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## Abstract

The objective of the study, which is a component of a comprehensive evaluation of the hydrologic and ecological effects of groundwater pumping from the Kirkwood-Cohansey aquifer, was to apply empirically determined hydrology-vegetation models to develop geographic information system (GIS)-based landscape models for three study basins in the New Jersey Pinelands. The landscape models were used to assess the basin-wide distribution of wetland-indicator species and five vegetation types in response to changes in water level as estimated by the various groundwater pumping scenarios. The groundwater withdrawal rates used in the scenarios were based on 5, 15, and 30% of basin recharge. For each groundwater withdrawal rate "best case" and "worst case" well-distribution configurations were implemented. The Best case scenarios located pumping wells towards the periphery of the basin, while Worst case scenarios had wells located closer in proximity to the wetlands and thus expected to have a greater impact (i.e., thus the worst case appellation). Water levels corresponding to areas dominated by wetland-indicator species were also associated with the three vegetation types at the wettest end of the depth to water table gradient (cedar swamps, hardwood swamps and hardwood-pine lowlands). Pitch pine lowland represents a transitional zone to upland pine-oak forest at the drier end of the gradient. The wetland- indicator modeling suggests that the area dominated by wetland species will decline in area with increased groundwater withdrawal due to the predicted drop in water table. While some patterns revealed in the results are reasonably consistent across basins, other changes are a function of the unique topographic form and hydrologic characteristics of a particular basin. At the highest level of groundwater withdrawal modeled (30% of basin recharge), the decline in area dominated by wetland species is predicted to range from a low of 25-27% in Albertson Brook basin to approximately 90% in Morses Mill basin. Two of the study basins, Albertsons Brook and Morses Mill Stream, did not exhibit much difference in the area dominated by wetland species between the Best and Worst case withdrawal scenarios, while McDonalds Branch had approximately a 25% difference between the Best and Worst case scenarios. In almost all cases, individual woody wetland vegetation types

were predicted to decline in area at the highest levels of groundwater withdrawal modeled (i.e., 30% of basin recharge). The results suggest that cedar and hardwood swamps which are at the wetter end of the water table gradient will show the greatest percent declines in area. In the case of Morses Mill stream basin, the predicted decline in cedar swamp area was over 90%. The landscape modeling suggests that at the higher levels of groundwater withdrawal the decline of wetland area will be especially severe in the upper headwaters of the basins, and that there will be ‘retreat’ of existing wetlands to a narrower streamside corridor. In addition to the predicted decline in area of the various woody wetland vegetation community types, the landscape modeling also suggests that there will be a change in the broader landscape pattern with a simplification of the wetland mosaic with fewer patches.

#### Acknowledgments

Funding for this study was provided through the Water Supply Fund in accordance with New Jersey Public Law 2001, Chapter 165.

We gratefully acknowledge the close collaboration with the various project partners at the Pinelands Commission, including Kim Laidig, Allison Brown, Robert Zampella, John Bunnell, Nick Procopio, and at the U.S. Geological Survey Water Resources Center including Robert Nicholson and Manny Charles.

## Introduction

Wetland loss and degradation is a serious environmental issue in the United States with over 50% of the wetland area either impacted directly through conversion to agricultural or urban land uses or otherwise impacted indirectly through altered hydrology (Dahl and Allord 1996). Consequently, increased attention has been focused on the conservation and restoration of wetlands nationwide (U.S. Environmental Protection Agency and U.S. Department of Agriculture 1998). As hydrology is the primary forcing function in wetland ecosystems (Mitsch and Gosselink 2000), maintaining adequate water tables is a critical element in maintaining and restoring wetland systems (Kentula 1996). Pumping of groundwater aquifers can lead to a lowering of the water table, thereby impacting wetland ecosystem structure and function.

The New Jersey Pinelands are noted for the amount and diversity of its wetland and aquatic ecosystems. The potential impact of increased groundwater withdrawal from the Kirkwood-Cohansey aquifer on Pinelands wetland and aquatic ecosystems has been of growing concern as New Jersey's human population has increased along with attendant demands on its water resources. The Kirkwood-Cohansey Project was initiated to evaluate the hydrological and ecological effects of groundwater pumping from the Kirkwood-Cohansey aquifer. The study was designed to explore the effect of various scenarios of groundwater pumping, including both well location as well as total amount of withdrawal, on wetland and aquatic community composition and distribution. More broadly, to what extent can the Kirkwood-Cohansey Aquifer continue to support the needs of a growing population without negative impacts to the aquatic and wetland communities that depend on it?

As part of the vegetation study component of the Kirkwood-Cohansey Project, Laidig et al. (2010) examined the relationship between groundwater levels, woody-species composition, and the percentage of wetland- and upland-indicator species across an upland-to-wetland gradient in the New Jersey Pinelands. The field investigation was focused on three study basins: McDonalds Branch, Albertson Brook, and Morses Mill Stream. Due to the functional relationship of hydrology with its correlated soil variables, hydrology represented a good proxy for the complex hydrologic-edaphic gradient associated with the upland-to-wetland vegetation gradient (Laidig et al., 2010). Two types of empirically determined models were developed to predict potential changes in vegetation associated with water-level declines; these included simple regression models that predict the relative abundance of wetland- and upland-indicator species as a function of water level and logistic regression models that predict the probability of encountering the different vegetation types in relation to water level. A companion study by Charles and Nicholson (2010) of the U.S. Geological Survey undertook an intensive hydrologic investigation of the three study basins. One outcome of this component of the project was the development of a spatially distributed groundwater model to estimate and map the water table level across each of the three study basins.

The objective of the Landscape Modeling component of the Kirkwood-Cohansey project was to integrate the vegetation and hydrology models to assess the potential effect of

ground-water level declines on the distribution of wetland indicator species and wetland-forest communities. To achieve this objective, the empirically determined hydrology-vegetation models were translated to a geographic information system (GIS)-based model to predict the probable distribution of wetland indicator species cover under baseline conditions across the three study basins. The effect of groundwater-pumping scenarios on the wetland-indicator or woody-wetland vegetation types were then evaluated by comparing the percentage of basin area with varying percentages of wetland- and upland-indicator-species cover or wetland-forest forest types under baseline conditions and conditions resulting from the different scenarios. Findings of this study will be utilized to forecast ecological responses to various water demand scenarios, and ultimately provide information to the New Jersey Pinelands Commission in making land-use planning decisions.

## Methods

### GIS-Modeling Framework

Three study basins were evaluated: McDonalds Branch, Albertson Brook, and Morses Mill Stream (Table 1). The three basins were selected to represent a range of ecological, hydrologic, and land-use conditions to ensure broad Pinelands-wide applicability (Laidig et al. 2010, Walker et al. 2008). Refer to Laidig et al. (2010) and Walker et al. (2008) for detailed study-basin descriptions.

Table 1. Area statistics for the three study basins. WTD = water table depth (cm).

Basin	Basin Area (km <sup>2</sup> )	WTD 2- 200cm % of basin	Wetland Area % of basin
Albertson's Brook	52.3	28.3	11.0
McDonalds Branch	14.3	61.7	33.0
Morses Mill Stream	21.8	51.6	20.6

The GIS modeling was undertaken using a raster grid-based approach implemented within the ESRI ArcGIS software. A cell resolution of 10 meters was adopted to provide reasonably detailed spatial detail but also was tractable in terms of the hydrological modeling computational demands. The GIS model employed a Universal Transverse Mercator (UTM) projection and a NAD83 datum. Open water areas (i.e. lakes) were masked out of the analysis using a digital GIS file provided by the U.S. Geological Survey.

## Water Table Models

The USGS provided mapped outputs for the various groundwater pumping scenarios as water level raster data sets (i.e., each grid cell contained a digital value representing depth to the water table). Each scenario differed by the amount of ground-water withdrawal, which is expressed as a percentage of basin recharge. In addition, each ground-water withdrawal scenario had one of two possible well-placement schemes. The "best" well-placement scheme located pumping wells at a relatively greater distance from wetlands. For additional details on the placement of wells for the various scenarios, refer to Charles and Nicholson (2010).

For Albertson Brook and McDonalds Branch, eight scenarios in addition to the baseline groundwater withdrawal were considered. For Morses Mill, ten scenarios in addition to the baseline groundwater withdrawal were included. The following scenarios were modeled: Best case - Baseline (0), 5, 10, 15, and 30%; and, Worst case - Baseline (0), 5, 15, and 30% of the available water recharge. The water level value then served as input to the landscape-level vegetation models (described below) to calculate the wetland indicator species cover or vegetation type probability across the entire study basin (e.g., to produce a 'wall-to-wall' map). Study basin locations with a baseline depth to water table of < 2 cm or > 200cm were excluded from further consideration, as these water table depths were outside the range of the wetland vegetation models. The mapped outputs were then further analyzed and summarized in various ways to examine changes in the overall predicted distributions.

## Wetland Indicator Modeling

We modeled the relative abundance of wetland-indicator species in our study based on the prior work of Laidig et al. (2010); who related the relative abundance (percentage of total cover) and relative richness of wetland-indicator species (obligate-wetland and facultative-wetland species) and upland-indicator species (facultative-upland and upland species) to mean study-period water levels using simple linear regression.

Examination of the wetland vs. upland-indicator models (Figure 1) shows that the transition point between wetland vs. upland species dominance occurs near water-table depths of approximately 35 cm. Thus relative abundance of wetland-indicator species exceeds upland indicators at water-table depths of 35 cm or less. Arcsine-transformed relative-abundance values and log-transformed water levels were used in the analysis. The model equations (Table 2; as found in Figure 8 of Laidig et al. 2010) were then translated into an ArcGIS-based model. Figure 2 presents the work flowchart of the process steps taken.

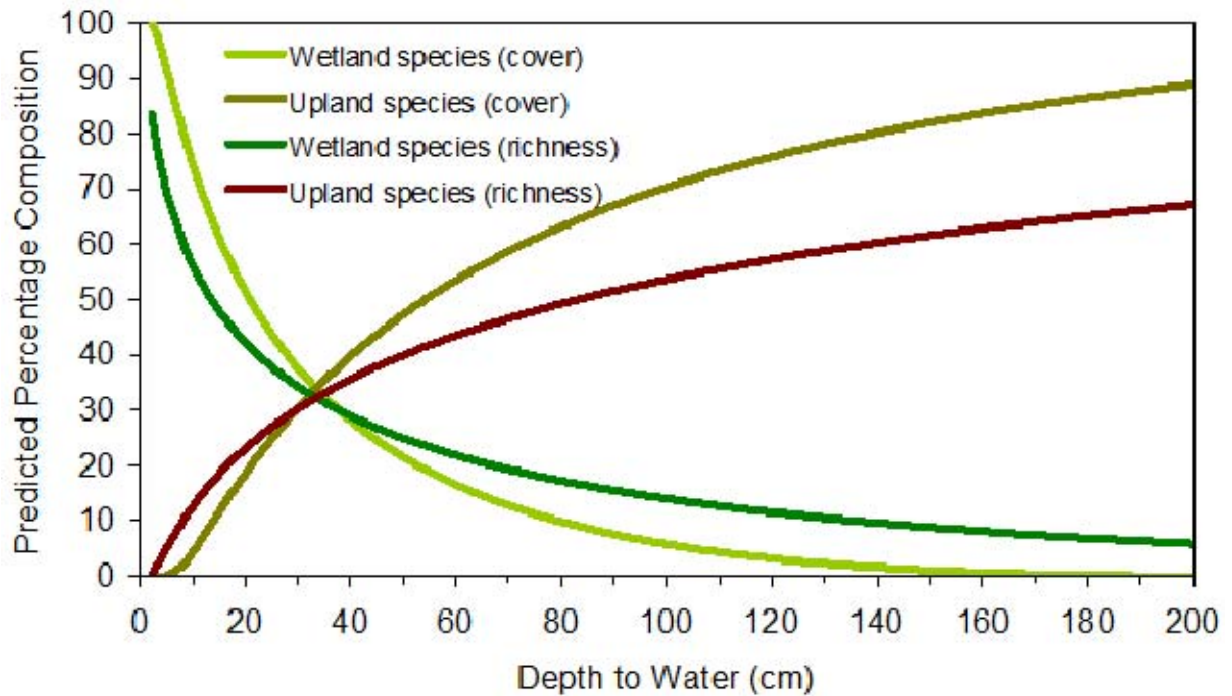


Figure 1. Predicted relative abundance (percentage of total cover) and relative species richness (percentage of total species richness) of wetland-indicator and upland-indicator groups in relation to the depth to water (cm). From Laidig et al., 2010.

Table 2. Equations for Wetland and Upland Indicator Species models (Laidig et al. 2010). Relationship between depth to water ( $\log_{10}$  cm) and the relative abundance (percentage of total cover: arcsine) and relative species richness (percentage of total species richness).

Model	Equation
Wetland Indicator Species - % Cover	$Y = -0.7991X + 1.8396$
Wetland Indicator Species - Richness	$Y = -0.4641X + 1.3113$
Upland Indicator - % Cover	$Y = 0.7857X - 0.5762$
Upland Indicator - Richness	$Y = 0.4592X - 0.096$

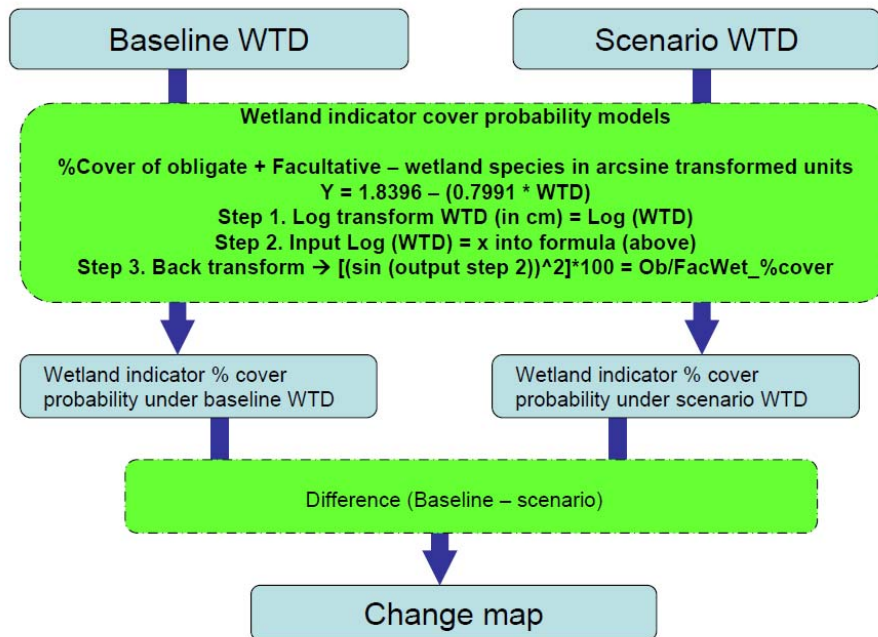


Figure 2. Process steps taken for the wetland indicator modeling. WTD = water table depth.

### Woody-Wetland Vegetation Type Modeling

Laidig et al. (2010) identified five main woody vegetation types along the wetland to upland gradient, including cedar swamp, hardwood swamp, pine-hardwood lowland, pitch pine lowland, and pine-oak upland. They then used logistic regression to determine the probability of occurrence of each vegetation type in relation to water level (Figure 3). The logistic regressions were based on presence/absence data and untransformed water-level data. We then translated the logistic regression model equations (Table 3; as found in Table 12 of Laidig et al., 2010) into an ArcGIS-based model.

### *Individual Vegetation Type Modeling*

For each water table scenario, the probability of occurrence of each of the five community types were simulated separately and the estimated probabilities were rescaled to a 0-100 range  $[(\text{prob value} - \text{min})/(\text{max} - \text{min})]$  and classified as high (67-100%), medium (33-67%), and low (1-33%) and no (<1%) probability of occurrence for graphic visualization purposes. Our evaluations were limited to the 2-200 cm area because this represented the range of water-level values used to derive the vegetation models (Laidig et al. 2010). While the change in the area of high, medium, and low probability due to simulated water-level declines associated with different groundwater-pumping scenarios

was then determined, only the results for the high probability class are presented and discussed in this report. A GIS cross-tabulation of the baseline vs. the individual scenarios was undertaken to produce from-to change maps (e.g., identify a pixel as going from high to low probability for a particular community type).

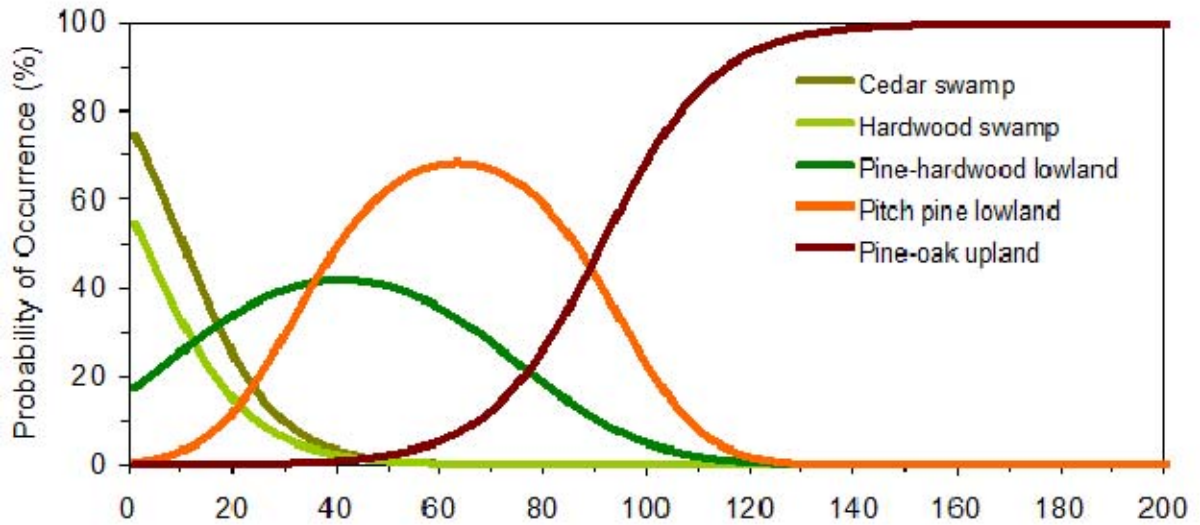


Figure 3. Logistic regression curves describing the probability of occurrence of five vegetation types in relation to depth to water (from Laidig et al., 2010).

Table 3. Equations for Community presence probability models (Laidig et al. 2010).

Community	Equation
Cedar Swamp	$\text{EXP}(1.17798 + (-0.11348) * \text{WTD}) / (1 + \text{EXP}(1.17798 + (-0.11348) * \text{WTD}))$
Hardwood Swamp	$\text{EXP}(0.288939 + (-0.1009) * \text{WTD}) / (1 + \text{EXP}(0.288939 + (-0.1009) * \text{WTD}))$
Hardwood pine lowland	$(0.72 * \text{EXP}(-0.5 * (\text{WTD} - 41.16)^2 / 25.61^2)) / (1 + (0.72 * \text{EXP}(-0.5 * (\text{WTD} - 41.16)^2 / 25.61^2)))$
Pitch pine lowland	$(2.16 * \text{EXP}(-0.5 * (\text{WTD} - 63.31)^2 / 18.38^2)) / (1 + (2.16 * \text{EXP}(-0.5 * (\text{WTD} - 63.31)^2 / 18.38^2)))$
Pine oak upland	$\text{EXP}(-8.3496 + (0.09132) * \text{WTD}) / (1 + \text{EXP}(-8.3496 + (0.09132) * \text{WTD}))$

### *Individual Vegetation Type Modeling*

For each water table scenario, the probability of occurrence of each of the five community types were simulated separately and the estimated probabilities were rescaled to a 0-100 range  $[(\text{prob value} - \text{min})/(\text{max} - \text{min})]$  and classified as high (67-100%), medium (33-67%), and low (1-33%) and no (<1%) probability of occurrence for graphic visualization purposes. Our evaluations were limited to the 2-200 cm area because this represented the range of water-level values used to derive the vegetation models (Laidig et al. 2010). While the change in the area of high, medium, and low probability due to simulated water-level declines associated with different groundwater-pumping scenarios was then determined, only the results for the high probability class are presented and discussed in this report. A GIS cross-tabulation of the baseline vs. the individual scenarios was undertaken to produce from-to change maps (e.g., identify a pixel as going from high to low probability for a particular community type).

### *Dominant Vegetation Type Modeling*

A second method ('winner takes all' method which evaluates the vegetation types simultaneously) that can more effectively reflect the relative dominance of the five vegetation type in each site (cell) was employed by assigning each site to a single vegetation type. The 'winner' or dominant vegetation type, i.e., the type with the maximum (using the original probability values, not rescaled) probability, was determined for every grid cell in the raster for each water level scenario.

Note that due to the similarity of the cedar and hardwood swamp models and the overall lower probability of occurrence of hardwood swamp, cedar swamp will always be estimated to have a higher probability of occurrence and come out as the 'winner'. A separate analysis would have to be completed using hardwood swamps instead of cedar swamps. We only used cedar swamps in this analysis.

The change in the area of the 'winner' due to simulated water-level declines associated with different groundwater-pumping scenarios was determined. A GIS cross-tabulation of the baseline vs. the individual scenarios to produce from-to change maps (e.g., identify a pixel as going from one 'winner' community to another). Figure 4 presents the general flowchart of the methods.

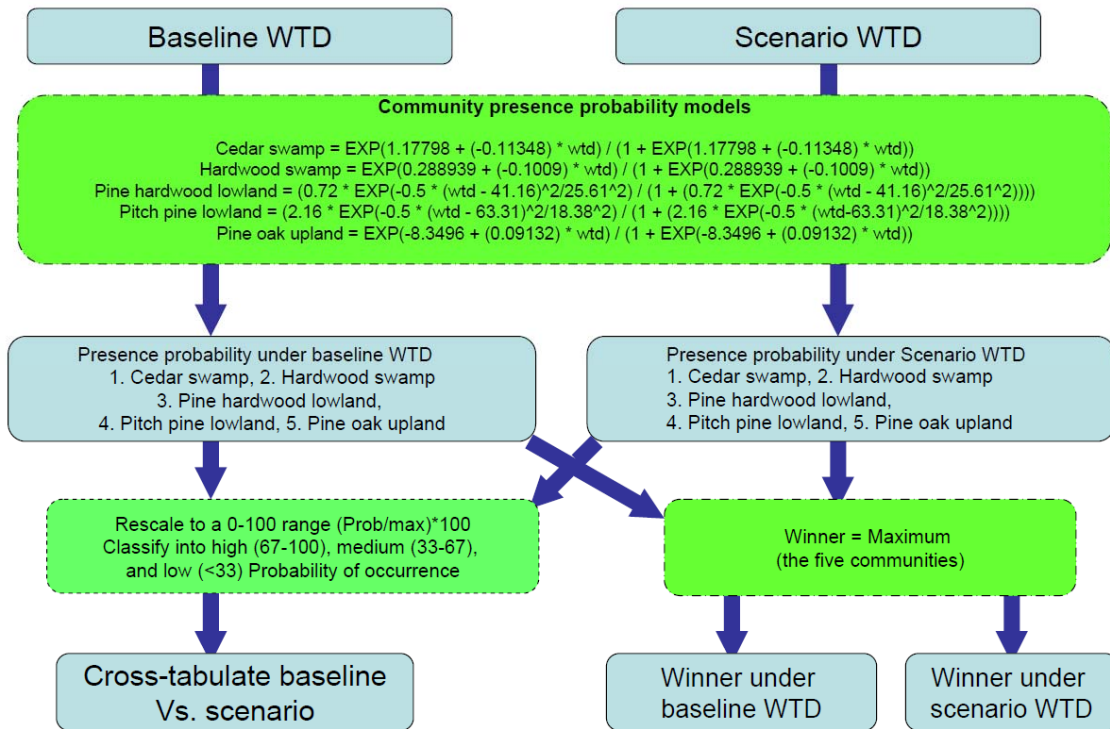


Figure 4. Flowchart for calculating vegetation community presence probability.

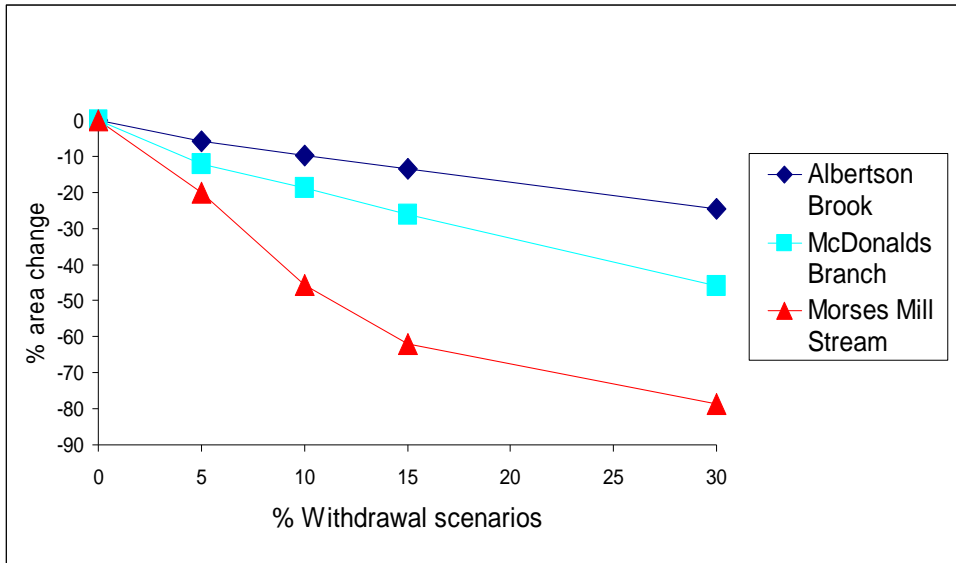
As an additional means of examining the projected change in landscape pattern, the number and size of contiguous patches of wetland vegetation community types were determined. Mean and median patch area, patch area range and patch number for each individual winning community under baseline and best30 scenarios were calculated using Fragstats (version 3, McGarigal, et al. 2002). The Fragstats program is an analysis package designed to calculate landscape metrics useful for determining landscape characteristics such as basic measures (e.g., area), theoretic information measures (e.g., diversity) and shape measures (e.g., fractal dimension).

## Results and Discussion

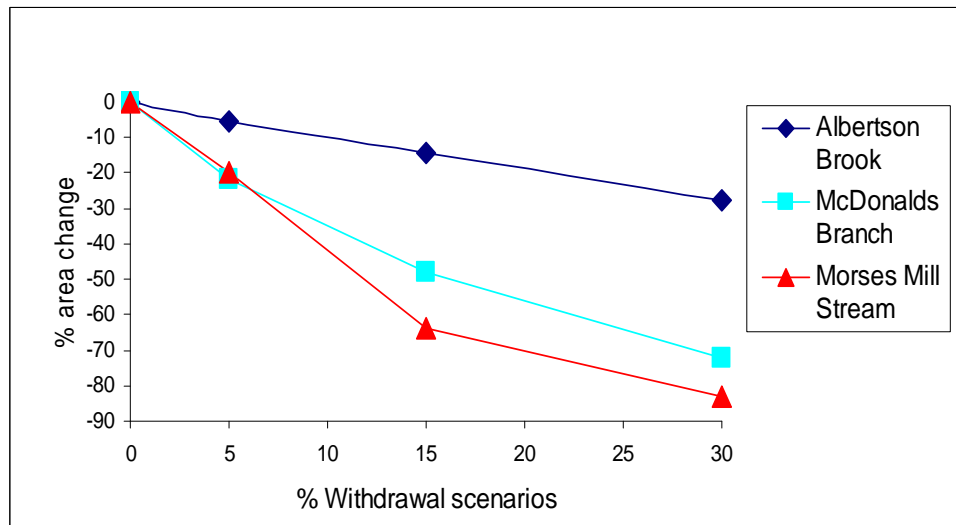
### Wetland Indicator Modeling

Based on the regression models, the percent cover of wetland indicator species were estimated for both the Best and Worst case scenarios. The resulting grid cell maps were compared and a grid cell was assigned to either a wetland or upland indicator group depending on which type had the highest estimated cover. The percent area dominated by wetland-indicator species (as compared to Baseline conditions) decreases with increasing ground-water withdrawal for all three study basins (Figure 5). Overall, the percent decline is slightly lower under the Best case scenario as compared to Worst case scenario (Figure 5a vs. 5b). The three study basins appear to differ in their sensitivity to withdrawal with Albertson Book showing the least change in wetland indicator type area

(25 to 27% decline for Best30 and Worst30 cases accordingly). Morses Mill Stream basin showed the highest change with between 79 and 83 % decline in wetland indicator type area for Best30 and Worst30 cases accordingly). Albertson Brook exhibits a relatively linear decline under both Best and Worst case conditions, while Morses Mill Stream shows a rapid decline under lower withdrawal rates before somewhat leveling off. McDonalds Branch behaved more similar to Albertson Brook basin under Best case conditions and Morses Mill Stream basin under Worst case conditions (46 to 73% decline for Best30 and Worst30 cases accordingly).



5a. Best case water withdrawal scenarios.



5b. Worst case water withdrawal scenarios.

Figure 5. The percentage change in area where the estimated wetland-indicator species % cover exceeds that of upland-indicator species % cover from baseline to various scenarios 5a). for best case scenarios, and 5b). for worst-case scenarios.

Examination of the mapped outputs reveals some subtle differences in the spatial distributions (Figure 6) as one goes from Baseline to Best30 (Best case 30% of basin recharge withdrawal) conditions. Within the Albertson Brook basin, most of the loss in wetland indicator area is focused on the headwaters (for example, see inset in Figure 6a). McDonalds Branch basin (Figure 6b) shows a significant loss of wetland indicator area in the headwaters and an overall decline (lateral retreat inwards towards the stream and riparian zone) elsewhere within the basin. Morses Mill Stream basin (Figure 6c) exhibits complete loss of wetlands indicator area in the headwaters and an overall decline elsewhere leaving only a narrow streamside corridor of wetlands under the Best case 30% withdrawal.

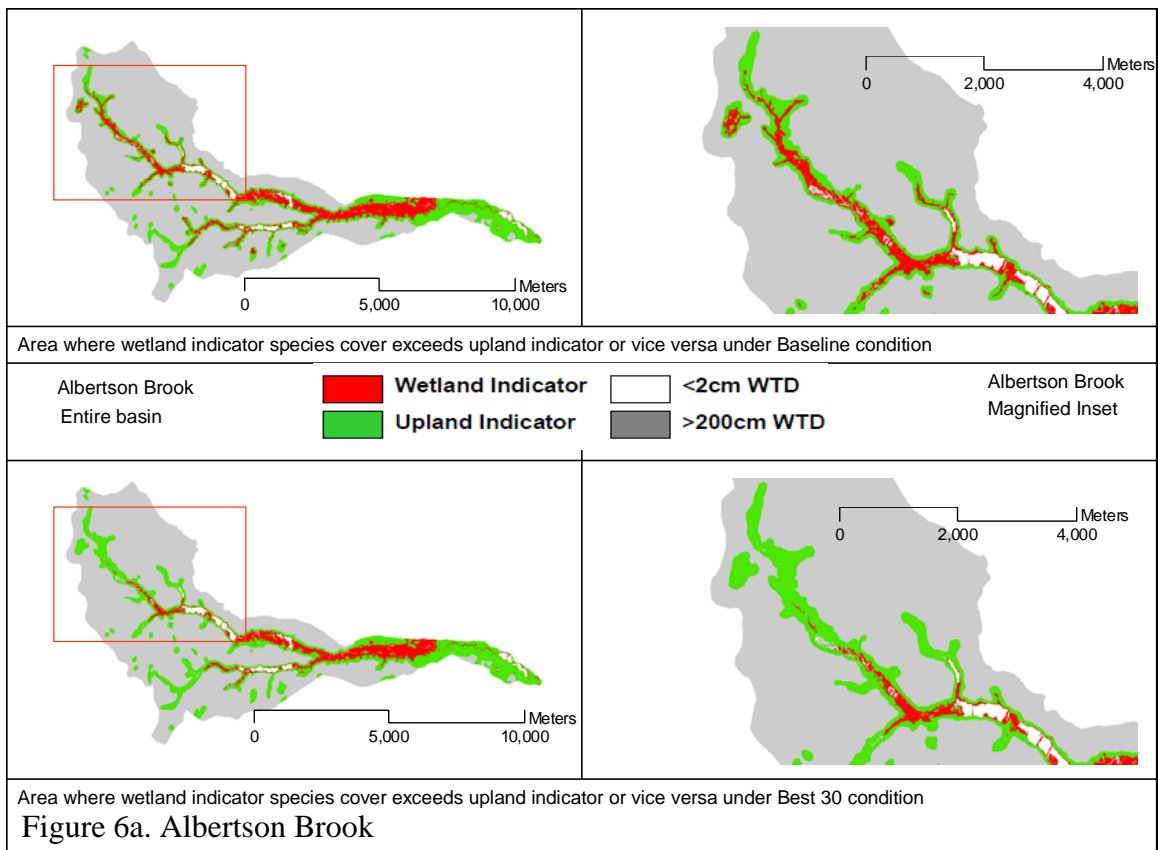
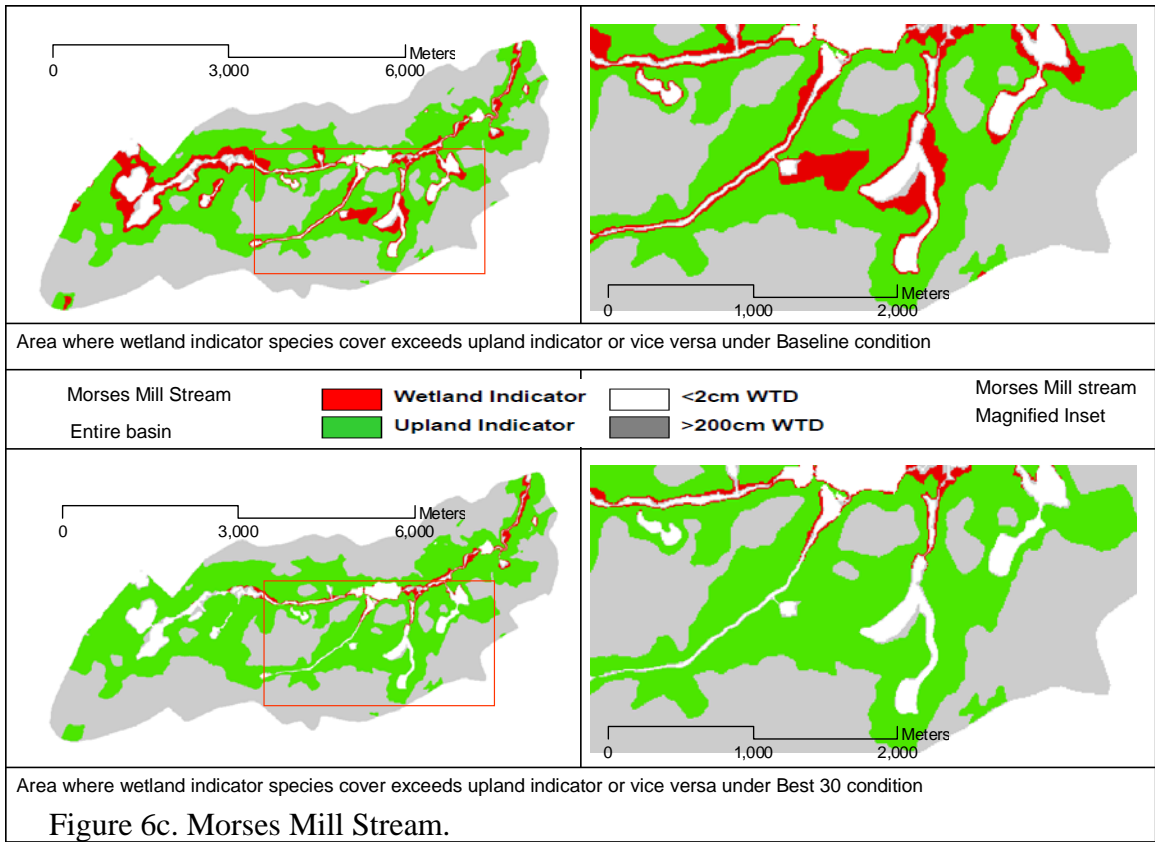
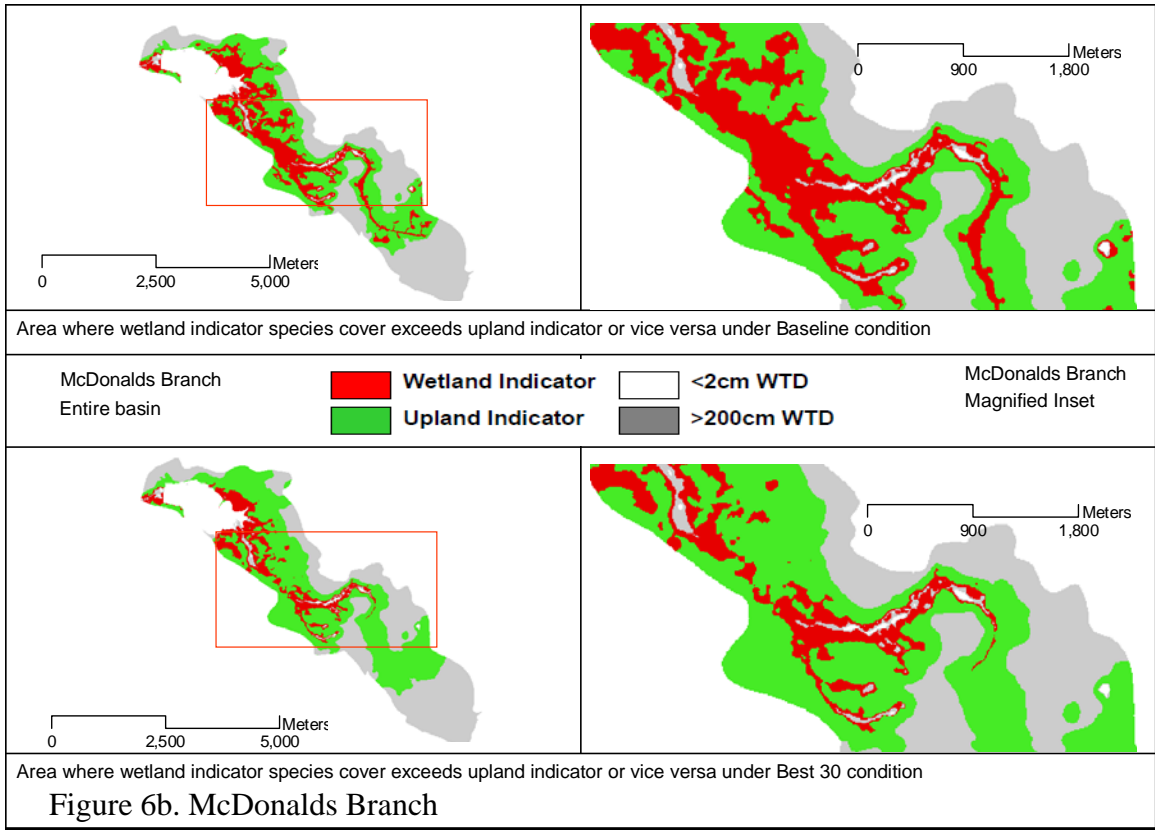


Figure 6. Study basin maps depicting where the estimated wetland indicator species % cover exceeds upland indicator species (where water table depth >2cm and < 200cm) and vice versa under Baseline and Best 30 conditions.



## Woody-Wetland Vegetation Type Modeling

### Individual Vegetation Type Modeling

Based on the logistic regression models, the probability of occurrence for the five woody-wetland vegetation types were estimated for both the Best and Worst case scenarios. The percent change in high probability (67-100%) area between the Baseline and groundwater withdrawal scenario conditions for each of the vegetation types was calculated. Figure 7 groups all the results for a particular vegetation type onto a single graph. While all four of the wetland vegetation types declined, the cedar and hardwood swamps showed the greatest decline across all three basins (with declines of 20 to 40% in Albertsons Brook and McDonalds Branch and over 90% decline in Morses Mill basin) (Figure 7a, b). In Morses Mill Stream basin, cedar and hardwood swamp declined rapidly to over 50% at 5% withdrawal before somewhat leveling off. Pine hardwood declined more slowly, while pitch pine lowlands increased slightly in area (up to 2%) under low to moderate levels of groundwater withdrawal (i.e., 5 to 15% withdrawal) before declining at 30% withdrawal (Figure 7c, d). As expected, with increasing groundwater withdrawal, the percent area of upland pine-oak vegetation type increased for each of the basins (Figure 7e).

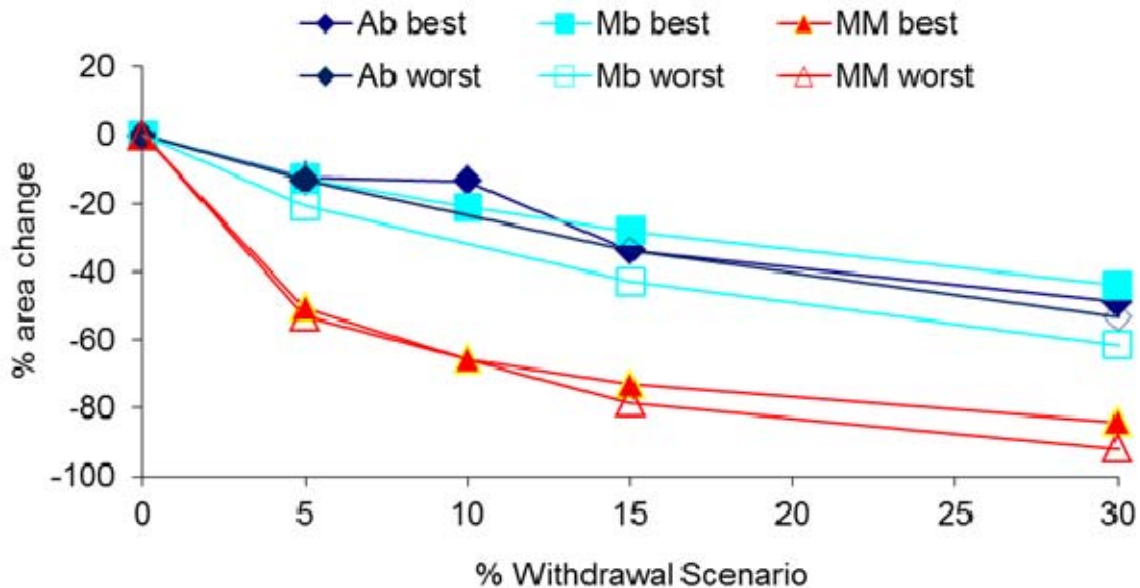


Figure 7a. Cedar Swamp

Figure 7. The percentage change in relative high-probability area from baseline conditions under various water-withdrawal scenarios for each vegetation community type.

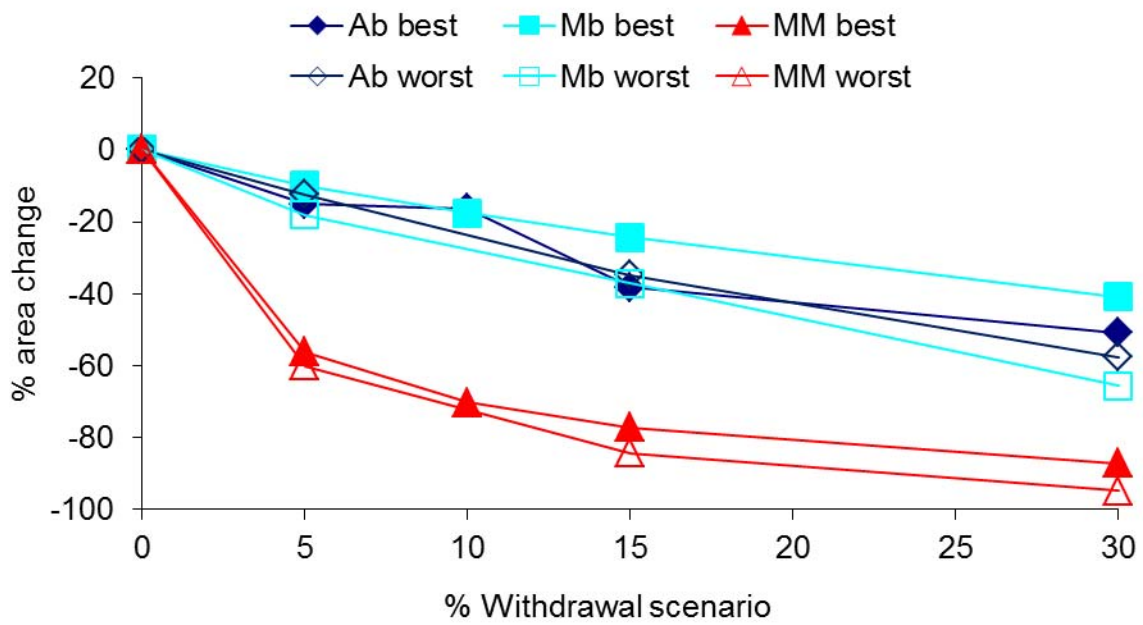


Figure 7b. Hardwood Swamp

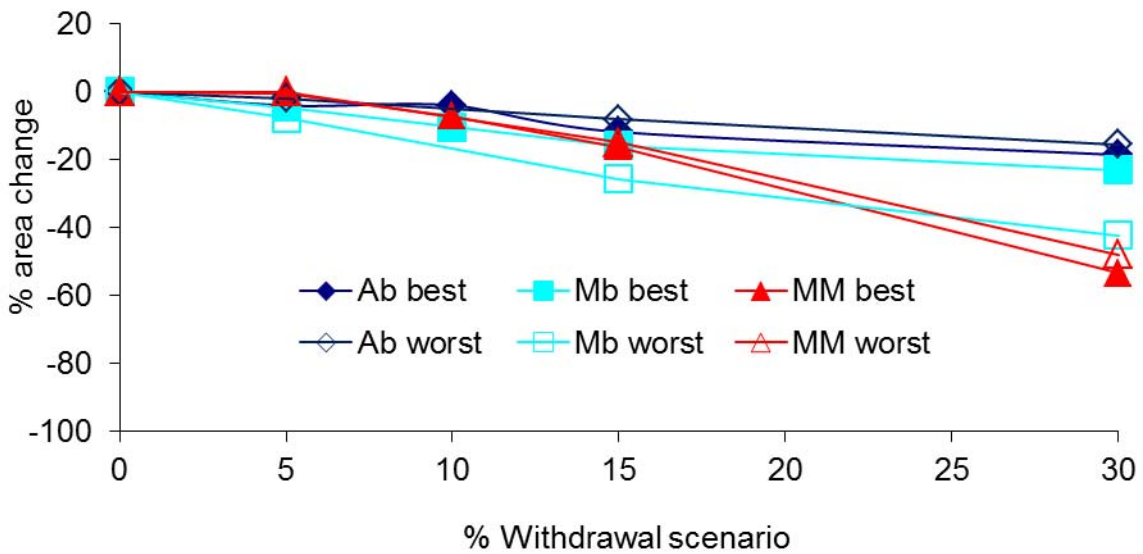


Figure 7c. Pine hardwood lowland

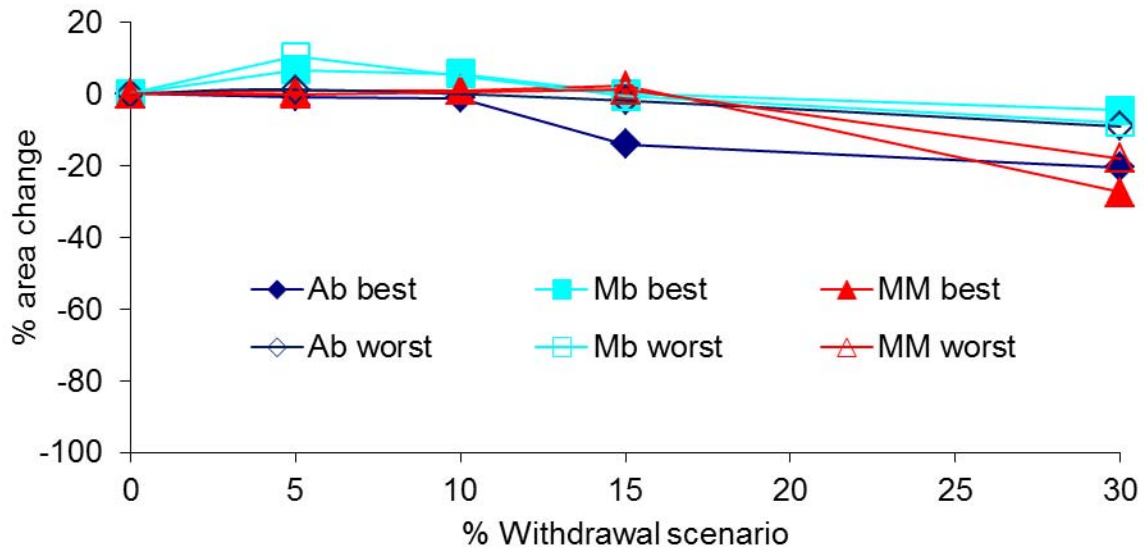


Figure 7d. Pitch pine lowland

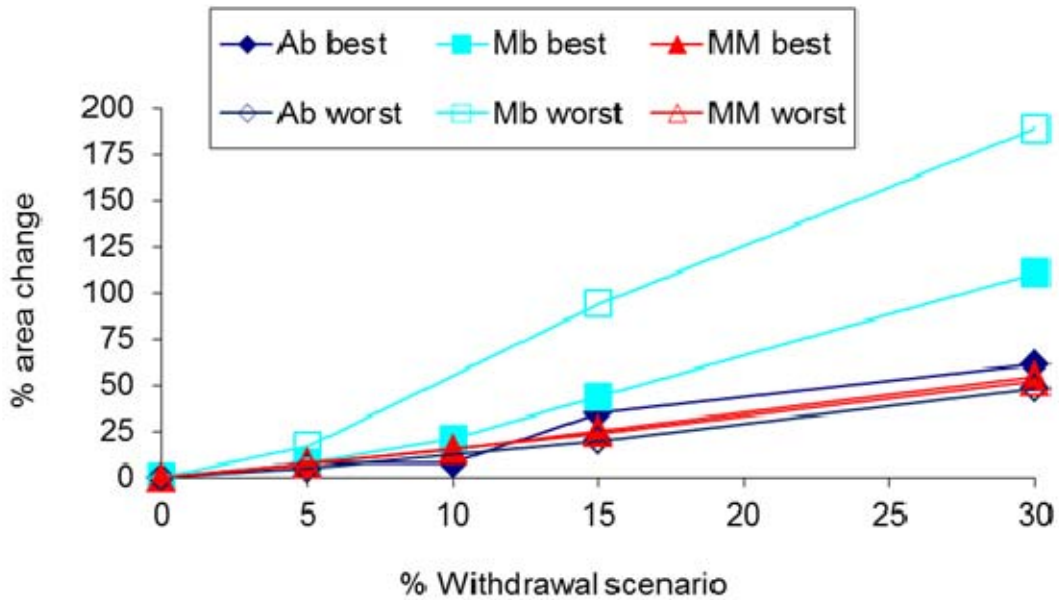


Figure 7e. Pine oak upland

### *Dominant Vegetation Type Modeling*

The 'winner' (i.e., the vegetation type with the maximum probability of occurrence) was determined for every grid cell in the raster for each water level scenario. Figure 8 compares the dominant vegetation type response for the Best vs. Worst case scenarios for each study basin separately. Overall, the Best vs. Worst case scenarios within a basin exhibited very similar patterns of the dominant vegetation type response (e.g., Figure 8a vs. 8b; 8c vs 8d; 8e vs. 8f). While both the Best and Worst case conditions for Albertson Brook and McDonalds Branch basin exhibited a steady but gradual decline in for all three wetland community types, Morses Mill Stream displayed a slightly different pattern (described below). In all cases, cedar swamp showed the greatest % area decline. Albertson Brook and McDonald's Branch exhibited the smallest % decline in cedar swamp areas with values from -37 to 49% (respectively, Figures 8a and 8c) for the Best Case scenario.

Worst case scenarios had somewhat lower % declines (-43 and -71% respectively, Figures 8b and 8d). Morses Mill Stream had larger % declines in cedar swamps of 80 and 85% for the Best and Worst cases respectively with a more rapid decline at lower groundwater withdrawal rates before leveling off slightly (Figures 8e and 8f). Pine-hardwood lowland exhibited greater % declines as compared to pitch pine lowland in all cases except one (Albertson Brook Best case scenario). In Morses Mill Stream basin, pine-hardwood held steady at 5% withdrawal rates before declining to over -66% at 30% groundwater withdrawal rates, while the pitch pine lowland held steady to 15% withdrawal rates before declining and then only to 20-29% of baseline conditions (Figure 8e and 8f). In all cases pine-oak upland steadily increased in dominance as groundwater withdrawal rates increased.

Examination of the mapped outputs for the Baseline vs. Best30% withdrawal scenario (Figure 9) illustrates the patterns described above with cedar swamp and pine hardwood lowland showing the greatest decline across all three basins. The headwaters for Albertson Brook basin (Figure 9a Inset) shows a replacement of cedar swamp and pine hardwood lowland with pitch pine lowland and pine oak upland. McDonalds Branch basin shows a similar pattern in the spatial distributions of the vegetation communities though cedar swamp remains as a narrow band along the main stem (Figure 9b). At the high levels of withdrawal, cedar swamp is largely eliminated from Morse Mill Stream basin (Figure 9c).

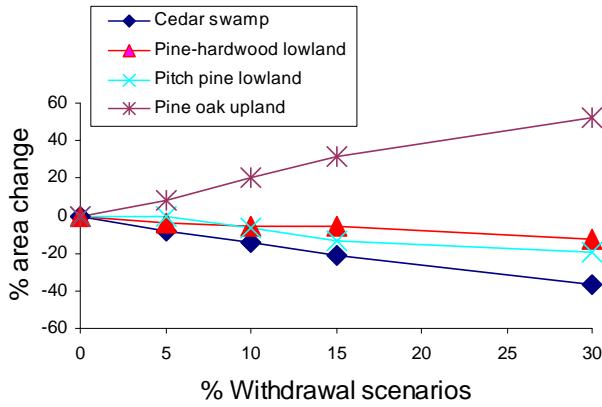


Figure 8a. Albertson Brook - Best case.

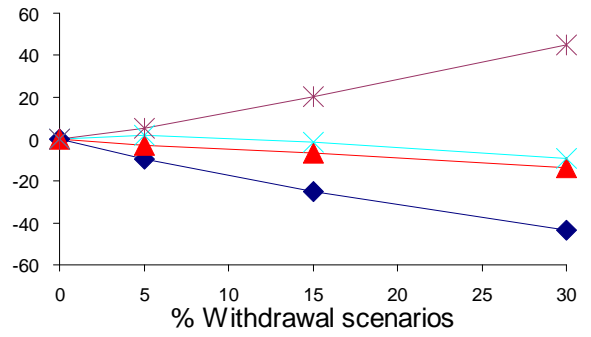


Figure 8b. Albertson Brook – Worst case.

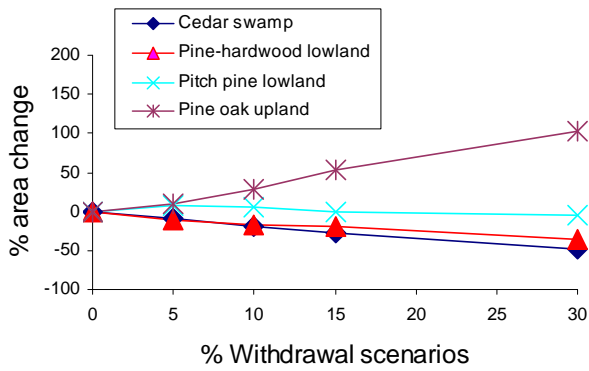


Figure 8c. McDonalds Branch – Best case.

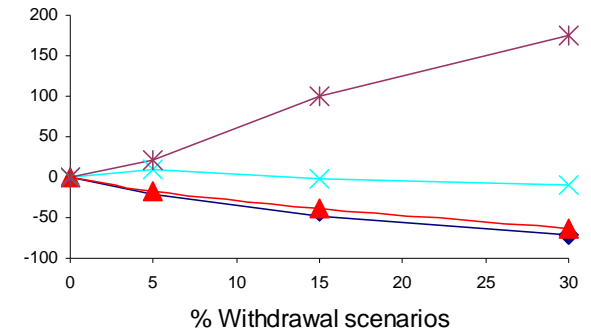


Figure 8d. McDonalds Br. – Worst case.

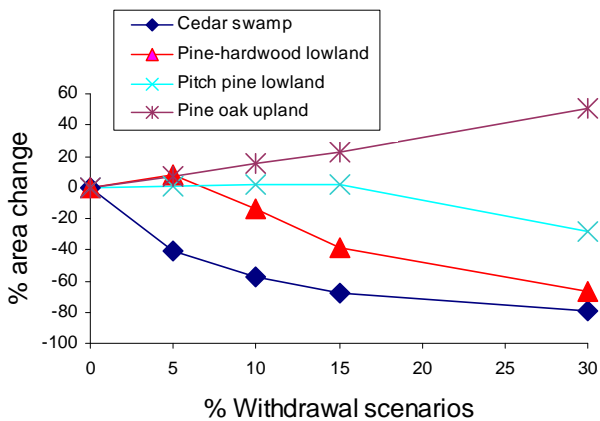


Figure 8e. Morses Mill Stream – Best case.

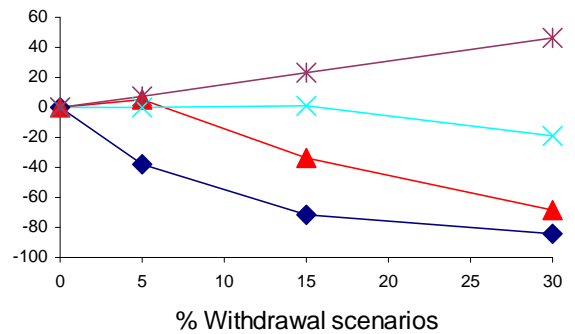
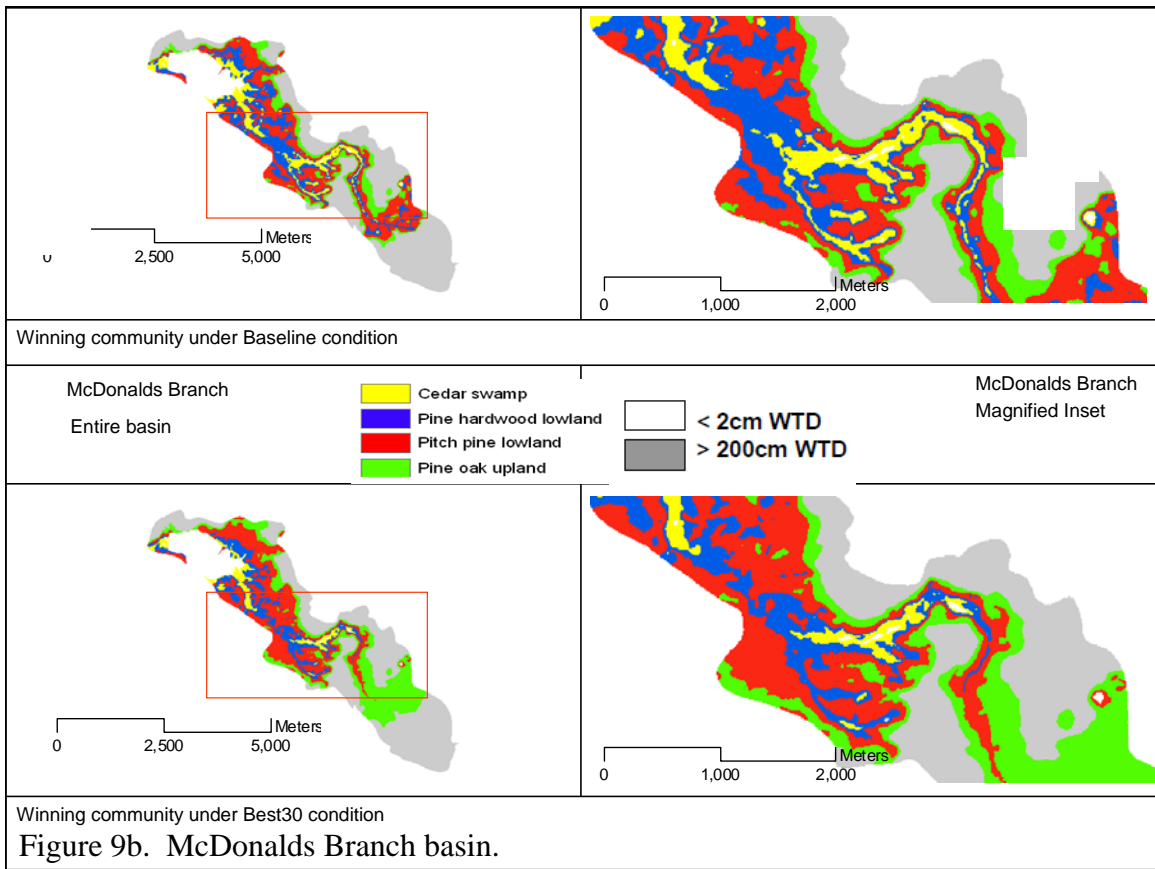
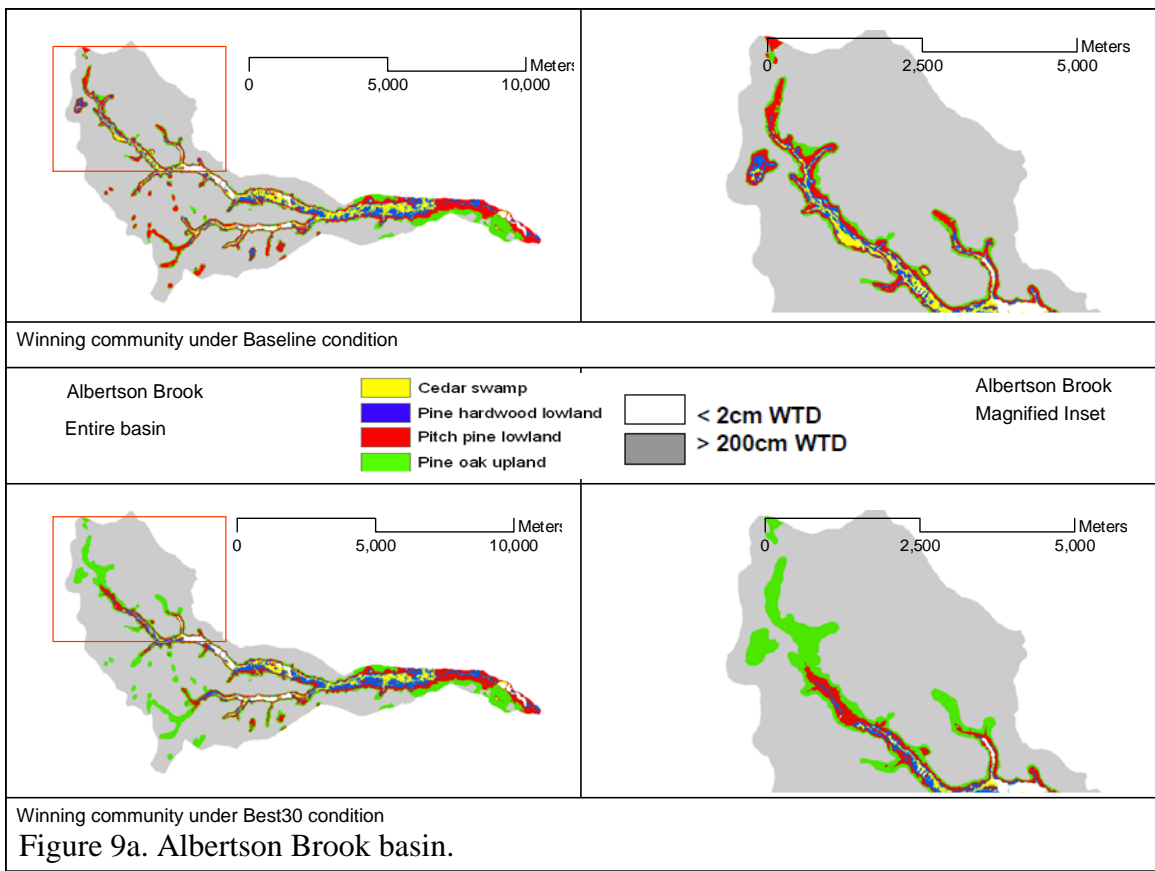


Figure 8f. Morses Mill Str. – Worst case.

Figure 8. The percentage change in area of the dominant vegetation type (“winner”) from baseline conditions under various water-withdrawal scenarios for the four wetland types in each basin.



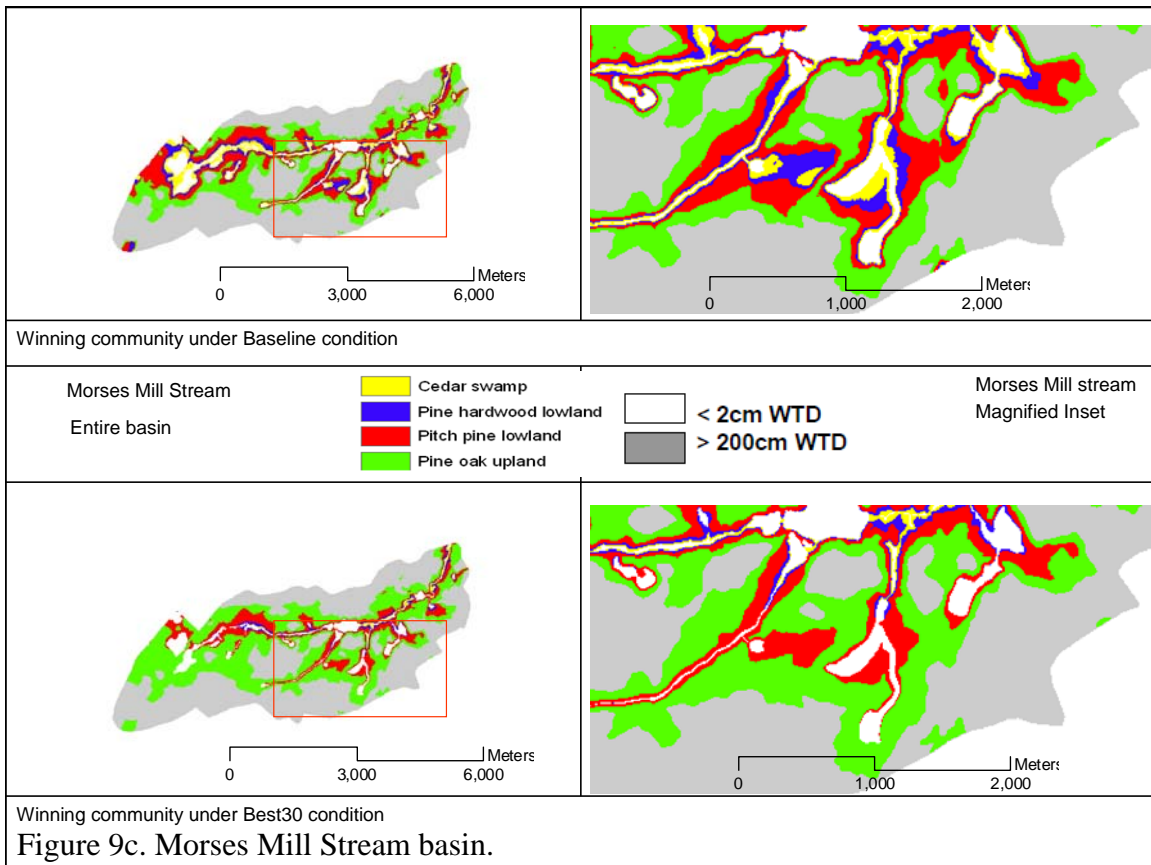


Figure 9. Study basin maps depicting areas where ‘winner’ wetland vegetation community dominates under Baseline and Best 30 conditions.

A GIS cross-tabulation of the baseline vs. the individual scenarios was undertaken to produce from-to change maps (e.g., identify a pixel as going from one ‘winner’ community to another as the water levels decline). These From-To maps were summarized as Figure 10. In Albertsons Brook and McDonalds Branch basin there is a progressive replacement of communities along the gradient (i.e., cedar and hardwood swamp is replaced by pine hardwood lowland which in turn is replaced by pitch pine lowland) at low to moderate levels of groundwater withdrawal (i.e., 15% or less). The pattern becomes a bit more complex at 30% withdrawal rates with some ‘jumping’ across the gradient (i.e., pine hardwood lowland replaced by pine oak upland). This more complex pattern is even more pronounced in Morses Mill Stream basin with significant amounts of ‘jumping’ occurring even at 15% withdrawal rates. For example, the Best 30% withdrawal scenario in Morses Mill Stream basin drops the water table to such an extent in some locations that cedar swamps are replaced directly by pitch pine lowlands and pine oak uplands (Figure 10a).

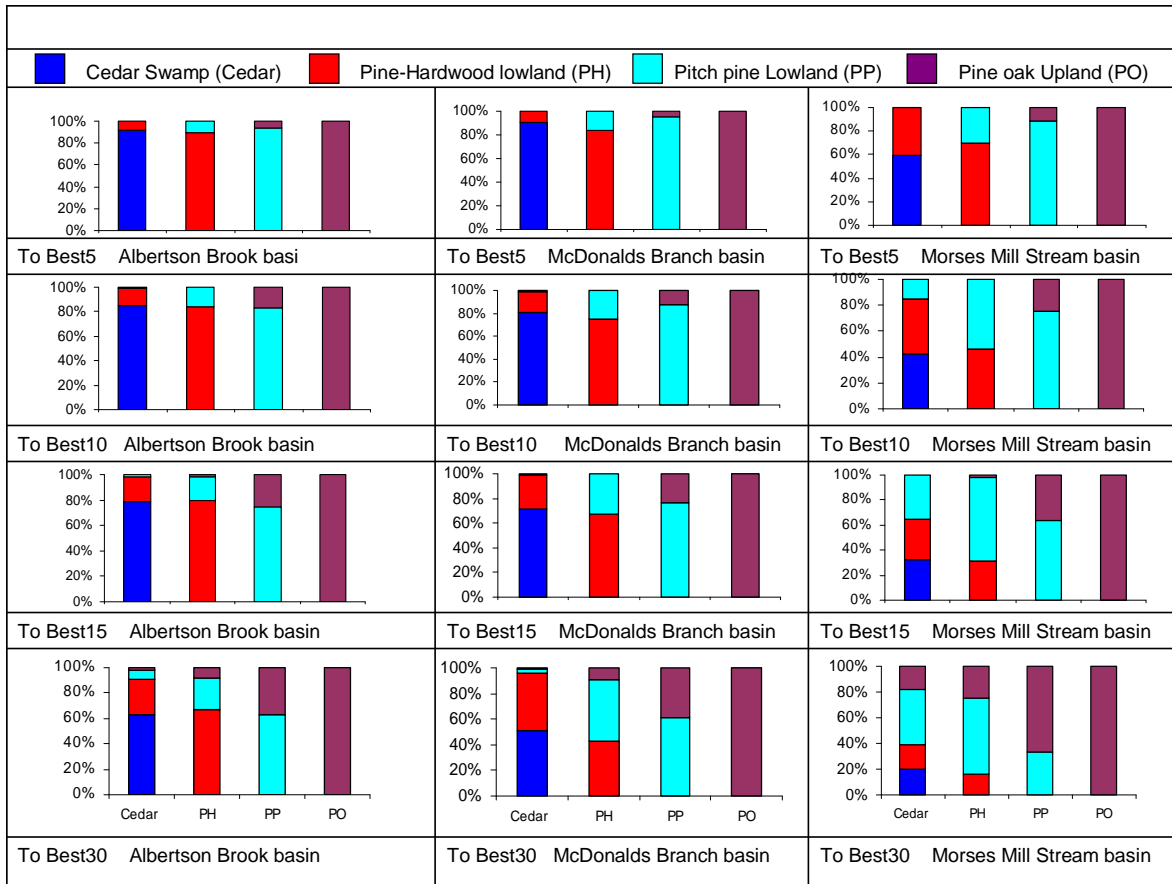


Figure 10a. Best case scenarios.

Figure 10. From-To change for ‘winning’ wetland community from Baseline condition to each Best and Worst case scenario. Each bar represents the proportion of the baseline community type that remained the same or changed. For example, for the baseline to Best30 simulation in the Albertson Brook basin, 63% of the baseline cedar area remained cedar, whereas 28% became pine-hardwood lowland, 7% became pitch pine lowland, and 2% became pine-oak upland.

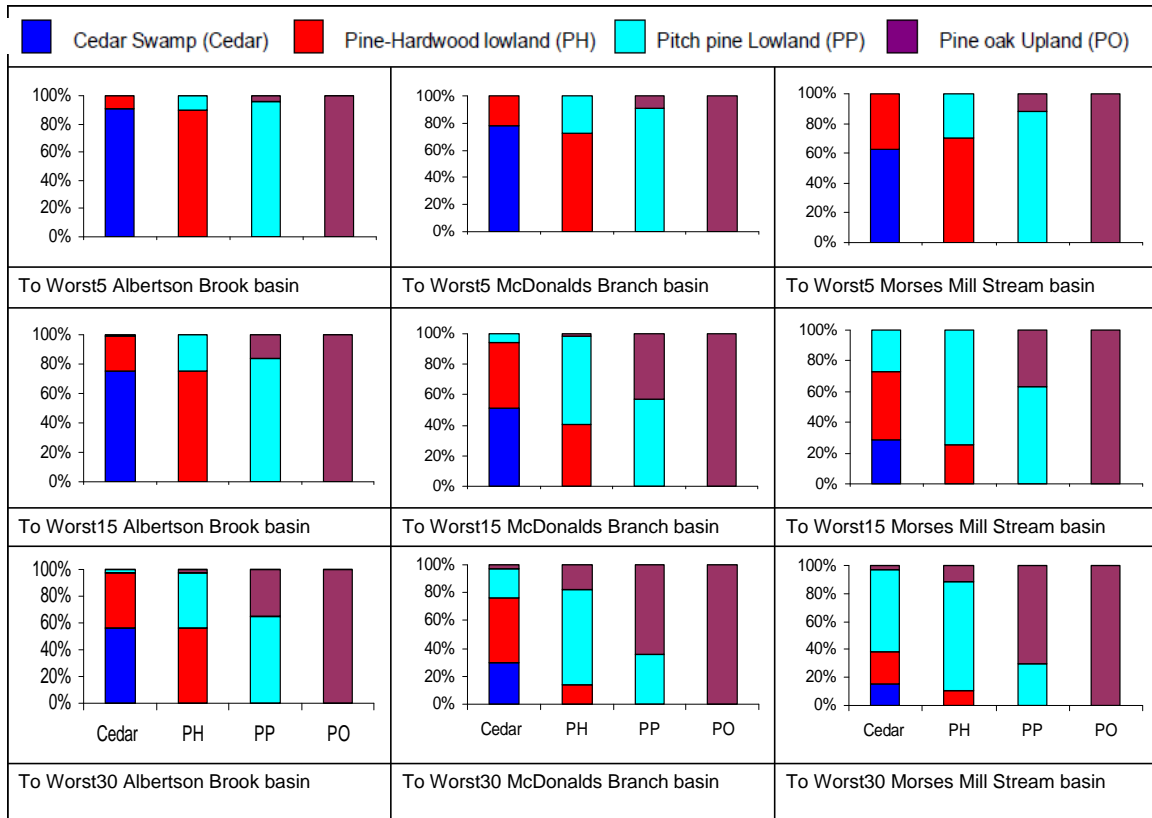


Figure 10b. Worst case scenarios.

### Fragmentation Effects

In all three study basins, as the water table drops and the overall area of wetland vegetation types decrease, individual wetland patches shrink in size, with some disappearing entirely. From a landscape perspective, the wetland vegetation community starts to fragment from a largely contiguous complex into smaller, more isolated patches surrounded by pine-oak uplands. During the initial phases of the fragmentation process, the number of patches often first increases as single large patches are fragmented into many smaller patches (Franklin and Forman, 1987). In this study, as the depth to water table increases due to groundwater withdrawal, some areas of the basin may no longer represent suitable conditions for the existing vegetation community type, fragmenting what once was a contiguous patch to smaller patches where conditions are still suitable. With successively larger groundwater withdrawals, more advanced fragmentation is evident with the number of patches declining as individual remnant patches disappear. The result is an overall simplification of the spatial pattern of the wetland community mosaic due to a lower number and smaller size of wetland vegetation patches. Due to its larger size and more heavily altered landscape (i.e., already fragmented), Albertson Brook basin has a higher number of wetland vegetation patches as compared to McDonalds Branch and Morses Mill Stream basins (Table 4). In Albertsons Brook and McDonald's Branch, all three wetland vegetation types decline in patch number between

the Baseline and Best30 conditions. In most cases the mean and median patch size also decline except for pine hardwood lowland in Albertson Brook and cedar swamp in McDonald's Branch. Morses Mill Stream basin exhibits more varied fragmentation behavior with pine hardwood patches as declining significantly in number, cedar swamp holding steady while the number of pine lowland patches increases greatly. In all three cases, mean/median patch size decline. Across all three study basins, the number of pine oak upland patches decreases as these patches increase in size and start to coalesce.

Table 4. Number of patches of the four vegetation community types for Baseline and Best30% scenarios for the three study basins: Albertsons Brook (AB), McDonalds Branch (MB) and Morses Mill Stream (MM). Hardwood swamp was excluded from this analysis.

		Baseline scenario			Best30 scenario		
AB basin	TYPE	Patch number	Mean patch area (ha)	Median patch area (ha)	Patch number	Mean patch area (ha)	Median patch area (ha)
	Cedar swamp	432	0.52	0.02	374	0.38	0.02
	Pine hardwood lowland	481	0.63	0.03	368	0.72	0.02
	Pitch pine lowland	171	2.97	0.04	148	2.77	0.04
	Pine oak upland	46	9.00	0.22	41	15.42	0.89
	Total	1130			931		
MB basin	Cedar swamp	61	1.66	0.04	27	1.91	0.18
	Pine hardwood lowland	45	4.84	0.06	42	3.30	0.04
	Pitch pine lowland	34	9.21	0.28	26	11.49	0.57
	Pine oak upland	29	4.80	0.51	17	16.58	0.37
	Total	169			112		
MM basin	Cedar swamp	87	1.23	0.02	89	0.25	0.02
	Pine hardwood lowland	163	0.71	0.04	89	0.44	0.02
	Pitch pine lowland	14	21.65	0.42	37	5.82	0.02
	Pine oak upland	11	44.55	2.54	9	81.86	1.10
	Total	275			224		

## Conclusions

The wetland indicator modeling suggests that the area dominated by wetland-indicator species will decline with increased groundwater withdrawal due to the predicted drop in water table. While some patterns revealed in the results are reasonably consistent across basins, other changes are a function of the unique topographic form and hydrologic characteristics of a particular basin. At the highest level of groundwater withdrawal modeled (30% of basin recharge), the decline in area dominated by wetland-indicator species is predicted to range from a low of 25-27% in Albertson Brook basin to approximately 90% in Morses Mill basin. Two of the study basins, Albertsons Brook and Morses Mill Stream, did not exhibit much difference in response between the Best and Worst case withdrawal scenarios. Thus it does not appear that shifting the well locations (i.e., Best vs. Worst case) has an overriding impact in these two basins. McDonalds Branch exhibited a greater shift in response between the Best and Worst case scenarios (e.g., 46% to 72% decline in wetland indicator area, respectively at 30% withdrawal). While the overall amount of pumping as a function of basin recharge is the critical factor, well location appears to play a larger role in McDonalds Branch, as compared to the other two study basins. .

A number of factors likely control the response of the wetland indicator and vegetation type distribution as groundwater withdrawal increases including the configuration of the underlying topography and stream channel network. Charles and Nicholson (2010) identified three major factors contributing to differences in the wetland drawdown response among the study basins: 1) average distance between wetlands and surface water (i.e. streams and lakes); 2) hydrogeologic properties; and 3) average distance from wetlands to the nearest potential pumping-well site. The average distance from wetlands to the nearest potential pumping-well site is a function of basin characteristics that control where pumping is feasible, given required setback from wetlands and surface water, along with consideration for whether "best case" or "worst case" well siting is assumed. The static basin characteristics that appear to affect this distance factor (# 3 above) are the percentage of the basin in wetlands and average distance to streams.

McDonald Branch basin features a flat topography with extensive areas of shallow depth to water table and correspondingly a greater percentage of basin area is comprised of wetlands (over 30%) (Table 1). At lower rates of groundwater withdrawal (i.e. 5-10%) regions with a shallow water table depths suitable for cedar swamp and hardwood swamp are still extensive (i.e., <40cm water table depth, Figure 3). Higher levels of groundwater withdrawal within the McDonalds Branch basin resulted in a significant loss of wetland indicator area in the headwaters and an overall decline (lateral retreat inwards towards the stream and riparian zone) elsewhere within the basin. Alberston's Brook basin has the lowest % of the basin in wetlands (11%, Table 1) with most of the wetlands area occurring in the relatively broad and flat riparian zone of the central and lower portion of the basin. This riparian zone has comparatively high water table depths and wetlands in close proximity to surface waters. Within the Albertson Brook basin, most of the loss in

wetland indicator area is focused on the headwaters. Examination of the black & white aerial photographs from the 1930's shows that the central and lower portion of the Albertson Brook basin was heavily impacted by the construction of a series cranberry bogs that may have resulted in an alteration and homogenization of the riparian zone topography. Morses Mill Stream basin has the greatest average distance between wetlands and surface water (186 m vs. 144m and 109 m for McDonalds Branch and Albertson Brook respectively) (Charles and Nicholson 2010). The model results suggest that comparatively low rates of groundwater pumping (i.e., 10-15% of basin recharge) will greatly reduce the wetland indicator area. The distribution of the most sensitive woody wetland types (i.e., cedar and hardwood swamps) will be greatly reduced except in close proximity to the stream corridor.

The individual wetland vegetation type modeling, predicts that the four woody wetland vegetation types (i.e., cedar swamp, hardwood swamp, pine-hardwood and pitch pine lowland) will decline in area at the highest levels of groundwater withdrawal modeled (i.e., 30% of basin recharge). The results suggest that cedar and hardwood swamps which are at the wettest end of the water table gradient will show the greatest percent declines in area. In the case of Morses Mill stream basin, the predicted decline in cedar swamp area was over 90% at the 30% withdrawal rate. The landscape modeling suggests that at the higher levels of groundwater withdrawal the decline of wetland area will be especially severe in the upper headwaters of the basins, and that there will be 'retreat' of existing wetlands to a narrower streamside corridor. In addition to the predicted decline in area of the various woody wetland vegetation community types, the landscape modeling also suggests that there will be a change in the broader landscape pattern with a fragmentation of the wetland mosaic. As groundwater withdrawal increases, later stages of fragmentation are evident with the number of patches declining as individual remnant patches disappear. The result is an overall simplification of the spatial pattern of the wetland vegetation community mosaic due to a lower number and smaller size of vegetation patch types.

In linking the distributions of woody wetland types or assemblages of an individual species to natural and induced changes in water levels through our modeling framework, a community gradient approach is employed. The assumption is that there is a stable equilibrium between the present vegetation community characteristics and the underlying environmental characteristics. Water table flux due to groundwater pumping will induce both short and long term impacts on the wetland communities. In the short term, the effects can be exhibited as physiological state changes such as transpiration and photosynthesis. It is expected that different species will respond differently, disrupting the existing community composition. In the long term, lowering water tables will impact the spatial distribution of individual species through the processes of competition, dispersal and establishment. As has been suggested by Laidig et al. (2010), in the absence of disturbances such as fire and timber harvesting, the transition to a new stable vegetation community, especially when considering longer-lived woody species, may take many years. We are assuming that as the hydrological regime changes, there will be a predictable shifting of the location of the existing vegetation communities but that there will not major changes in the composition of the individual community types or their

‘preferred’ relationship to water table depths. In other words, we are assuming that the vegetation communities will reach a new future equilibrium while still operating under the same basic ‘ground rules.’ The landscape vegetation modeling results described above should only be interpreted in this context.

While the wetland indicator/vegetation type modeling should be more broadly applicable to elsewhere within the Pinelands, we were only able to map the models onto the landscape in these three study basins where detailed depth to water table mapping was available. This same mapping approach could be applied elsewhere within the Pinelands where similar detailed depth to water table mapping is available.

## References

- Charles, M., and R. S. Nicholson. 2010. Simulation of Groundwater Flow and Hydrologic Effects of Groundwater Withdrawals in the New Jersey Pinelands. U.S. Geological Survey Scientific Investigations Report 2010–xxxx (in preparation). West Trenton, NJ.
- Dahl, T.E. and G. J. Allord. 1996. History of Wetlands in the Conterminous United States. In U.S. Geological Service Water Supply Paper 2425. On-line version <http://water.usgs.gov/nwsum/WSP2425/history.html>.
- Franklin, J.F. and R.T.T. Forman. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. *Landscape Ecology* 1:5-18.
- Laidig, K. J., R. A. Zampella, A. M. Brown and N. A. Procopio. 2010. Development of vegetation models to predict the potential effect of groundwater withdrawals on forested wetlands. Pinelands Commission, New Lisbon, New Jersey, USA.
- McGarigal, K., S. A. Cushman, M. C. Neel, and E. Ene. 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: [www.umass.edu/landeco/research/fragstats/fragstats.html](http://www.umass.edu/landeco/research/fragstats/fragstats.html)
- Mitsch, W. J. and J. G. Gosselink. 2000. *Wetlands*. Third Edition. John Wiley and Sons, Inc., New York, NY, USA.
- Kentula, M. E. 1996. Wetland restoration and creation. Pages 87-92 in J. D. Fretwell, J. S. Williams, and P. J. Redman, editors. National water summary of wetland resources. U.S. Geological Survey Water-Supply Paper 2425. U.S. Government Printing Office, Washington, D.C., USA.
- Walker RL, Reilly PA, Watson KM. 2008. Hydrogeologic framework in three drainage basins in the New Jersey Pinelands, 2004–06: U.S. Geological Survey Scientific Investigations Report 2008–5061. West Trenton, NJ.