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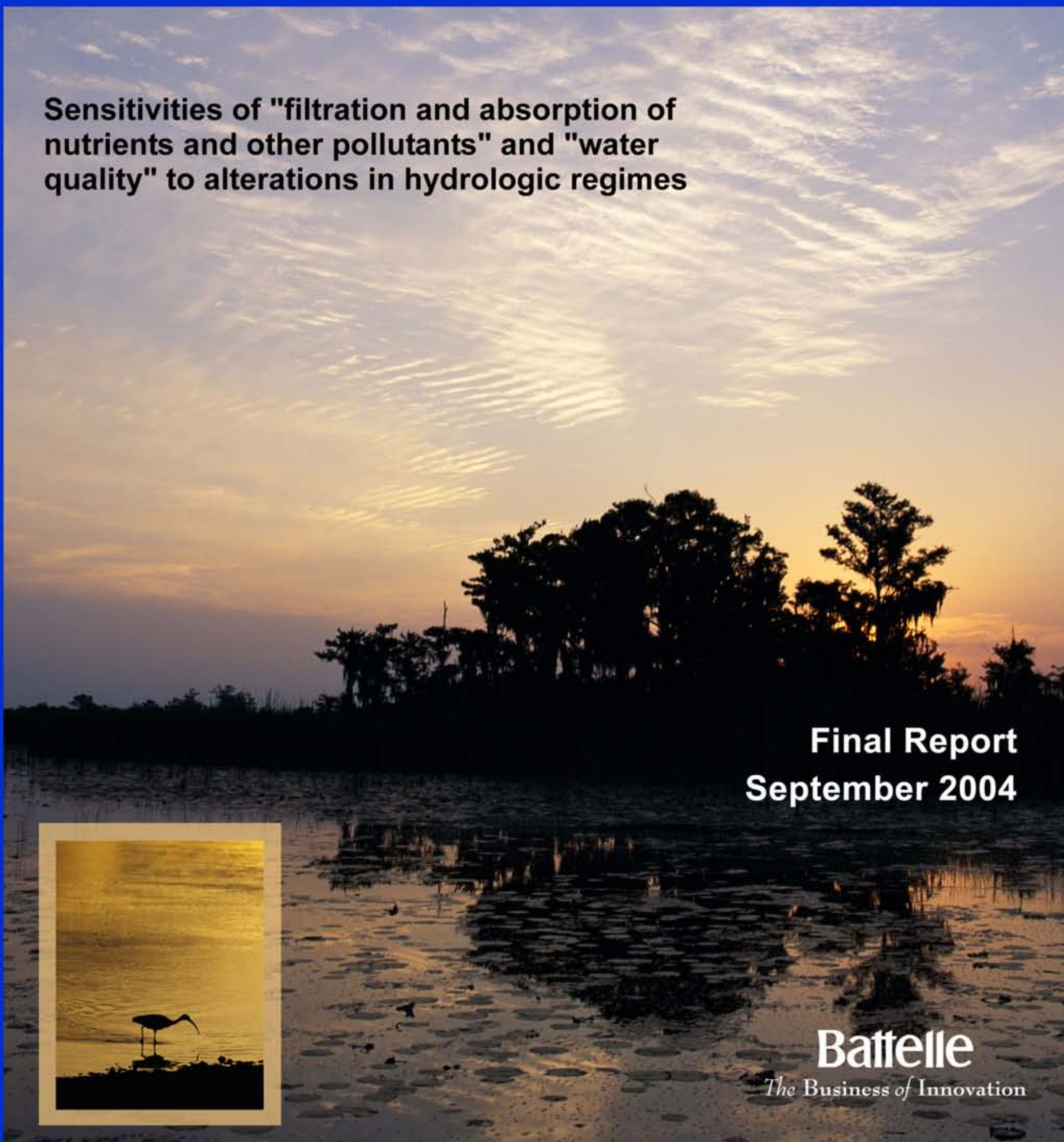
Minimum Flows and Levels in the St. Johns River Water Management District

Sensitivities of "filtration and absorption of nutrients and other pollutants" and "water quality" to alterations in hydrologic regimes



Final Report
September 2004

Battelle
The Business of Innovation

Final Report

Sensitivities of “Filtration and Absorption of Nutrients and Other Pollutants” and “Water Quality” to Alterations in Hydrologic Regimes

submitted to

St. Johns River Water Management District
4049 Reid St.
Palatka, FL 32177

in support of

Recommendations Regarding “Filtration and Absorption of Nutrients and Other Pollutants” and “Water Quality” Related to Hydrologic Conditions Imposed by Minimum Flows and Levels

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1.0 EXECUTIVE SUMMARY

The St. Johns River Water Management District's (SJRWMD) Minimum Flows and Levels (MFLs) Program, mandated by state water policy (section 373.042, *Florida Statutes)*, establishes MFLs for lakes, streams and rivers, wetlands, and groundwater aquifers. According to Section 62-40.473 of the *Florida Administrative Code [F.A.C.]*, MFLs should be evaluated to safeguard non-consumptive uses of water such as navigation, recreation, fish and wildlife habitats, and other natural resources values. This report addresses influences of altered hydrologic regimes to changes in two of these environmental values: (1) "filtration and absorption of nutrients and other pollutants" and (2) "water quality" (Rule 62-40.473[1][g] and [i] respectively, *F.A.C.)*

This report identifies and documents a series of appropriate methods for assessing changes to "filtration and absorption of nutrients and other pollutants" and "water quality" related to hydrologic conditions imposed by MFLs. Conceptual models have been developed that relate functional responses of filtration and absorption processes and water quality to variations in flows and levels. A comparison of models to assess these responses among lakes, rivers, streams, wetlands, and springs was performed and summarized.

Results of this analysis include a summary of potential modeling methods that can be used to assess changes in "filtration and absorption of nutrients and other pollutants" and "water quality" related to hydrologic conditions imposed by MFLs. Out of thirty models reviewed, six were considered as potentially useful to the SJRWMD MFLs program: SWAT, HSPF, MIKE-SHE/MIKE-11, ISGW, SPAW, and PREWET models. The Soil and Water Assessment Tool (SWAT) model predicts the impact of land management practices on water, sediment and agricultural chemical yields in large watersheds with varying soils, land use and management conditions over long periods of time. The Hydrologic Simulation Program - Fortran (HSPF) model simulates watershed hydrology and in-stream water quality processes, such as temperature and sediment, organics and pesticides, bacteria, metals, and biochemical reactions (dissolved oxygen and BOD, inorganic nutrients, plankton and refractory organics, pH and inorganic carbon). The MIKE SHE/MIKE 11 model is a physically-based and spatially distributed, integrated surface and groundwater model, that simulates all components of a hydrologic cycle; however simulation of flow through the soil (in MIKE-SHE) is simulated in more detail through 3-dimensional groundwater equations for the saturated soil layer. The Integrated Surface and Groundwater (ISGW) model enhances the HSPF model by integrating it into the 3-dimensional groundwater model, MODFLOW. The simplified model Soil-Plant-Atmosphere-Water (SPAW) is a daily hydrologic budget model for agricultural fields and ponds, and is not applicable to rivers, streams, and springs. The Pollutant Removal for Wetlands (PREWET) screening model estimates water quality improvement through wetlands with minimum input data.

Limitations of existing models and recommendations for further model development and selection criteria are presented.

2.0 INTRODUCTION

The St. Johns River Water Management District's (SJRWMD) Minimum Flows and Levels (MFLs) Program, mandated by state water policy (section 373.042, *Florida Statutes)*, establishes MFLs for lakes, streams and rivers, wetlands, and groundwater aquifers. MFLs define the frequency and duration of high, average, and low water events needed to prevent significant ecological harm to aquatic habitats and wetlands from permitted water withdrawals. The MFLs Program is subject to rule (chapter 40C-8, *Florida Administrative Code [F.A.C.])* and provides technical support to the SJRWMD regional water supply planning process and the consumptive use permitting program. Section 62-40.473, *F.A.C.*, specifies that an MFL should be evaluated to safeguard non-consumptive uses of water such as navigation, recreation, fish and wildlife habitats, and other natural resources values. These environmental values must also be protected from significant harm.

This report addresses influences of altered hydrologic regimes to changes in two of these environmental values: (1) "filtration and absorption of nutrients and other pollutants" and (2) "water quality" (Rule 62-40.473[1][g] and [i] respectively, *F.A.C.)*. Hydrologic changes to systems where MFLs are established typically result from water withdrawals and can be assessed using hydrologic models and other forms of analysis. An understanding of the effects to water quality from altered water levels and flows is required for the implementation of ecologically meaningful MFLs.

The objectives of this report are to identify and document the most appropriate methods for assessing changes to "filtration and absorption of nutrients and other pollutants" and "water quality" related to hydrologic conditions imposed by MFLs. A series of conceptual models have been developed that relate functional responses of filtration and absorption processes and water quality to variations in flows and levels. The report compares these responses among lakes, rivers, streams, wetlands, and springs because each water body type possesses different physical and biogeochemical properties. Therefore, each water body type responds differently to the type and magnitude of hydrologic variations.

A critical review of scientific literature has been conducted to support the understanding of the influence of MFLs to water quality, particularly within the SJRWMD. The most appropriate methods for assessing the influence of altered hydrologic regimes to changes to filtration and absorption processes and water quality is based on this review and corresponding conceptual frameworks. The relative suitability of assessment methods (e.g., models) is described. A series of recommendations is also provided that identifies further analyses, data acquisition, and study design needed to assist the SJRWMD in assessing the influence of MFLs on the biogeochemical and physical process related to "filtration and absorption of nutrients and other pollutants" and "water quality."

The recommendations emphasize development of modeling tools for evaluating the interrelationships between MFLs and water quality. The key issue regarding models is the sensitivity of computed changes in water quality to small changes in water withdrawals. The water bodies of the SJRWMD are diverse with respect to their hydrologic and water quality processes. Existing hydrologic, hydraulic and water quality models were developed for a wide range of water bodies and vary in the level of complexity of their methods. There are models that are designed to simulate only specific water bodies and processes, and there are more general models. The later are used to simulate less complex situations for planning purposes, such as relative comparison of alternatives. The former are used for more site-specific situations where high-resolution results, both spatially and temporally, are required. These types of models tend to be more sensitive to changes in withdrawals, but they typically can only be applied to very specific water bodies and hydrologic settings. There is no "one-model-fits-all." The recommendations provide an approach to identifying the modeling needs and for developing and testing new models.

3.0 FUNCTIONAL INTER-RELATIONSHIP BETWEEN "FILTRATION AND ABSORPTION OF NUTRIENTS AND OTHER POLLUTANTS" AND "WATER QUALITY" FOR LAKES, RIVERS, AND STREAMS

Filtration and absorption of nutrients and other pollutants is a natural system process and an environmental value associated with aquatic and wetland ecology, which is protected under Florida Administrative Code (FAC) 62-40.470 (Natural Systems Protection and Management) and 62-40.473 (Minimum Flows and Levels). Water quality, as indicated by various state variables (constituent concentrations and indices), is affected by this process. There are several ways in which filtration and absorption of nutrients and other pollutants affect water quality in the SJRWMD. The various kinds of inter-relationships between this process and water quality are described herein. Not all of these inter-relationships are directly related to water discharge (flow) or stage (level) in rivers, lakes, springs and aquifers within the SRJWMD. The inter-relationships that are more directly related to water flow and level (and therefore are subject to minimum flows and level rules) are described in greater detail below.

Filtration is comprised of physical, chemical and biological processes that occur as water flows through another medium. Physical removal of substances from the water occurs during filtration. Essentially the filter media acts as a screen. Passage is allowed for particles of smaller size than the screen openings. Absorption is a chemical process that occurs during filtration. Substances which are mixed or dissolved in water can become absorbed to the component particles of the medium. Conversely, substances on the component particles of the medium can also be desorbed into water. Biological filtration is basically a combination of physical and chemical processes, which are part of an organism's metabolism. These are the fundamental descriptions of the filtration and absorption process. Where these processes occur is more important to minimum flow and level rules.

Filtration and absorption processes in the natural environment can take place at many points throughout the hydrologic cycle. These processes occur in the atmosphere as rain drops can absorb air pollutants. They occur where the rain drops fall on the pervious ground surfaces. Infiltration does not occur on impervious surfaces. A portion of the precipitation will infiltrate into the soil when the upper soil horizons are not completely saturated with groundwater. The remaining portion runs off through the surface water drainage network. Absorption of pollutants from the ground surface is a process that can occur as water flows through the drainage network. A portion of the runoff will infiltrate along a pervious flow path, again depending on the groundwater level. Stormwater ponds typically are designed to capture surface runoff and provide additional infiltration. The remaining runoff eventually discharges to a lake or river unfiltered.

Filtration and absorption processes continue as the portion of water that does not runoff flows through the soil. Generally, water flows down through upper and lower layers of top soil layer, which is unsaturated, and then into saturated soils of the underlying aquifer. Roots of vegetation in the top soil layers absorb water, along with the minerals, nutrients and pollutants contained within. This biological absorption is associated with evapo-transpiration (ET), which is a biologically-mediated physical process. The vast majority of water remaining in the soil after ET removal infiltrates into the aquifer. This is referred to as aquifer recharge. Physical filtration processes remove relatively larger particles from the water. Pollutants adsorb/desorb between soils and infiltration/groundwater. Groundwater eventually discharges to the surface in a spring, lake, river, estuary or off-shore. The organisms of the benthic community provide a final biological processing before discharge to the overlying water column.

Among the factors influencing chemical composition of soil moisture are the solution or alteration of silicate and other minerals, precipitation of sparingly soluble salts (notably calcium carbonate), selective removal and circulation of nutrient elements by plants, biochemical reactions producing carbon dioxide, sorption and desorption of ions by mineral and organic surfaces, concentration of solutes by ET, and conversion of gaseous nitrogen to forms available for plan nutrition. Of these, one of the most important is the production of carbon dioxide (Hem, 1970). The air in soil interstices has a carbon dioxide concentration that is commonly one to two orders of magnitude greater than normal air concentrations. Water moving through soil dissolves some of this carbon dioxide and the resulting hydrogen, biocarbonate and carbonate ion concentrations greatly influence the pH of the water.

The degree to which filtration and absorption occur may be significantly influenced by governing physical forces such as water residence time. Residence times can directly limit the extent of biogeochemical and physical processes in aquatic and subterranean environments. For instance, the bulk rate of decay in concentration of a water column, or aquifer, chemical constituents due to microbial action is sensitive to the "exposure" time available. Likewise, realized rates of primary production by phytoplankton are quite closely related to the amount of time nutrients are available for assimilation. Assimilation in and critical nutrient loads to freshwater systems have been studied by Vollenweider (1976) and many others. Assimilation time is largely a function of water residence time and other physical events such as stratification. Water residence times (within water columns, sediments, and aquifers) are determined by flows and levels. Therefore, the processes associated with filtration and absorption of biological and chemical constituents are responsive to these physical components.

The emphasis of this document is on regulatory setting of minimum flows and levels, and how these settings affect filtration and absorption processes, and the consequences from a water quality perspective. One of the objectives for setting regulatory minimum flows and levels is to prevent unacceptable harm to environmental values or resources. This document will focus on those processes within the hydrologic cycle that are directly affected by minimum river flows and water levels in rivers, lakes and aquifers.

4.0 SIMILARITIES AND DIFFERENCES BETWEEN "FILTRATION AND ABSORPTION OF NUTRIENTS AND OTHER POLLUTANTS" AND "WATER QUALITY" FOR LAKES RIVERS AND STREAMS

Conceptual models are useful for characterizing the similarities and differences between filtration and absorption of nutrients and other pollutants and water quality. A conceptual model will be developed for each of four water body types found in SJRWMD: lakes, rivers, streams and springs. Before getting into the specifics of each water body type, the basic similarities and differences between filtration and absorption processes of nutrients and other pollutants and water quality (in general) should be re-iterated. The fundamental similarity is that both are environmental values associated with aquatic and wetland ecosystems and both are affected by water flow and levels. The fundamental difference is that filtration and absorption are natural system *processes*, whereas water quality is a *condition* indicated by various state variables (constituent concentrations and indices). An overview of the relationship between the two was described above in Section II. The three following sub-sections discuss how the filtration and absorption processes affect water quality in each water body and in wetlands. It is in the wetlands on the fringe of these water bodies that the filtration and absorption processes predominantly occur. This section will conclude with a summary of other processes which affect water quality in the four types of water bodies.

4.1 Lakes

Water quality, and the processes that control water quality, can vary significantly in lacustrine environments. This variability can be due to physical and geomorphological differences among various classes of lacustrine systems. The relative magnitudes of the biogeochemical processes that influence water quality within lakes is dependent upon factors such as depth, aquatic edge (i.e., shoreline and surface area), and the ratios between these. Coupling between the water column and benthos (bottom sediment communities) are a function of depth, volume and physical exchange (vertical and longitudinal). Shallow lakes tend to have very strong coupling between the water column and benthos and this level of communication becomes diminished with increasing depth and flushing. The result of strong benthic-pelagic coupling is often more noticeable responses of water column biogeochemical constituents to benthic processes. Typical water quality constituents that are significantly sensitive to this coupling include nutrients (phosphorus, nitrogen, silica), dissolved oxygen (DO), benthic macroalgae and microalgae, phytoplankton, and water transparency (e.g., Secchi depth or light extinction coefficient).

As previously stated, physical characteristics of receiving lake waters can govern many biological processes that drive water quality dynamics. Not only will fluctuations in hydrologic regime affect the rates of biogeochemical processes along riparian margins, these fluctuations are related to a more general concept called water residence time. Early work associated with eutrophication of lakes (Vollenwieder 1976) focused on the rate of turnover time of a water body, in addition to other characteristics such as water column stratification. The general concept is that the relationship between loads of limiting nutrients (in this case, phosphorus) and water quality (in this case, algal production and subsequent oxygen demand) is governed by the amount of time a water body is exposed to a given source of nutrient. The longer a particle of nutrient-enriched water exists within a water body (some given volume), the more likely it will be assimilated by primary producers (algae, macrophytes, etc.). Conversely, rapid exchange across water bodies (or export) allows a lower likelihood of that nutrient-enriched water particle to become available for assimilation. Studies in freshwater, estuarine, and marine systems (including mesocosm and chemostat studies) have proven the direct linkage between the effect of nutrients, and pollutants, on biological systems and water residence time.

Stratification due to density differences imposed by temperature or dissolved solutes acts to vertically segregate lake and river water columns. This not only affects the influence of water residence time on biogeochemical processes (different volumes and exchange rates), but also limits diffusion of nutrients, pollutants and oxygen across surface and bottom waters. Stratification is, to some extent, influenced by flows because higher flows result in higher turbulence and, therefore, a decrease in stratification strength. It is also influence, to some degree, by water levels (depths) due to physical limitations of temperature-induced stratification events; shallow systems tend to possess uniformly consistent vertical temperatures compared to deeper systems. Deeper systems also tend to be less affected by turbulent energy such as that caused by wind events.

These physical and biogeochemical processes are important in driving water quality conditions in lacustrine environments and vary based on area, depth and hypsography of each system.

Communication between the water column and fringe wetlands also impacts the role of biogeochemical processes and resulting water quality. Fringe wetlands also intercept nutrients and other pollutants entering or leaving lacustrine systems and, therefore, can influence net import/export budgets of various constituents, particularly nutrients.

In many cases, alterations in lake volumes and levels can influence any number of factors that contribute to biogeochemical processes and water quality. The magnitude of drawdown from historically established levels will likely have a dramatic effect on fringe wetlands in all such systems. Significant impacts associated with benthic-pelagic coupling are likely in shallow lakes. Not only will variations in levels influence *in situ* processes associated with water quality, but the sources and fates of constituents of interest will likely be affected.

According to FAC 40C-8.031, a set of three minimum water levels are specified for all lakes (except for Shaw Lake in Volusia County, which specifies five levels). The three levels are specified with a corresponding frequency of occurrence and duration (those are implied by the hydroperiod categories which are defined in FAC 40C-8). There is a minimum lake level specified for the frequent high, average and frequent low occurrences. Typically, the difference between the minimum frequent high and frequent low levels is about 2 to 3 feet. About 10 percent of the lakes have differences greater than 4 feet. The filtration and absorption processes which occur in the immediate area adjacent to the lake shoreline are affected by fluctuations in lake levels between the minimum frequent low and high. Given the flat topography in SJRWMD, this area can be quite large. The conceptual model of the filtration and absorption processes in this area illustrates how water quality is affected by lake levels (Figure 1).

Land cover and use in the shoreline area greatly influence the effectiveness of filtration and absorption of nutrients and other pollutants. Land cover can range from totally impervious, to bare, pervious soil, to totally vegetated. Land use can range from typical urban uses (industrial, commercial, and high- and medium-density residential), to rural uses (low-density residential and agriculture), to totally undeveloped (wetlands and forests). For example, the main feature of the conceptual model for impervious, urban areas is wash-off and absorption of nutrients and pollutants that have built up on the surface between runoff events. EPA conducted numerous non-point source pollution studies during the 1980s for their National Urban Runoff Program (NURP). Ranges of unit-area pollutant loadings for several different kinds of land uses were published (EPA, 1982). The loadings in large part were determined by the extent to which each land use altered the natural functioning of the filtration and absorption processes.

The conceptual model for filtration and absorption processes in urban areas surrounding a lake was used as the example above because it is relatively simple concept (Figure 2). As precipitation runs off pervious surfaces it washes off particulates and transports them to the lake. Typically, the transport is via an engineering conveyance, such as a drain pipe or open channel. Particulates which build up on impervious surfaces are a result of the type of land use. Other pollutants, such as oil and grease and metals, typically build up on impervious surfaces, such as parking lots and roads. These pollutants are attached to soil particles. Runoff washes away the pollutants, which can desorb into the water as it is conveyed to the lake. The amount of desorption depends on the concentration of the dissolved fraction in the water relative to the concentration of the solid fraction on the particulates. Upon discharge to the lake, additional desorption will take place.

The conceptual model for urban residential and rural landuses surrounding a lake include nutrient loading and filtration and absorption processes. The associated land covers include vegetated, pervious soils, such as lawns and crops. Like impervious surface runoff, pollutants and particulates build up and are washed off. On the other hand, pervious soil and vegetation reduces pollutant loading by adding the filtration and absorption processes. Runoff is reduced by infiltration of precipitation through pervious soils. Filtration by vegetation slows down runoff and reduces washoff. Absorption by vegetation uptake of nutrients reduces the runoff concentration. Bioswales and crop buffers are common best management practices (BMPs), which are designed to take advantage of the (in)filtration and absorption processes to reduce nutrient loading.

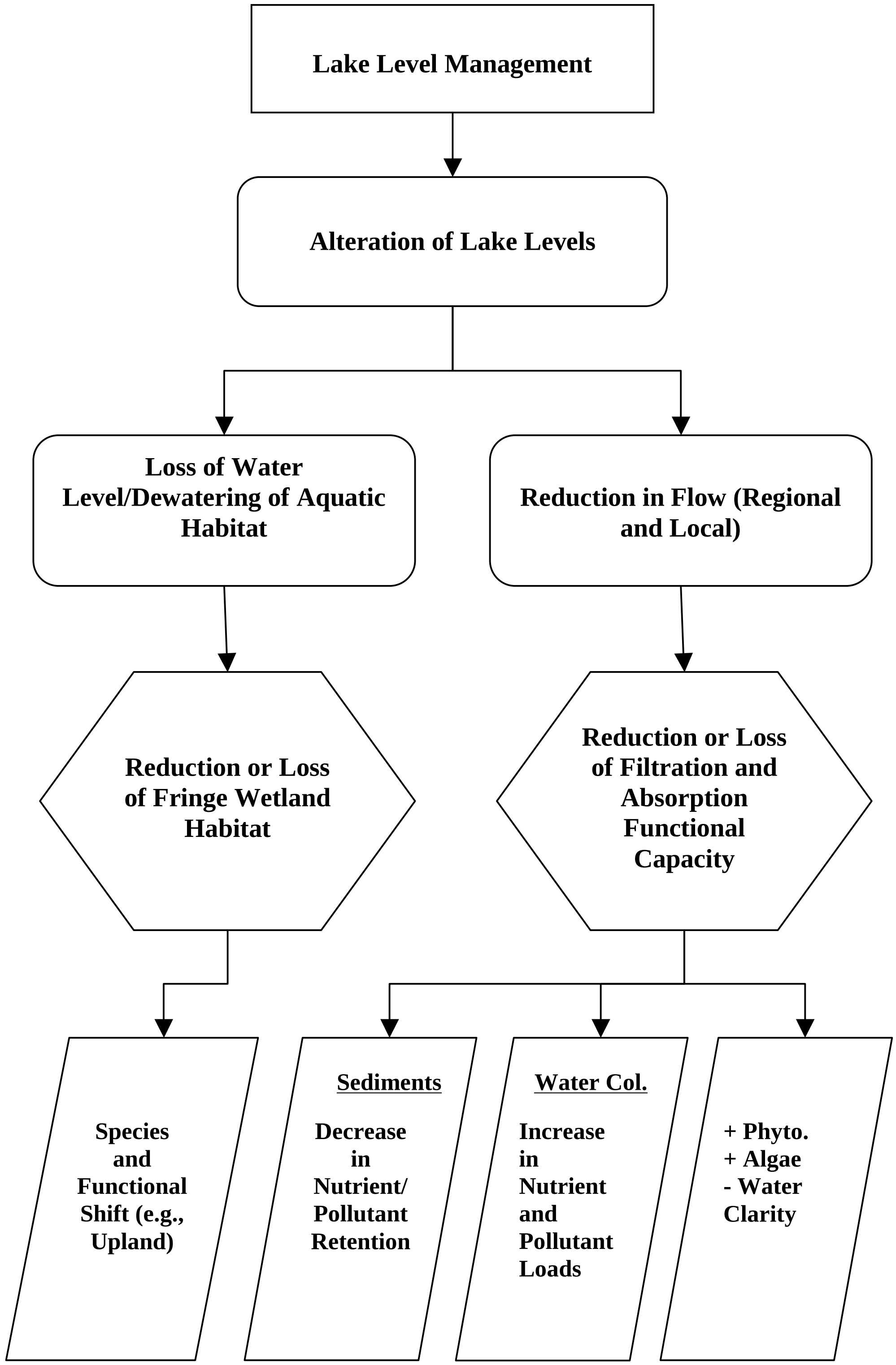

Figure 1. Conceptual Model Diagram of Water Quality Responses to Changes in Lake Levels.

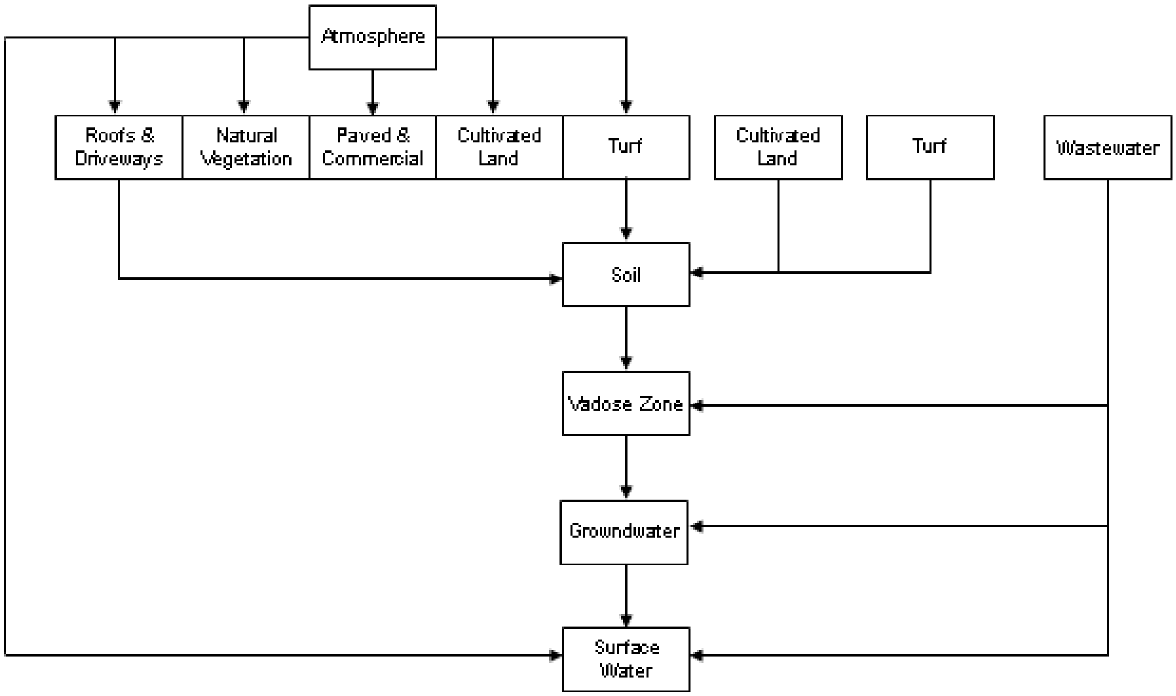

Figure 2. Conceptual Model Diagram Relating Filtration and Absorption, and Other Related Processes in Lake Watersheds.

Undeveloped land uses include filtration and absorption processes in naturally deposited muck soils in wetlands. The conceptual model of wetlands is more complex than the more impervious land covers. The top soil horizons, the vegetation growing within them, and the soils of the underlying aquifers take a prominent role in controlling the flow of groundwater and the biogeochemical reactions in the wetlands. The interaction of ground and surface water is a critical factor in the filtration and absorption processes. Wetlands along the fringes of lakes rely on a fluctuating water level to maintain their hydrogeomorphic functions. Removal and sequestration of elements and compounds, and retention of particulates are two of these functions which are highly influenced by filtration and absorption.

There are two basic conceptual models of the hydrologic regime for surface water in hydraulic continuity with groundwater. Wetlands surrounding isolated lakes and lakes connected to rivers or riverine wetlands have different hydrologic regimes. For wetlands surrounding isolated lakes, surface water levels fluctuate in unison with groundwater fluctuations. Generally, groundwater flows into a hydraulically connected isolated lake, but lake water does not flow back into the groundwater. For wetlands surrounding lakes with outflows or within riverine floodplains, groundwater levels generally lag behind surface water level fluctuations. In this case, water flows in both directions across the bottom of the lake. Well pumping can induce infiltration from surface water in lakes into an adjacent aquifer.

Many lakes in SJRWMD, particularly in the Sandhill Region, are not in hydraulic continuity with underlying aquifers. These lakes are perched above the water table. The lake levels depend on local storm runoff. Leakages from these isolated lakes recharge the aquifer and create a groundwater mound.

4.2 Rivers and Streams

The conceptual model of filtration and adsorption processes for the flow paths which deliver nutrients and other pollutants to rivers is similar to the lake model. The main difference is that after delivery of nutrients and other pollutants, the river transports them downstream and can redistribute them over the floodplain. Hydrographs of rivers and streams usually exhibit greater variability than lakes and typically have more pronounced responses to meteorological events. These responses form short- and long-term characteristics that govern biogeochemical processes that affect water quality. For instance, Pinay et al. (2002) described nitrogen cycling in fluvial systems with regard to three basic ecological principles (1) mode of delivery, (2) contact (or communication) between water and soils, and (3) the role of hydrological variability such as floods and droughts. Similar to lakes, frequency is specified for rivers and streams (river is used hereafter to refer to both rivers and streams) in Florida minimum level and flow regulations. The regulations specify minimum flows for five river reaches. Minimum levels are also specified for four of the five river reaches. Two of the five rivers have two additional frequency categories, which represent extreme conditions: minimum infrequent high and low. In addition to flow, duration and return interval are specified for each frequency in three of the five river reaches.

For two river reaches, a hydroperiod category is listed, which corresponds to frequency. Because filtration and absorption processes occur in pervious soils adjacent to the river and in the floodplain, the hydroperiod of flooding is the main feature of the conceptual model for rivers. The frequency, duration and return period of overbank (wetlands) flooding are used to characterize the hydroperiod for the conceptual model. Water level is used to quantify these hydroperiod characteristics.

The interaction of surface water in rivers interact with groundwater in adjacent aquifers is similar to that of lakes connected to rivers or riverine wetlands. During storm events, the initial contribution to river flow is from drainage of groundwater from the soils of the river banks and adjacent floodplain. The river level rises towards the groundwater level, which is also rising. Surface water drainage from the watershed follows. The delay between the rise in river level due to groundwater and surface water drainage depends on the location downstream on the river. The arrival of surface water flows from the upstream watershed causes the river level to rise above local groundwater levels. At this point, the direction of flow between the river and aquifer reverses. A portion of the surface water in the river and flooded overbanks will infiltrate into the soil until the soil become saturated. Following the end of precipitation, the river level recedes and surface water in the floodplain drains to the river. As the river level drops below groundwater level, the direction of flow between the river and aquifer reverses again. Groundwater drains into the river. Filtration and absorption processes occur during these exchanges of water between the river and aquifer. The exchanges through wetlands are of critical importance to water quality.

4.3 Springs

FAC 40C-8.031 specifies head and discharge for eight springs in the SJRWMD. Filtration and absorption of nutrients and other pollutants related to springs occurs in the flow path through the aquifer from the recharge area to the point of discharge. Filtration is primarily a function of the soil porosity. Absorption is also primarily a function of the soil properties. Geochemical reactions are driven by the water quality of the source water and the chemical constituents of the aquifer soils. Alteration of groundwater level by pumping or diversions from surface water bodies could have an indirect affect on filtration and absorption. Lowering of the groundwater level by pumping or river level reduction may affect retention time of water in the aquifer, which is a factor in geochemical reactions involving absorption.

4.4 Wetlands

The conceptual model for filtration and absorption processes in wetlands during flooding-drying cycles is described here according the hydrogeomorphic approach (HGM) for wetland classification. This approach was referred to in the description of the lake conceptual model above (see Figure 3). The approach is used by the U.S. Army Corps of Engineers (ACOE) for implementation of their wetland regulations. The approach identifies the ecological functions performed by each class of wetlands and describes the characteristics and processes that influence the function. Flooding modifies chemical conditions in alluvial floodplains by depositing and replenishing mineral nutrients and importing and removing organic matter (Wharton, 1981). The ground-surface water interactions described above relate to two ecohydrological functions: temporary storage of surface water, and maintenance of characteristic subsurface hydrology. The filtration and absorption processes relate primarily to two other wetland functions: remove and sequester elements and compounds, and retain particulates. These and four other functions were recently defined and characterized by the Wetlands Research Program of the ACOE Engineer Research and Development Center (Uranowski et al., 2003).

The U.S. Army Corps of Engineers developed "The Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Low-Gradient Blackwater Riverine Wetlands in Peninsular Florida" for use the area within Southwest Florida Water Management District. The wetlands functions performed by this category of wetland are reasonably applicable to flow-flooded, sandy and depressional wetlands in SJRWMD. The wetland functions which remove and sequester elements and compounds, and retain particulates, are summarized here.

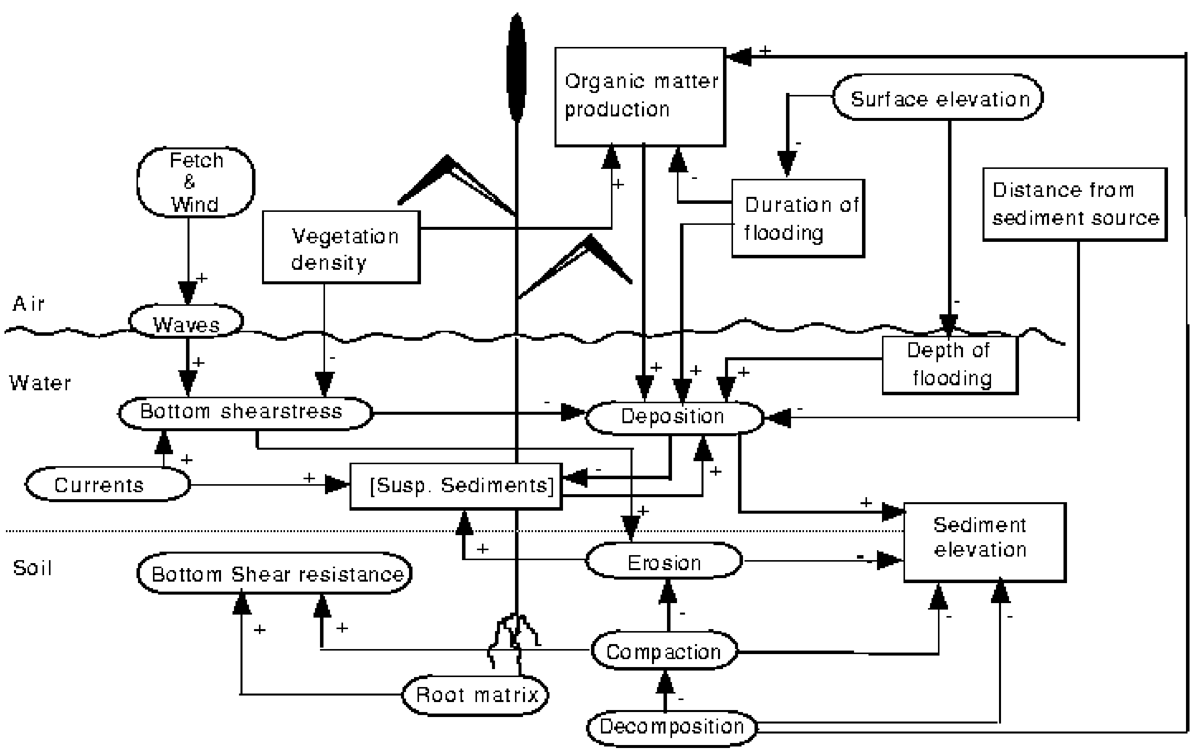

Figure 3. Conceptual Model Diagram of Wetland Physical and Biogeochemical Processes.

Nutrients and other pollutants are imported to riverine wetlands via overbank flooding from ground and surface waters. Figure 4 illustrates potential variations in flood-duration characteristics over seasons. Riverine wetlands have the capacity to remove (semipermanent immobilization) and sequester (long-term accumulation) these elements and compounds. The elements listed include macronutrients (nitrogen and phosphorus) and heavy metals (zinc and chromium). The only compound listed is pesticides. These elements and compounds may be removed and sequestered through a variety of biogeochemical processes: complexation, chemical precipitation, adsorption, denitrification, decomposition to inactive forms, hydrolysis, uptake by plants and other processes, such as filtration.

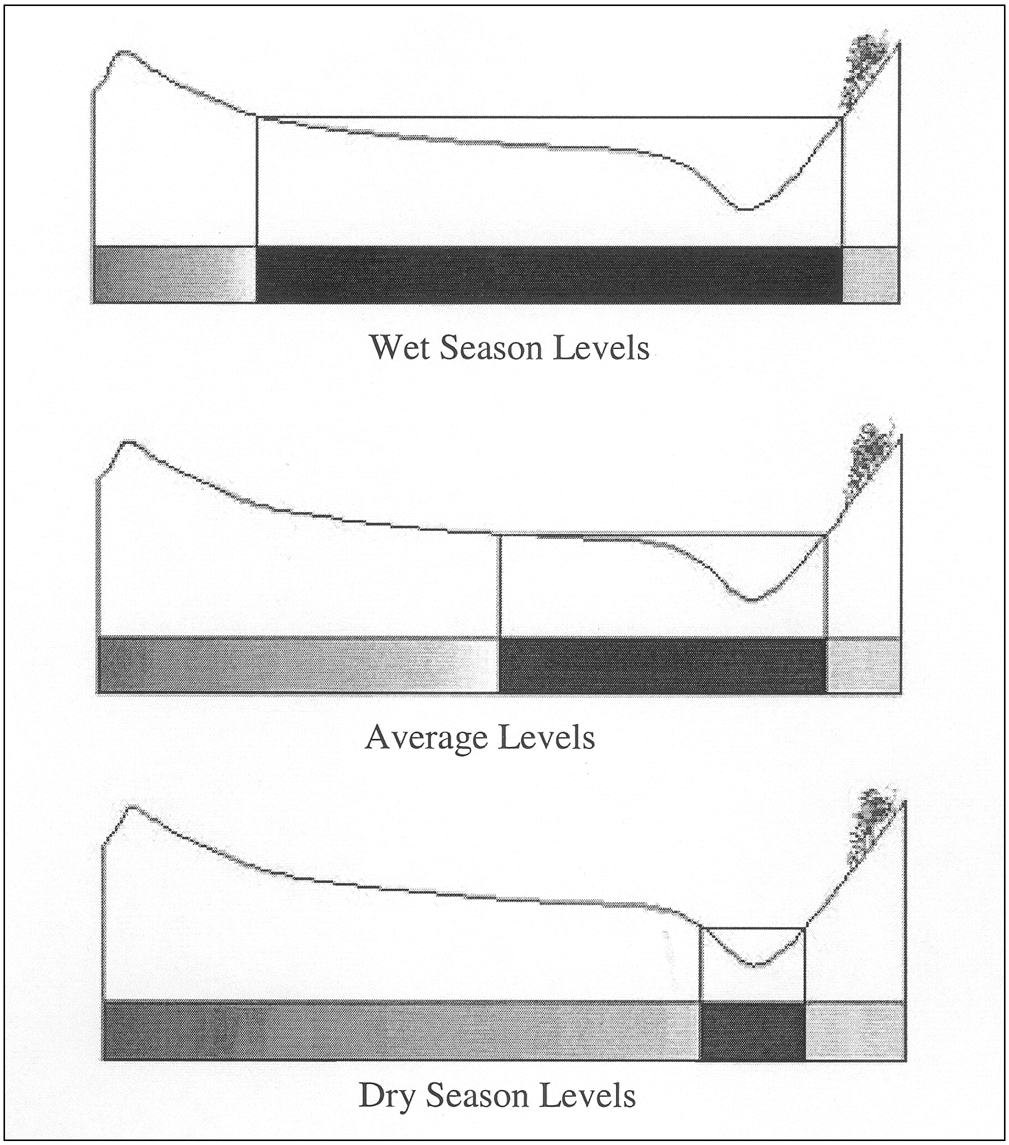

Figure 4. Conceptual Model Diagram Showing the Hypothetical Variations in Wetland Flooding Regimes.

Reduction is a major removal process. Nutrients are reduced as water transports them through anoxic soils (low redox potential). In these soils, nitrates are removed from the water and released as nitrogen gas into the atmosphere via denitrification. Also, other nutrients, such as sulfates, are reduced, which leads to removal of bioavailable (dissolved) metal cations (such as copper, iron, aluminum and lead) via formation of insoluble metal sulfides.

Adsorption is another major removal process. Elements and compounds adsorb to soil particles comprised of clay and organic matter. Cation exchange is the fundamental electro-chemical process of adsorption. Clay and organic matter soils have a high cation exchange capacity (CEC) because of their high electrostatic charge. Dissolved metal cations and nitrogen (in the ammonium form) can be removed from water via adsorption as it flows through soils with a high CEC. The soluble orthophosphate ion can be sequestered by adsorption to clay and iron and aluminum oxide minerals. These soils are generally abundant in riverine wetlands, but they need to have a pH of 5.5 or less to adsorb phosphorus and metals. The CEC of a soil is a function of the amount clay and organic matter in the soils and the type of clay.

Adsorption and reduction mechanisms work together to sequester nutrients. Riverine wetlands retain nutrients and other pollutants by storing and cycling them between plant, animal, detrital, and soil compartments. Net uptake of phosphorus by plants is made possible in part by reduction of iron oxide minerals. This is a significant sequestration of phosphorus, but small relative to other phosphorus soil/sediment sinks.

The assessment of this ecological function provided by wetlands considers five parameters. They are: frequency of overbank flooding, water table depth, soil clay content, hydric soil indicators, organic (O) soil horizon biomass, mineral (A) soil horizon biomass. The first three parameters are directly influenced by river water levels. The last two are indirectly influenced because water contributes to the growth of plants that contribute biomass to the O and A soil horizons. The frequency of overbank flooding indicates the import of elements and compounds to the wetland from alluvial sources. The water table depth indicates the extent to which groundwater levels are supporting biogeochemical processes of reduction and adsorption. The soil clay content and biomass in the O and A soil horizons indicate the adsorptive capacity. The hydric soil indicates represent the reducing environment and level of microbial activity needed for this function to occur.

Removal and retention of inorganic and organic particles greater than 0.45 micrometers from the water column is the other wetland function that is relevant to filtration and absorption of nutrients and other pollutants. Retaining particulates comprised of nutrients and other pollutants, which are imported to riverine wetlands via overbank flooding from ground and surface waters, is primarily a filtration process. This is an important process because sediment accumulation contributes to the nutrient balance in a wetland. It is also important to downstream areas because it reduces sediment loading. Deposition of sediments in a wetland affects river hydraulics and provides more diverse physical habitat as well as influencing biogeochemical and biotic processes. Particulates in the form of organic matter are important for sustaining biomass in upper soil horizons, detrital food webs and nutrient cycles. Additionally, the wetland function of organic carbon export is sustained by the retention function.

The assessment of this ecological function provided by wetlands considers four parameters. They are: frequency of overbank flooding, and floodplain storage, roughness and slope. All of these parameters, except for floodplain slope, are directly influenced by river water levels. A reduction in the frequency of overbank flooding indicates alteration of the recurrence interval (with respect to a reference site) due to changes in the watershed, channel and/or diversion and consumptive use of water. Floodplain storage is primarily influenced by encroachment of the floodplain and reduction of storage volume by structures or fills. It could also be influenced by a reduction in flood level due to changes in the watershed, channel and/or diversion and consumptive use of water. Floodplain slope and roughness are indicators of the ability of the wetland to settle out sediment by reducing the velocity of water flowing through the wetland. The roughness due to vegetation is supported in part by providing groundwater levels that are high enough to supply water to the roots.

Isolated depressional wetlands function differently than low-gradient blackwater riverine wetlands in peninsular Florida. In general, an isolated wetland stands alone and is separated from other wetlands or other waters. Isolation can be viewed from a number of perspectives. Wetlands surrounded by upland may be considered isolated, since they are separated from other wetlands by dry land. This is isolation from a geomorphic perspective. From a hydrologic perspective, isolated wetlands may be defined as wetlands not connected to other wetlands or waterbodies by ground or surface water.

The topographic position of the wetlands in the watershed largely determines the degree of isolation. Wetlands in the floodplain of rivers can be isolated during dry periods, but not during floods and throughout the wet season. Wetlands higher up in the watershed and formed by groundwater flowing through a local depression are not fully isolated. Wetlands in the upper watershed can be formed as a result of breaches in the aquitard separating the shallow aquifer and the lower Floridan Aquifer. The existence of these wetlands depends on the peizometric head in the Floridan Aquifer.

Examples of isolated depressional wetlands in Florida include cypress domes and sinkhole wetlands. Sinkhole wetlands form in regions of karst topography. Dissolution of underlying limestone causes the land surface to subside, creating basins which may or may not be connected to ground or surface water. Many cypress domes wetlands form in sinkhole basins. Cypress swamps found in isolated depressions are called cypress domes. The wetlands have a dome appearance with the tallest trees growing in the center. Cypress domes often form within pine flatwood regions. Cypress domes receive water from precipitation, groundwater flow, and sometimes runoff. Most of the water arrives with winter and summer rains, as opposed to river flood flows.

The hydrogeomorphic approach can be used to assess differences in the functions provided by low-gradient blackwater riverine wetlands and isolated depressional wetlands in peninsular Florida. The type and value of parameters considered in the functional assessment would be different for the two types of wetlands. Isolated depressional wetlands underlain by an impermeable soil layer and perched above the water table layer are biogeochemically closed systems which recycle nutrients internally. These wetlands serve as sinks for a variety of chemicals and would have hydric soils. Sinkhole wetlands are typically are not perched and water can leak through the bottom soils to recharge the Floridan karst aquifer. This is not a closed system, and the hydrogeomorphic characteristics and functions would be quite different than a perched, isolated and riveriene wetland.

5.0 THE FUNCTIONAL INTER-RELATIONSHIP BETWEEN THE "FILTRATION AND ABSORPTION OF NUTRIENTS AND OTHER POLLUTANTS" AND "WATER QUALITY" WITH RESPECT TO NATURAL VARIATION IN THE FREQUENCY AND DURATION OF HYDROLOGIC EVENTS

SJRWMD set minimum flows and levels using a natural variation approach, which strives to retain natural functions by mimicking the natural hydrologic regime. The magnitude, duration and return period (expressed in number of years) of flows and/or levels are specified for lakes, springs and rivers. In SJRWDM, FAC 40C-8.031 specified flows and/or levels for five river segments, eight springs and about

100 lakes. Only one river segment, St. Johns River at SR 44 near DeLand, Volusia County, has a specification for each of the four parameters mentioned above. Not only are there four parameters, but there can be a set of four parameters specified per frequency (expressed in a percent exceedance category) of occurrence. This is one of the most comprehensive instream flow specifications in the nation. Implementation of such a rule should be challenging because it requires consideration of inter-annual variation. Management of the flow level to achieve some long-term frequency is more complex than simply specifying one intra-annual flow pattern of minimum flows. Nevertheless, the functional inter-relationship between filtration and absorption processes and water quality is affected by the natural variation in water flows and levels. What changes in the parameter specifications should be allowed, based on sustaining such a functional inter-relationship, is the central question addressed by this document.

SJRWMD has identified several biological and physical indicators for specifying minimum flows and levels (SJRWMD, 2002). Elevation and thickness of surficial organic soil layers within a wetland were measured. The required water level percent exceedences for protecting the ecological functions within the soil layer were determined from previous studies. This protection was referred to as wetland rehydration. The rehydration levels were plotted on duration curves representing a specific year (1988), historic (pre-anthropogenic), and future (2010) water use conditions. The historic and future curves were determined by previous modeling studies. Both the field- and model-based curves indicate the need to sustain filtration and absorption processes in the surficial soil layers identified in the study. This document will focus on the processes as they function within these soil layers and their affect on water quality.

Statistical analysis streamflow time series data has been used to characterize the alteration of the hydrologic regime (Richter et al, 1997). This approach assumes that the normative flow regime sustains the aquatic ecosystem. Water quality that is protective of the aquatic ecosystem must also be supported by maintaining a normative flow regime. It follows that statistical indicators of hydrologic alteration (IHA) also indicate water quality alteration. In Florida, a methodology has been developed that uses flow duration curves (FDC) to accurately, quickly, and easily integrate streamflow data and ecologically significant hydrologic data for the development of minimum flows and levels (Jacobs, 2002). Pre- and post-development flow duration curves (and other hydrological statistics) can be used to indicate water quality impacts of flow diversions and regulation; however, there is a need for further research to quantify the relationships between IHAs and concentration-based water quality indicators (standards).

Depressional wetlands provide an example of a functional inter-relationship between filtration and absorption of nutrients and water quality with respect to natural variation in the duration of hydrologic events. Organic soils accumulate in depressions that are inundated for much of the year, particularly during the summer months when litter decomposition rates are high. Extended inundation in the still waters found in wetlands limits the amount of oxygen reaching the ground surface and then is assimilated by decomposing litter. The resulting anaerobic condition allows the accumulation of organic soils up to a point where the ground surface is exposed to air for less than approximately eight months during an average year (SFWMD, 2001).

The normal hydrologic regime includes droughts and low groundwater level. Flows of low magnitude provide ecological benefits associated with water quality. Periods of low flow may present recruitment opportunities for riparian plant species in regions where floodplains are frequently inundated (Poff, 1997).

An example of an assessment related to controlling lake levels to mimic desired inter-annual and seasonal patterns is in Lake Tarpon, Florida. In October 1998, the Pinellas County Board of County Commissioners formally adopted the Lake Tarpon Drainage Basin Management Plan. A major component of the plan calls for the implementation of an enhanced lake-level fluctuation schedule. This management action involves modifying the operational schedule of the Lake Tarpon outfall canal control structure to reestablish a more natural pattern of seasonal and inter-annual variation in lake levels that is to be repeated every four years. High water elevations of 3.4 feet occur during both the winter and summer months. These lake level highs are intended to flood littoral vegetation and control the expansion and proliferation of nuisance species. Low water elevations range from 1.8 to 2.2 feet, and are to occur in the spring and fall. The spring discharge should result in the flushing and dilution of in-lake nutrient concentrations prior to the summer growing season. The fall discharge is intended to flush nutrient rich runoff accumulated from the summer rainy season. The recommended inter-annual variation in lake level to be repeated every four years is intended to better simulate the natural hydrologic regime, while still maintaining consistency with the operation range established by the U.S. Army Corps of Engineers for flood control. It was estimated that this management action would result in the annual loss of over 1.8 billion gallons of water to tide (Robison, 2002). A subsequent feasibility study was conducted to evaluate the storage and beneficial reuse of surface waters discharged from Lake Tarpon.

Other considerations beyond the inter-annual scale of natural variation include other event scales such as El Nino and the North Atlantic Oscillation Index (NAOI) that occur on decadal scales. These periodic events produce multiple annual shifts in climate across North America that can affect both managed and unmanaged hydrologic systems in a multitude of ways. Furthermore, projections of long-term climate change need to be considered in managing flows and levels not only in terms of precipitation and evapotranspiration rates (versus demand), but also with regard to sea level rise and the potential for increased saltwater intrusion and coastal margin habitat changes.

6.0 A REVIEW OF METHODS USED TO ASSESS CHANGES CAUSED BY ALTERATIONS OF FREQUENCY AND DURATION OF HYDROLOGIC EVENTS

Section 3 of this report identified conceptual models used to characterize similarities of interactions between filtration and absorption of nutrients and other pollutants and water quality for lakes, streams, springs, and wetlands. The conceptual models discussed changes in filtration, adsorption and other removal processes due to the variation in the hydroperiod (for rivers, lakes and springs), and changes in frequency of overbank flooding, water table depth, soil clay content, hydric soil indicators, and soil horizon biomasses (for wetlands). The conceptual models are included in more complex methods and numerical models, that either simulate all processes and their interactions in detail, or simplify the processes based on the objective for which particular model was developed.

SJRWMD tested out a statistical method for the Wekiva River System. A linear regression analysis was performed on water quality data to determine if water level or stream flow could be used as a predictor of nutrient concentrations at times of low flow (Hupalo et al., 1994). The relationships between flow, level and nutrient concentrations of total phosphorus and nitrite plus nitrate were very weak. SJRWMD concluded that water quality is not affected sufficiently by flow rates to influence their determination of minimum flows. This method is mentioned here for completeness of review, but it is not brought forward into the following method evaluations.

A series of selection criteria have been developed to assist in the evaluation process of what model, or suite of models, are most appropriate for use in MFL analyses. These selection criteria are consistent with the objectives of this report and include the following:

1. **Target processes**: Is a model (method) capable of assessing changes in filtration and absorption of nutrients and other pollutants and changes in water quality over varying hydrologic conditions in the District? Specifically, can the model evaluate rehydration, frequency of overbank flooding, and other physical processes that affect wetland biogeochemistry?

2. **Hydrologic variability**: Is the model (method) capable of assessing sensitivities of responses to alterations in changes in hydrological regimes in the District?

3. **Model generality:** Can the same model be used for simulations in rivers, lakes, springs, and wetlands in SJRWMD?

4. **Accuracy**: How accurately can the model simulate the target processes in SJRWMD? Can the model accuracy be improved with better calibration?

5. **Minimum data requirements and cost**: Does the modeling method exceed reasonable data requirements and cost?

6.1 Models/methods rejected

Numerous models were considered but were not recommended in these MFL analyses because they did not satisfy main criteria 1 and 2. For example, the USDA Agricultural Research Station models (EPIC, GLEAMS, APEX and OPUS, used widely for modeling erosion runoff from agricultural areas in the southeastern United States) and other groundwater contaminant loading models (such as an EPA model PRZM-3) are not recommended because they do not satisfactorily represent changes in absorption and filtration through soils and vegetation due to alterations in hydrologic regimes (Criteria 1 and 2). The Stormwater Management Model (SWMM) (widely used across United States, including Florida) is not appropriate as it does not simulate absorption of pollutants in soil and wetlands. Specialized in-stream water quality models were also excluded as they mostly simulate advection and dispersion of pollutants in waters, and rarely simulate absorption and filtration in soils. The Water quality Analysis Simulation Program (WASP) was used in other parts of Florida (for simulating eutrophication in Tampa Bay estuary, and phosphorus loading of Lake Okeechobee); however, it does not track absorption of pollutants in soil. Similarly, the Linked Watershed/Waterbody Model (LWWM) merges SWMM and WASP models, and does not simulate sorption processes, nor track pollutants in the soil. TOPO-G (Commonwealth Scientific Industrial Research Organization (CSIRO) Land and Water) is also not recommended because of its poor representation of sorption processes. However, some of these models can be coupled with other models capable of simulating absorption and filtration.

6.2 Models/methods rejected, but could be potentially accepted in future

Several models satisfy one or more of the selected criteria; however they could not be recommended with certainty, because all of the modeling details could not be verified. Specifically:

- Integrated Hydrology Model (InHM) (VanderKwaak, 2003-04) has a poorly written User's Manual and Theoretical Background documentation. Although it considers transportation of pollutants in water and soil, it is unclear if and how absorption processes are included.

- The Watershed Analysis Risk Framework (WARMF) Model, developed by Systech Engineering was specifically developed for watershed assessments and TMDL evaluations; it is very questionable whether and if it simulates absorption in soils. The User's manual for this model is proprietary and is not available for public use.

- South Florida Regional Simulation Model is currently under development by South Florida Water Management District. It currently simulates surface flow, groundwater flow and infiltration. It does not simulate absorption processes and water quality; However the developers state that "it is impossible to predict exactly how the model will be used in the future and what components will be added."

- Next generation watershed model being developed by the Florida Department of Environmental Protection for TMDL assessments in the Lower St. John River Basin. This model is based on the GIS improved version of the Watershed Assessment Model (WAM)(Soil and Water Engineering Technology, 1994). The User's Manual for this model was not yet available as of August 2004.

- Gridded Surface-Subsurface Hydrologic Analysis (GSSHA) Model is currently under development at the University of Connecticut and at the U.S. Army Corps of Engineers Experiment Station in Vicksburg. Complete modeling details have not yet been disclosed.

- Watershed Environmental Hydrology (WEHY) Model is currently being tested at the University of California,Davis. This model is characterized by real physical presentation of every single model property through GIS input.

- Distributed hydrologic models, such as Distributed Hydrology Soil Vegetation Model (DHSVM) (Battelle Pacific Northwest National Laboratory and University of Washington) is mostly used and tested in the Pacific Northwest, and could be applied in SJRWMD in future.

- The Regression Partitioning Method (RPM) was developed for estimating the proportion of reactive solute uptake occurring within transient storage zones of streams (Thomas, 2003). The RPM is a technique for analyzing solute addition data in which whole stream uptake is determined from the longitudinal pattern in plateau tracer concentrations. Times series of samples are collected that define the rising limb of the solute breakthrough curve. The y-intercept estimated by regressing a measure of reactive tracer availability and the percentage of tracer that has resided within, and returned from, the transient storage zone (i.e. hyporheic zone) was used to predict channel-specific nitrate uptake rates. Uptake within the transient storage zone of stream-derived material is calculated by difference.

6.3 Models that could be used in specialized cases

The following models were specifically developed to simulate hydrodynamics, sediment transport and water quality simulations in coastal environments, including estuaries, rivers, and lakes. These models simulate in 3-dimensional detail water quality constituents in the main water body and their deposition in in-stream sediments, resuspension, and absorption through wetland vegetation. However, they poorly simulate fate and transport of contaminants through the soil. These models also require a sophisticated programming knowledge to activate specific modeling commands. These models also require outside input from a separate hydrology model, that represents changes in hydrologic regime, such as climate, precipitation, and flow rates. All of these models can be used for simulation of hydrodynamics and water quality in rivers, bays and estuaries; including all parts of St. Johns River. The models require significant input data in order to calibrate hydrodynamics (data on bathymetry, river velocity, currents, tides, wind, waves. etc) and water quality components (i.e. temperature, dissolved oxygen, salinity, metals, etc.). These models are:

- RMA11/RMA10 model - water quality and hydrodynamic models that simulate transport and fate of BOD, dissolved oxygen, nitrogen cycle, phosphorus cycle, algae growth, and selected water quality constituents.

- Estuarine and Coastal Ocean Model (ECOM) - hydrodynamic and water quality model that simulates water levels, temperature, salinity, and selected water quality variables.

- Finite Volume Community Ocean Model (FVCOM) - hydrodynamic and water quality model that simulates water levels, temperature, salinity, and selected water quality variables.

- Environmental Fluid Dynamics Code (EFDC) and Water Quality Analysis Simulation Program (WASP) models - hydrodynamics and water quality models that simulate advection, dispersion, and absorption of water quality constituents, salinity, and temperature.

6.4 Selected Models and Methods

Based on our professional judgment, the following modeling methods embody techniques that satisfy many of the selection criteria. However, they do not simulate target processes identified under Selection Criterion 1 in extensive detail. These recommended methods can be applied in specialized cases or used for screening evaluations. These methods are:

- Soil-Plant-Atmosphere-Water (SPAW) method (Washington State University)
- Pollutant Removal Estimates for Wetlands (PREWET) (US Army Corps of Engineers - Vicksburg)
- Groundwater Models

Groundwater models that have contaminant transport capabilities can be used to assess the target processes, but their accuracy is limited. For example, **MT3D** is a contaminant transport model that can simulate advection, dispersion, sink/source mixing, and chemical reactions of dissolved constituents (including metals, nutrients, trace elements, etc.) in groundwater flow systems. When these models are applied at the regional scale, the accuracy of modeling the target processes is limited. The filtration and absorption and other water quality processes will vary with local variations in soil, vegetation and geochemical properties. The karst aquifers of Northern Florida are extremely complex due to their heterogeneity. The network of flow conduits and connection with surface water needs to be mapped to model accurately the flow through springs to lakes, rivers and streams. It is at these small-scale water bodies where site-specific MFLs are to be established. MODFLOW is a commonly used groundwater model for regional scale analysis, and it uses the finite-difference numerical method. Other groundwater models use the finite-element numerical method. The accuracy of both types of models is limited is due to applying the models at the regional scale rather than the numerical method used. Of course, it is possible to apply the model to a smaller scale for a specific location, but that application requires reconstruction of the refined (smaller scale) model grid, and model re-calibration to specific local data, that is usually cost prohibitive. Groundwater models have been improved to better represent localized ground-surface water interactions. The MODFLOW Stream and Wetland Packages are good surface water extensions to the groundwater model. MODFLOW has been coupled with surface water models to make a more comprehensive tool. One such model is called ISGW, and it is describe later in this section.

Based on our professional judgment, the following models simulate most completely absorption, filtration, and other target processes identified under Selection Criterion 1. We will not attempt to rank these models in this report, but we will use the above selection criteria to define conditions under which these models can be used. These models are:

- Soil Water Assessment Tool (SWAT) model
- Hydrologic Simulation Model - Fortran (HSPF) model, and particularly the WinHSPF version of the model (within BASINS)
- MIKE SHE/MIKE-11 model
- Integrated Surface and Groundwater (ISGW) Model, linking HSPF and MODFLOW models

Table 1 summarizes main features of two methods and four models, including the name of each model developer (or sponsor), interconnection between the models (where applicable), model's level of analysis (screening or evaluation level, or detail analysis), scale of model's application (confined areas, such as fields or parking lots; small or large watersheds), model type with respect to definition of its parameters (distributed or lumped), model simulation capabilities (event models, simulating responses only during storm events; and continuous models, simulating hydrological cycle in real time). Table 1 further identifies which pollutants are simulated and tracked in each model, and which chemical and biological processes (if any) are modeled. Model's capability of simulating responses to changes in water levels during the season (seasonal variability), year (annual variability) and from year to year (inter-annual variability) are addressed. Finally, data required for each model and the cost of acquiring the model software are ranked into three groups: low, medium, and high.

Table 1. Comparison of Model Types and Potential Applications.

Model		SWAT	HSPF/BASINS	MIKE SHE/MIKE 11	ISGW	SPAW	PREWET
Sponsor/Developer		Texas A&M/USDA ARS	U.S. EPA, USGS, AQUATERRA	UK Institute of Hydrology and DHI	BCI, Schreuder Davis and Univ. of South Florida	Washington State University	US Army COE
Connection to other models		HSPF (in BASINS)	SWAT (In BASINS)	linked MIKE SHE and MIKE 11	linked HSPF and MODFLOW		
Level of Analysis	Screening	X	X	X	X	X	X
	Detail	X	X	X	X		
Model Space scale	Field	X	X	X	X	X	
	Small Watershed	X	X	X	X	X	X
	Large Watershed	X	X	X	X	X	
Model Type[1]	Distributed			X			
	Lumped	X	X		X	X	X
Model Time scale	Event		X	X	X	X	X
	Continuous	X	X	X	X		
	Annual	X	X	X	X		
Pollutants	Nutrients	X	X	X	X	Only N	X
	Pesticides	X	X	X	X	X	
	Other Chemicals	X	X	X	X		X
Processes	Filtration/Absorption	X	X	X	X	X	X
	Transport	X	X	X	X		
	Other	Algae, DO, BOD					Microbial metabolism
Hydrologic Variability	Seasonal changes	X	X	X	X		
	Inter-annual changes	X	X	X	X		
Minimum Data Requirements	Low					X	X
	Medium	X	X	X	X		
	High		X	X	X		
Cost Requirements	Low					X	X
	Medium	X	X	X			
	High		X	X	X		

Table 1. (continued)

Model		**SWAT**	**HSPF/BASINS**	**MIKE SHE/MIKE 11**	**ISGW**	**SPAW**	**PREWET**
Application Domain	Streams	X	X	X	X		
	Springs	X	X	X	X		
	Lakes	X	X	X	X	X	
	Wetlands		X	X	X	X	X

[1] Distributed models = These models have parameters assigned spatially throughout the model (i.e. at each location of a stream system)
Lumped models = These models have spatial parameters lumped at only selected locations of the system. For example, lateral inflow along the reach is lumped to the inflow at selected location of the streamflow system

Each model in Table 1 tracks history of a pollutant and its transportation from its source by runoff, water and sediment, filtration and absorption into the soil, transportation into the groundwater, diffusion, advection, and dispersion in water bodies (rivers, lakes, estuaries) and other processes. Typically, pollutant concentration decreases along its path, until it merges with other pollutants from other sources. Each model in the table has unique features of tracking these processes and they are described in more detail in the following sections.

6.5 SWAT Model

The Soil and Water Assessment Tool (SWAT) model was originally developed by the USDA Agricultural Research Service (ARS) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large watersheds with varying soils, land use and management conditions over long periods of time. The SWAT is a physically-based model and requires detailed data input such as meteorological information, soil properties, topography, vegetation, and land management practices on the watershed. Specifically, SWAT input files include a watershed configuration file (defining routing network in the watershed), input control code files, basin input file (specifying basin parameters), precipitation input file, temperature input file, solar radiation input file, wind speed input file, relative humidity input file, potential evapotranspiration input file, land cover and plant growth input file, tillage database file (specifying tillage operations), pesticide database file (mobility and degradation of all pesticides), fertilizer file (information on nutrient content), urban database file (for build-up of solids in urban areas), weather generator input file, pond/wetland file, water use input file (information on consumptive use), main channel input file (parameters for movement of water and sediments), watershed water quality input file (parameters for tracking fate and transport of pollutants on the watershed), stream water quality (parameters for tracking fate and transport of pollutants in the stream), management input file (describing management scenarios), soil physics and soil chemistry input files, groundwater input file (describing shallow and deep aquifer), reservoir input file, lake water quality input file, and point sources file. The physical processes associated with water and sediment transport, crop growth, water quality, nutrient cycling, and the fate and transport of pesticides are directly modeled in SWAT using this input data.

SWAT simulates water particles, sediments, nutrients, pesticides, algae (algal biomass), dissolved oxygen (DO) and carbonaceous biological oxygen demand (CBOD) , throughout the hydrologic cycle. Alterations in hydrologic regimes are represented as variations in daily precipitation and other climate variables and variations in water levels in a water body (stream, lake, wetland or spring). Thus, this model can effectively simulate long-term changes (due to prolonged drought or flood), such as seasonality and interannual variability. It is not suited to simulate hydrology of detail, single event floods. The variations in hydrologic regime are associated with variations in the rates of flow and sediment transport through soils via infiltration from the surface runoff, lateral flow exchange between soil and surface water, percolation from soils into aquifers, and return flow from aquifers to the surface water body. Figure 5 illustrates in detail these processes. Variations in these processes can affect filtration and absorption of nutrients and other pollutants in several ways.

The model is generally applied to land covers associated with non-urban areas, specifically agricultural land (several classes), orchards, hay and pasture (summer and winter), mixed forest, deciduous forest, evergreen forest, wetlands (forested and non-forested), range-grasses, range-brush, and water bodies.

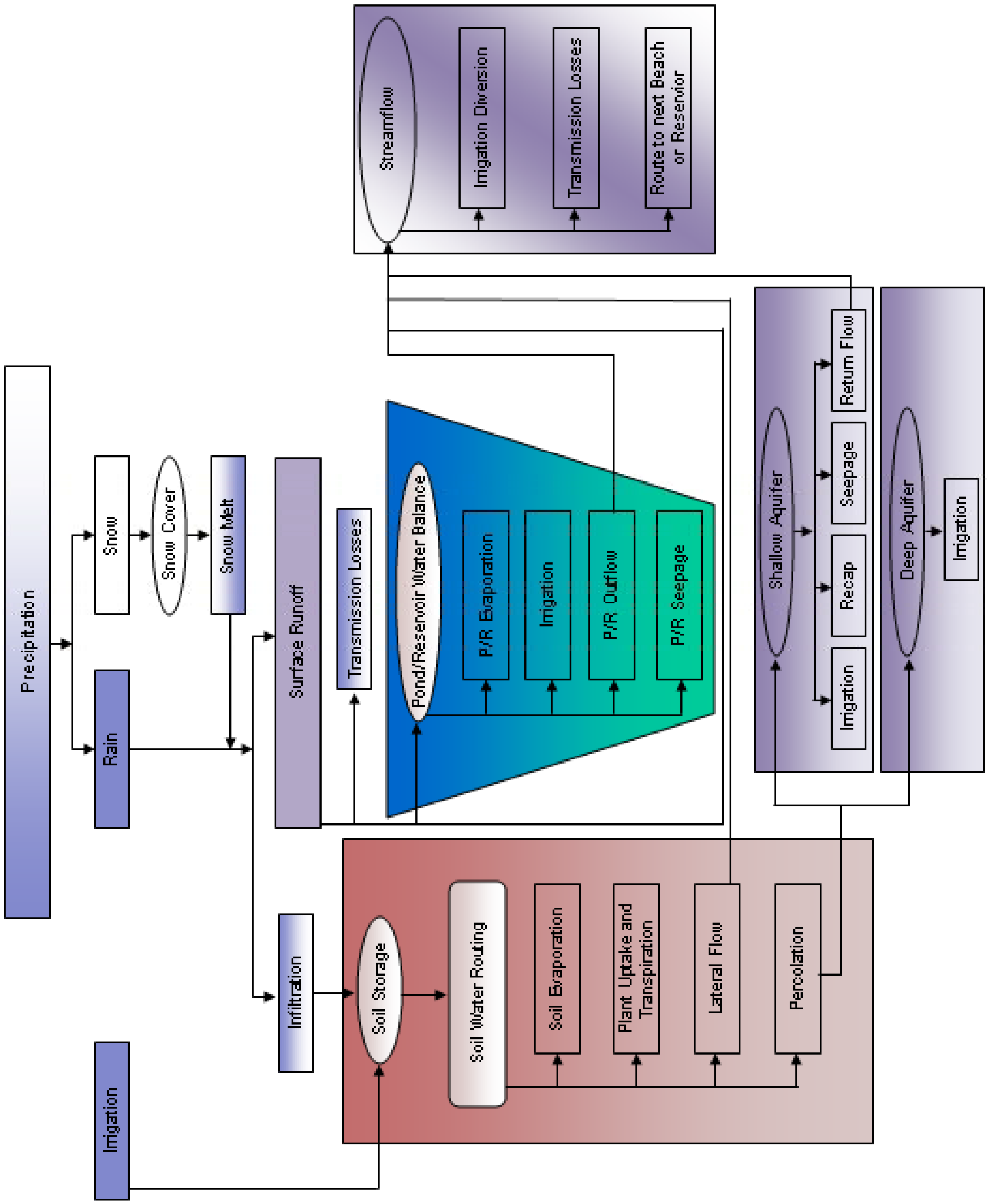

Figure 5. Conceptual Model of Typical Hydrologic Regime.

SWAT tracks movement and transformation of nutrients in the soil (according to either nitrogen cycle or phosphorus cycle, as presented in Figures 6 and 7), transport of diluted nutrients via surface runoff into the water body, or transport of nutrients from the soil into the water body via subsurface runoff. Pesticides are simulated in movement via surface runoff (in solution and sorbed to sediment transported by the runoff), and into the soil and aquifer by percolation (in solution). SWAT tracks loadings of sediments, pesticides, nutrients, algae, DO, CBOD, throughout the watershed and models their transformation in stream and channel floodplains. Except for computing algae biomass, SWAT does not simulate any other biochemical or microbiological processes.

SWAT addresses separately sorption processes of inorganic phosphorus, nitrates, and pesticide transport. After an application of soluble P fertilizer, solution P concentration decreases rapidly with time due to reaction with the soil. This initial "fast" reaction is followed by a much slower decrease in solution P that may continue for several years. In order to account for the initial rapid decrease in solution P, SWAT assumes a rapid equilibrium exists between solution P and an "active" mineral pool. The subsequent slow reaction is simulated by the slow equilibrium assumed to exist between the "active" and "stable" mineral pools.

Most soil minerals are negatively charged at normal pH and the net interaction with anions such as nitrate creates repulsion from particle surfaces. This repulsion is termed negative adsorption or anion exclusion. Anions are excluded from the area immediately adjacent to mineral surfaces due to preferential attraction of cations to these sites.

Pesticide in the soil environment can be transported in solution or attached to sediment. The partitioning of a pesticide between the solution and soil phases is defined by the soil adsorption coefficient for the pesticide. Pesticide in the soluble phase may be transported with surface runoff, lateral flow or percolation. Pesticide attached to soil particles may be transported by surface runoff to the main channel. This phase of pesticide is associated with the sediment loading from the watershed and changes in sediment loading will be reflected in the loading of sorbed pesticide.

For *rivers and streams*, SWAT simulation results can be used to compute frequency, duration and return period of overbank flooding (as specified in Section 3 of this report).

For *lakes and reservoirs*, alterations in lake volumes and water levels are simulated in SWAT by defining lake geometry and including specific routines describing movement through the lake (lake outflow, movement of sediments, lake nutrients and lake pesticides). The model assumes a fully-mixed water column and the lake bottoms underlain by a well-mixed sediment layer. Significant responses from water withdrawal, or other types of diversions, are immediately represented in the model (e.g., altered biochemical processes, such as filtration, absorption, settling and resuspension).

For *springs*, alterations in hydrologic regime, such as lowering of the groundwater table, are immediately reflected in the model. In this case there is no transport of sediments, nutrients, pesticides, etc. via surface runoff, but transport does occur through the soil below the surface (subsurface runoff) and through aquifer discharge. Similarly, the injection of water into wells results in an increase of local groundwater tables, and a subsequent increase in surface discharge from associated springs.

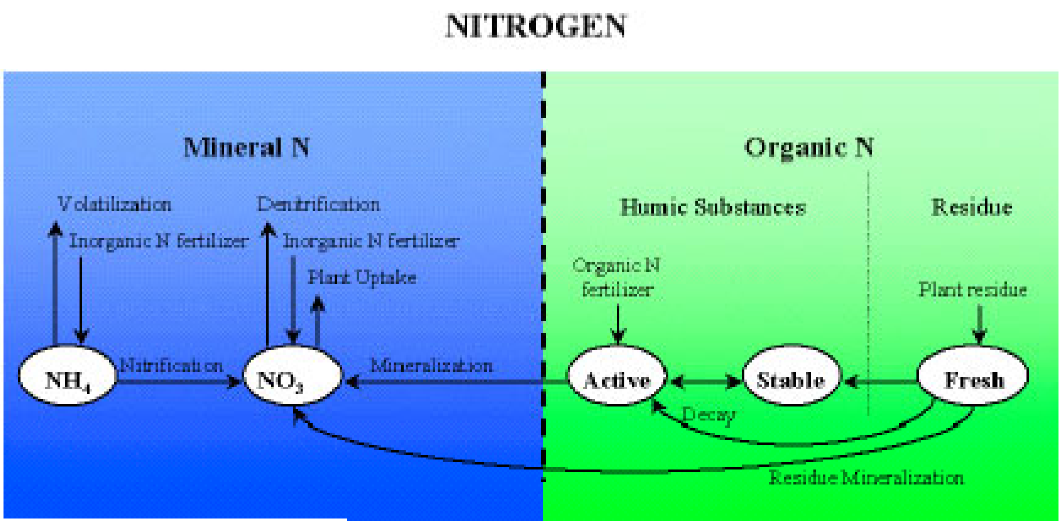

Figure 6. Partitioning of Nitrogen in SWAT Model.

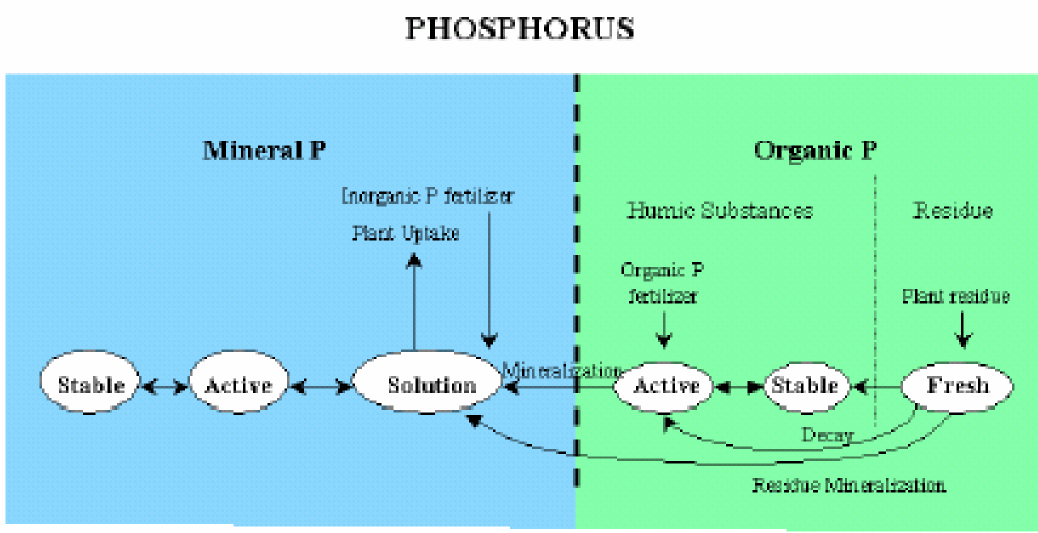

Figure 7. Partitioning of Phosphorus in SWAT Model.

Wetlands are modeled in SWAT as water bodies (located within the watershed) that receive inflow from a fraction of a watershed area. The wetlands are modeled in a similar manner to lakes and the model tracks movement (see Figure 5) and transformation of the nutrients (see Figures 6 and 7), movement and transformation of pesticides (including washoff, volatilization, degradation, infiltration, and leaching), algae, DO, CBOD). Thus, removal of nutrients from the wetlands is accounted in calculation of loading entering and exiting the wetlands.The SWAT model addresses the ecological wetland parameters, such as frequency of overbank flooding, water table depth, soil clay content, and hydric soil indicators.

Cost and data requirements: The model requires significant data input; however, these data are typically available from government agencies. The model is publicly available, but it requires an appreciable level of expertise to run. An excellent user manual is available from the software developer, and 3-day workshops are usually being offered semi-annually by a developer at the University of Texas at College Station at a typical cost of $500 per person. Please refer to the following website: http://www.brc.tamus.edu/swat/ for more information.

This model has been applied in Florida in many previous studies. For example the University of Florida in Gainesville used SWAT integrated in GIS for assessment of land resource management in northern Florida. Because of accuracy and ease of use, SWAT has also been selected by the National Resources Conservation Service (NRCS) as the decision support system to perform a national assessment of the environmental benefits derived from the Conservation Reserve Program and the Environmental Quality Improvement Program that was requested by the Office of Budget and Management. The result of this new 5-year effort will be the first comprehensive assessment of the benefits of best management practices in reducing nutrient and sediment loading in the Nation's streams, lakes, and groundwater systems.

6.6 HSPF Model

Hydrologic Simulation Program - Fortran (HSPF) was developed for simulation of watershed hydrology, and overland and in-stream water quality processes. Simulation of water quality includes temperature and sediment modeling, modeling of organics/pesticides, bacteria, and metals, and modeling of biochemical reactions (such as dissolved oxygen and BOD, inorganic nutrients, plankton and refractory organics, pH and inorganic carbon). . The HSPF uses information on climate, land surface, land use, soil properties, and land management practices, to model water and sediment movement throughout the watershed. Simulation of hydrologic processes includes surface water and sediment runoff from impervious and pervious surfaces, infiltration of surface runoff into the upper soil zone, lower soil zone and aquifer, and interflow between these three soil zones and the waterbody. Movement, losses and transformations of water quality constituents are modeled. The model tracks pollutant accumulation and washoff from watershed surfaces and subsequent fate and transport through soils and receiving waters. Losses and transformation processes include pesticide sorption, decay and fate, transformation and fate of nutrients, and movement of moisture and dissolved gas.

Alterations in hydrologic regime are associated with variations in hourly precipitation, temperature, wind speed (and other meteorological/climatological variables) and variations in water level and water temperature in a waterbody (stream, lake, wetland, and spring). The model can simulate long-term changes through seasonal or annual variations, or short-term changes through responses to individual storm events. Variations in hydrologic regime result in changes to interflow, infiltration into soils, percolation between the three soil zones, and uptake by plants (transpiration). Thus, variation in overall water budget affects the status of nutrients and pesticides in the soil and in-stream water quality constituents such as organics, bacteria and metals.

The AGCHEM module of HSPF simulates nitrogen cycle in the soil through nitrification, immobilization, mineralization, and leaching; and phosphorus cycle in the soil through immobilization, mineralization, and leaching. The cycling of pesticides into the soil is simulated through wet and dry deposition during application, leaching fromm the plants into the soil, volatilization, absorption and irrigation, and decay and exudation organic matter in the soil and water. The model tracks fate of water quality constituents, within the water column, through simulations of hydrolysis, oxidation, photolysis, volatilization, and biodegradation. HSPF can also simulate and track fate of water quality constituents involved in biochemical transformations, such as dissolved oxygen (DO) and biochemical oxygen demand (BOD), inorganic nutrients, primary production (algal growth), pH and inorganic carbon.

Volumetric flux through channels and lakes is simplified in HSPF, as a volume of water in a reach (or reservoir) is always expressed as a function of the water surface in the channel. For example, during the flood, water from the main channel spreads into the floodplain and into the floodplain side channels. Distribution of water can vary between the main channel and many side channels, and the model does not accurately represent this distribution of water, nor water surface in all the channels. Similarly, distribution of sediment depositions between the multiple channels is approximated in this model.

HSPF simulates sorption of nutrients in the water quality module and the AGCHEM module. The AGCHEM module mimics degradation of pesticides and nitrogen transformation (see Figure 8).

HSPF simulates *rivers, streams, lakes, and reservoirs* in the module RCHRES that includes hydraulic routing (flux), transport, and fate of sediments and all pertinent water quality parameters. The simulation in this reach is tied to the other reaches through watershed/soil and channel network.

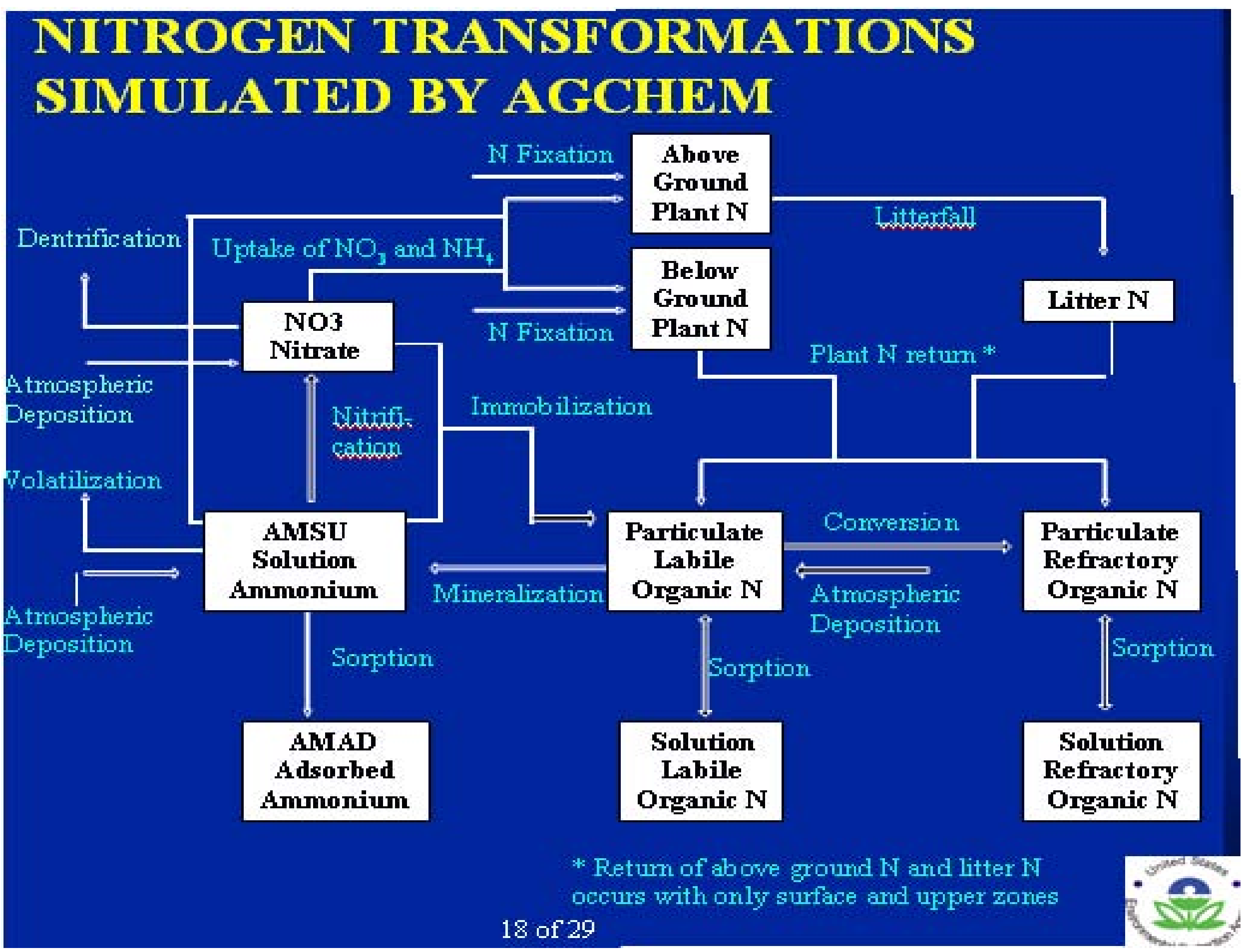

Figure 8. Conceptual Model Indicating Nitrogen Transformations Simulated by AGCHEM.

There is no specific module associated with *wetlands* in HSPF. However, wetland is modeled as an individual hydrologic system that consist of a watershed, inflow stream, wetland reservoir, and an outflow. Changes in a wetland hydrology result in changes to that hydrologic system and different hydroperiods, including different inflows and outflows of different durations. These flows trigger different responses of water quality constituents through alterations in rates and magnitudes of absorption and filtration processes. The absorption and filtration also depend on the pre-existing soil properties, including antecedent conditions.

HSPF simulation results can be immediately used with the HSPF post-processing software (ANNIE, SWSTAT, WDMUTIL) to determine frequency, duration, and return periods of various parameters, including overbank flooding. Depth to groundwater table, soil texture, and other wetland parameters identified in Section III must be provided in the model input.

HSPF input files include meteorological data, snow and ice data, data on soil and interflow, land use data, sediment geometry and sediment property data, groundwater data, dissolved gas data (DO and CO_2), information on pollutants (pesticides, nutrients, bacteria, metals, planktons), watershed delineation data, digital elevation data (DEM file), channel geometry and hydraulic data (as water surface elevation - channel storage - channel flow), heat conduction and ground temperature data, biochemical data required by AGCHEM and other water quality modules, and model structure indicating connections between various model components.

Cost and data requirements**:** The model requires significant data input (although somewhat less than the SWAT model). The model is publicly available from the USGS and from EPA within the BASIN GIS interface. The Windows^{TM} version of the model within the BASINS (WinHSPF) is significant improvement and more user-friendly than the USGS version. The Environmental Protection Agency (EPA) and its consultants offer 4.5 day workshops (usually annually) on the BASINS HSPF. Typical cost for one workshop is over $1,000 per person. Please refer to the following website: http://www.epa.gov/OST/BASINS/b3webdwn.htm for download of BASINS and WinHSPF.

HSPF model has been widely applied throughout Florida, for example on the St.Lucie Estuary watershed, the model was modified to enable representation of the region-specific hydrologic features prevalent in South Florida. The goal of the model modifications was to develop a viable simulation package that represents the South Florida hydrologic conditions and can be used to evaluate the impacts of management options that must be applied to maintain discharge to the St. Lucie estuary within an acceptable range. The modifications provide the capability to handle control structures (i.e., pumping, gates, weirs, culverts, etc.) that are dominant features in the watershed, and better represent such phenomena as wetlands hydrology, high water table, irrigation practices, and detention/retention ponds. In St. John's District, the model was applied in the South Prong watershed. SJRWMD developed HSPF models to estimate potential impacts on the ecological systems of Sebastian River and adjacent Indian River Lagoon and to assist planners in devising strategies to prevent further degradation of water resources. In the South Prong system, a storm water sampling program was carried out to calibrate the water quality components of the HSPF model for TSS, total phosphorous, and total nitrogen.

6.7 MIKE SHE/MIKE 11 Model

MIKE SHE/MIKE 11 (Danish Hydraulic Institute (DHI), University of Newcastle, Laboratorie d'Hydraulique de France) is a physically-based and spatially distributed, integrated surface and groundwater model. Similar to SWAT and HSPF models, it simulates all components of a hydrologic cycle; however simulation of flow through the soil (in MIKE-SHE) is simulated in more detail through 3-dimensional groundwater equations for the saturated soil layer. The overland flow on the watershed (overland module), and flow below the surface in the saturated and un-saturated soil (saturated and unsaturated zone modules) is simulated in the rainfall-runoff module. MIKE-11 model receives inputs of flows, sediment, and water quality constituents, from the MIKE-SHE model at selected locations, then routes these inputs through the streamflow system of channels, lakes, and reservoirs . MIKE-11 simulates distribution of flow from the main channel into the floodplain with selective flood options.

Alterations in hydrologic regime are first included in the rainfall-runoff module, and are presented as either decreased or increased flows at various locations of a stream network in the MIKE-11 model. These inflows are allocated as inputs at known stream locations (i.e. confluence with another stream or tributary, known discharges from point sources, or lateral inflows along various stream reaches). MIKE -11 conveys these inflows downstream through the stream network, consequently affecting transport of both sediment and water quality constituents.

The water quality module of MIKE-11 simulates physical, chemical and biological interactions in the water body, specifically oxygen processes, temperature, degradation of organic matter in water, nitrification and denitrification, coliforms, phosphorus exchange with the streambed, phosphorus decay, phosphorus uptake by plants, degradation of organic matter at the bed, sedimentation of suspended organic matter, adsorption of organic matter, and resuspension. This module does not simulate microbiological processes, trace elements and pesticides. The simulations of these processes are not only included along the riverbed, but also in the floodplain with the specifically constructed Wetland module.

The Wetland module of MIKE-11 has been designed to simulate nutrient removal processes, their interrelationship, and their effects on the river water quality. When a stream system branches with adjacent floodplains, and selected branches constitute a wetland, these wetlands can be modeled by the Wetland module in conjunction with water quality modeling of the main stream branch. The inclusion of wetlands into the modeling is determined with a pre-defined flooding level. If a flooding level from the stream is below that level then there is no effect on water quality. If the model flooding level from the stream is above that level, the Wetland module calculations will influence the stream water quality proportional with the water volume that is in contact with the floodplains. However, water quality processes in the main river channel will also be affected.

Thus, MIKE-11 simulation results (with the Wetland module) can be used to compute frequency, duration and return period of overbank flooding for *rivers, streams and wetlands* (as specified in Section III of this report).

The MIKE-SHE component of the model defines *lakes and reservoirs* by specifying pre-delineated flooding areas within the stream network. Thus, hydrologic alterations in volumes and water levels of lakes and reservoirs are modeled in MIKE-11/MIKE-SHE by increased flooding area that, in turn, activates the Wetland module water quality calculations of the model, including absorption and filtration processes. The subsurface and groundwater flow from the lake into the soil and vice versa are simulated in detail in MIKE-SHE.

The inflow from a *spring* to the model stream network is specified as a point source computed by the rainfall-runoff module. Fluctuations in the water table affect rates of spring discharge. The alterations in hydrologic regime, such as lowering of a groundwater table, are immediately reflected in the model by cessation of surface runoff component in the rainfall-runoff module. This in turn results in no nutrients or other pollutant transport via surface runoff, but only through the transport below the soil surface (subsurface runoff) and through groundwater aquifer. Similarly, the injection of water into wells will be translated into an increase of the local groundwater heads.

Details on absorption and filtration of nutrients are proprietary, and are available only to the users who have purchased this expensive program.

Cost and data requirements: The data input into this model is proportional to the number of modules applied in the model. The model is proprietary and is commercially available from DHI. The model cost varies from $4,000 for all basic modules to up to $20,000 for all modules of MIKE-11 and MIKE-SHE. DHI provides users with easily understandable user's manuals, and offers courses upon request (cost for these courses vary, but DHI offers discounts for non-profit organizations and agencies). Please refer to the following website:
http://www.dhisoftware.com/index.htm for DHI software prices.

MIKE-11/MIKE-SHE model has been applied successfully in South Florida on Everglades Restoration projects.

6.8 ISGW Model

The Integrated Surface and Groundwater (ISGW) model (developed by University of South Florida and Schreuder Davis Inc. (SDI)) couples the HSPF model and 3-dimensional groundwater model, MODFLOW. It has all characteristics of the HSPF model regarding transport of water, sediments, and pollutants throughout hydrologic cycle, including filtration and absorption in the groundwater. The HSPF model simulates groundwater recharge at each model reach and the MODFLOW model uses these values together with comprehensive data on soil, geology, and soil and aquifer hydraulic characteristics, to simulate groundwater levels. While MODFLOW provides detail simulation of groundwater flow, all chemical reactions, and fate and transport of contaminants, are still simulated in the HSPF model.

Loading estimates for nutrients and pesticides are estimated in the HSPF model. Movement of pesticides and nutrients through soil and groundwater is tracked in the MODFLOW model. Any biochemical processes such as estimate of an algal growth are computed in the HSPF model.

Cost and data requirements: This model requires greatest number of data to use both in the HSPF model and the MODFLOW model. The model is free for public use, but requires modelers experienced in running both models. Please refer to the software developer's website:
http://www.isgw.com/home.html for more information about this model.

This model was successfully applied in South Florida by University of South Florida and in the Central Northern Tampa Region by SDI.

6.9 SPAW Method

The Soil-Plant-Atmosphere-Water (SPAW) method (USDA and Washington State University) is a daily hydrologic budget model for agricultural fields and ponds. It is applicable only to wetlands, ponds and reservoirs, and is not applicable to rivers, streams, and springs. This method can only track water budget and nitrogen cycle in the soil. Most processes of surface and subsurface hydrology are simulated including seepage from lakes into soils (and vice-versa), and diversions from lakes due to water supply needs. Thus, alterations in lake water levels cause reduced infiltration from lakes to soils and altered uptake of nitrogen from the wetland vegetation. The model results can be used to estimate frequency of overbank flooding by a standard statistical package.

This model does not satisfy all of the selection criteria; however it requires a minimal amount of input data and is relatively simple to use. It can be applied on a limited basis.

Cost and data requirements: This model is free for public use and requires minimum data. Please refer to the following website: http://www.bsyse.wsu.edu/saxton/spaw/Index.htm#Delay=0 for more information.

This model can be applied in the District, subject to the above limitations (constraints).

6.10 PREWET Method

The Pollutant Removal for Wetlands (PREWET) screening model was developed by the US Army Corps of Engineers for estimating water quality improvement through wetlands with minimum input data. Given basic wetland characteristics, pollutant removal efficiency (RE) can be computed for total suspended solids (TSS), total coliform bacteria, BOD, total nitrogen (TN), total phosphorus (TP), and other contaminants (metals and organic chemicals). The RE depends on the wetland detention time and the removal rate for the constituent. The removal rates depend on microbial metabolism, adsorption, volatilization, settling, and ambient conditions.

Alterations in hydrologic regime (i.e., reduced inflow to the wetland or reduction in free-standing water surface) affect wetland biogeochemical processes, including filtration and absorption. This simplified screening model works only when a stream feeds the wetland and has an outflow from the wetland. Water quality processes and hydrology outside the wetland are not addressed. Thus, many of the wetland parameters identified in Section III of this report cannot be estimated.

Cost and data requirements: This model is free for public use and requires a minimal amount of input data. Please refer to the following website: http://www.wes.army.mil/el/elmodels/index.html#wqmodels for more information.

This model can be applied in the District, subject to the above limitations (constraints).

6.11 Comparative Evaluation/Summary of Select Models

Based on our professional judgment, we have identified the models capable of assessing changes in filtration and adsorption of nutrients and other pollutants and changes in water quality over varying hydrologic conditions. Additionally we have evaluated model responsiveness to alterations in hydrologic regimes, and specific model abilities to represent these responses in streams (including rivers, canals, and drainage ditches from agricultural fields), lakes and reservoirs, springs, and wetlands. We have also discussed model accuracy in predicting flows and pollutant loadings. Finally, we have elaborated on data requirements, and cost of acquiring these models. All of these models have been tested and applied in Florida. The following table summarizes the main models features:

Table 2. Comparative Evaluation of Selected Models.

Model\Selection Criteria	SWAT	HSPF (WinHSPF)	MIKE SHE/MIKE 11	ISGW
1. Modeling all target processes	Yes	Yes	Yes	Yes
2. Modeling some biochemical and microbiological processess	Yes	Yes	No	No
3. Model responds to alterations in hydrologic regime	Yes	Yes	Yes	Yes
4. Model changes in streams, lakes, springs, and wetlands	Yes (all 4)	Modeling of wetland requires additional effort	Yes (all 4), and the wetland module is tailored to one of this project objective	Modeling of wetland requires additional effort
5. Evaluate model accuracy	Only simplified channel geometry routed, not accurate water level predictions	Cannot accurately simulate frequency of overbank flooding and depositions in multi-channel floodplain	Accurately simulate water levels, water flows, and multiple channels. Simulation of subsurface flow in MIKE-SHE is simplified.	Increased accuracy in water level predictions, but still cannot simulate multi-channel depositions. Accurately simulate groundwater and subsurface flows.
6. Data requirements/ Purchase Cost	High/None	Medium to High/None	Medium/High	High/None

We do not attempt to rank these models, but we can give directions on when some of these models can be used. For example, SWAT and HSPF can be used in all MFL analyses with a minimum initial investment. Although these models require significant amount of data, many of these data exist and are available from government agencies. Both models become more accurate if calibrated to local data and observations. If a project shows significant affect from the groundwater, and the existing groundwater model (i.e. MODFLOW) is already developed in the study area, the ISGW model can be recommended. MIKE SHE/MIKE 11 model will require higher initial investment, but will be more user friendly if modeling of wetlands within the stream network is required. Otherwise, all four models equally well predict pollutant transport and concentrations in the stream network.

7.0 POSSIBLE CRITICAL THRESHOLDS WITH RESPECT TO THE FREQUENCY AND DURATION TO BE USED IN MFLS ASSESSMENTS

Fluctuations in flows and levels of lakes, river, streams, springs and wetlands directly influence water quality thresholds. These thresholds determine some point in response to stressors where desired conditions are no longer present. Examples include, but are not limited to, dissolved oxygen concentrations, water quality constituent concentrations or masses (e.g., nutrients, toxics), algal and nuisance algal stocks, temperature and light penetration. Thresholds associated with desired conditions vary across systems. For example, differences in water volume, depth, flow, and residence times between lakes and rivers result in varying influences of physical, and biogeochemical, processes. Thus different values for certain thresholds will exist. Furthermore, differences in habitat structure and function will influence the type and degree of related water quality thresholds.

A series of thresholds are illustrated in Table 3 associated with the processes of "filtration and absorption of nutrients and other pollutants" and "water quality." This table provides a general framework of similarities and differences between lakes, rivers and streams, and wetland (including riparian) environments with regard to these water quality (nutrient and pollutants) attributes that are influenced by filtration and absorption, and fluctuations in flows and levels. (An example of critical thresholds at the site-specific scale are illustrated in Table 4 of Section 7).

Table 3. A Series of Critical Thresholds and Their Association with the Frequency and Duration of Flows and Levels in Lake, River and Stream, and Riparian/Wetland Environments.

Threshold Type	Nature of Threshold	Effect of Frequency and Duration of Flows and Levels on Thresholds		
		Lake Environments	**River and Stream Environments**	**Riparian and Wetland Environments**
Nutrients	• High nutrient concentrations associated with eutrophication (increased algal growth, biomass, and decay). • Possible toxicity to biological and human populations (e.g., NH_4. NO_3).	• Fluctuations in lake levels may directly influence horizontal transport of nutrients. • High phosphorus retention times and internal cycling results in buildup within sediments and higher availability to primary producers. • High phosphorus concentrations due to sediment release and horizontal transport can result in blooms of noxious cyanobacteria. • High flows to receiving lake waters can result in lower water residence times which result in lower rates of biological assimilation of nutrients, and hence, reduced symptoms of eutrophication. However, this depends on the relative ratio of flow (input) rate to lake volume.	• High flow frequency and duration typically results in lower concentrations if source is constant. • If source is flow (or discharge) dependent then complex response in concentrations due to variations and timing of flow. • High flows typically result in lower water residence times which result in lower rates of biological assimilation of nutrients, and hence, reduced symptoms of eutrophication. • Storm events typically possess asymmetrical concentration response curves.	• Riparian, benthic and wetland habitats require minimum frequency and duration of flooding events to remain functional and influential on nutrient dynamics. • Water levels along riparian and within wetland habitats determine nutrient delivery rates, retention, and transformations.

Threshold Type	**Nature of Threshold**	**Effect of Frequency and Duration of Flows and Levels on Thresholds**		
		Lake Environments	**River and Stream Environments**	**Riparian and Wetland Environments**
Pollutants (organics, pesticides, metals)	• Various concentration-based thresholds associated with biological, ecosystem and human health. • Bioaccumulation and trophic transfer of pollutants is a potential risk.	• High flow frequency and duration typically results in lower concentrations if source is constant. This is usually dependent upon flow:volume ratio. • If source is flow (or discharge) dependent then complex response in concentrations due to variations and timing of flow.	• High flow frequency and duration typically results in lower concentrations if source is constant. This is usually dependent upon flow:volume ratio. • If source is flow (or discharge) dependent then complex response in concentrations due to variations and timing of flow. • Storm events typically possess asymmetrical concentration response curves.	• Suboptimal water levels reduce pollutant buffering capacity of wetlands to receiving water bodies (lakes, rivers and streams).
Dissolved Oxygen (DO)	• Hypoxic or anoxic conditions create inhospitable habitat for fauna. • Frequency and duration of low DO events has different effects on various biological communities. • Duration usually more deleterious to biological communities than frequency.	• Low flows and levels are positively correlated with low DO events due to: (1) smaller volume of water relative to rates of community respiration and (2) poor vertical and horizontal exchange of water and diffusion of oxygen.	• Low flows and levels can be positively correlated with low DO events due to: (1) smaller volume of water relative to rates of community respiration and (2) poor vertical and horizontal exchange of water and diffusion of oxygen.	• Wetlands are often reduced environments that result in low oxygen conditions in both the sediments and water column. However, like lakes and rivers, wetland DO levels are influenced by flows and levels of water for the same reasons. Relatively small volumes can result in extreme changes in DO over diel

Threshold Type	Nature of Threshold	Effect of Frequency and Duration of Flows and Levels on Thresholds		
		Lake Environments	**River and Stream Environments**	**Riparian and Wetland Environments**
	• High frequency and/or duration of low DO events results in significant die off of benthic infauna, epifauna, and pelagic species (invertebrates and fish). • Chronic low DO influences long-term water and sediment chemistry.			cycles (daytime production vs. nighttime respiration).
Temperature	• Extremes in water temperature (deviations from normal ranges) put biological communities at increased risk. • High temperatures associated with low DO due to lower saturation capacity and higher rates of community respiration (oxygen consumption).	• Low flows and levels can result in reduced exchange and volume, therefore higher temperatures.	• Low flows and levels can result in reduced exchange and volume, therefore higher temperatures.	• Low flows and levels can result in reduced exchange and volume, therefore higher temperatures.
Light Penetration	• Decreased light penetration (water transparency) negatively affects	• Low flows and levels associated with higher water residence times and, therefore, greater likelihood of	• Low flows and levels associated with higher water residence times and, therefore, greater	• Light penetration less important in the support of wetland macrophytes as they are typically

Threshold Type	Nature of Threshold	Effect of Frequency and Duration of Flows and Levels on Thresholds		
		Lake Environments	**River and Stream Environments**	**Riparian and Wetland Environments**
	benthic and water column primary producers (algae, macrophytes).	phytoplankton production which results in increased light attenuation. • However, high flows can be associated with increased suspended sediments and organic matter, causing decreased light penetration. This is typically a periodical occurrence (e.g., storm events or releases). • Low levels may increase light availability to benthic communities, resulting in greater production in the benthos. • Low flows and levels may increase likelihood of water column stratification due to decreased turbulent energy.	likelihood of phytoplankton production which results in increased light attenuation. • However, high flows can be associated with increased suspended sediments and organic matter, causing decreased light penetration. This is typically a periodical occurrence (e.g., storm events or releases). • Low levels may increase light availability to benthic communities, resulting in greater production in the benthos. • Low flows and levels may increase likelihood of water column stratification due to decreased turbulent energy.	emergent.
Sediments	• Water column sediment concentrations are associated with light penetration, habitat	• High flows associated with increased suspended sediments. • Low flows can be associated with reduced rates of	• High flows associated with increased suspended sediments. • Low flows can be associated with reduced	• High flows associated with increased suspended sediments. • Low flows can be associated with reduced

Threshold Type	Nature of Threshold	Effect of Frequency and Duration of Flows and Levels on Thresholds		
		Lake Environments	River and Stream Environments	Riparian and Wetland Environments
	quality, and substrate type.	sedimentation in receiving water bodies.	rates of sedimentation in receiving water bodies.	rates of sedimentation in receiving water bodies.
Volume	• Volume of water associated with direct human consumption demand and biological community habitat.	• Low flows and levels associated with lower volume and, therefore, limits supply for water demand. • Low volumes associated with low DO events and subsequent negative impacts on invertebrate and fish communities. • High flows and levels may have negative effects on lake benthos and fringing wetland habitat through decreased light availability and extreme saturation events, respectively.	• Low flows and levels associated with lower volume/water supply. • Low volumes associated with low DO events and subsequent negative impacts on invertebrate and fish communities. • Low volumes and flows result in negative impacts on riparian zones.	• Low levels associated with negative impacts on wetland vegetation (drying events) and dependent invertebrate and fish communities. • Low volume can result in extreme anoxic events that are deleterious to invertebrate and fish communities.
Stratification	• Vertical stratification isolates water columns and impedes diffusion of dissolved oxygen, nutrients, pollutants, and the transport of organic matter.	• Low flows and levels can increase likelihood of stratification events.	• Low flows and levels can increase likelihood of stratification events.	• Stratification is typically not an issue in wetland environments due to their shallow nature.

Study designs based on determining thresholds and biogeochemical responses to changes in hydrologic regime can benefit from previous and ongoing research in system classification (also called typology) and reference site studies. For instance, in recent years work on the development of water quality criteria and long-term responses to perturbations and restoration efforts in aquatic systems have focused on geomorphologic classifications as the basis for categorizing systems. This is because complexity, even among same system types (e.g., lakes, rivers, streams), varies significantly due to a series of governing factors. Typically these factors are associated with geomorphologic characterizations (size, depth, and associated ratios) and physical forces (water residence times, meteorology). Classifying systems by similar attributes helps to decrease uncertainty associated with system responses to changes in physical and biogeochemical processes. It also allows the establishment of “reference sites” that act as controls to altered aquatic systems. For example, reference sites are typically desired in restoration efforts in that they help identify and explain natural variability or the effects of regional or global perturbations.

8.0 THE EFFECTS OF HYDROLOGIC CHANGES FROM PERMITTED WITHDRAWALS COMPARED TO BASIN INPUT CHANGES FROM LAND USE

Water quantity and quality are so closely related that it in many cases there appears to be no such distinction. The adage, “Dilution is the solution to pollution,” is pervasive, but it is misleading. The approach to pollution control entailing dilution of high concentration inflows with receiving water is feasible only if the concentration of the receiving water is lower than the inflow. Similarly, increasing receiving water discharge to raise water levels could provide more dilution capacity to receiving waters. This approach is feasible only if the concentration of the additional discharge is lower than the receiving water. In either case, pollutant loading from basin inflows needs to be managed on a watershed basis in conjunction with withdrawals that affect receiving water discharge.

Filtration and absorption of nutrients and other pollutants affects the concentration of inflows originating from surface and subsurface runoff from the watershed. This was discussed in earlier sections. Generally, land use type dictates the concentration of pollutants in the runoff and the partitioning of runoff between the surface and subsurface flow paths. Also, land use dictates water demand and withdrawal quantities. Combined high demand for withdrawals and high pollutant concentrations in runoff from both agricultural and urban land uses could more than double the water quality impact in receiving waters. In this case, there would be less receiving water available to dilute the higher concentrated inflows. In this section, the impact of permitted withdrawals and basin input changes from land use are evaluated qualitatively and independently, and then compared to each other and the combined impacts.

The primary effect of permitted withdrawals on water quality is through alteration of the normal hydrologic regime. This effect is evaluated assuming that loading from the watershed remains constant. The hydrologic regime can be defined by the intra- and inter-annual characteristics of the timing and magnitude of discharge. Changes in these discharge characteristics affect the flow level and velocity, which in turn affects filtration and absorption processes and water quality. Flow level and velocity is dictated by discharge and the geomorphology (shape, slope and roughness) of the water body and surrounding floodplain. In the case of the St. Johns River and coastal streams, flow level and velocity is also dictated by tides. Also, dams, spillways, weirs and other in-stream hydraulic structures dictate flow level and velocity. Withdrawals, however, directly affects discharge, flow level and velocity, and subsequently water quality.

Statistical analysis streamflow time series data has been used to characterize the alteration of the hydrologic regime (Richter et al, 1997). This approach assumes that the normative flow regime sustains the aquatic ecosystem. Water quality that is protective of the aquatic ecosystem must also be supported by maintaining a normative flow regime. It follows that statistical indicators of hydrologic alteration (IHA) also indicate water quality alteration. In Florida, a methodology has been developed that uses flow duration curves (FDC) to accurately, quickly, and easily integrate streamflow data and ecologically significant hydrologic data for the development of minimum flows and levels (Jacobs, 2002). Pre- and post-development flow duration curves (and other hydrological statistics) can be used to indicate water quality impacts of flow diversions and regulation; however, there is a need for further research to quantify the relationships between IHAs and concentration-based water quality indicators (standards).

Residence time and transient storage are two hydraulic characteristics that vary with discharge and influence filtration and absorption of nutrients and water quality. The bathymetry of a lake and the cross-sectional shape of a river are primary factors that govern the relationship of discharge with level and velocity. Standard stage-, area- and volume-discharge curves are used to show these relationships. Resident time can be controlled in lakes, reservoirs and canals with man-made outlets by adjusting the lake level and outflow. Also, the water level controls in isolated water bodies and wetlands affects leakage rates to groundwater and subsequently affects resident time. Resident time can simply be computed knowing the discharge and the corresponding volume. This represents that amount of time available for reactive solute (nutrient) uptake in the water column. Also, it approximates the time available for contact with soils and interstitial pore water in the hyporheic zone.

The region of mixing between subsurface water and surface water is the hyporheic zone; a region of intensified biogeochemical activity (Sophocleous, 2002). Flow is temporarily stored in these zones and in eddies off the main flow path. Transient storage in the water column increases residence times via eddy diffusion. Transient storage in the bed and bank sediments increases mixing of flow with groundwater and filtration and absorption of flow in the shallow aquifer. In the floodplain, wetlands and depressions become transient storage sites during floods.

There have been several recent investigations of hydraulic control of nutrient uptake in streams. The investigations did not explicitly examine the relationship between discharge and nutrient concentrations; however, their experimental results shed some light on this relationship. Nutrient enrichment studies were conducted in North Carolina and New Hampshire to estimate nitrification, ammonia, nitrate and phosphate uptake in streams. The studies examined transient storage and nutrient uptake at several discharges. In the New Hampshire studies, researchers concluded that hydraulic parameters, such as transient storage, exert some control on ammonia, but no relationship was found between transient storage and nitrate uptake (Thomas, 2003). Phosphate uptake was not related to transient storage, presumably because phosphate uptake is predominantly by chemical sorption in the bed sediments (Hall, 2002). In the North Carolina study, the uptake within the transient storage zone accounted for 44–49% of the total uptake (Bernhardt, 2002). The amount of uptake in transient storage zone increased with discharge in North Carolina study, but nutrient uptake was negatively correlated with transient storage in a study of Sycamore Creek in Arizona (Hall, 2002). More research is needed to assess the propensity for transient storage zones (the hyporheic zone in particular) to affect nutrient uptake in different systems. It is anticipated that the influence of the storage zone will reflect both the hydrological and biological features that may exist in various combinations across the diversity of freshwater ecosystems (Thomas, 2003).

These studies also attempted to determine how different types of transient storage affect nutrient uptake. Transient storage was partitioned between the water column (eddies or pools) and the hyporheic zone. Water flowing through transient storage in the sediments of the hyporheic zone would encounter nutrient-hungry biofilms which would increase both resident time and the rates of biogeochemical processes. Water in flowing through transient storage in pools would encounter less contact with biofilms as in the hyporheic zone, hence, the uptake would be less in pools. On the other hand, organic matter often deposits in pools, and thus creates a high nutrient demand. The variation of this size and sediment characteristics of the types of transient storage zones with discharge are site-specific data that should be collected to determine in-channel water quality impacts.

Depressional wetlands in the floodplain and buffer zones along the shoreline also provide transient storage. Their effectiveness in providing nutrient uptake is obviously dependent on discharge and flow level. Their biogeochemical processes will not function to their fullest capacity without inundation. Organic soils accumulate in depressions that are inundated for much of the year, particularly during the summer months when litter decomposition rates are high. Extended inundation in the still waters found in wetlands limits the amount of oxygen reaching the ground surface and then is assimilated by decomposing litter. The resulting anaerobic condition allows the accumulation of organic soils up to a point where the ground surface is exposed to air for less than approximately eight months during an average year (SFWMD, 2001). These organic soils support unique plant communities, and allows for higher biogeochemical process rates.

Organic soils accumulate very slowly, on the order of about 1 to 2 feet per 1000 years, but they can be lost much more rapidly. Similar depths can oxidize in less than a decade due to increased exposure to air associated with a lowered water table following drainage. They can be lost even more rapidly, in a matter of days, when consumed by fires following drainage (SFWMD, 2001). Response to restoring the normal hydrologic regime would be very slow, probably taking centuries, but it would limit further organic soil loss and provide a setting for the long-term recovery of the site.

The normal hydrologic regime includes droughts and low groundwater level. Flows of low magnitude provide ecological benefits associated with water quality. Periods of low flow may present recruitment opportunities for riparian plant species in regions where floodplains are frequently inundated (Poff, 1997).

The magnitude, duration and frequency of groundwater levels establish a transition of vegetation and soil types in the riparian buffer zone going away from the shoreline. Temporary storage of ammonium on riparian sediments may influence biotic nitrogen cycling, and alter the timing and form of dissolved inorganic nitrogen transport from the watershed (Triska, 1994). Absorption and filtration of nutrients varies between vegetation and soil types. Groundwater level changes would affect water quality because the vegetation and soil mix and subsequently the uptake by plant and soil absorption and filtration will change.

The final aspect of water quantity effects on water quality discussed here applies to tidally influenced rivers and streams. Specifically, the freshwater/salinity transition between the St. Johns River and the Atlantic Ocean would be affected by permitted withdrawals. The Suwannee River was used as a case study for setting MFLs using the FDC allocation methodology. The study used three control points and allowable shifts in the FDC that were derived from ecological studies (Jacobs, 2002). The second control point addressed the moderate- low in the flow regime and was derived from the location of the freshwater/salinity transition between the Suwannee River and the Gulf of Mexico. The change in location of transition would apply to both ground and surface water.

The magnitude of changes in filtrations and absorption of nutrients and other pollutants and water quality due to the effects of hydrologic changes from permitted withdrawals were evaluated qualitatively. The hydraulic characteristics of surface water bodies dictate how changes in flows would affect resident time. Resident time is a critical factor in instream or in-lake nutrient uptake. Transient storage in the water column and in the hyporheic zone also affects resident time, but there are conflicting reports on the correlation with nutrient uptake. More detailed characterization of the absorption and filtration of nutrients in the transient storage zone are needed to determine its affect on water quality. Wetlands are effective transient storage zones when the duration and frequency of inundation are adequate to produce organic soils. Low flows are also required to recruit riparian vegetation and create a diverse soil and vegetation mix in the wetlands and riparian buffer zones. Groundwater fluctuations in this zone influence biotic nutrient cycling by absorbing and desorbing ammonium ions on the riparian sediments. In tidally influenced waters, withdrawal-induced changes in flow would change the location of the freshwater/saline transition. These effects of hydrologic changes from permitted withdrawals were evaluated independent of basin inputs changes from land use.

Several categories of land use changes have significant impacts on hydrology, pollutant loading, filtration and absorption of nutrients, and on water quality. These categories are increased impervious surfaces due to urbanization or significant change in a land cover from other activities (i.e. de-forestation), septic discharges and non-point discharges to water bodies, expanded agricultural practices, and increased construction activities adjacent to water bodies.

An increase in impervious surfaces (or significant de-forestation) affects hydrology resulting in increase in runoff peak and associated pollutant loading transported by runoff. The increase in pollutant loading consequently affects deposition of constituents in floodplain, wetlands, and elsewhere. Thus, absorption and filtration to the soil and vegetation are affected. Because of the increased loading, water quality (concentration and other indices) in the waterbody and in the soil is also affected.

Septic discharges at specific locations of a waterbody can affect both water quality and pollutant loading (but do not affect flows), especially near the source of the discharge. However, impacts on water quality downstream from the discharge location are reduced. Impacts on water quality and loading from various non-point discharges into the waterbody could be more pronounced, as they have cumulative effects. Consequently, filtration and absorption in this category are also affected.

Expanded agricultural practices usually result in increase loading of nutrients, pesticides, and other chemicals on the soil. These loading immediately affect water absorption and filtration processes to the underlying soil and groundwater and to the existing vegetation. In addition to the subsurface and groundwater transport, some constituents are left on the surface and are then washed off into the overland flow during a storm event, or are picked and re-deposited during a flood event from an adjacent waterbody. Again, they become sources of water quality contamination.

Construction areas could become potential pollutant sources to the surrounding soils and the water body. Pollutants from these areas are generally entrapped into the sediments that could be washed off into the adjacent waterbody (unless these sites have well-designed erosion control and sediment containment measures). Even if the pollutants are contained on the construction site (i.e. in a landfill), that containment could become a pollution source to the soil through leaching into it, affecting filtration and absorption in localized areas.

The last three categories above could also affect flow hydrology by prolonging or reducing time of concentration from the watershed (e.g. flow is re-routed through irrigation channels, and through or around the construction site).

In comparing the magnitude of the effects of withdrawals and land use, it is useful to qualitatively contrast the nature of the effects. Withdrawals affect the capacity of the streams and lakes to assimilate nutrient loading; whereas, loading comes from the mosaic of land uses within the basin. Withdrawals affect assimilative capacity by reducing flow, which affects residence time. An increase in residence time allows for more uptake of nutrients, which increases biochemical oxygen consumption. Substandard dissolved oxygen concentrations, and possibly hypoxic conditions, could result from only a decrease in flow. On the other hand, the cumulative affect of loading and flow changes on the buffering capacity of the spring-wetland-lake-stream-river flow system could be severe. The system's absorption and filtration processes would not function, and there would be no uptake of the existing loading of nutrients and other pollutants.

There is a specific increase in loading that is equivalent to the decrease in assimilative capacity resulting from a specific change in discharge. Without having site-specific data, this equivalence cannot be determined. The thresholds discussed in Section VI are critical in this regard. Table 4 shows some published threshold values for indicators that are relevant to low-gradient, blackwater riverine wetlands in peninusular Florida (Uranowski et al. 2003, SFWMD 2001). Once a water level threshold is surpassed, the water quality effects could increase exponentially. For example, if the duration of groundwater levels below the root zone in the riparian buffer causes vegetation to die off, then buffers would no longer be effective at removing nutrients. In agricultural areas, this could drastically affect water quality. On-farm treatment would be needed to compensate for the loss of riparian buffer treatment. A similar scenario could be envisioned for urban areas, which could result in expensive expansion of wastewater treatment facilities.
A change in trophic state could result from either one or both of these anthropogenic effects. Paleolimnological characterization techniques have been used to study Florida lakes. Pre-disturbance water quality conditions were inferred and the effect of nutrient-mitigation actions on lake eutrophication was evaluated. Some lakes appear to have undergone euthrophication that has relaxed somewhat during their recent history, possibly because of nutrient-mitigation programs (Whitmore, 2002). In other lakes, high productivity values were attributed to edaphic factors rather than human influence. The fact that there is naturally high productivity suggests that the lakes are not nutrient limited. In the lakes where nutrient-mitigation is effective, both flow reductions and load increases would exasperate dissolved oxygen problems. In the lakes where there is naturally high productivity, the effect on water quality due to increase in loading would probably be less than the effect due to a reduction in flow.

Table 4. Indicators and Thresholds of Wetland Filtration and Absorption Processes.

Indicator	Threshold
Overbank Flooding at connecting side channels	Return Period less <= 3 years Average year duration >= 8 months
Tree Basal Area	> 30 m^2/ha
Understory Vegetation Biomass Density	> 150 stems/ha
Ground Vegetation Cover	< 50 percent
Soil clay content	> 9 percent
Seasonal High Water Table	Sandy soil: > 6 inches below ground surface Loamy/Clayey soil: > 12 inches below ground surface
Soil PH	< 5.5
Sulphate Concentration in groundwater.	None Published

This is not an argument for allowing increased loading in water bodies influenced highly by edaphic factors. Excess nutrients would be flushed through the drainage basin to the mouth of the river and discharged into the ocean. This situation has occurred on the Mississippi River Basin. The current hypoxia problem in the Gulf of Mexico has its root causes in the watershed: cumulative increases in nutrient loading and decreases in assimilative capacity.

9.0 FURTHER ANALYSES, DATA ACQUISITION, OR STUDY DESIGN NEEDED TO ASSIST SJRWMD IN ASSESSING CHANGES TO "FILTRATION AND ABSORPTION OF NUTRIENTS AND OTHER POLLUTANTS" AND "WATER QUALITY" IN THE CONTEXT OF MFLS

9.1 Objective of Methods

Any recommended method or model should be capable of assessing changes in filtration and absorption of nutrients and other pollutants and changes in water quality constituents over varying hydrologic conditions. The model should be capable to evaluate rehydration, frequency of overbank flooding and other physical processes that affect soils and wetland biochemistry. It is important that the model tracks the nutrient or pollutant history in surface water, underlying soil (subsurface) and the groundwater, evaluating processes of filtration, absorption, uptake of pollutants by plants, and its decomposition. The model must be able to simulate these processes in lakes, springs, rivers and streams, and wetlands. Preferably, the model should also simulate at least some biochemical processes. For MFL analyses, the model must be accurate enough to track a degree of changing absorption and filtration of pollutants with changing MFL target flows and levels.

The model or method should be easy to use, have an understandable user's manual, and be able to graphically present inputs and outputs. The model outputs should also be accessible for use in a statistical data package, for example as a part of a post-processing model option. In this way, the model results can be further analyzed. Equally important, the model should be widely accepted in a technical community and be geographically appropriate for use in Florida.

9.2 Limitations in Existing Methods

Some of the model limitations for selected methods and models are described in Table 2. Both SWAT and HSPF models have simplified flow modeling in rivers and streams, although both models simulate well target processes of water quality, absorption and filtration of nutrients. For very accurate presentation of MFL in rivers and streams, one should consider two-dimensional and three-dimensional hydrodynamics models that can be used in special cases (for example see description of RMA, ECOM, FCOM, EFDC models). However, these models will have to be coupled with other groundwater models to better represent flow below the surface. One of the compromise models to use might be MIKE11/MIKE-SHE model, as this model appears to integrate hydrodynamics of surface flow with subsurface and groundwater flow. However, simulation of subsurface flow in that model is very simplified. Likewise, there is no simulation of microbiological processes.

Several promising models are currently being developed in Florida: Florida Regional Simulation Model (South Florida Water Management District), and the next generation WAM model (Florida Department of Environmental Protection). Both of these models will be tailored to the Florida regional conditions; however their ability to simulate absorption and filtration processes is unknown.

9.3 Recommendations for New Methods

Aquatic systems offer a wide variety in scale and complexity. At some level the analysis of these systems becomes thwarted by complex associations among contributing biological and abiotic (physical) factors. Uncertainty in the analysis of responses of aquatic ecosystems (and water quality attributes therein) can be reduced considerably by the process of grouping similar systems by their primary influential factors such as system type (lake, river or wetland), area, depth, volume, water residence times and flow characteristics, primary vegetation or habitat types, and others. This process of characterization or classification or "typology" has been applied to several large-scale coastal and freshwater habitat studies. In essence, providing analytical methods and tools to systems with similar attributes allows an increased understanding (quantifiable) of uncertainty and analytical performance. In addition, this type of classification within major aquatic types (e.g., lakes) allows for the assessment of reference conditions in the face of (1) response to change (i.e., perturbation, managed hydrology) and (2) natural variability (e.g., regional perturbations).

Aquatic system classification can be achieved through low effort methods (e.g., application of simple comparisons/simple GIS analysis) or quite refined statistical assessments. Systems that possess more data will likely allow for better classifications, particularly over the temporal scale. However, more data volume makes manual classification a laborious, potentially expensive task. Large databases can be analyzed by innovative statistical tools (e.g., OmniViz™) and put through a series of cluster analyses which result in either unbiased or biased assessments of cross-system similarities and differences. Ultimately, this type of system classification process will allow for the reduction in uncertainty, the application of more general approaches to specific system types, and the development of improved long-term monitoring and assessment methods.

Following the application of analytical methods to determine system water quality dose-response characteristics associated with MFLs, implementation of management practices within watersheds and managed aquatic zones may be necessary. Beyond the typical watershed management practices that are prescribed by processes such as the Total Maximum Daily Load program, managers may opt to utilize relatively new, innovative approaches such as nutrient (and pollutant) trading practices. These can be tailored to work in a complimentary fashion with flows and levels management as resulting water quality is not necessarily exclusive of both loads and physical controls.

9.4 Next Steps in Model Selection

The next step in model selection would be to further refine the model selection to minimum flows and level (MFL) determinations within the SJRWMD. The selection will winnow the field of models to a specific set that will be capable of aiding the user in assessing responses in water quality (and associated biogeochemical processes) to alterations to flows and levels of lakes, wetlands, rivers, streams and springs, and visa-versa. The modeling approach must embody watershed characteristics associated with hydrologic and other processes that influence water quality. The spatial, temporal and complexity scales vary across watersheds and surface water bodies and it is unlikely that one specific model will adequately simulate all the processes of interest. Therefore, Battelle proposes to develop a modeling framework, or "toolkit", that will allow the user to customize analytical approaches based on case-specific needs. Battelle also proposes to expand onto the current model selection by analyzing the existing sediment models and short-listing their capabilities with respect to absorption, filtration, and water quality. We suggest the following steps to finalize the model selection process:

<u>Step 1: Provide Short-List of Sediment Models</u>

Conceptual models for sediment transport and quality would be developed for the range of water body types existing within the District. A short-list of sediment models would be made using the filtration/absorption and water quality model selection approach.

<u>Step 2: Identify Key Questions to Be Answered By Models</u>

The models would be used to set MFLs by evaluating the effect of water level and flow on filtration and absorption processes and sediment and water quality. Questions regarding model performance metrics (e.g., sensitivity at various spatial and temporal scales) would be identified and confirmed with SJRWMD.

Step 3: Develop Model Testing Protocol and Selection Framework

Testing scenarios would be identified for evaluating model performance and sensitivity. The existing model selection framework would be enhanced to include sediment models and to incorporate model testing results.

Step 4: Make an Inventory of Data Available For Model Testing

A list of minimum required parameters for the short-list of models would be developed. District databases would be reviewed to determine availability of these data and identify critical data gaps. Data gaps would be filled by identifying typical ranges from the literature.

Step 5: Select, Acquire and Test Models for Tool-Kit

An assessment of the relative performance of models, which often vary in complexity, is required to avoid unnecessary effort. The performance and sensitivity of the models to the application and the range of key parameters would be tested. The decision to use a model for a specific water body type would be based on the selection framework developed in Step 3. A platform of modeling tools for integration of all practical combinations of MFL configurations (e.g., HUC-level, water body types and aggregations) would be identified. A work plan would be developed for testing the integrated modeling tool-kit.

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