HYDROLOGIC ANALYSIS OF THE WETLAND HABITAT OF THE FEDERALLY THREATENED BOG TURTLE

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Abstract: Protecting the natural environment while fostering local development is one of the main challenges that engineers face today. New species are added to the federally threatened and endangered species lists as their habitats are altered or destroyed by development. The bog turtle (*clemmys muhlenbergii*) is threatened by new development that damages not only its wetland habitat, but the upland areas that store and discharge water into the wetlands. The bog turtle is one of the smallest North American turtles with the adults reaching only 10 to 11 centimeters in length. They are a fresh water turtle that inhabits open wet meadows, shallow water marshes, spring seeps, flood plain wetlands, bogs, and fens. Destruction of habitat and illegal capture have caused significant declines in turtle populations. The bog turtle was listed as federally threatened in 1997. Protection of bog turtle habitat is a concern to many state and local governments because the bog turtle's habitat is often located in prime land slated for commercial, residential, and transportation related development. Until recently, there was little information available about the source water that feeds these wetland habitats. The Maryland State Highway Administration (MDSHA), in conjunction with other Maryland and federal agencies, has formed a biological assessment team in order to develop a protection plan for one such bog turtle habitat by investigating the hydrology associated with bog turtle habitats.

The hydrologic assessment conducted by Parsons Brinckerhoff and the MDSHA had five primary components: 1) field monitoring; 2) surface water modeling; 3) groundwater modeling; 4) evaluation of hydrologic impacts of proposed development scenarios; and 5) recommendations to minimize the impacts of development on the wetlands and to maintain the hydrology of the bog turtle wetlands.

Although there has been much recent research on the habitat, genetics, and movements of bog turtles, this is the first large scale study of the hydrology of the bog turtle habitat. An extensive field monitoring network has been installed throughout the 1.9 km^2 watershed, including 15 mechanically dug monitoring wells (approximately 15 meters deep), 42 shallow, hand-dug piezometers (1.2 to 2.8 meters deep), six streamflow gages with low flow weirs, two precipitation gages, and an evaporation pan. The field data were used to set up and calibrate the groundwater and surface water flow models. Low flow weirs constructed at a series of gaging stations allowed the computation of both baseflow and stormflow conditions. Although the surface and groundwater modeling of the wetland habitat is complete, field monitoring at the site will be ongoing until after the completion of the proposed highway bypass.

The bog turtle habitats within the project area are predominately groundwater fed. Although the proposed highway bypass and associated development does not directly contact the bog turtle wetlands, the secondary and cumulative impacts resulting from the loss of groundwater recharge do. The hydrologic impacts on the bog turtle wetlands were determined for three proposed development scenarios. The first scenario analyzed was the construction of the highway bypass only. The roadway construction with proper stormwater management was determined to have a minimal effect on the hydrology of the bog turtle wetlands. The MDSHA was considering the construction of a flyover ramp in order to provide access from the proposed bypass to a proposed industrial park in trade for right-of-way donation. Thus, MDSHA had to consider the secondary and cumulative impacts of the industrial park development on the sensitive bog turtle wetlands. The second scenario was the industrial development located east of the proposed bypass and the third scenario was the industrial development located both east and west of the proposed bypass and near the sensitive wetlands. Groundwater and surface water models were developed for each modeling scenario. The results of the groundwater and surface water modeling showed that construction of the proposed industrial park may be potentially harmful to the sensitive wetland habitats.

The results of the hydrologic modeling were used in conjunction with the results of a separate biological study of the bog turtle to develop an impact mitigation plan. One of the primary components of the mitigation plan was identification of the Zone of Primary Hydrologic Influence. Land use changes within this zone have the potential to cause detrimental impacts to the bog turtle wetlands. Thus, special measures are needed in order to protect the sensitive wetland habitat. Recommendations regarding suggested recharge rates and stormwater management practices within this zone were made to minimize the hydrologic impacts to the bog turtle habitat.

The information gained in this study will be used as input to develop the first major bog turtle preserve in the state of Maryland. It is hoped that the information will also be valuable to other states who are facing similar declines in their bog turtle or other hydrologically sensitive habitats and populations.

Introduction

As part of the biological assessment effort, Parsons Brinckerhoff was commissioned by the Maryland State Highway Administration (MDSHA) to compute a hydrologic analysis of several bog turtle habitats that may be impacted by a proposed highway bypass and commercial/industrial development. Because Maryland is the home to numerous bog turtle wetlands, this study is likely to serve as a model for future studies in determining the hydrological impacts of development on bog turtle wetlands. This project is unique because it provides local planners and regulatory officials with a scientific model that is able to show the impacts that upland development can have on bog turtle wetlands. Although a limited number of modeling scenarios were examined for this study, future land use proposals can be analyzed as they become available.

Bog Turtle Background

Bog turtles are a freshwater species that inhabit shallow spring-fed fens, sphagnum bogs, swamps, open wet meadows, spring seeps, open canopies, pastures that have soft, muddy bottoms, and clear, cool, slow-flowing water often forming a network of rivulets (Shiels 1998, USFWS 1997, Howard 1999). Their habitat is widely scattered across the eastern United States from northern Georgia through the lower New England States. A study by the Maryland Department of Natural Resources (Smith 1994) suggested that there was a 43% decline in bog turtle populations over a fifteen-year period, and recommended that the bog turtle population be listed as threatened by the state of Maryland. Several other states along the East Coast were reporting similar findings (Howard 1999). Therefore, in November 1997, the northern populations of the bog turtle were listed as federally threatened.

Loss of habitat is one of the primary reason for declines in the bog turtle populations in recent years. Land development; draining and filling of wetlands for agricultural, commercial, and residential use; pollution; and other poor land-use practices have all contributed to the decline of turtle populations. At one time, most bog turtle habitats were connected by waterways and wetlands, which allowed individuals in adjoining populations to mingle and maintain the genetic diversity of the species. Bog turtles prefer to live in "early successional" open meadows and fields with open canopies. As open-canopy wetlands are slowly invaded by woody vegetation, they undergo a transition and become closed-canopy, woody swamplands that are unsuitable for habitation by the bog turtle. Historically, as succession occurred, the turtles would move on to other open-canopy wetlands within the adjacent area (NJ FG 2000). However, due to increasing development, the areas in which turtles can migrate have become extremely fragmented.

Site Description

PB examined two primary bog turtle sites in this analysis. Each site is located near perennial streams and numerous groundwater seeps and springs. Bog turtles burrow into the soft, mucky wetland substrate up to 60cm below the ground surface. The wetlands in this study experience year-round artesian conditions. The artesian conditions create a "quick" mud condition allowing the turtles to easily burrow into the ground. The continuous groundwater flow into the wetland helps to maintain a relatively constant wetland temperature.

Site #1 is located in the northern portion of the study area close to agricultural farmland and a residential sub-division. It contains one bog turtle wetland and is comprised of 10% wetlands and 9% impervious area such as roads and buildings. The contributing watershed area is 0.2 km^2. A small stream runs directly through Site #1.

Site #2 contains two prime bog turtle habitats (#2a and #2b) and is currently agricultural and forested lands. It is comprised of 4% wetlands and 3% impervious area with a contributing watershed area of 1.5 km^2. Site #2 contains three streams that join just downstream of the bog turtle habitat #2b (Figure 1).

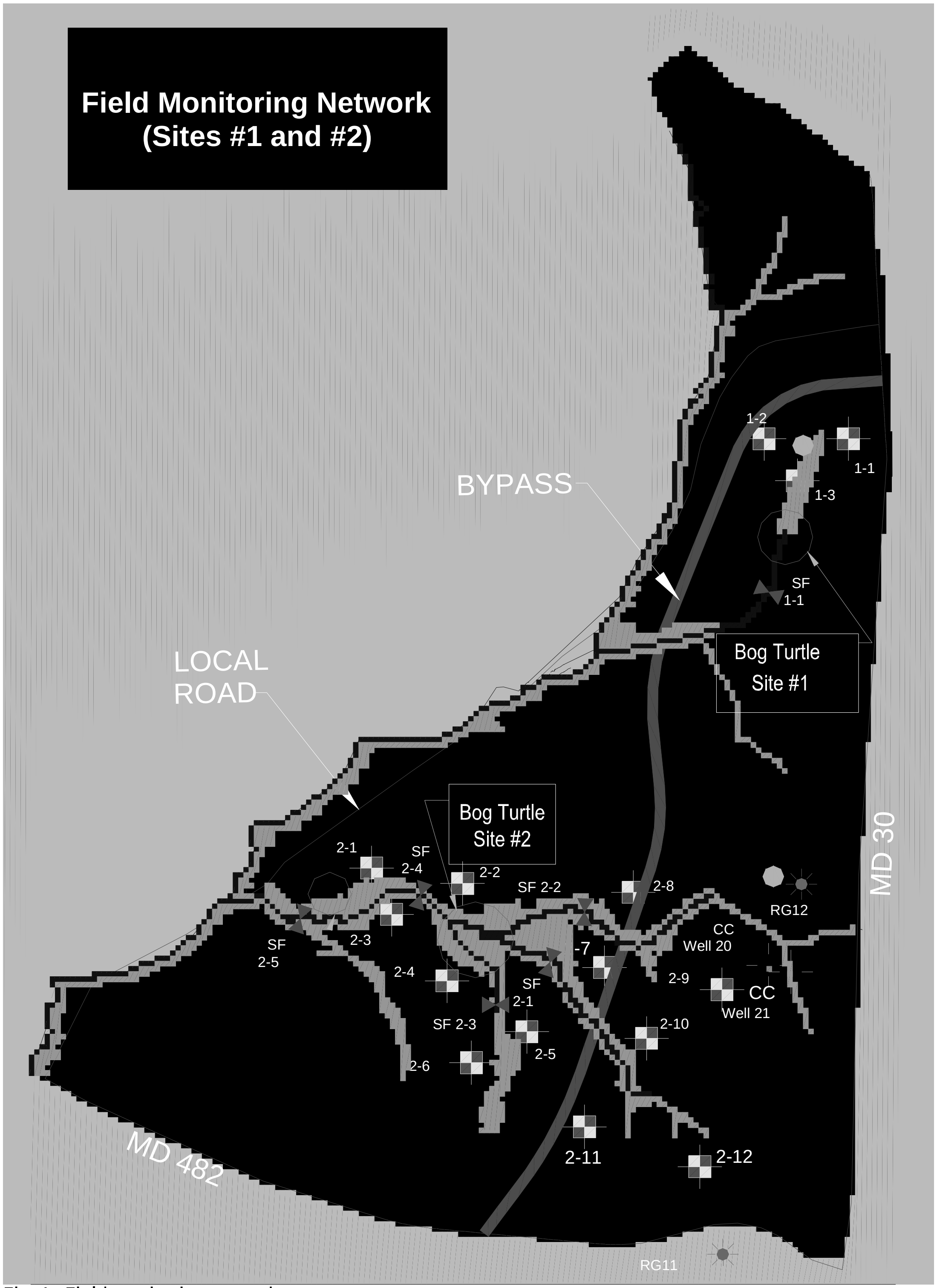

Fig. 1: Field monitoring network
None of the streams run directly into either bog turtle habitat. Local developers want to convert the current agricultural and forested lands into an industrial park. Because the bypass may include a fly-over ramp that will provide access for the industrial park to the new roadway, the impacts of the industrial park must be included as a secondary and cumulative impact of the roadway.

Project Objectives

The main focus of the overall study was to determine the primary hydrologic sources to the bog turtle wetlands. An extensive field monitoring network was established throughout the study area to provide baseline hydrologic data. Preliminary field data was used to develop conceptual surface and groundwater models of the bog turtle habitats and surrounding areas. The final field monitoring data produced annual values of precipitation, evapotranspiration, recharge, runoff, and baseflow for each of the sub-watersheds. These data was used as inputs to develop existing condition surface and groundwater models. The results of the surface water modeling and field data collection were used as inputs into the groundwater modeling portion of this research. The existing conditions models were modified to incorporate changes caused by the three proposed development scenarios: 1) construction of a highway bypass; 2) construction of a highway bypass and an industrial park in the eastern portion of Site #2; and 3) construction of a highway bypass and an industrial park covering the majority of Site #2.

Field Network

Field monitoring began in May 1999, and continued through late October 2000. The primary objective of the field monitoring was to establish baseline data regarding both surface and groundwater flows in the subject watershed. Fifteen mechanically dug monitoring wells (approximately 15 to 30 meters deep) were installed throughout both project sites. Forty-two shallow, hand-dug piezometers (approximately 1 to 3 meters deep) were nested in and around the sensitive wetlands. Six streamflow gages and low-flow weirs were constructed on the major tributaries at each of the habitat sites. An evaporation pan was located at each site. Two precipitation gages were also located within the study area. Figure 1 shows the locations of the field monitoring devices within the study area.

Site #2 was given the highest priority due to the quality of the wetland, number of bog turtles found at this location, the proximity of the highway bypass, and the potential development of the upland areas into an industrial park. Additional soils testing and water sampling were also performed at this location. Site #1 is similar to Site #2 in that it has a quality bog turtle habitat and is in close proximity to the proposed bypass. However, the contributing watershed of Site #1 is considerably smaller than Site #2.

The deep wells, streamflow gages, and precipitation gages were continuously monitored at fifteen-minute intervals. The piezometer water levels were read on a weekly basis and after major precipitation events. Evaporation pan water levels were measured on a daily basis. A database was created to store all of the hydrologic data for future use.

Hydrologic Inputs

The bog turtle habitats in this study receive their primary water supply from groundwater sources and secondary supply from surface water sources. Although Site #1 has a small stream running directly through the wetland, this stream dries out periodically throughout the year. Site #2 does not have any streams running directly through it. Field observations during the first summer of field monitoring confirmed that groundwater discharges were vital to wetland survival. In 1999, Maryland experienced one of its worst droughts of the century and although the amount of surface water and precipitation supplied to the wetlands dramatically decreased, the wetlands never completely dried up. The drought of 1999 was the third dry year in a row for Maryland, and caused dramatic decreases throughout the region in available water supply in both reservoirs and from groundwater. Because the first year’s monitoring demonstrated the importance of groundwater in maintaining the bog turtle wetlands, a detailed groundwater model was developed in order to more accurately simulate the impacts of development on the local wetlands.

Surface Water Modeling

Surface water modeling and calibration was performed based on streamflows measured at the streamflow gages. Baseflow and runoff values obtained at each of the gages were used in the calibration of the groundwater model. The surface water field monitoring network consisted of six weirs and continuously recording water level gages. After defining the existing hydrologic conditions of the study area, runoff estimates were developed for each of three proposed development scenarios. Runoff estimates were developed and distributed using NRCS (1986) methods as a foundation in accordance with standard Maryland procedures.

Surface Water Measurements
At each gage, water surface elevation measurements were continuously recorded at fifteen-minute intervals. Applying the appropriate weir equation to the flow depth results in the determination of a flow rate in the channel at that time. From the discrete flow rate, the flow volumes over the weirs are determined. This flow volume from each gaged basin is transformed into runoff depth over the contributing watershed for the period of the study with weirs in place (April 2000 - October 2000). Two of the flow monitoring gages were in place for the duration of the study, however weirs were not in place at the beginning of the project (May 1999 - March 2000). For this time frame, flow rates were determined from channel rating curves developed in HEC-RAS (v.2.2) based on the measured channel geometry. Knowledge of the flow volumes in these streams allowed for the estimation of the flow volumes at the other gages prior to the construction of their flow gages. The estimated yearly runoff for each gage is summarized in Table 1.

Distribution of Runoff Volume
The groundwater model allows for spatial distribution of runoff values. Therefore, an annual runoff volume for each land-use category within each sub-basin was determined by distributing the measured runoff. This was accomplished by assuming all rainfall becomes runoff for impervious areas. The remaining runoff volume is distributed over pervious areas based on a weighting of the curve number for each land use.

Proposed Condition Surface Water Modeling
Three proposed conditions were considered in this analysis: 1) construction of highway bypass only; 2) construction of highway bypass and an industrial park east of the Site #2 wetlands; and 3) construction of highway bypass and an industrial park both east and west of the Site #2 wetlands. All alternatives were analyzed without the benefit of stormwater management. This assumption was made in order to model the worst case scenario. Innovative stormwater management techniques may reduce the impacts of the proposed development. The annual runoff generated from each proposed land use was estimated in a similar fashion as used for the existing conditions. For all impervious land areas, all rainfall is assumed to become runoff. The runoff from the remaining pervious areas was determined based on a weighting of the land-use curve number compared to the existing conditions for each basin. Table 1 shows the estimated increase in runoff volume due to the development of Sites #1 and #2. The runoff volumes presented here are used in the groundwater model to estimate the potential groundwater recharge.

Table 1
Increased runoff due to proposed conditions.

	Avg. Existing condition runoff (in/yr)	Bypass Only Runoff (in/yr)	Percent Increase Over Existing Conditions (%)	Bypass & Half Industrial Park Development Runoff (in/yr)	Percent Increase Over Existing Conditions (%)	Bypass & Full Industrial Park Development Runoff (in/yr)	Percent Increase Over Existing Conditions (%)
Site #1	7.2	9.7	21.6	N/A	N/A	N/A	N/A
Site #2	4.5	5.4	35	20.7	360	28.2	530

Groundwater Modeling
Because groundwater sources play such an integral role in the bog turtle habitat hydrology, groundwater modeling was conducted with the modular finite-difference groundwater flow model (MODFLOW). MODFLOW was developed by the USGS to simulate common features in groundwater systems (McDonald and Harbaugh 1988; Harbaugh and McDonald 1996). MODFLOW can be used to model multi-layer, saturated, steady-state, or transient groundwater flow systems. It is one of the most widely used groundwater modeling programs in the world. Visual MODFLOW (Waterloo Hydrogeologic, v 2.8.2.49) was used to set up and analyze the MODFLOW data sets.

Conceptual Groundwater Model

The study area is located in the Eastern Piedmont province in Central Maryland where groundwater occurs chiefly in fractures in crystalline metamorphic rocks such as schist and phyllite. The area is comprised of two active flow layers representing the topsoil/saprolite and weathered/fractured rock conditions. Although the layer below the weathered/fractured rock zone is not completely impermeable, it is assumed to be a no-flow boundary because the hydraulic conductivities and permeabilities are significantly lower than the adjacent layer.

A decision was made to create one groundwater model to encompass all three bog turtle habitat sites. In the study area, it is typical for the groundwater divides to closely follow the surface water divides (Devilbiss 2000). Figure 1 shows the groundwater modeling area. Ridge lines along the southern and eastern boundaries were taken as no-flow boundaries in the groundwater model. The river that runs west of the three habitats makes the third model boundary.

Groundwater Model Grid Design

The land surface within the model boundaries is relatively steep. The maximum model relief is 282.4 meters at the northwestern boundary and 209.6 meters at the southwestern model boundary for a total relief of 72.8 meters. Because MODFLOW is not designed to handle steep changes in topography, the horizontal cell spacing was set at 15.2 meters by 15.2 meters in order to minimize impacts of steep topography in the study region.

Groundwater Model Inputs

Information for the groundwater model was obtained from several sources including local geologic reports, field measurements, and the surface water analyses. Limited geologic information was available directly inside the model boundaries. Two municipal pumping wells are located in the eastern, central portion of the model. These wells provided the only detailed geologic information in the model area. There were however, numerous geologic studies conducted within a 1 km^2 radius of the study site. Detailed soils analysis was performed in and around the wetlands in Site #2. In addition, drilling records were available for the 15 deep wells that were installed throughout the project area. The combination of this information was used to make assumptions regarding the model layer thickness and hydraulic properties.

Although there was a large volume of geologic information available within the project area, it was not detailed enough to develop a transient groundwater model. Thus, a steady state groundwater model was developed that analyzes the average annual groundwater elevation for the existing and proposed hydrologic conditions.

Annual recharge was the primary hydrologic input into the groundwater model. Annual recharge for each land use condition was determined by subtracting the annual runoff and annual evapotranspiration from the annual precipitation recorded at the site.

Annual runoff and annual evapotranspiration were determined for each existing land-use condition from the field data. The proposed conditions groundwater model assumes that only the net recharge to the land surface will change for the developed conditions. Due to lack of detailed proposed condition information, changes in surface topography were not directly accounted for in the groundwater model. Increases in impervious area in the developed conditions will increase annual runoff and thus decrease annual recharge.

Groundwater Model Calibration

Matching the observed water budget was the primary focus of groundwater modeling because it was such a critical factor in the sustainability of the wetland habitat. Head values were calibrated using the average annual water level in the 15 deep monitoring wells. Relatively uniform conductivity values were used throughout the model, except in the discharge areas. Because many of the wetlands experience artesian and even “quick-sand” conditions, the vertical conductivities in these regions were assumed to be equal to the horizontal conductivities.

Groundwater modeling was complicated by the presence of drainage tile throughout the lowlands areas. In the early part of the century, the entire model area had been used for agricultural purposes. In order to make the land suitable for farming, drainage tile had been installed throughout the lowland areas to dry out the surrounding wetlands; the model area was then farmed up to the stream. Historical aerial photographs provide important clues about the location of those drainage tiles. In addition, several tile were encountered during the installation of the shallow piezometers in and around the wetlands. The drainage tile consist of a series of angular rocks laid on top of a series of parallel logs. Although the tiles have become partially clogged with sediment, they still carry a significant portion of the stream's baseflow. It is believed that the clogging of the drainage tiles has allowed for the development of the wetland habitats. The tributary between streamflow gage SF 2-4 and SF 2-5 loses approximately 80% of its baseflow due to drainage tile immediately below and parallel to the stream. The drainage tile in this region is at least 5m wide and is located 0.6m to 1.2m below the streambed.

The groundwater model accounts for the drainage tile by adding a series of drain nodes at the assumed bottom elevation of the tile with very high conductivity values. Although the locations of some of the drainage tile are known, it is assumed that there are numerous other locations of drainage tile throughout the wetlands. Unknown drainage tile may affect local model variability, but should not have a significant impact on overall model results.

Groundwater Model Results

The calibrated groundwater model produced the Layer #2 head values shown in Figure 2. The majority of the groundwater table is located in Layer #2 - the weathered/fractured rock zone. The model slightly underestimates the baseflow received in the upland areas of Site #2 and slightly overestimates the baseflow received in the downstream sub-basins of Site #2. This may be caused by the steep local gradients and lack of resolution of detailed hydraulic properties in and around the streambeds. In general, the model is simulating approximately 85% of the gaged baseflow.

Fig. 2: Existing condition head values, Layer 2

Proposed Condition Groundwater Modeling

Three proposed conditions were simulated with the groundwater model. The first proposed condition examines the impacts caused by the construction of the highway bypass alone. It does not include any additional development. The second proposed condition evaluates the development of the highway bypass and the construction of the industrial park east of the proposed bypass. The third alternative examines the impacts of the highway bypass and the construction of the industrial park both east and west of the proposed bypass. Although the industrial park plans include the required stream and wetland buffers, they pave over a majority of the upland watershed.

The proposed conditions were modeled by adjusting the runoff, evapotranspiration, and ultimately net recharge received in the affected areas. All precipitation that falls on the impervious portion of the watershed is assumed to be lost as runoff without any benefit of infiltration or stormwater management. While this is an extremely conservative assumption, it was made in order to model the worst case scenario. The impacts of development on groundwater levels may be reduced with innovative infiltration practices.

Proposed condition #1 (bypass only) produced less than a 0.5m change in the local groundwater model. This is negligible when the accuracy of the model is considered. Proposed conditions #2 (bypass and eastern development) and #3 (bypass and full development) produce significant impacts to the groundwater table within the area. In the southeast corner of the study area, the head values drop over 10m in depth. Although the head values are not impacted at the wetlands themselves, the reduction in hydraulic head in the upland areas will dramatically reduce the groundwater discharge throughout the area. Existing artesian conditions in the wetlands may be adversely impacted by reduced head values. Bog turtles frequently burrow up to 60cm into the soft, mucky wetland soils. Reductions in artesian conditions may impact the turtles ability to burrow below the ground surface. The streamflow gage just downstream of the wetland habitat will receive approximately 50% less recharge from the groundwater system. The reduction in groundwater discharge may also influence the temperature of the wetland habitats. Refer to Figures 3 and 4 for anticipated impacts caused by proposed conditions #2 and #3 respectively.

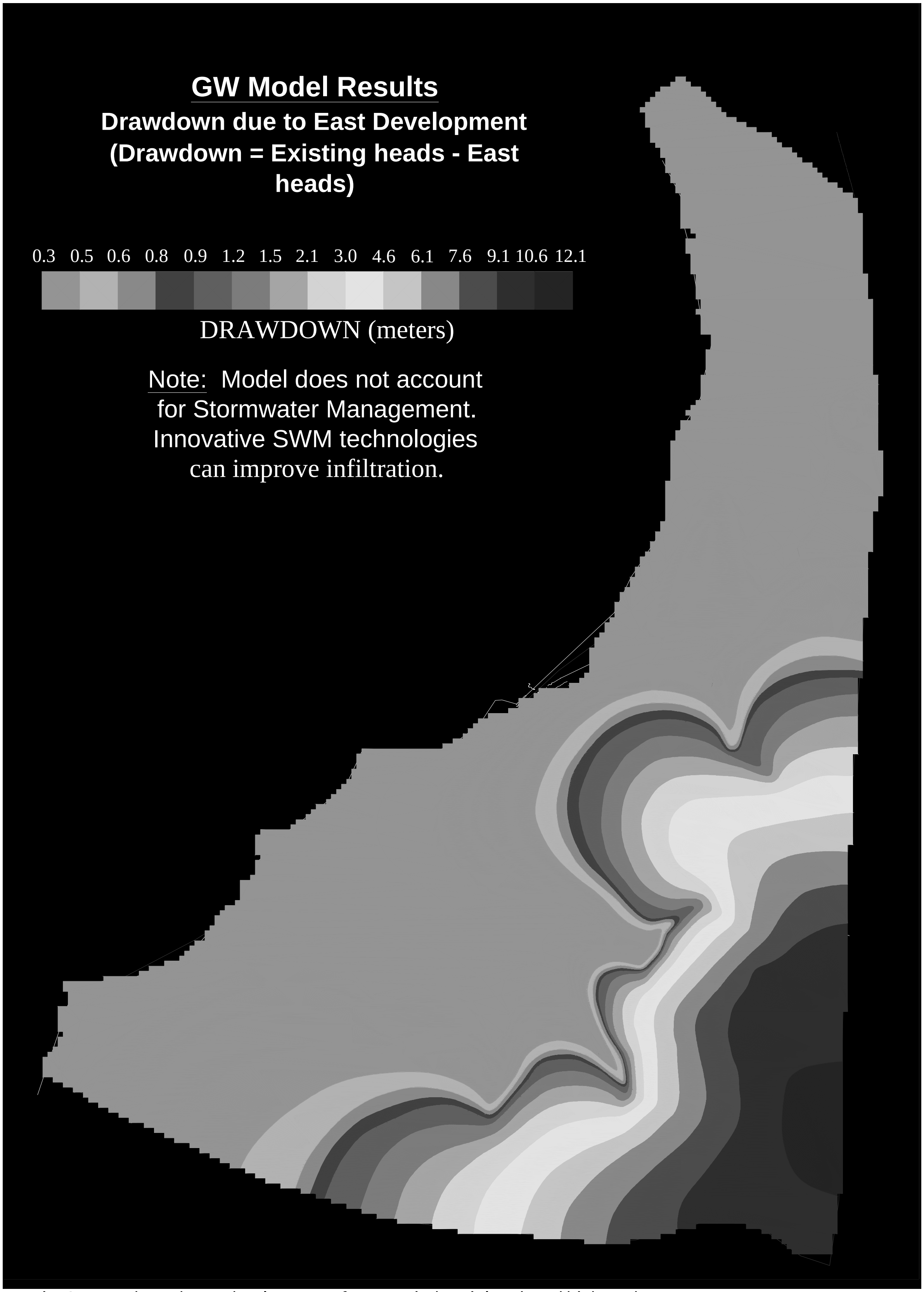

Fig. 3: Drawdown due to development of eastern industrial park and highway bypass.

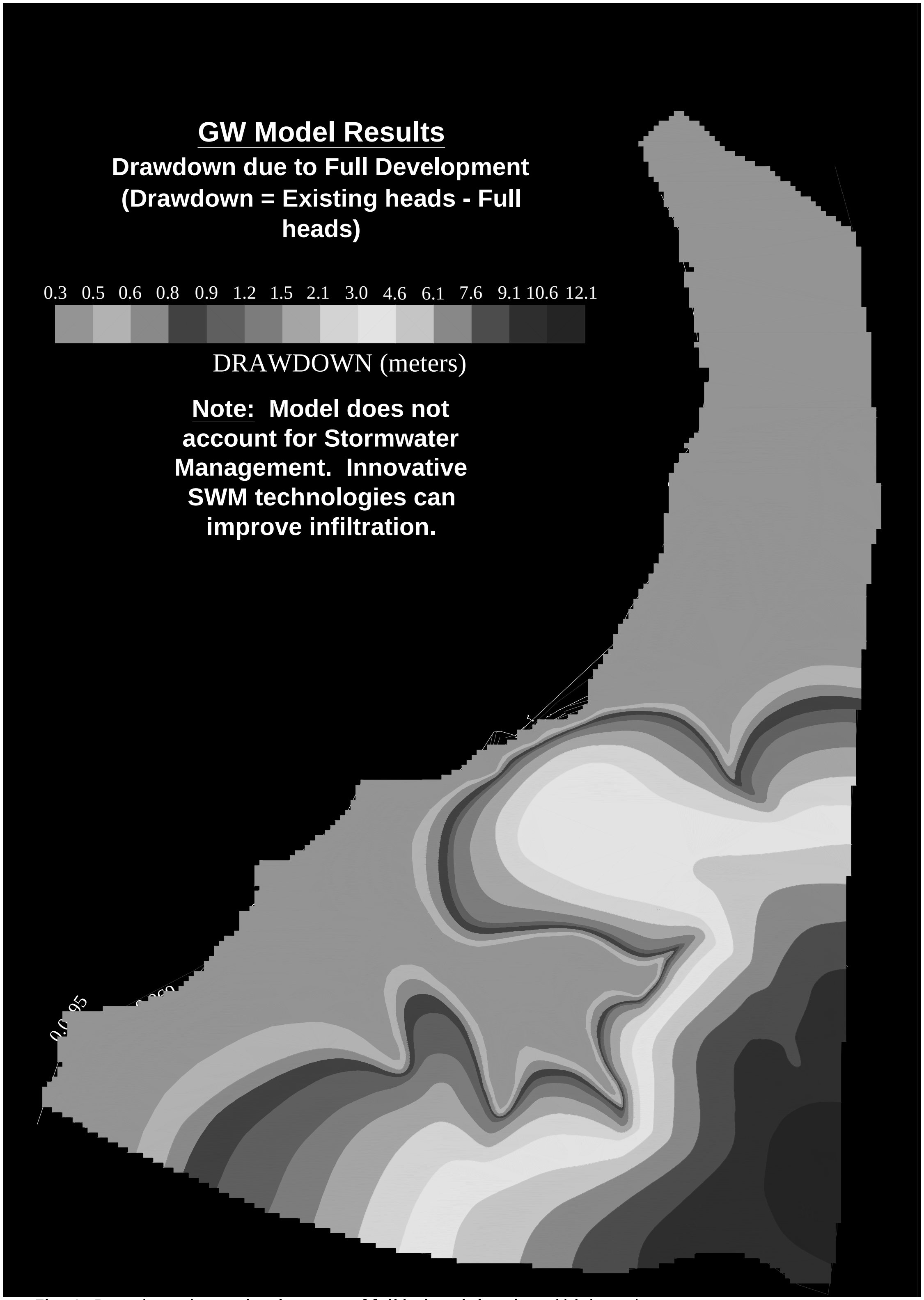

Fig. 4: Drawdown due to development of full industrial park and highway bypass

It is important to remember that these modeling alternatives represent a worst case modeling scenario. Because an infinite combination of stormwater management, grading, and land-use options exist for the project site, the worst case scenario was developed as a basis for study. Development related impacts may be reduced if the *2000 Maryland Stormwater Design Manual* criteria which focus on water quality and quantity control are followed, impervious cover is minimized, and infiltration practices are encouraged.

Recommendations

The results of the groundwater modeling portion of this study have shown that extensive development without stormwater management in the upland areas of this study will have a detrimental impact on the bog turtle wetlands. The best way to maintain present hydrologic conditions in any watershed is to not change the land-use or present drainage patterns. In reality, as land values increase, the pressure to develop land increases. The second best way to preserve a hydrologic balance in a watershed is to minimize the effects of land use change through the use of "Best Management Practices" or BMPs. BMPs typically reduce the after development peak discharge rate while providing some water quality benefits. Typical urban BMPs include wet ponds, dry (extended detention) ponds, shallow marsh ponds, infiltration practices, and runoff-filtering practices.

Because the bog turtle wetlands can be adversely affected by changes in hydrology, the BMPs recommended for consideration go beyond the requirements in effect today. To the extent possible, stormwater management plans for any development in the watersheds supporting bog turtle habitats should be comprehensive and watershed-based. The focus of stormwater management in the upland areas should be on pretreatment, infiltration, and maintenance. Infiltration volumes provided after development should meet or exceed the predevelopment recharge volumes determined in this study.

In order to insure the necessary watershed recharge for bog turtle wetland survival, it is recommended that developed sites within the study boundaries generally follow the criteria and procedures found in the *2000 Maryland Stormwater Design Manual* with the exception of the Groundwater Recharge Volume, Re_v, calculation. Because decreases in recharge can have a significant impact on wetland hydrology, within the study boundary the Re_v formula should reflect actual predevelopment annual groundwater recharge and actual rainfall depths. The equation should be written as follows:

$$\mathrm{Re}_v = \frac{(\mathrm{Re}_{watershed})(A_{disturbed})}{(P_{annual})\left(12\,{}^{in}\!/_{ft}\right)}$$

where:

Re_v = Recommended watershed recharge volume, acre-feet
$Re_{watershed}$ = Average annual watershed recharge = 17.6in / yr
P_{annual} = Average annual watershed precipitation = 41.35in / yr
$A_{disturbed}$ = Area disturbed during development, acres

Zone of Primary Hydrologic Influence

The information obtained in the surface and groundwater modeling will be used by local and state agencies in an effort to protect and sustain the bog turtle habitats. The modeling information was combined with information gained in a biological study of the bog turtle by Frostburg State University and MDSHA (2001) to create a boundary in which special care needs to be exercised in order to sustain the bog turtle wetland habitat. This boundary was called the "Zone of Primary Hydrologic Influence." The Zone contains a large portion of the upland watershed that drains to the bog turtle habitats. The idea behind the creation of the Zone was to insure that extreme care would be used in any planning and development activities within the Zone in order to maintain the bog turtle wetlands. The creation of the Zone does not inhibit development from taking place, but it does list suggestions for state and local planners to follow when considering any development options. The maintenance of recharge and surface water flows within the Zone are essential to the survival of the bog turtle wetlands. Also, if development does take place, the amount of impervious area must be minimized. State and local agencies are currently trying to purchase or obtain easements for areas that fall within the Zone to create a bog turtle preserve. This preserve will help ensure that the hydrology of the bog turtle wetlands is maintained.

Conclusions and Future Work

Although the groundwater modeling depicted the worst case development scenario, it clearly demonstrates that extensive development in the upstream watershed areas will have a detrimental impact on the hydrology of bog turtle habitats. The groundwater model was able to physically show that the reduction in recharge due to the development of the upland watershed will hydrologically influence the bog turtle wetland. Although groundwater levels within the wetland should remain unchanged, reductions in upland hydraulic head will cause significant reductions in groundwater discharge to the wetland.

This study was intended to provide an objective hydrologic analysis of the area and does not recommend the prohibition of all development in the upland watershed. However, it does provide local and state agencies with target recharge numbers that must be maintained in order to minimize the impacts of development on the wetland areas. The local and state agencies must work with developers to insure that these levels of recharge are achieved. Because the exact development scenario of the upland watersheds is not yet known, the groundwater model was designed to facilitate the analysis of other potential land uses with ease.

The current analysis used the geologic data that was presently available. The model clearly shows that the development of the industrial park will cause significant impacts to the downstream wetland areas. It is not intended to provide an exact drawdown value, but the general magnitude of impacts on the groundwater table. If more detailed and accurate information regarding the impacts of proposed development is required, additional field information would need to be acquired and added to the current groundwater model.

Although it was assumed that the recharge from the upstream areas is critical for the protection of bog turtle habitats, there are no previous studies showing the range of impacts that development could have on groundwater levels in and around bog turtle habitats. Because a large number of bog turtle habitats experience artesian conditions and are primarily supplied by groundwater flow, this model can be used as a guide in determining the impact zones at other bog turtle locations. The information obtained during this study will be used to develop the first major bog turtle preserve in the state of Maryland. This information should also be valuable to other Mid-Atlantic states who are facing similar declines in bog turtle populations.

Biographical Sketch: Kelly E. Brennan, P.E., received her B.S. and M.S. in civil engineering, with an emphasis in hydrosystems, from Penn State University. As a water resources engineer for Parsons Brinckerhoff, she has worked on a variety of hydraulic and hydrologic studies throughout Maryland and the eastern U.S. Kelly is active in the American Society of Civil Engineers and is a member of the Urban Stream Restoration subcommittee.

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