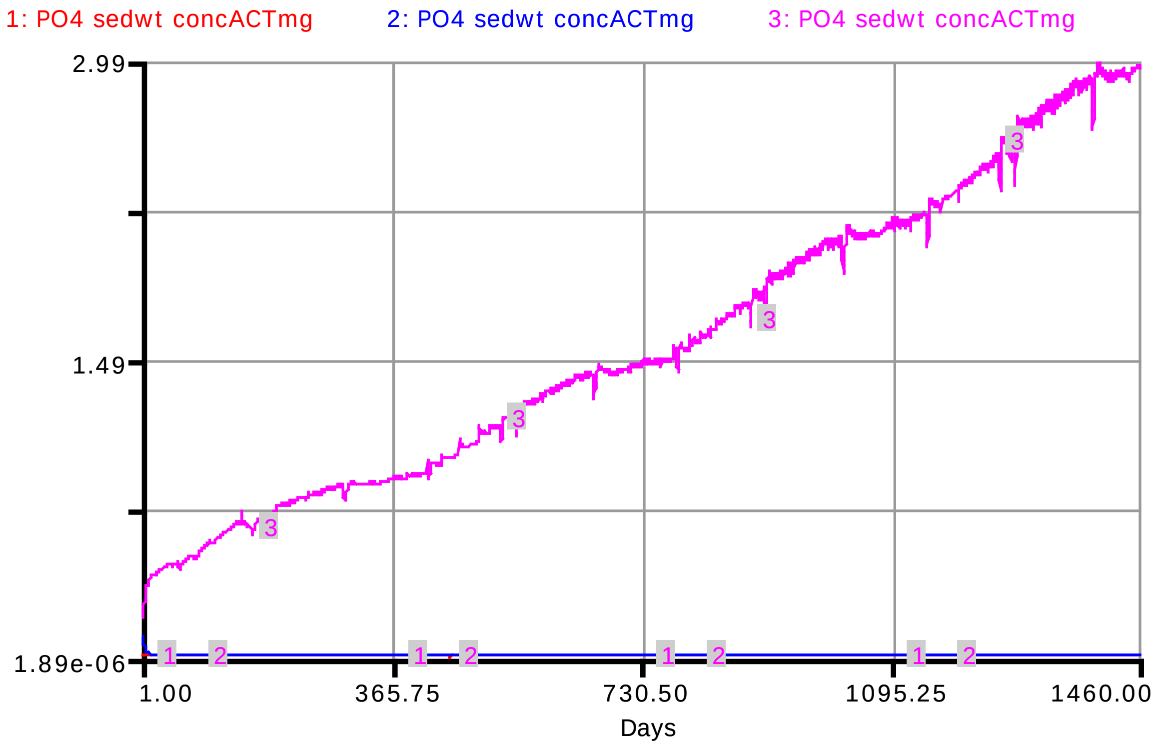


Figure U5a. Four-year response to varying all of the parameters together.



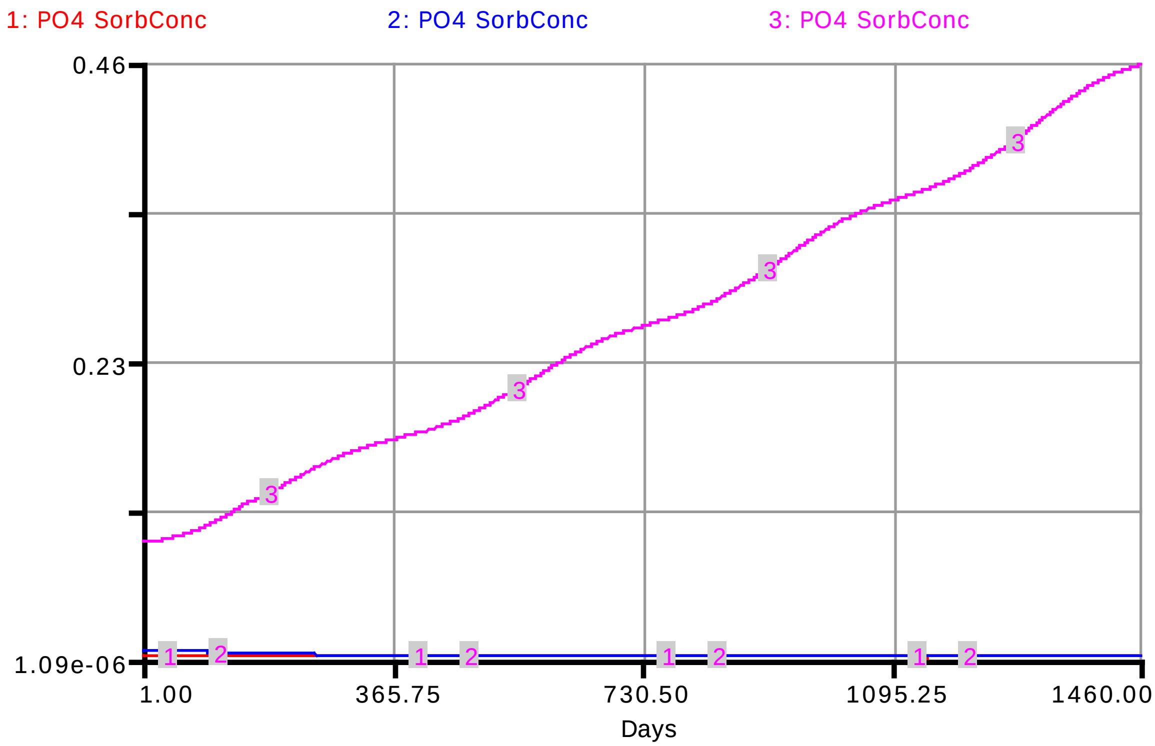
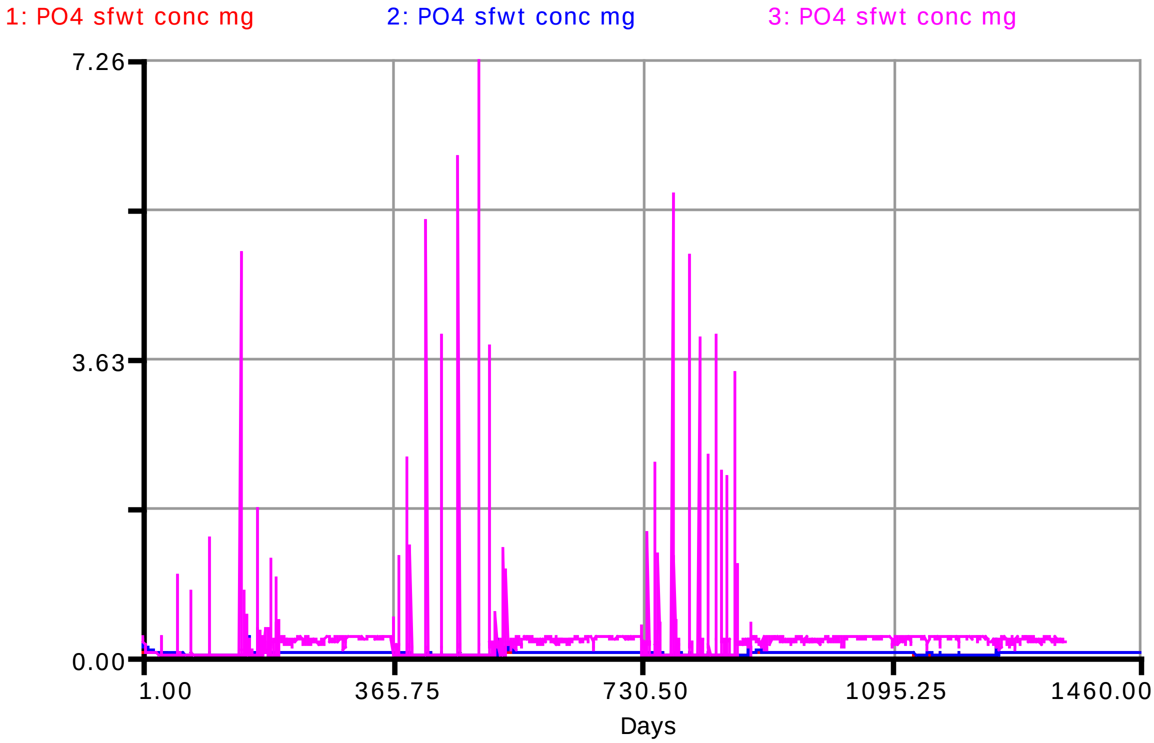


Figure U5b. Four-year response to varying all of the parameters together.


1: PO4 sfwt conc mg
2: PO4 sfwt conc mg
3: PO4 sfwt conc mg
7.26
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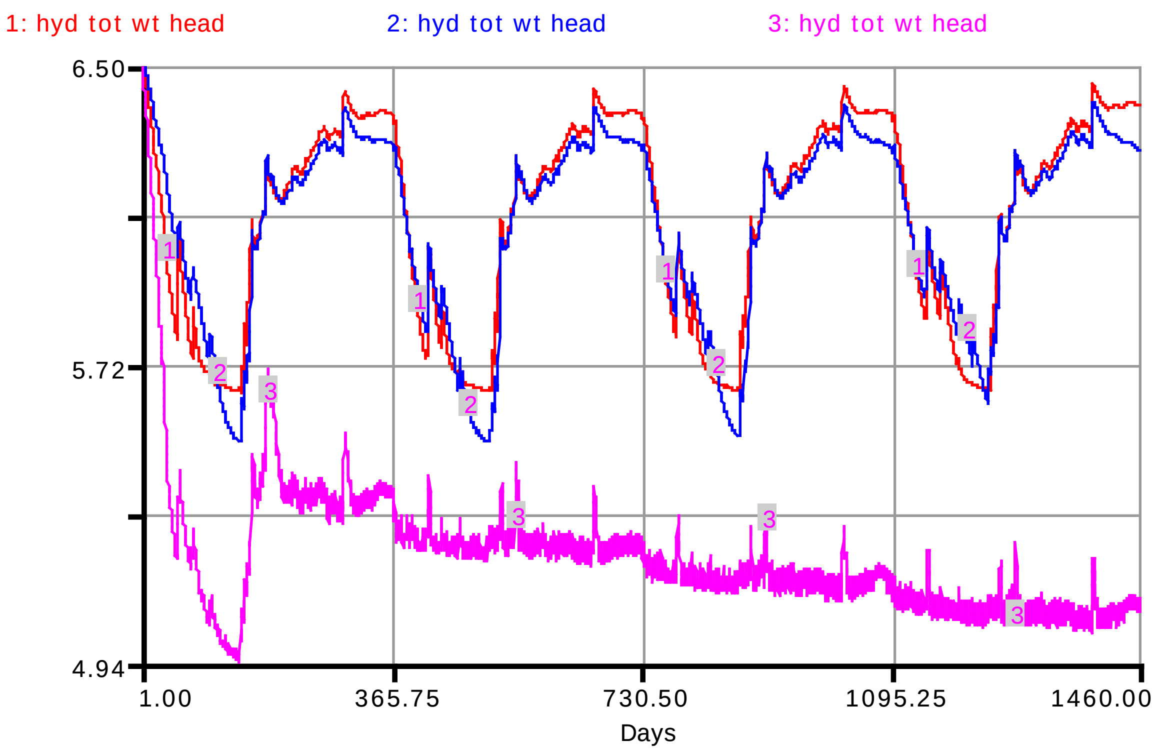
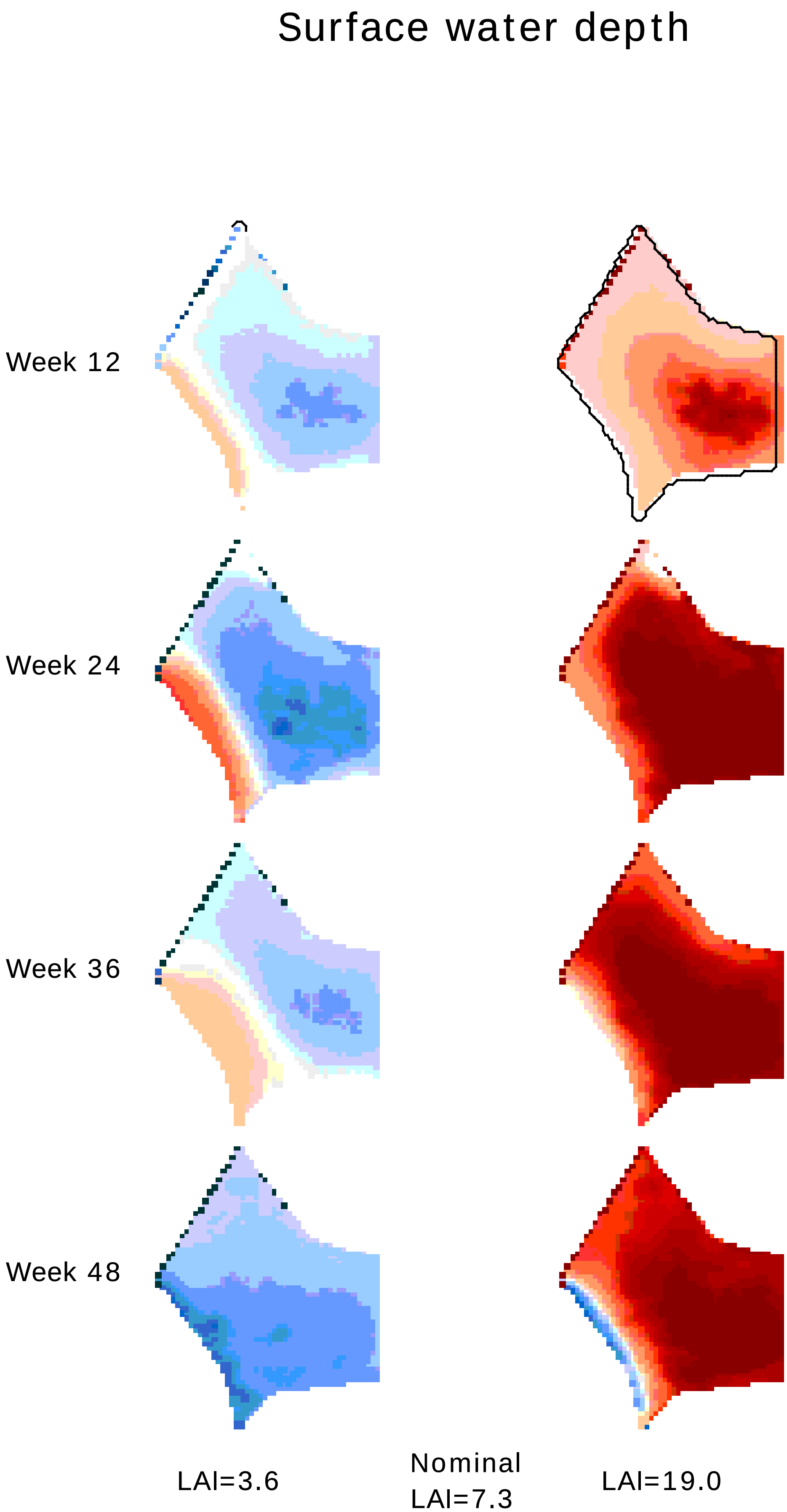
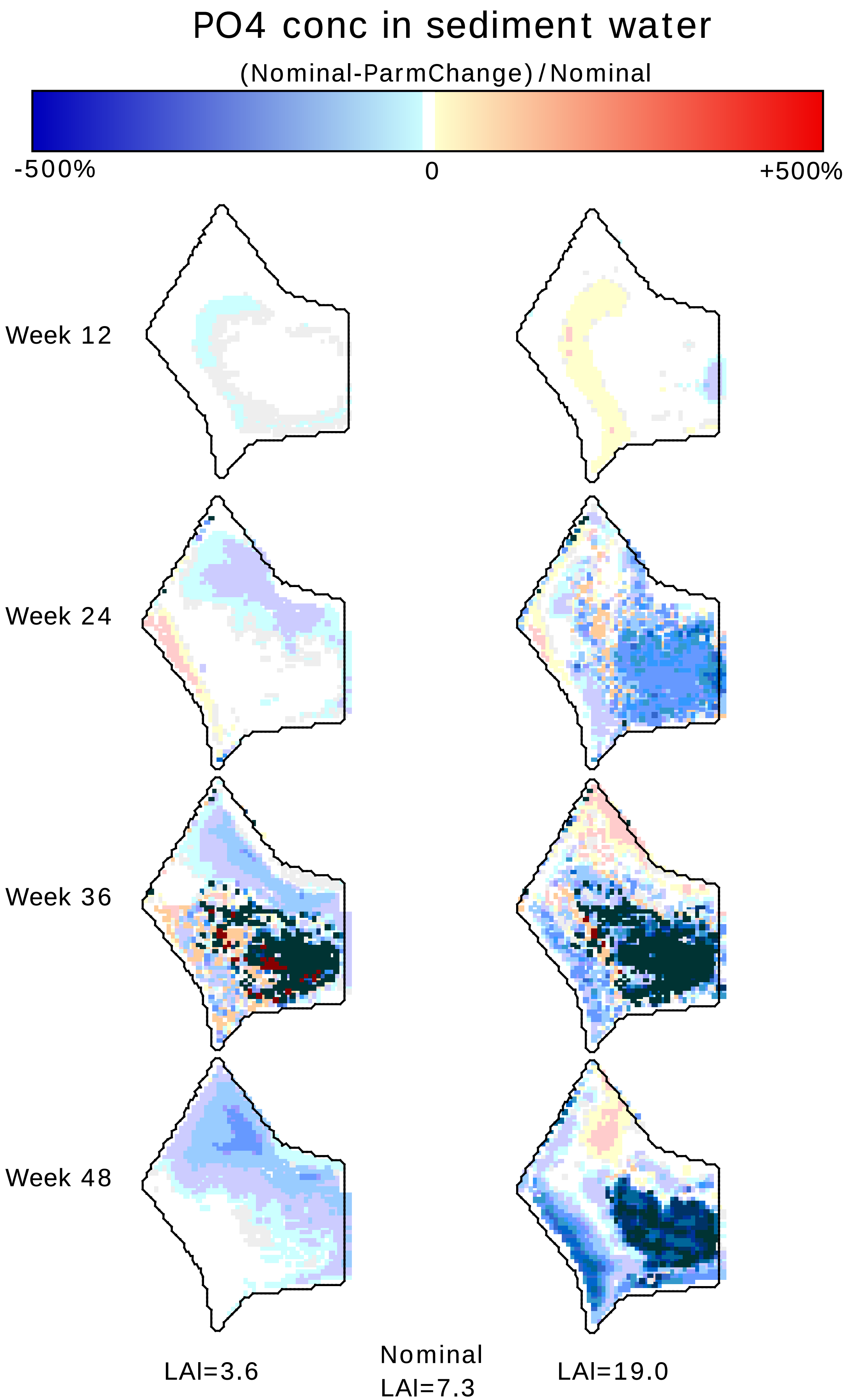
0.00
1.00
365.75
730.50
1095.25
1460.00
Days


1: hyd tot wt head
2: hyd tot wt head
3: hyd tot wt head
6.50
5.72
4.94
1.00
365.75
730.50
1095.25
1460.00
Days

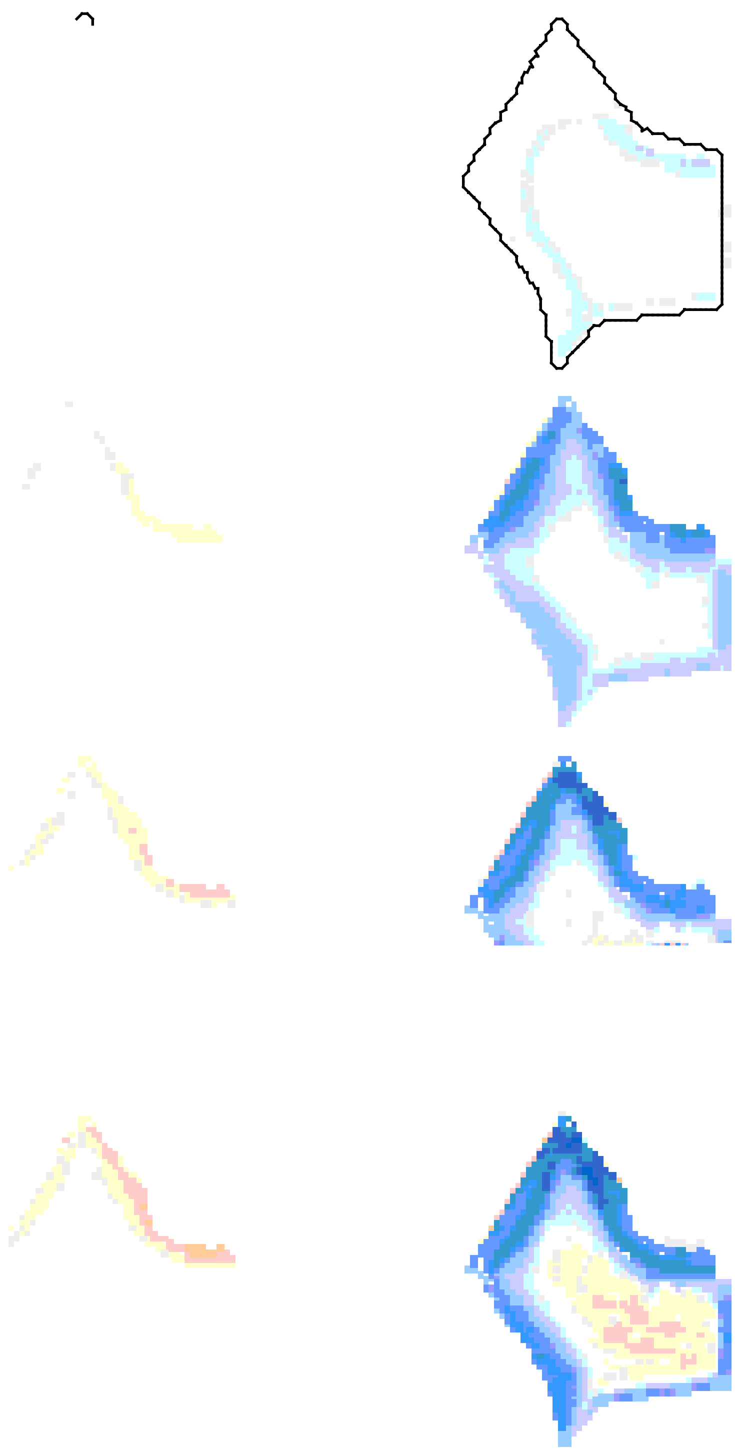


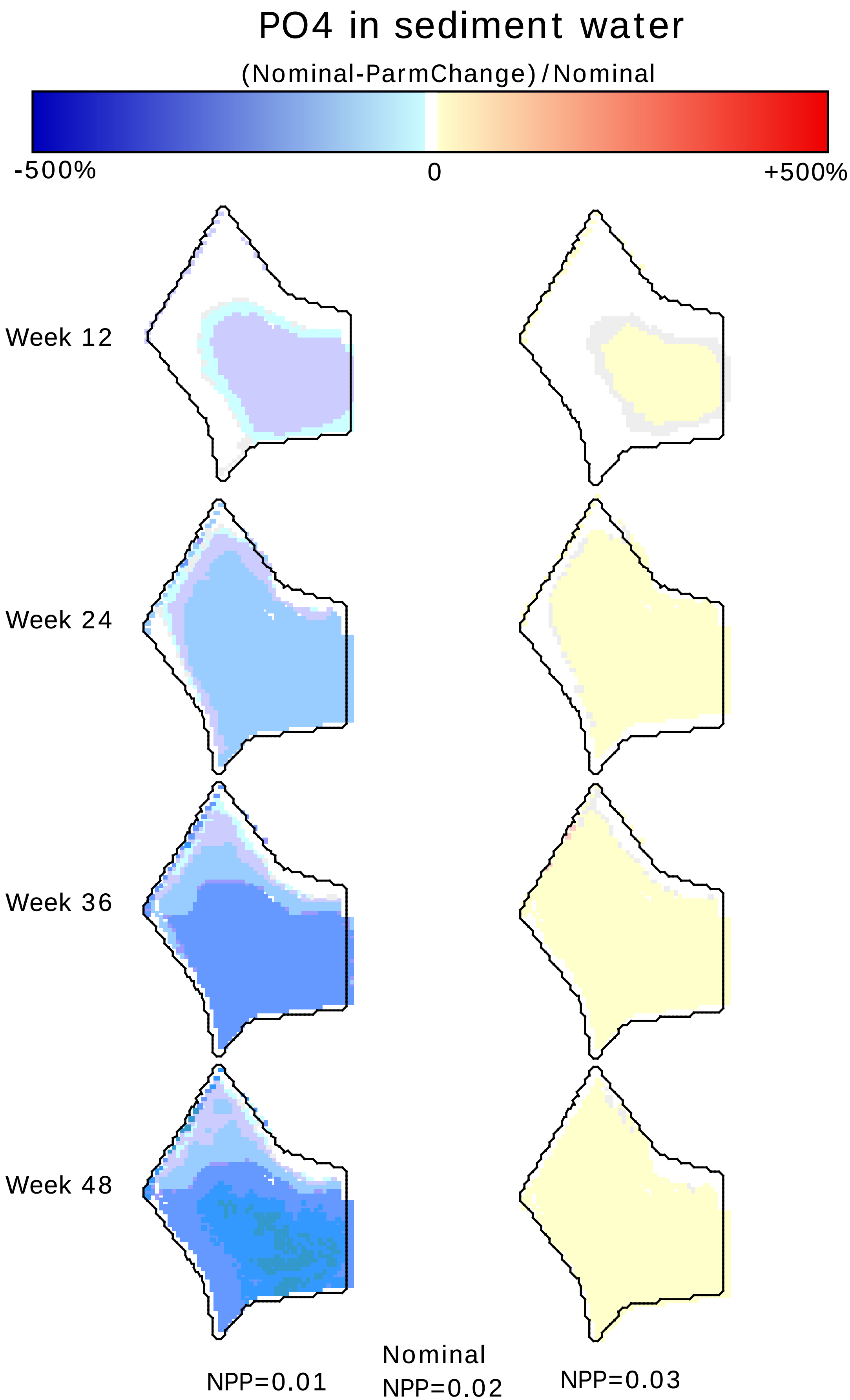
Surface water depth
Week 12
Week 24
Week 36
Week 48
LAI=3.6
Nominal
LAI=7.3
LAI=19.0

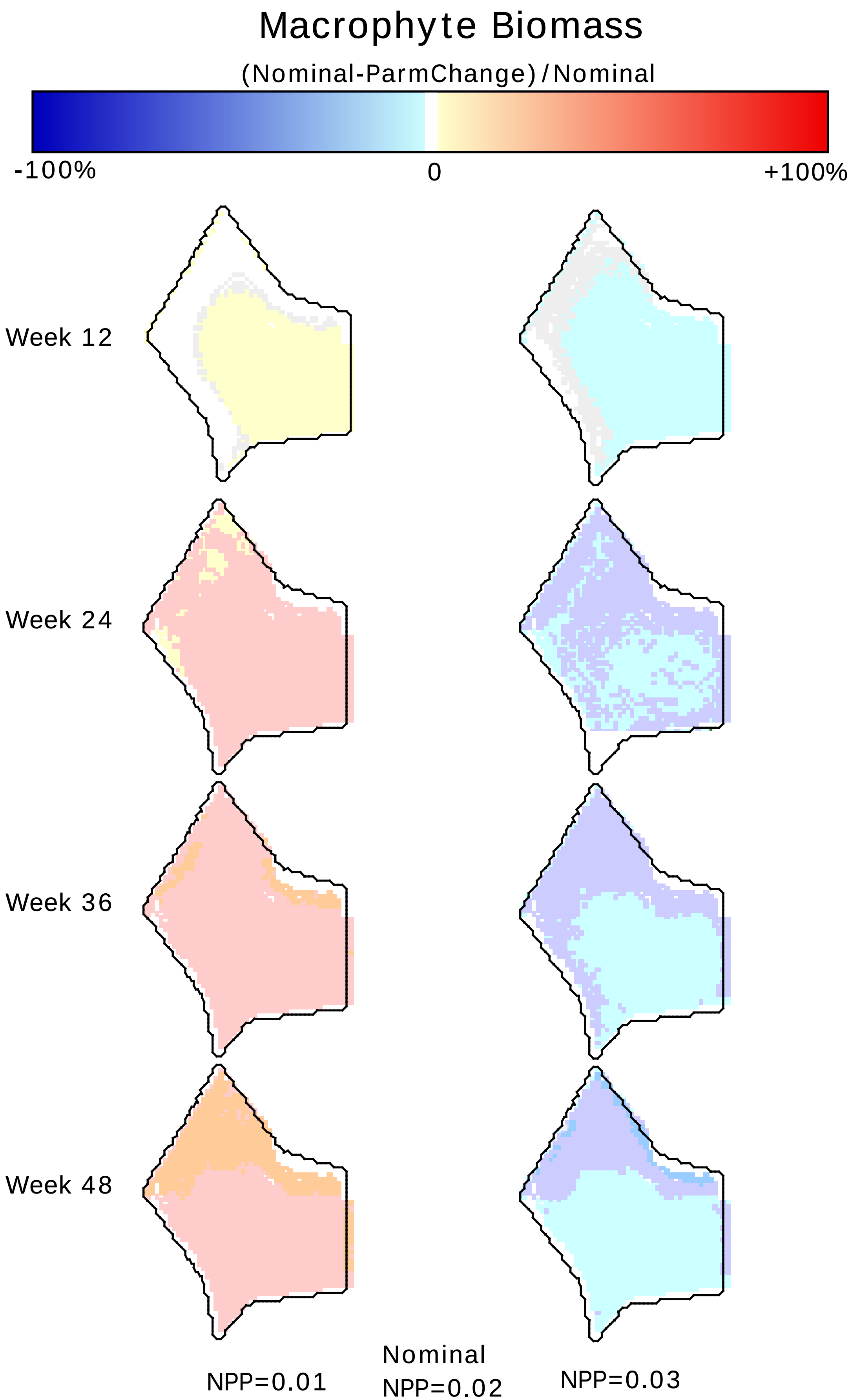


PO4 conc in sediment water
(Nominal-ParmChange)/Nominal
-500%
0
+500%
Week 12
Week 24
Week 36
Week 48
LAI=3.6
Nominal
LAI=7.3
LAI=19.0

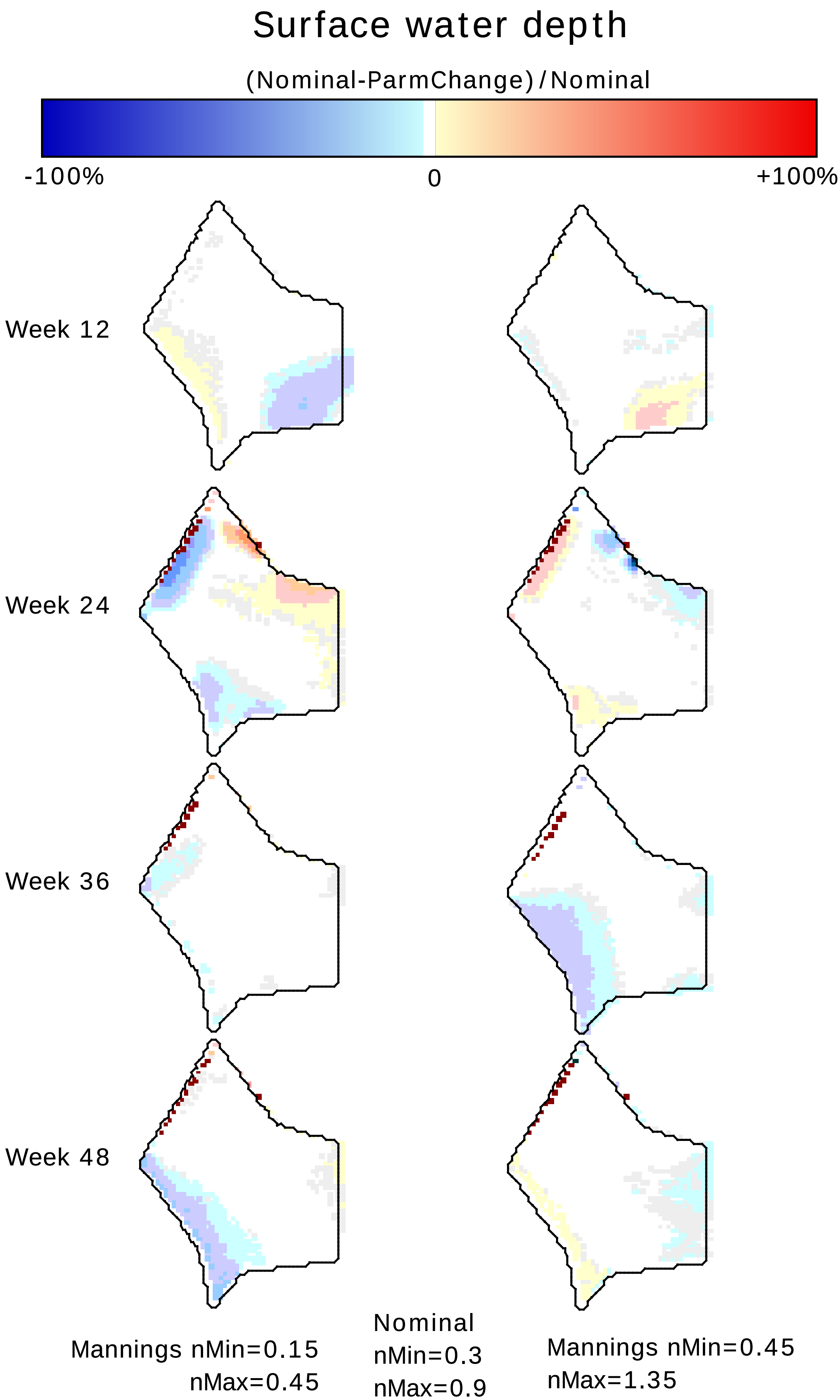
Macrophyte Biomass

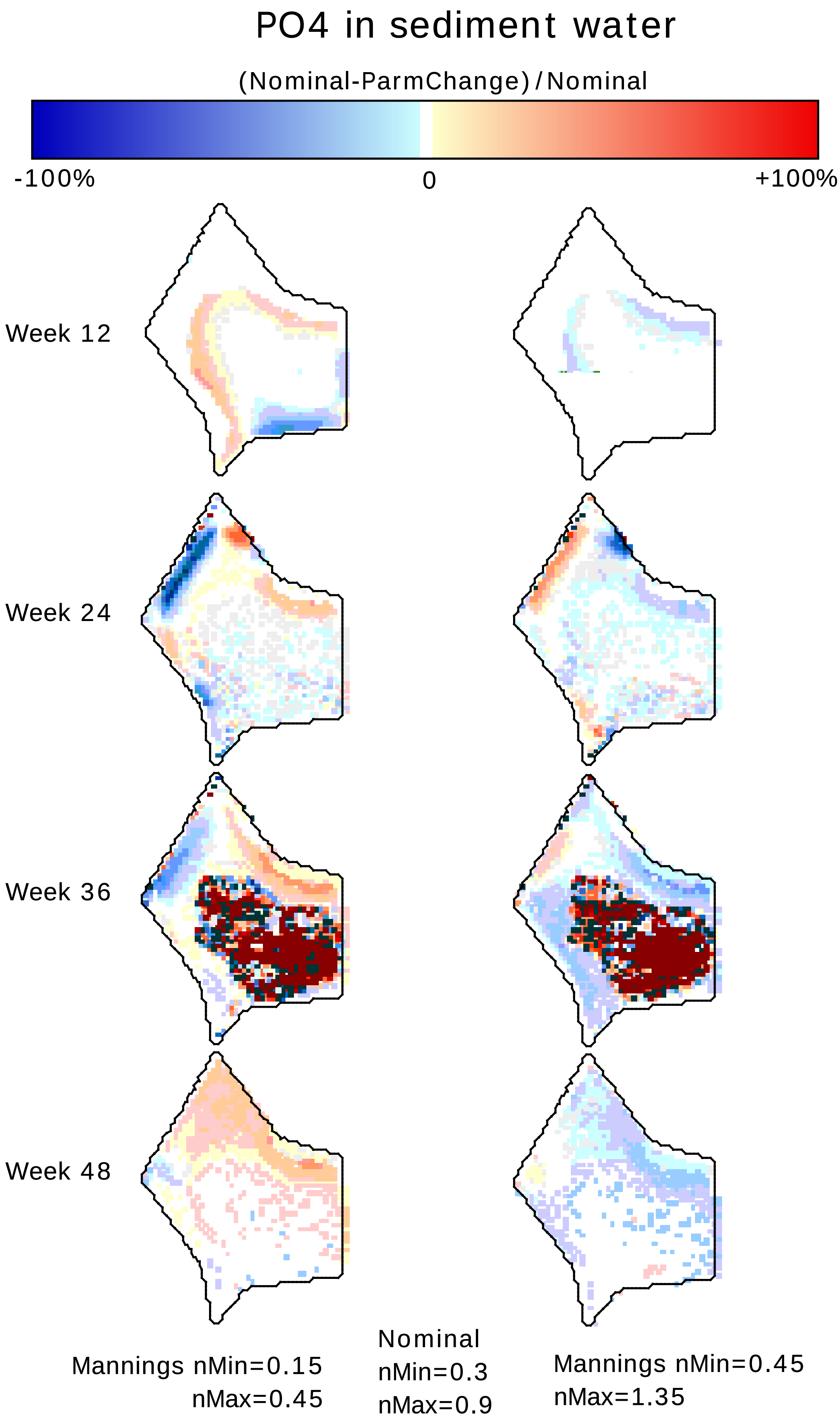



PO4 in sediment water
(Nominal-ParmChange)/Nominal
-500%
0
+500%
Week 12
Week 24
Week 36
Week 48
NPP=0.01
Nominal
NPP=0.02
NPP=0.03

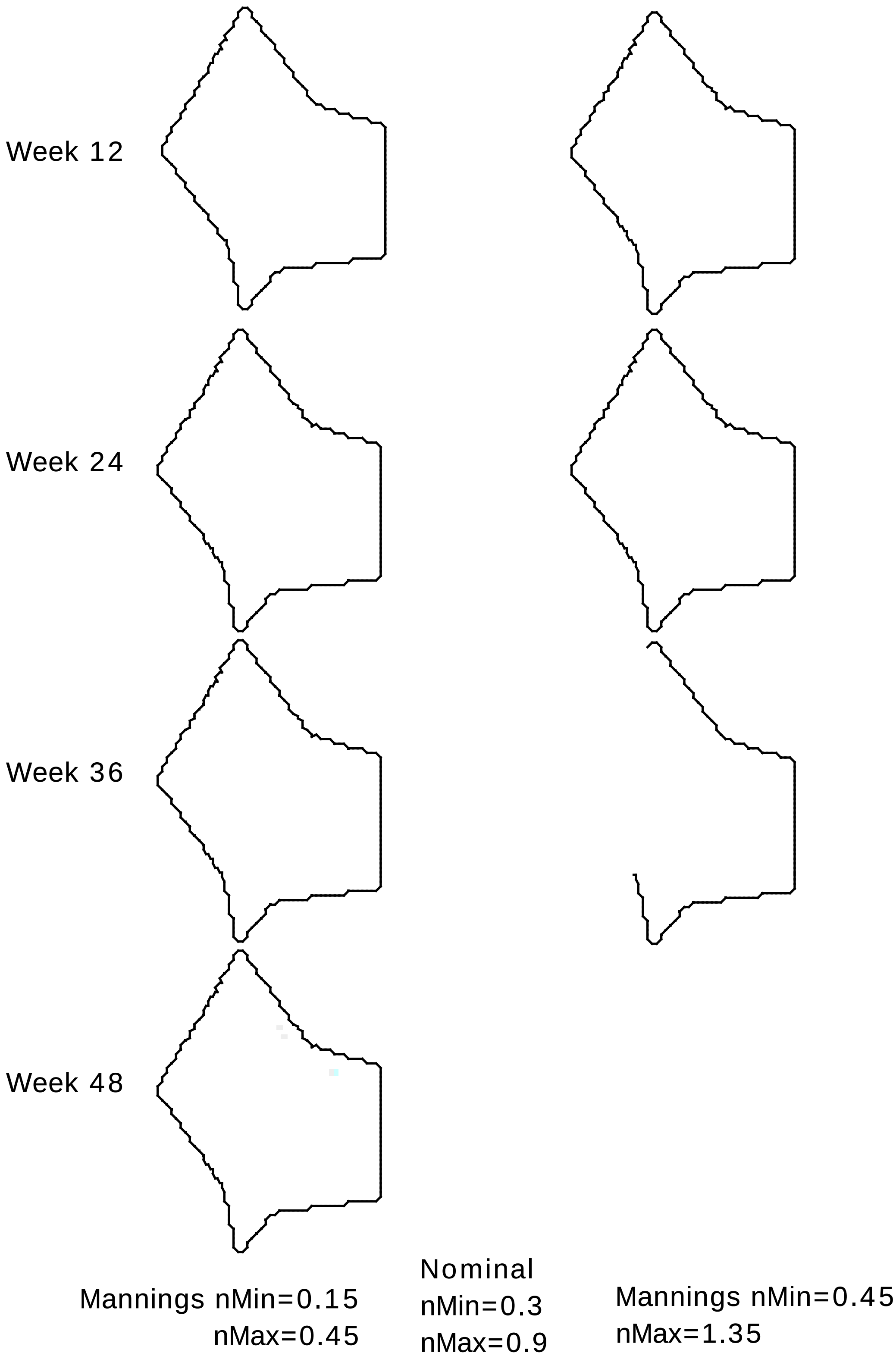


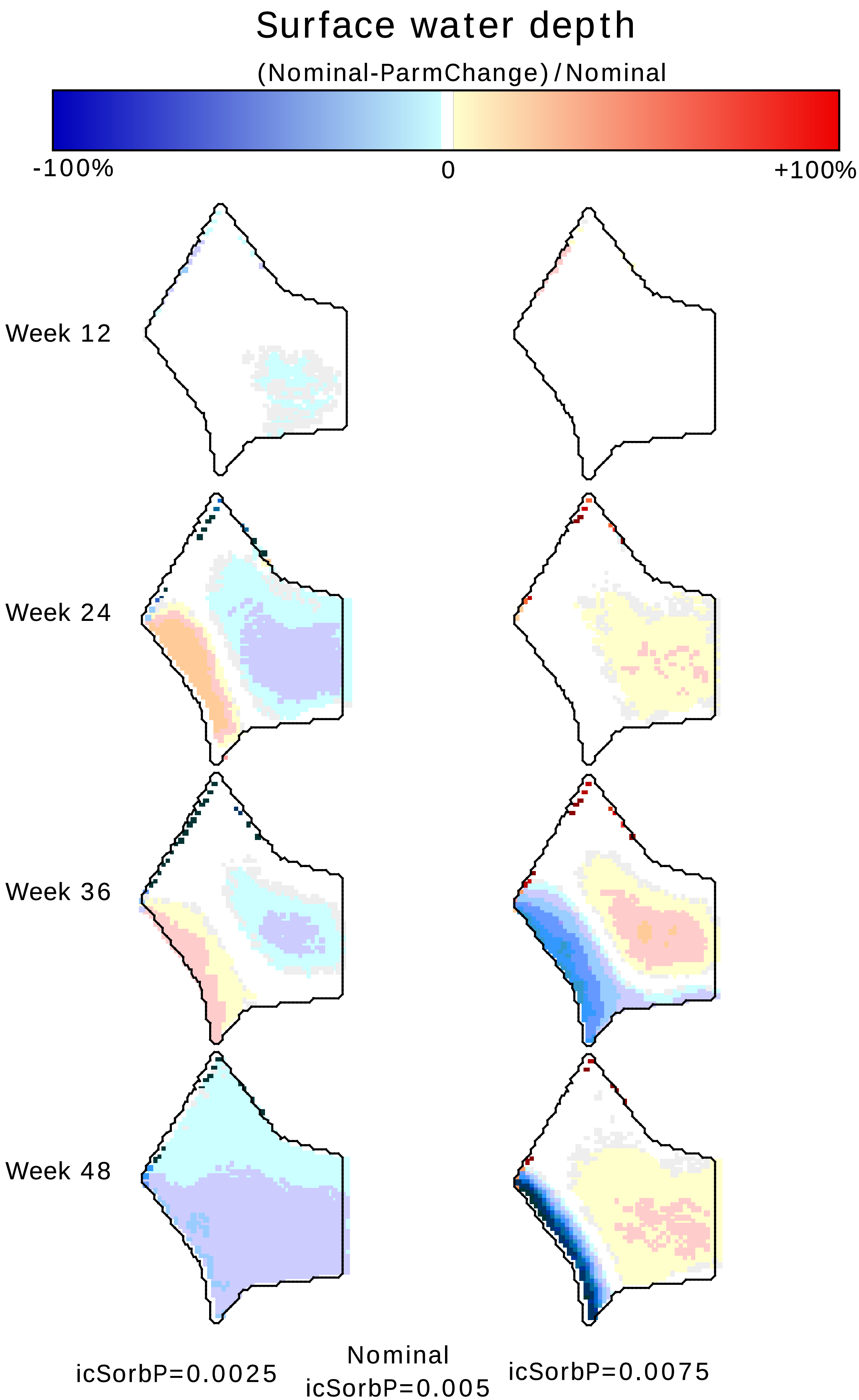
Macrophyte Biomass
(Nominal-ParmChange)/Nominal
-100%
0
+100%
Week 12
Week 24
Week 36
Week 48
NPP=0.01
Nominal
NPP=0.02
NPP=0.03


Surface water depth
(Nominal-ParmChange)/Nominal
-100%
0
+100%
Week 12
Week 24
Week 36
Week 48
Mannings nMin=0.15
nMax=0.45
Nominal
nMin=0.3
nMax=0.9
Mannings nMin=0.45
nMax=1.35

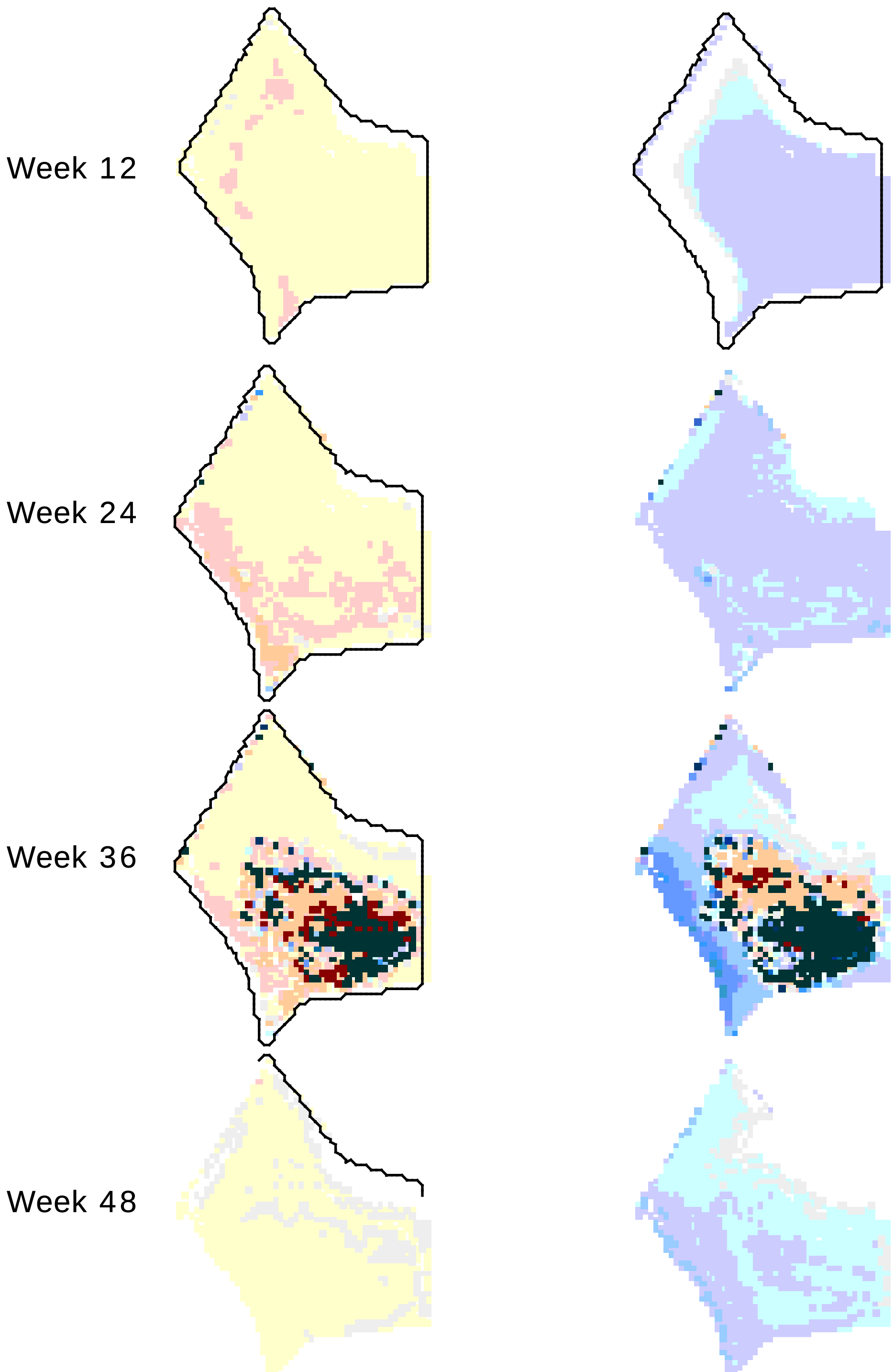

PO4 in sediment water
(Nominal-ParmChange)/Nominal
-100%
0
+100%
Week 12
Week 24
Week 36
Week 48
Mannings nMin=0.15
nMax=0.45
Nominal
nMin=0.3
nMax=0.9
Mannings nMin=0.45
nMax=1.35

Macrophyte Biomass

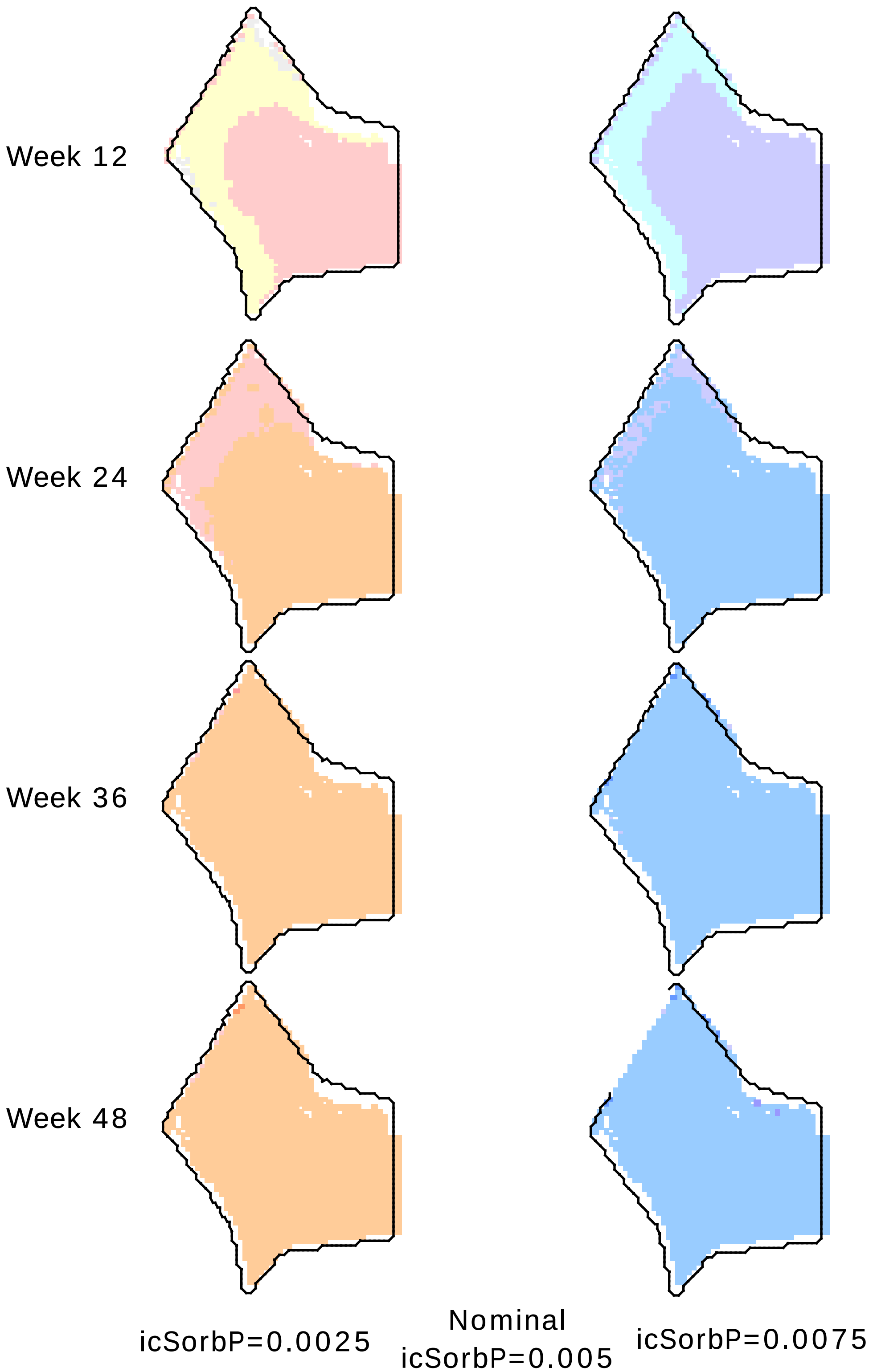


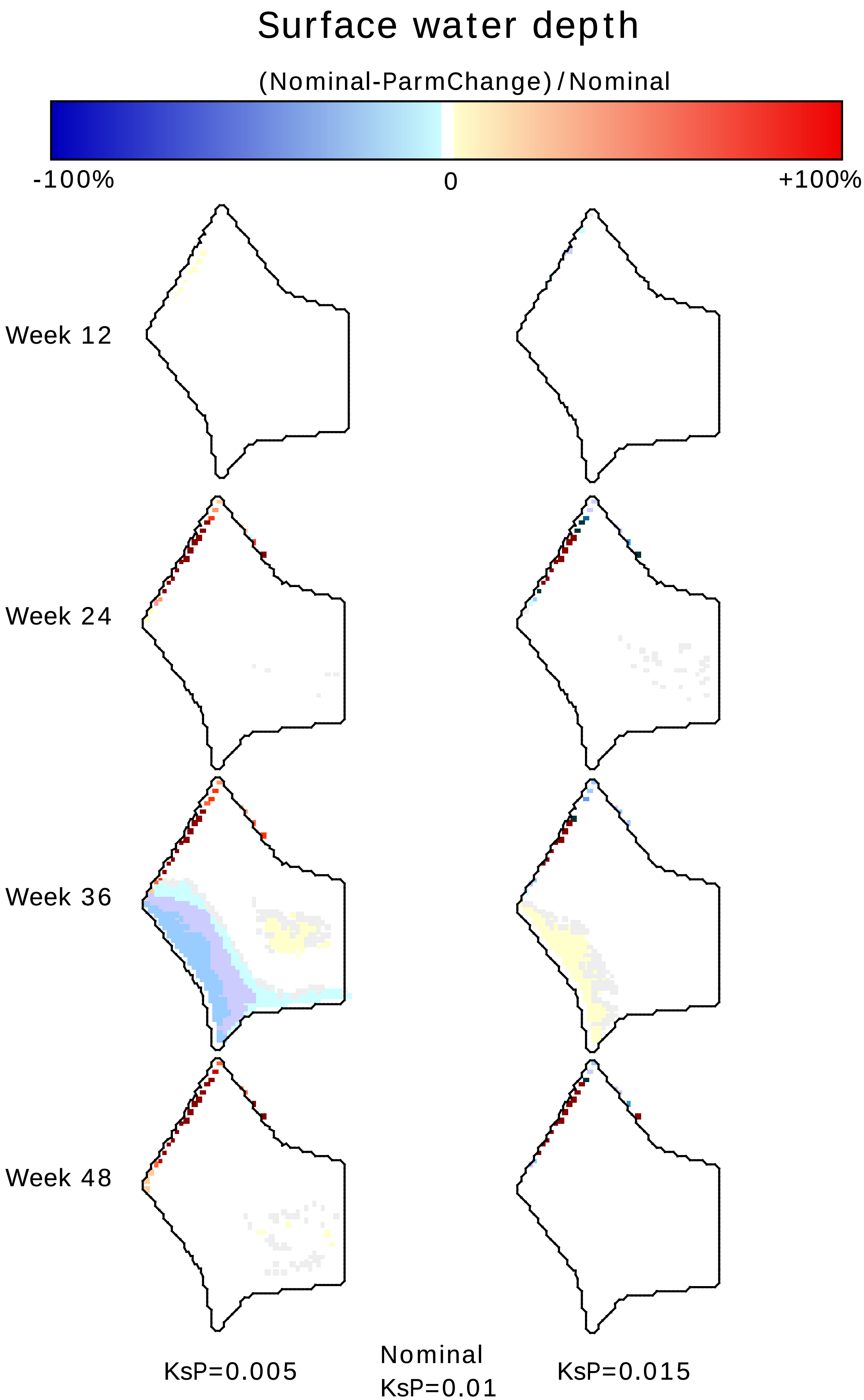

Surface water depth
(Nominal-ParmChange)/Nominal
-100%
0
+100%
Week 12
Week 24
Week 36
Week 48
icSorbP=0.0025
Nominal
icSorbP=0.005
icSorbP=0.0075

PO4 in sediment water

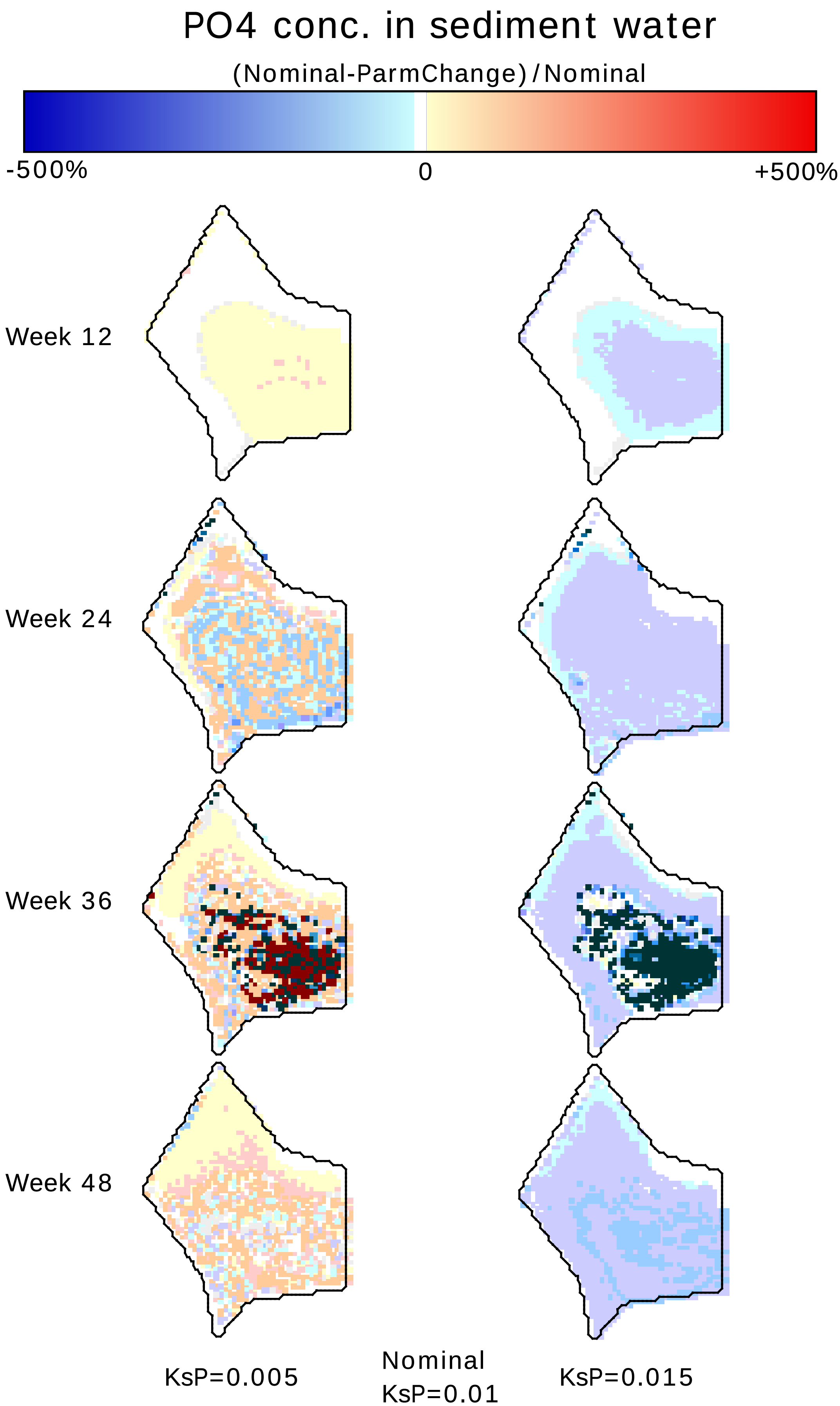


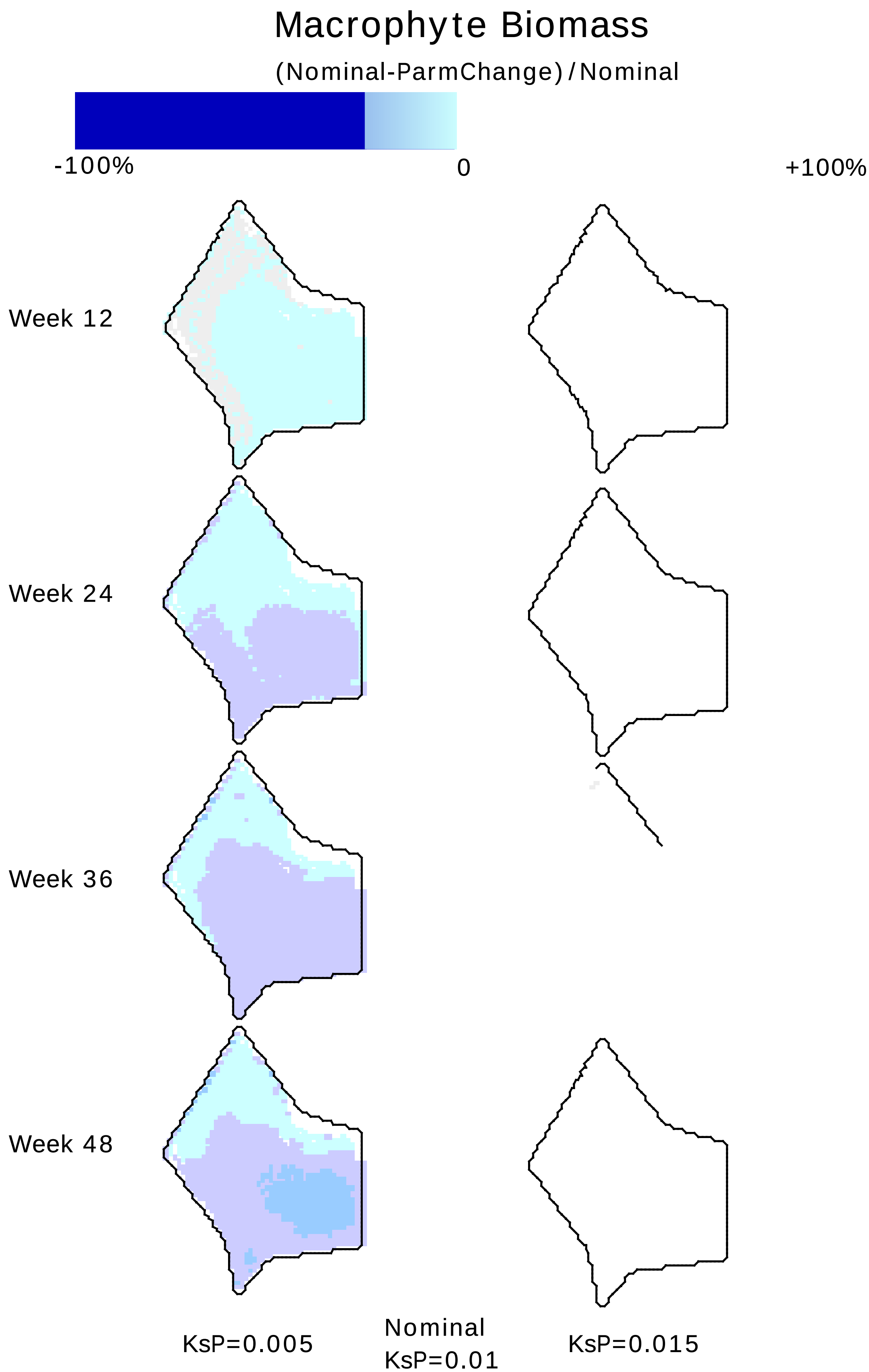
Macrophyte Biomass



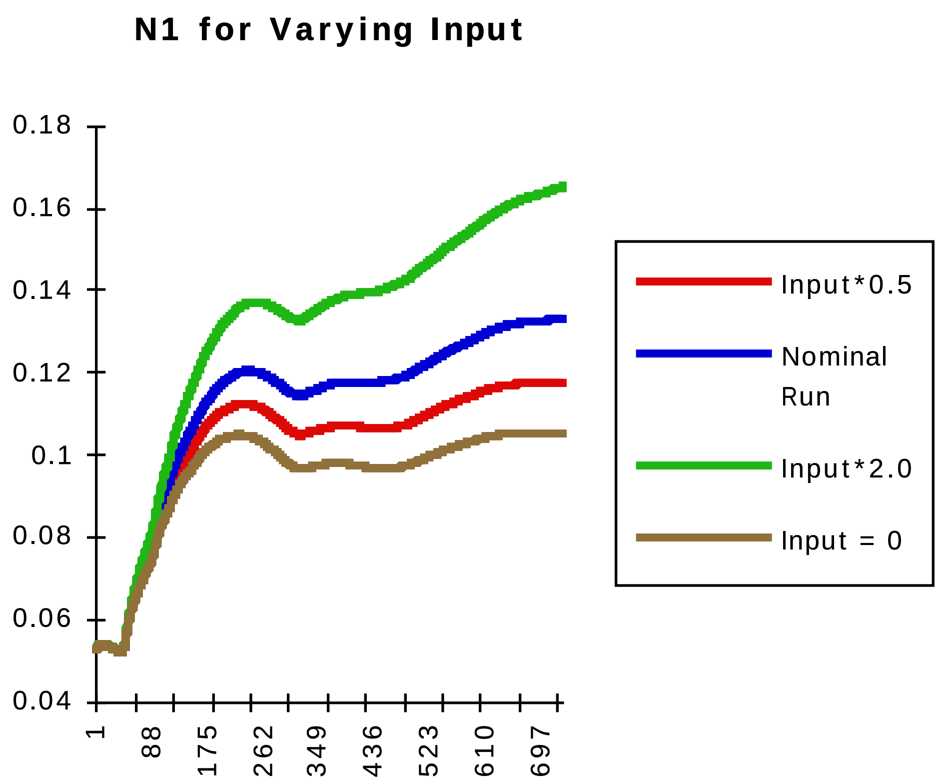


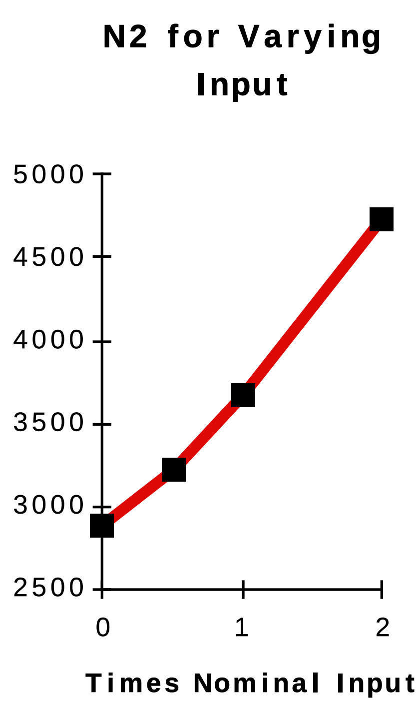
Surface water depth
(Nominal-ParmChange)/Nominal
-100%
0
+100%
Week 12
Week 24
Week 36
Week 48
KsP=0.005
Nominal
KsP=0.01
KsP=0.015


PO4 conc. in sediment water
(Nominal-ParmChange)/Nominal
-500%
0
+500%
Week 12
Week 24
Week 36
Week 48
KsP=0.005
Nominal
KsP=0.01
KsP=0.015

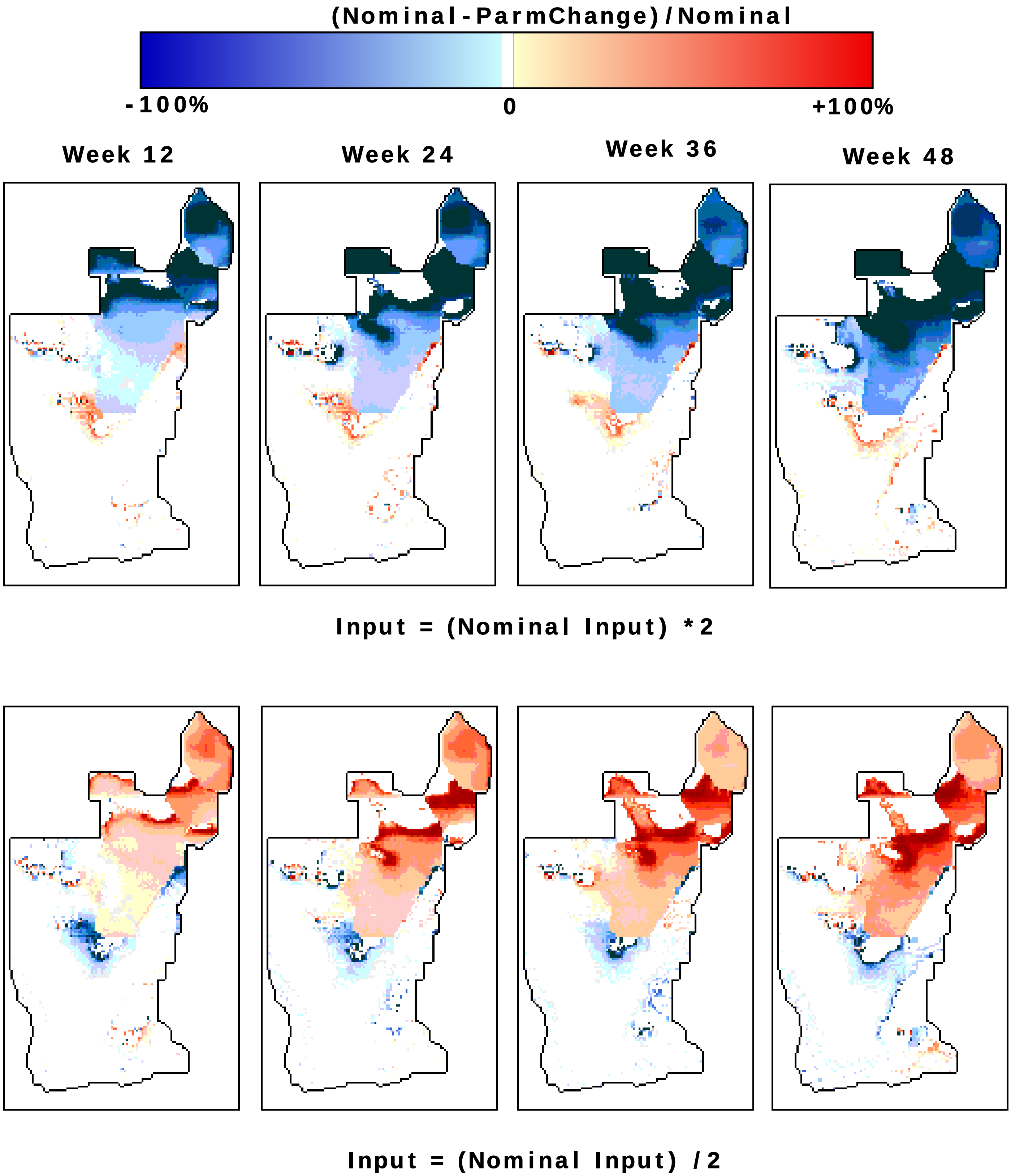


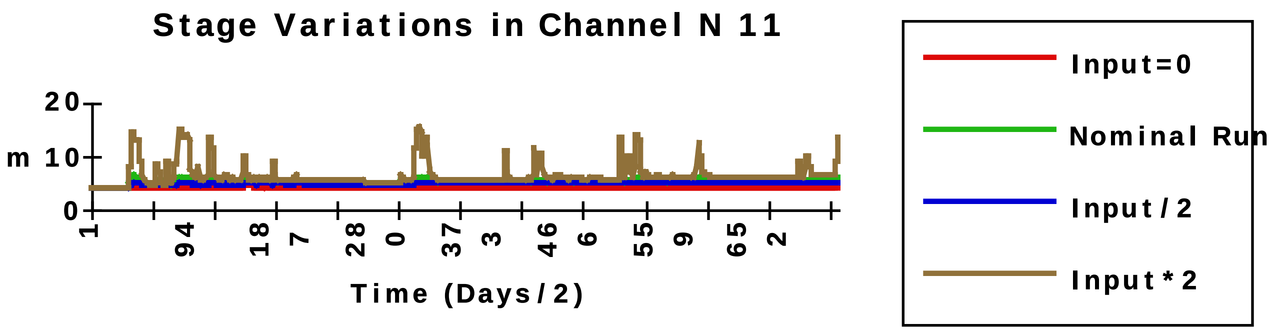
Macrophyte Biomass
(Nominal-ParmChange)/Nominal
-100%
0
+100%
Week 12
Week 24
Week 36
Week 48
KsP=0.005
Nominal
KsP=0.01
KsP=0.015

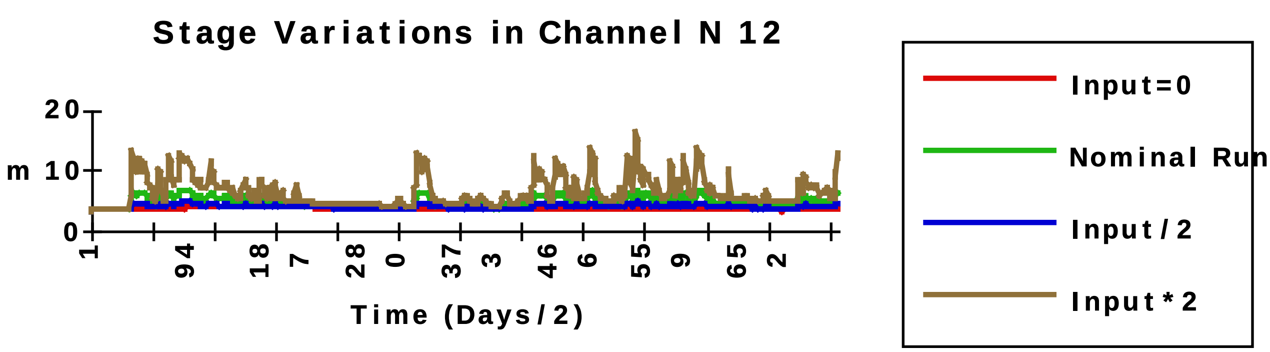

N1 for Varying Input
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
1
88
175
262
349
436
523
610
697
Input*0.5
Nominal Run
Input*2.0
Input = 0


N2 for Varying Input
5000
4500
4000
3500
3000
2500
0
1
2
Times Nominal Input

Surface Water Variations in Response to Changes
Water Input Through Pumping Structures

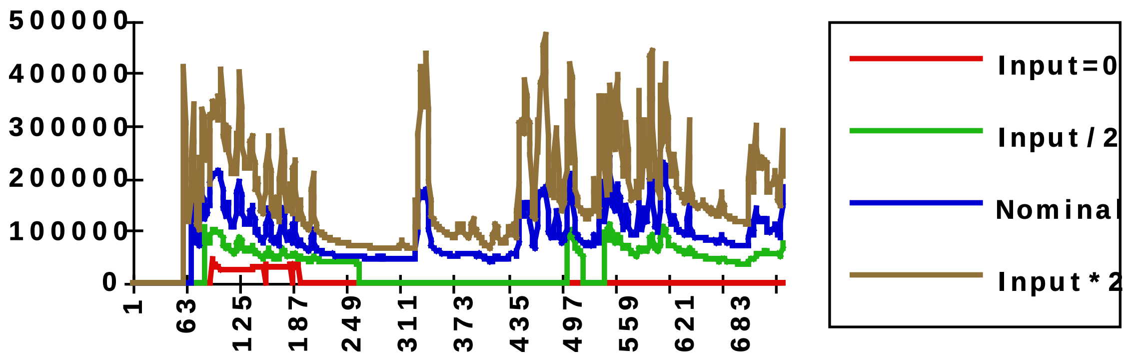



Stage Variations in Channel N 11
20
m 10
0
1
94
18
7
28
0
37
3
46
6
55
9
65
2
Time (Days/2)
Input=0
Nominal Run
Input/2
Input*2

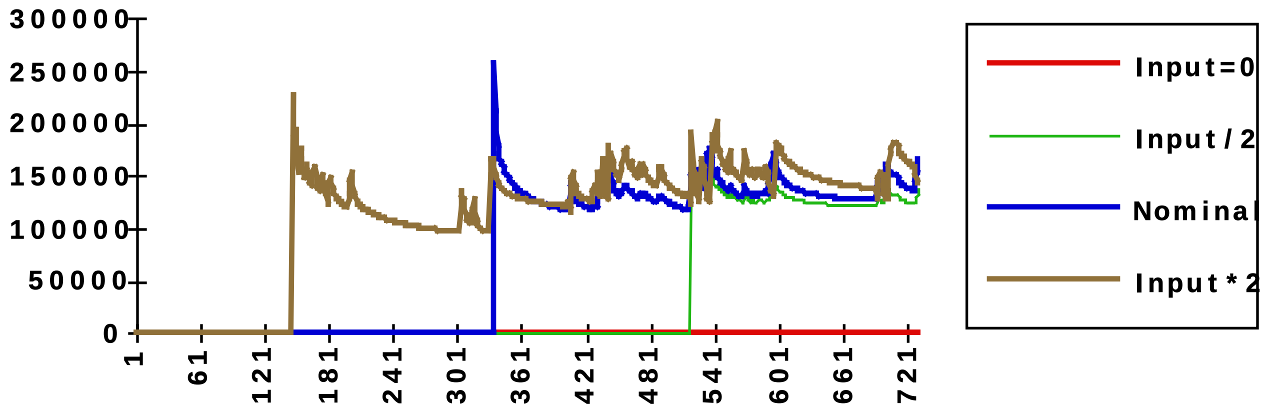


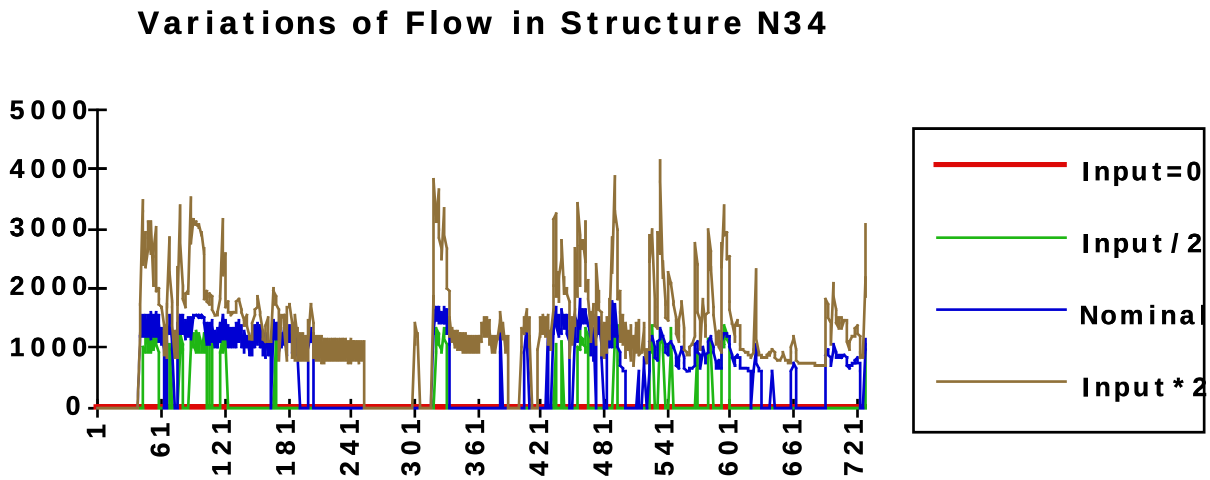
Stage Variations in Channel N 12
20
m 10
0
1
94
18
7
28
0
37
3
46
6
55
9
65
2
Time (Days/2)
Input=0
Nominal Run
Input/2
Input*2

Variations of Flow in Structure N113

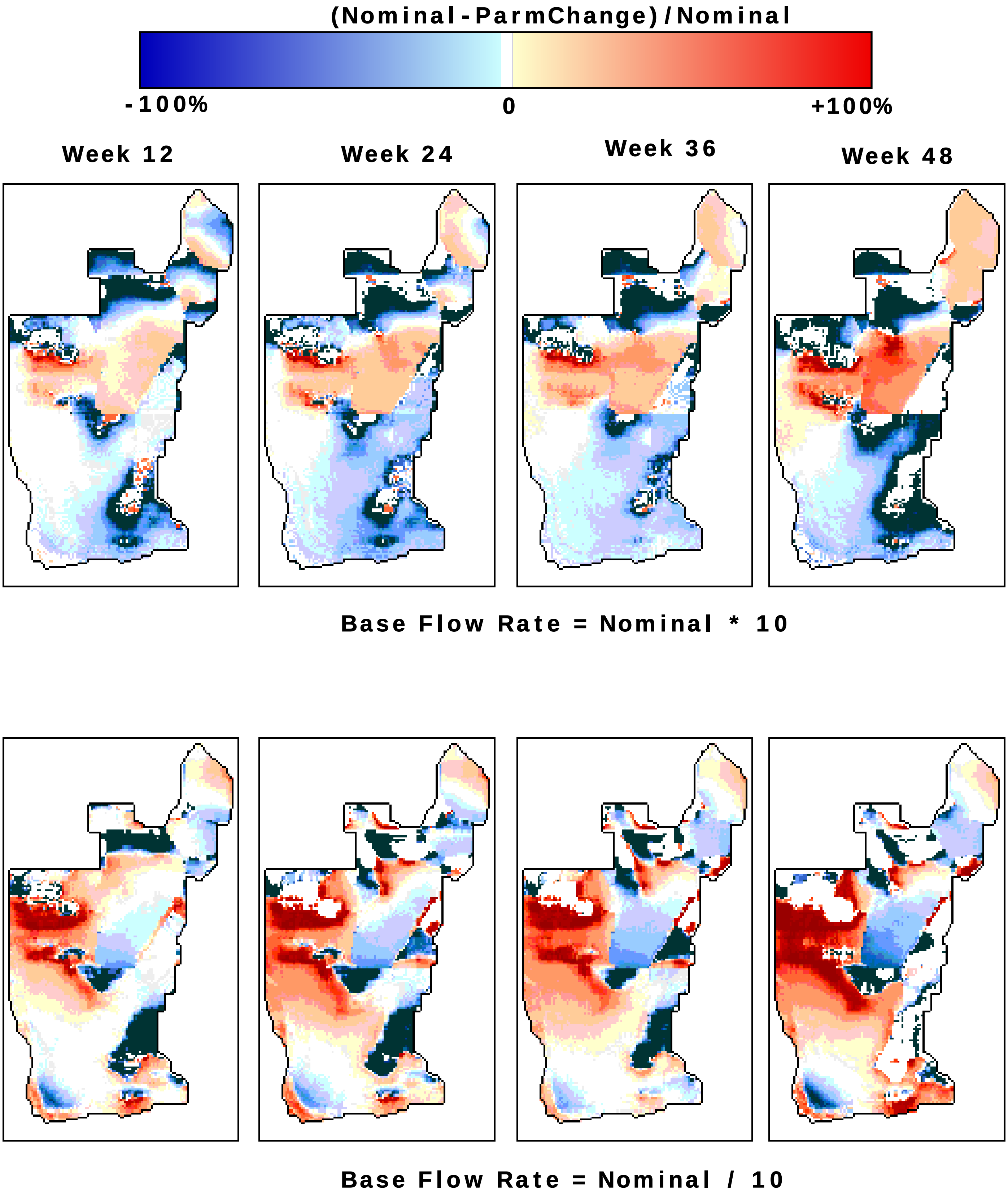


Variations of Flow in Structure N 103



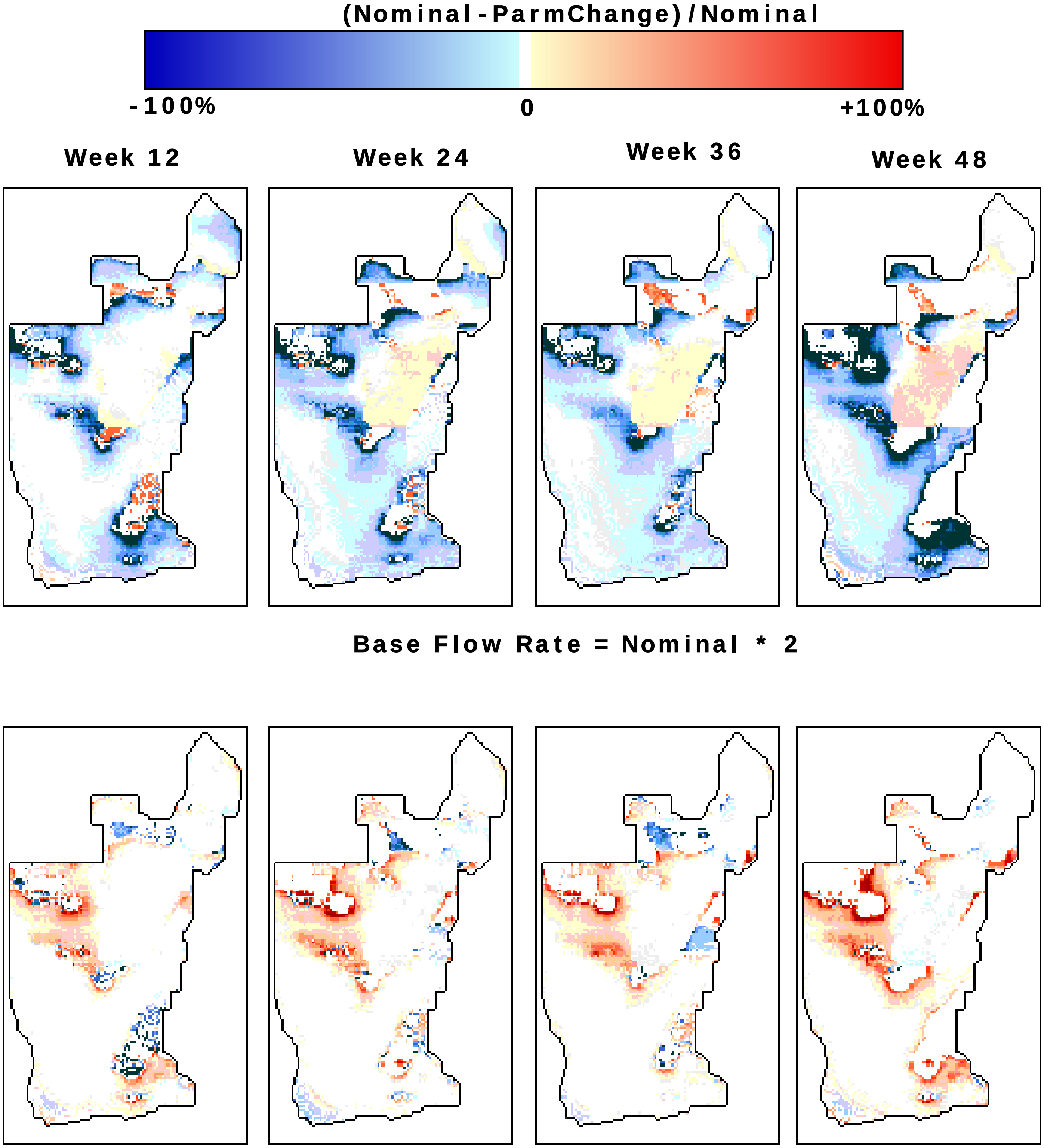

Variations of Flow in Structure N34
5000
4000
3000
2000
1000
0
1
61
121
181
241
301
361
421
481
541
601
661
721
Input=0
Input/2
Nominal
Input*2

Surface Water with Variations in Base Flow R



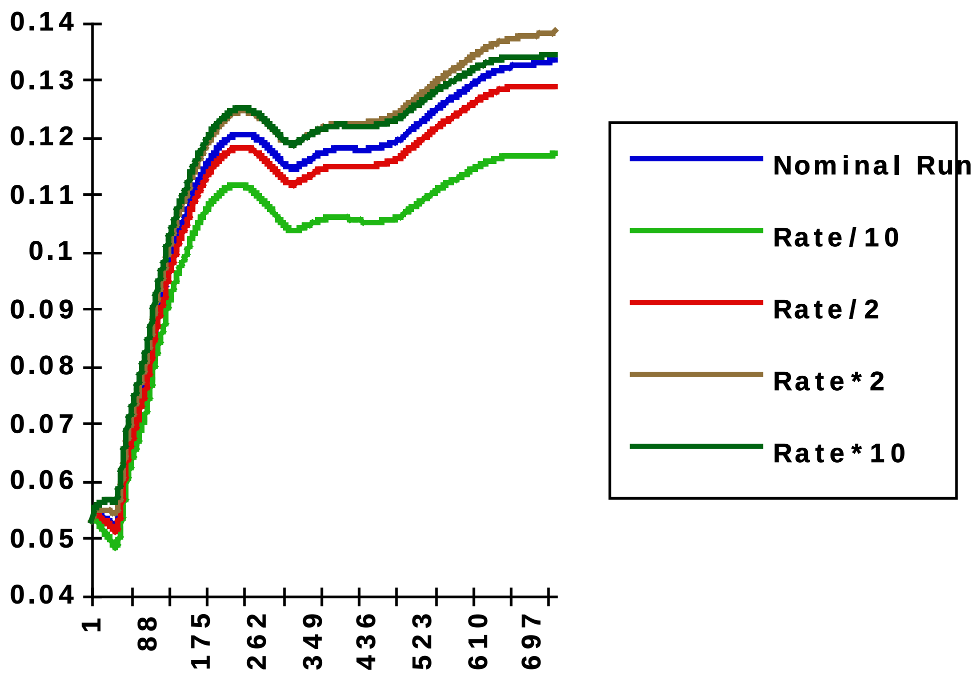
Surface Water with Variations in Base Flow R

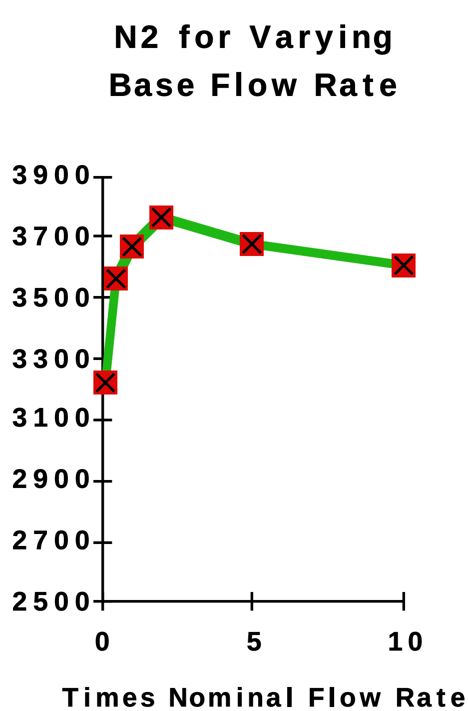
(continued)

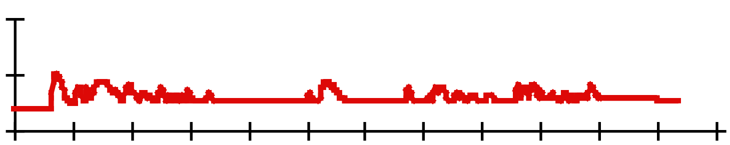


Base Flow Rate = Nominal / 2

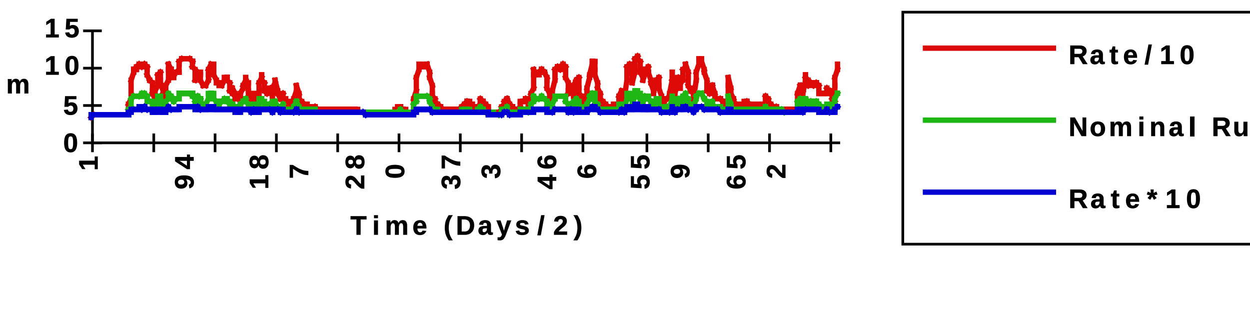
N1 for Varying Base Flow Rate



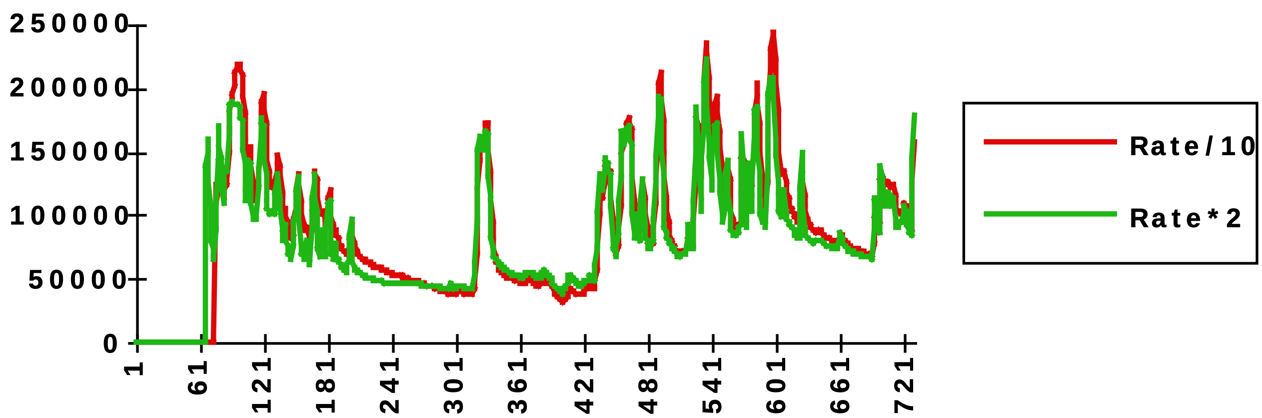

N2 for Varying
Base Flow Rate
3900
3700
3500
3300
3100
2900
2700
2500
0
5
10
Times Nominal Flow Rate



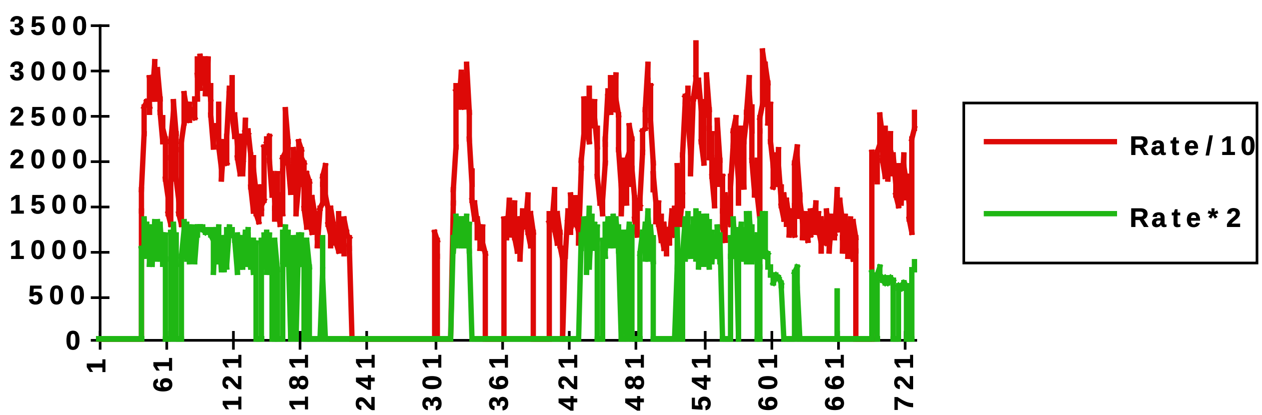
Stage Variations in Channel N 12 Under Modified Rate



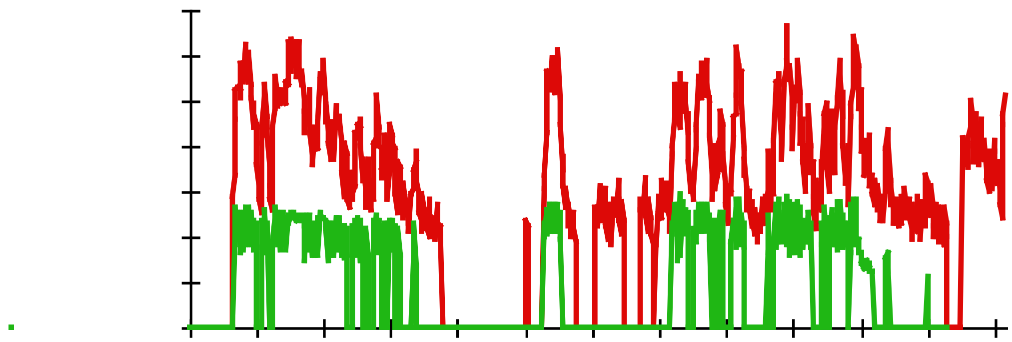
Variations of Flow in Structure N113



Variations of Flow in Structure N103



E10.VS34_r



Surface Water Variations when Structures Are Re