A FUNCTIONAL ASSESSMENT OF SOUTH FLORIDA FRESHWATER WETLANDS AND MODELS FOR ESTIMATES OF RUNOFF AND POLLUTION LOADING

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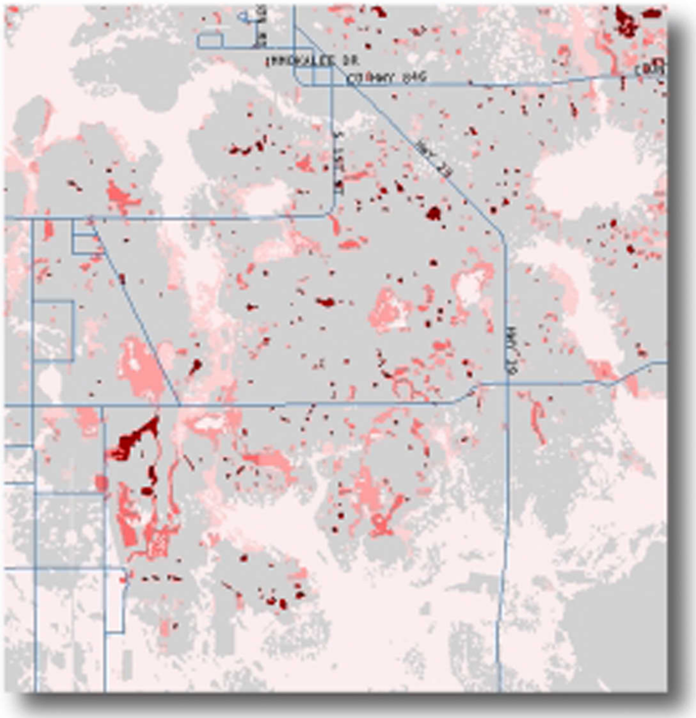

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DISCLAIMER

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ABSTRACT

New techniques for assessing freshwater wetland function, pollution risk to freshwater wetlands, runoff volume from drainage basins, and potential pollution loading have been developed utilizing existing databases and geographic information systems (GIS). This report presents three separate, but related, methodologies: wetland assessment, pollution risk analysis, and basin runoff and pollution loading estimates. These methods are based upon landscape-level screening models that assign ratings or values if certain conditions are found. The wetland functional assessment and pollution risk assessment rates freshwater wetlands according to a qualitative scale ("low", "moderate", and "high") based on the inherent capacity to mitigate a pollution type and for the risk of receiving that pollutant, respectively. The basin runoff and potential pollution loading estimates are quantitative analyses that can be useful for watershed and water quality application.

The inherent capacity to improve water quality is a function of the physical, biological, and chemical characteristics of the wetland. Some wetlands have conditions (such as pH) that promote the function of specific pollution-mitigating mechanisms, while others have unfavorable conditions. Models were developed to describe the major pollution mitigating mechanisms in freshwater wetlands (e.g. denitrification, sorption to soil particles, and settling out of suspended solids) with respect to physiochemical characteristics. Databases with the appropriate attribute data were combined and used to screen wetlands for characteristics that support these pollution-mitigating mechanisms. The following pollutants were considered: nitrogen, phosphorus, micronutrients, heavy metals, suspended solids, pathogenic organisms, and pesticides.

The risk to freshwater wetlands for receiving pollution is derived from a pollution load screening model developed for the St. Johns River Water Management District. In this method, annual potential pollution loads were estimated using mean annual loads for land use types, average annual rainfall, soil type, and the presence of on-site treatment systems. This pollution load was then applied in two very different ways to determine the pollution risk to wetland areas. In one method, the cumulative potential annual load within a wetland buffer of 300 meters was used to assign relative risk to each wetland. The pollutants considered in this analysis were nitrogen, phosphorus, lead, zinc, suspended solids, pathogenic organisms, and pesticides. In a second method of application, runoff volume was estimated for a basin and potential pollution load was calculated. The pollutants considered in this analysis were nitrogen, phosphorus, lead, zinc, biochemical oxygen demand, and suspended solids.

INTRODUCTION

This document outlines the methods and results for several new analyses that have been developed as part of the Comprehensive Wetlands Conservation, Permitting, and Mitigation Strategy (Wetlands Conservation Strategy). These methods were initially developed in an effort to assess freshwater wetland function within the landscape using a geographic information system (GIS) and existing databases. The freshwater wetland function and pollution risk analyses, both qualitative assessments, are the products of this strategy. Further application of the pollution risk analysis to other projects, such as the Water Preserve Area Feasibility Study (USACE and SFWMD 2001), has demonstrated a need for a more quantitative approach. The basin runoff and pollution loading models presented below are the results of that effort.

Wetlands perform numerous important functions within the landscape including soil stabilization, ground water interaction, water quality improvements, and provision of habitat to numerous wildlife species. The chemical and biological processes that occur in wetlands are critical in maintaining an environment that supports a wide diversity of wildlife and people in this region. Concerns about wetland loss and the need for the preservation of South Florida's quality of life have arisen due to rapid urban growth over the past three decades. These concerns have led to the development of various evaluation techniques for assessing the benefits that wetlands provide. These benefits go beyond the protection of wildlife habitat and endangered species and aesthetics to the maintenance of clean water, clean air, and pollution moderation. Protection of wetlands and their respective functions requires both regulation and planning. These functions are usually carried out by various government agencies. In an attempt to reduce or mitigate the impacts of development, these agencies attempt to recognize wetlands of high quality that are candidates for protection. Where preservation is not feasible, losses are mitigated by the improvement or creation of another wetland elsewhere.

In 1996, the South Florida Water Management District (SFWMD) convened a committee of wetland scientists to identify the most important landscape functions of South Florida's wetlands and to describe methods for evaluating how well these functions could be met under various planning scenarios. The Science Subgroup of the South Florida Ecosystem Restoration Task Force identified the development of "technically sound landscape-level wetland functionality assessment methods" as a critical information need for ecosystem restoration. The subgroup recommended developing a GIS approach that relies on landscape ecology concepts, provides general assessments of wetland functions, and is user friendly. The Strategy Team, a multiagency team of wetland scientists, hydrologists, and water quality experts charged with developing the Wetlands Conservation Strategy, has used the scientific committee's input as the direction for developing methods to assess the function of wetlands at the landscape level. This report provides the documentation of how this evaluation method was developed for the Strategy Team.

WETLAND ASSESSMENTS

The wetland functional analysis consists of two components: the inherent capacity of a wetland to mitigate a specific pollutant and the wetland's risk for receiving pollutants. The first component of the functional analysis addresses a wetland's ability to reduce, degrade, or offer long-term storage of a specific pollutant. The inherent capacity of wetlands to affect water quality is irrespective of whether or not the wetlands are actually receiving pollutants. A basic assumption of our approach is that not all wetlands are created equal and, therefore, do not function the same with respect to their ability to deal with pollution inputs. The various soil and plant community components that can influence water quality are not evenly distributed between wetlands, allowing for different degrees of functionality. This qualitative rating is also useful in understanding the sensitivity of wetlands to pollution.

The second component of the wetland functional analysis addresses the pollution risk. Since specific pollutants are associated with certain land use types, we examined the landscape surrounding wetlands to derive a potential pollution loading value. This qualitative rating is useful in understanding the relative pollution risk to wetlands within a subbasin resulting from human activities and in identifying potential pollution "hot spots" within the landscape (i.e., areas where wetlands may be impacted by a particular pollutant).

The wetland functional analysis provides water managers with specific information about wetlands at the landscape level. The analysis is useful in determining where water quality problems are most or least likely to occur and why. Although this analysis is not intended to replace site-specific inspection and sampling of individual wetlands, it does provide an indication of what to expect. The analysis also provides a regional view of wetland function and characterizes the benefits they provide in protecting water quality within watersheds.

Runoff and Pollution Loading Estimates

This method calculates the potential runoff and pollution loading for a given basin. By considering land use type, rainfall volume, soil type, and the presence or lack of on-site treatment systems, an estimate of the runoff volume can be calculated. From the runoff volume, a pollution loading and concentration can be estimated for each land use type. Since the method is time-independent, it can be used to calculate runoff for any time interval for which historic or modeled rainfall data are available.

The wetland functional assessment and pollution risk analyses take two separate approaches at defining the function of wetlands in the landscape and the potential pollution risks to those wetlands. In each, qualitative ratings are derived for each function and pollutant. The process of summing disparate items in order to arrive at a single numerical rating for a wetland, an approach used in Hydrogeomorphic Wetlands Assessment Procedure (HGM) (Brinson 1996) and Wetlands Rapid Assessment Procedure (WRAP) (Miller and Gunsalus 1997), is avoided. The components of the functional analysis are shown in **Figure 1**. The specific methods for each assessment are provided below.

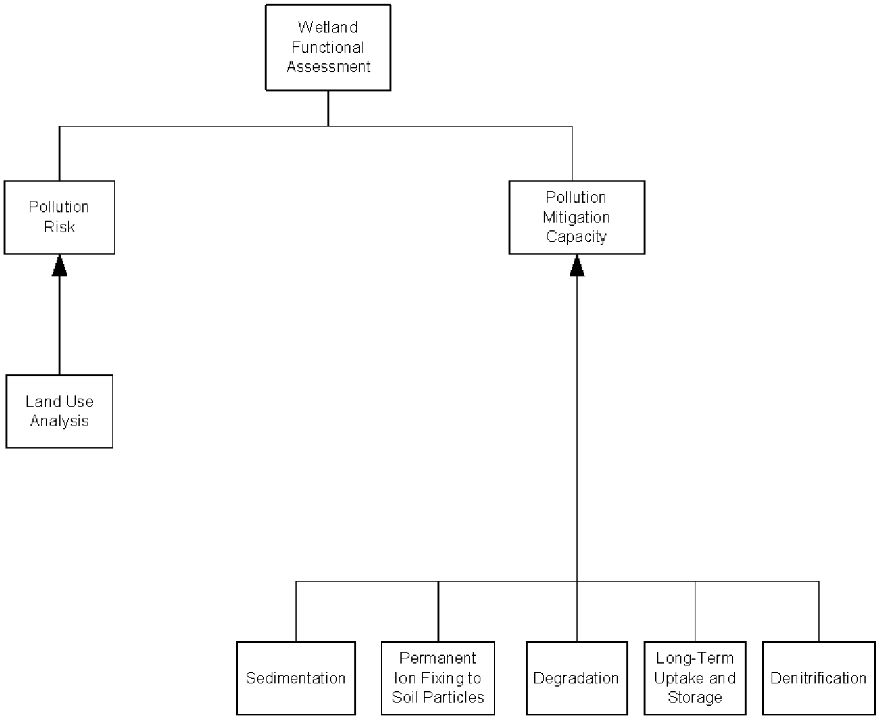

Figure 1. General components of the water quality functional assessment.

Pollution Mitigation Capacity

This component of the functional assessment analyzes the inherent capacity of a wetland to mitigate pollution inputs (**Figure 2**). This assessment is based upon the major pollution-reducing mechanisms of wetlands, including uptake, sorption, and chemical alteration. The hydrological, chemical, and biological properties of a wetland are considered and qualitative ratings are assigned based upon the potential function of these mechanisms under the conditions found in the wetland. For example, under certain conditions denitrification (an important mechanism of nitrogen loss in wetlands) occurs at relatively high rates. Conversely, under other conditions, denitrification is suppressed. In both of these examples, it is recognized that in order for denitrification to occur, nitrogen must be available. However, if the same amount of nitrogen were available to both sets of conditions, the amount of nitrogen that is denitrified will vary due to differences in wetland conditions. The differences in wetland conditions are irrelevant to the amount of pollutant present, so are referred to as a wetland's "inherent" capacity for function.

The inherent capacity ratings of wetlands are derived from models (outlined below) that consist of the major mechanisms that reduce surface water pollution uptake in wetlands. The components and conditions required for each mechanism's function were based on extensive scientific literature searches. Using these models, we classified wetlands by conditions that favor or inhibit the function of important pollution-reducing mechanisms. The specifics of the models are covered in each respective section below. It

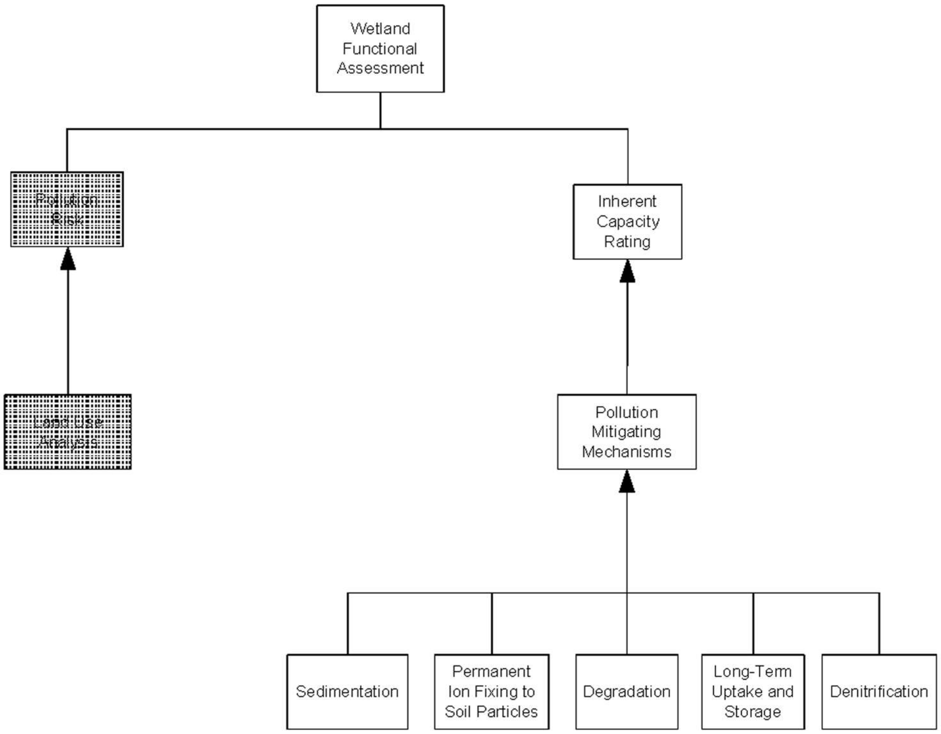

Figure 2. The white boxes in the flowchart indicate the general components of the inherent capacity analysis.

is important to note that this analysis does not tell us if a particular pollution mitigating function is actually operating, since that process requires that the pollutant is present. This rating does tell us, however, if the conditions at the wetland site can support a pollution removal function. The focus of this analysis is to identify wetlands that have inherent conditions that favor optimum function of pollution removal processes, which is a prerequisite for effective maintenance of water quality.

We used GIS databases with the appropriate attributes to supply the input data to the models. Usually, these databases consisted of tables of values derived from ground-based and remotely sensed observations or analysis. In some cases, raw data first had to be transformed into nonnumerical ratings (“low”, “moderate”, and “high”) for input into the model, the guidelines of which are covered in **Appendix A**. The range of limits for each of these rating classes generally followed conventions used by other published sources, such as the United States Department of Agriculture’s (USDA’s) *National Soil Survey Handbook* (USDA 1993).

Soils data were taken from the USDA’s Natural Resources Conservation Service[1] (NRCS) Soil Survey Geographic (SSURGO) Database (NRCS 1995). This database consists of several tables of attribute data. The SSURGO component (COMP) table lists general attributes of a map unit (a polygon), such as hydrological conditions, depth to bedrock, and drainage conditions. We also used the Field Office Technical Guide (FOTG)

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[1] The National Resources Conservation Service was formerly known as the Soil Conservation Service.

developed by the NRCS (SCS, 1992) for leaching and runoff characteristics for wetland soils. Wetlands were delineated using the *National Wetlands Inventory GIS Images for South Florida, 1990 Update* (NWI and SFWMD 1996).

Each SSURGO map unit identification number (MUID) is capable of having more than one soil type or *series* present. Each soil series is referred to as a *component*. We calculated a weighted average value for the attribute of the MUID from the individual components. The MUID attribute data values within NWI (National Wetland Index) wetland polygons (NWI and SFWMD 1996) are then summarized into a single value, based on weighted averages. This data set is used to supply the models with input values, which then yield a functional assessment rating for the wetland with respect to a specific pollutant. Definitions of the rating products from the analysis are shown in **Table 1**. The relative terms of "low", "moderate", and "high" are used here to provide a qualitative assessment of the inherent capacity of a wetland to remove pollutants. The specific value ranges for these ratings are discussed in each respective section.

Table 1. Definitions of ratings used in the inherent capacity analysis.

Rating	Implied Definition
Low	Conditions unfavorable for processes that remove, degrade, or offer long-term binding/storage of a particular pollutant
Moderate	Conditions moderately or somewhat favorable for processes that remove, degrade, or offer long-term binding/storage of a particular pollutant
High	Conditions highly favorable for processes that remove, degrade, or offer long-term binding/storage of a particular pollutant

The processing of the capacity analysis was handled by an Arc/Info automated markup language (AML) program written for this specific application. The program script for this module is provided in **Appendix B**, with annotations to describe the general process method.

Nitrogen Fixation and Reduction Mechanisms in Wetlands

Nitrogen (N) is by far the most abundant gaseous element, comprising some 78% of the Earth's atmosphere. Atmospheric N, or dinitrogen gas (N_2), is very unreactive and biologically unavailable because of the strength of the three covalent bonds between the atoms. Some organisms, mostly bacteria and cyanophytes, are able to "fix" dinitrogen, that is they are able to convert it to forms that are biologically available. This process is also carried out artificially by humans to produce fertilizers for crops. Other sources of "fixed" N include volcanism, lightning, and combustion of fossil fuels. Most N fixed by organisms results in the formation of ammonium (NH_4^+):

$$N_2(g) + 3H_2(g) + 2H^+ = 2NH_4^+ \qquad (1)$$
$$\Delta G^0 \text{ (standard conditions)} = -39.4$$

$$2N_2(g) + 3CH_2O + 3H_2O + 4H^+ = 3CO_2(g) + 4NH_4^+ \qquad (2)$$
$$\Delta G^0 \text{ (standard conditions)} = -60.3$$

Other important N-fixing reactions are as follows:

$$2N_2(g) + 6H_2(g) = 4NH_3(g) \tag{3}$$

$$N_2(g) + O_2(g) = 2NO(g) \tag{4}$$

$$N_2(g) + 2O_2(g) = 2NO_2(g) \tag{5}$$

Equation 3 is carried out in the presence of a suitable catalyst, whereas **Equations 4** and **5** occur in combustion processes. Some of these different N compounds introduced into wetlands have the potential to cause adverse ecological effects, such as toxicity, eutrophication, and acidification of soils (Stumm and Morgan 1996).

The ability of wetlands to attenuate N inputs can vary due to the complexity of the N cycle and differences between wetlands. Blood (1981) found that the Okefenokee Swamp reduced inorganic N inputs by 96% to 98% and total N inputs by 39%. Day et al. (1976) found that a Louisiana cypress swamp reduced N inputs by 50%. A summary of numerous natural and constructed wetlands indicate a range of total N reductions between 40% and 90% (Knight et al. 1985, 1992, 1993; Reed et al. 1979).

N is by far the most mobile nutrient and subject to the greatest loss from the system (Patrick et al. 1976). The most important processes that affect N in wetland soils are denitrification, volatilization, ammonium fixing, and leaching (Johnston 1991). Denitrification and ammonium fixing rates are rapid under certain soil conditions and are the most important mechanisms responsible for N loss from wetlands (Gale et al. 1993a). Leaching is a function of N species and soil drainage properties. These three processes, leaching, denitrification, and fixing, are considered in this analysis, since they significantly affect water quality and the conditions controlling them can be described. Volatilization (e.g., ammonia) was not considered to be an important mechanism of N loss from flooded soils and sediments, except under more extreme conditions of high pH and high concentration (Johnston 1991). N is also effectively stored in plant tissues, both as living biomass and in accreted organic material for soil deposition. This process is covered in the **Long-Term Uptake and Storage of Nutrients in Plants** section on **page 15** of this document.

Nitrogen Loss from Wetlands via Denitrification

Nitrate can be readily reduced to dinitrogen gas or to nitrous oxides (N_2O) and lost via gas flux to the atmosphere through a process known as denitrification (Bryan 1981, Engler and Patrick 1987, Stumm and Morgan 1996). Denitrification is mediated by soil organic matter or by soil microbes. This process is irreversible and is held to be a major pathway of N removal from wetlands (Patrick et al. 1976, Stumm and Morgan 1996). Denitrification occurs under anaerobic conditions by the following reaction (Johnston 1991, Stumm and Morgan 1996):

$$4NO_3^- + 5\{CH_2O\} + 4H^+ = 2N_2(g) + 7H_2O + 5CO_2(g) \tag{6}$$
$$\Delta G^0 \text{ (standard conditions)} = -594.6$$

The sources of ammonium, other than the fixing of atmospheric N, are fertilizers, animal wastes, and atmospheric deposition. Excessive ammonium that is not converted to NO_3^- can be permanently sorbed to soil particles (see the **Ammonium Fixing to Soil Particles** section on page 10), lost to runoff, or converted to ammonia that can be lost to the atmosphere by volatilization. Rates of ammonium conversion to NO_x (NO_3^- and NO_2^-), which are then converted to dinitrogen by denitrification, are positively correlated with soil carbon content and are highest in organic wetland soils (Johnston 1991). This process may be especially efficient in the removal of substantial amounts of N from surface waters, especially peat-based wetlands such as the Everglades.

Nitrous oxide gas (N_2O, a biologically unavailable form of nitrogen) can be produced as a by-product of denitrification, resulting in further loss of fixed N. This can be formed by two different reactions (Stumm and Morgan 1996):

$$2NO_3^- + 2\{CH_2O\} + 2H^+ = N_2O(g) + 3H_2O + 2CO_2(g) \qquad (7)$$

$$\Delta G^{0'} \text{ (standard conditions)} = -417.1$$

$$2NH_4^+ + 2O_2 = N_2O(g) + 3H_2O + 2H^+ \qquad (8)$$

$$\Delta G^{0'} \text{ (standard conditions)} = -260.2$$

Denitrification in temporarily anaerobic conditions (such as those found in wetlands with occasional or seasonal surface water) has been long recognized and studied (Russel 1961, Patrick et al. 1976). It has been demonstrated experimentally that appreciable denitrification can also occur in flooded wetland soils if atmospheric oxygen is available for nitrification, which then supplies denitrification (Tusneem and Patrick 1971, Broadbent and Tusneem 1971, Patrick et al. 1976). However, the highest rates of denitrification are found under wet-dry hydrological conditions. Some wetland plants create aerobic conditions surrounding their root zones, which can supply oxygen needed for this process (Wetzel 1979, Chen and Barko 1988, Gernsberg et al. 1986). The rate of denitrification is related to soil pH, available nitrate, the presence of organic matter, and temperature (Graetz et al. 1980, Engler and Patrick 1987, Reddy et al. 1976, 1980). Because of the warm climate of South Florida, temperatures low enough to restrict denitrification rarely, if ever, occur. In fact, the mean temperatures throughout much of the year are near optimal for denitrification processes (25°C). Low concentration of available nitrate can limit the rate of denitrification. However, lower concentrations of nitrate are desirable from the standpoint of N pollution reduction. The nitrate ion is not retained in soils and readily leaches to ground water under favorable conditions, posing a potential health hazard.

The denitrification model assigns a high potential N removal rating to nonacidic soils with moderate to high soil depth, some organic matter present, low to moderate leaching potential, and low to moderate soil runoff potential (**Table 2**). The pH of the soil is an issue primarily with respect to denitrifying bacteria, which are sensitive to high hydrogen ion (H^+) concentrations (low pH). Gale et al. (1993b) found that low pH could inhibit the final step of denitrification. Leaching potential is included in the model to address the issue of ground water contamination of nitrate, although some downward movement is necessary for denitrification to occur. Soil depth expresses a relative amount of soil substrate available for the denitrification process to occur. The rate of denitrification will be low to none when there is a low pH (see the **Soil pH** section in **Appendix A**), little organic matter present, high leaching and runoff potential, or thin to no soil. Other combinations of conditions are rated as moderate (or intermediate). The presence of organic matter enhances the rate of denitrification by providing both a nonbiologically mediated pathway as well as a food source for denitrification bacteria, but it is not necessary for the process to function.

Table 2. Model component that describes the conditions influencing denitrification processes in wetland soils.

Denitrification Activity	Soil Organic Matter Content	Soil Thickness	Soil Runoff	pH	Hydroperiod
High	Moderate or High	Moderate or High	Low or Moderate	Moderate or High	Any
Moderate	Moderate or High	Moderate or High	High	Moderate or High	High
Moderate	Low	Moderate or High	Any	Moderate or High	Any
Low	Any	Any	Any	Low	Any
Low	Any	Low	Any	Any	Any

The capacity of wetlands to reduce nitrogen through denitrification in Lee County was selected as a representative figure displaying results of the wetland assessment analyses. **Figure 3** shows wetlands in Lee County with the respective color value indicating capacity for function. Yellow areas indicate wetlands that have a low capacity to remove nitrogen (via denitrification), pink areas indicate wetlands that have a moderate capacity to remove nitrogen (via denitrification) and red areas indicate wetlands that have a high capacity to remove nitrogen (via denitrification). Blue areas indicate wetlands for which there are insufficient data to analyze. The results for each model component for all of the wetlands within the SFWMD boundary can be found on the compact disk accompanying this document or on the Wetland Conservation Strategy web site (http://www.sfwmd.gov/org/pld/proj/wetcons).

Ammonium Fixing to Soil Particles

Under certain conditions, adsorbed cations are held so strongly by clays that they cannot be recovered by exchange reactions (Tan 1982). The most important of this type of fixation reaction occurs with ammonium and potassium (K^+) ions. Many soils are capable of retaining considerable amounts of the ammonium ion in nonexchangeable forms (Tan 1982). Fixation can be regarded as resulting from the substitution of ammonium for interlayer cations (Ca^{2+}, Mg^{2+}, Na^+) within the expandable lattice of clay minerals (Stevenson 1986). The exchange reaction proceeds as follows (Stumm and Morgan 1996):

$$RK^+ + NH_4^+ \leftrightarrow RNH_4^+ + K^+ \qquad (9)$$

Soils vary in their ability to fix ammonium. The presence of organic matter interferes with the fixing process by converting ammonium to NO_3^-, since nitrate produced by ammonia oxidation is used in denitrification (see **Equation 8**). The ammonium fixing mechanism varies according to the amount of organic matter, amount of clay, cation exchange capacity (CEC), wetland hydrology (regular cycles of wetland inundation and drying are best), and pH status (nonacidic soils are preferred). An abundance of potassium ion concentrations can reduce the efficiency of ammonium fixing due to competition for binding sites on the clay particles. The ammonium-fixing model (**Table 3**) assigns a high potential to nonacidic soils with high amounts of clay (with high CEC), low organic matter content, moderate to high active zone depth, low to moderate runoff potential, and a wet-dry hydrology.

Table 3. Model component that describes the conditions influencing NH4+ fixing processes in wetland soils.

NH_4^+ Fixing Activity	Organic Matter Content	Clay Content	Soil Thickness	Soil Runoff	pH	Hydroperiod
High	Low	High	Moderate or High	Low or Moderate	Moderate or High	Low or Moderate
Moderate	Conditions other than those found in "low" or "high" NH_4^+ fixing activity					
Low	Any	Low	Any	Any	Any	Any
Low	Moderate or High	Any	Any	Any	Any	Any
Low	Any	Any	Low	Any	Any	Any
Low	Any	Any	Any	Any	Low	Any

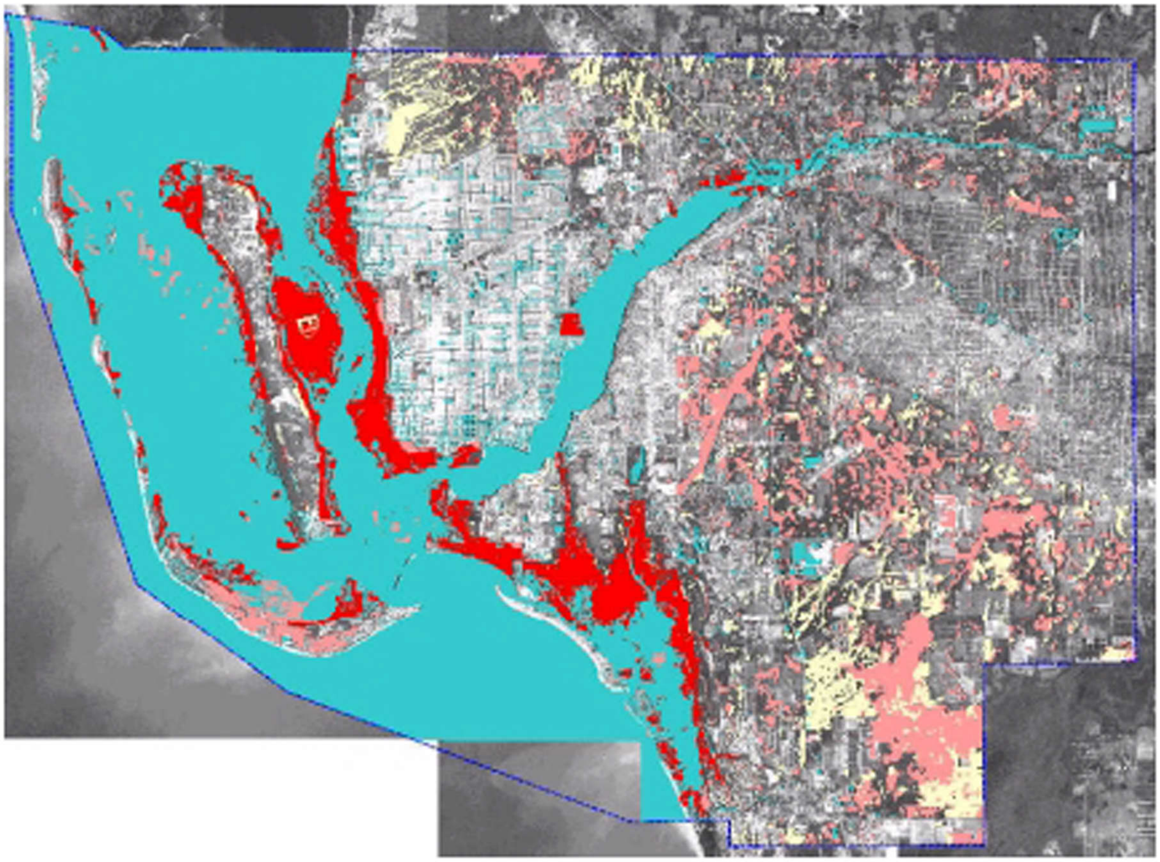


Figure 3. Estimated functional capacity of Lee County wetlands with respect to nitrogen removal by denitrification.

Phosphate Fixing to Soil Particles

Phosphorus (P) is an essential nutrient for all life forms, as it is a key structural component and necessary for several important biochemical pathways. Natural inorganic P deposits weather, are mineralized from organic forms, or are mined for phosphate, which then becomes available for uptake from runoff or as applied fertilizer. Much of the P in soils is adsorbed to soil particles or incorporated into organic matter by plant uptake (Smith 1990, Craig et al. 1988, Holtan et al. 1988). Adsorption of dissolved phosphate is of great importance in controlling the concentration of P in both soils and lakes (Khalid et al. 1977, Syers et al. 1973). Phosphate has a strong tendency to adsorb on colloidal surfaces and will readily form insoluble complexes with divalent and trivalent cations.

Phosphate in most wetland systems is freely soluble (available) in acidic solutions and under reduced conditions. In aquatic and soil environments, P can be readily immobilized as calcium, iron, or aluminum phosphates. Under conditions of pH 5 through 9, the range of pH found in most wetlands, the predominant dissolved orthophosphate species are $H_2PO_4^-$ and HPO_4^{2-} (Stumm and Morgan 1996). Strengite ($FePO_4$) and variscite ($AlPO_4$) are the stable solid phase products if phosphate is precipitated in the acidic portion of this range (pH 5 to 6). In acidic soils, these insoluble phosphates of iron or aluminum, and also magnesium, may form complexes that can sorb to oxides and clays. Phosphate has been shown to adsorb strongly on calcium carbonate ($CaCO_3$) and this is believed to be why calcium carbonate-rich sediments contain generally low concentrations of dissolved phosphate in their pore waters (Berner 1974, Morse and Cook 1978). Under alkaline conditions, the much less soluble apatite [$Ca_{10}(PO_4)_6(OH)_2(s)$] can be readily formed by the following pathway (Stumm and Morgan 1996):

$$10CaCO_3(s) + 2H^+ + 6HPO_4^{2-} + 2H_2O = Ca_{10}(PO_4)_6(OH)_2(s) + 10HCO_3^- \qquad (10)$$

Overall, calcium carbonate is not limiting in South Florida wetlands, due to the vast limestone bedrock substrate and relatively thin soils of the region. Iron, aluminum, and magnesium concentrations can be very low in most soils due to the relatively high annual rainfall that can leach away these elements, high soil porosity, and lack of igneous or metamorphic parent rock sources. However in permeable spodic soils, the spodic layer contains high concentrations of these metals which can bind P, especially under acidic conditions. This activity is affected by fluctuating oxic-anoxic conditions, which can cause some P to be remobilized from the spodic layer. The spodic layer can more permanently bind P in wetlands that have prolonged hydroperiods. Therefore, the formation of apatite in alkaline soils and the presence of a spodic layer in porous acidic soils will offer the greatest potentials for P removal.

Soil organic matter has not been demonstrated to effectively sorb P (Richardson 1985). However, the presence of undecayed plant material suggests conditions that favor plant uptake and storage of P as organic soil. In estuaries, the observed concentration of dissolved phosphate may be entirely controlled by processes of adsorption and desorption on particles (Pomeroy et al. 1965, Butler and Tibbitts 1972). Desorption rates of P are much higher in the estuaries than in freshwater systems where P is bound by sediment particles with little recycling to the water column.

For the phosphorus functional component of the soil model, we assigned a high rating to wetlands with alkaline soil, and low to moderate runoff potential (**Table 4**). Wetlands which have acidic spodic soils, moderate to high clay contents, low to moderate runoff potential, and no wet-dry hydrology also rate high in P-removal function. Wetlands that have acidic nonspodic or thin soils were rated the lowest in P-fixing function.

Table 4. Model component that describes the conditions influencing phosphate fixing processes in wetland soils or formation of calcium phosphate complexes.

Phosphate Fixing Activity	Clay Content	Spodic Soil (Y/N)	Soil Thickness	Soil Runoff	pH	Hydroperiod
High	Any	Either	Low	Low or Moderate	High	Any
High	High or Moderate	Yes	Moderate or High	Low or Moderate	Low	Low or High
Moderate	Conditions other than those found in "low" or "high" phosphate fixing activity					
Low	Any	No	Any	Any	Low	Any
Low	Any	Either	Low	Any	Low	Any

Micronutrient Fixing to Soil Particles

The term micronutrient, or trace element, refers to a group of nutritive elements that are required in minute amounts and are necessary for an organism to complete its life cycle. Important micronutrients include iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and boron (B). Molybdenum is another micronutrient, but behaves different chemically than those previously mentioned, so it is not considered in this model. Sources of these elements are 1) parent rocks and minerals from which the soil was formed; 2) impurities in fertilizers, lime, pesticides, manures, or contaminants of sewage sludge; and 3) debris from industrial and mining wastes, fossil fuel combustion products, wind-eroded soil particles, and meteoric and volcanic material that settles out or is added via rainfall.

Although trace amounts of these elements can be essential for growth and development of organisms, they can be toxic to some organisms at higher concentrations. Wetlands have been found to be efficient in the reduction of micronutrients (Kadlec and Knight 1996). The solid-water interface plays a large role in the regulation of most dissolved reactive micronutrients in wetland systems, and often the concentrations of these elements are much higher in the solid phase than in the water phase (Stumm and Morgan 1996). The major micronutrient removal mechanisms within soils include binding to sediments or particulates and incorporating precipitated insoluble complexes. Uptake and long-term storage by the plant community is also an important mechanism by which micronutrient concentrations are effectively reduced in wetlands, a process that is covered in the **Heavy Metals Fixing to Soil Particles** section on **page 14**.

The binding of micronutrients to soils and solids occurs by cation exchange or chelation. The process of binding to clay particles with a high CEC is similar to that found in other fixing reactions. Humic substances, such as are present in organic soils, form divalent and trivalent bonds with the trace metals.

As with P, solubility of the micronutrients in aquatic systems is pH-controlled. Generally, micronutrients are most available (soluble) when the media pH is slightly acidic (between 5.0 and 6.5). Media pH greater than 7.0 can result in limiting conditions, primarily due to the formation of insoluble complexes, while media pH below 4.5 can lead to micronutrient toxicity. Liming or high $CaCO_3$ concentrations further reduce solubility of most micronutrients and can lead to deficiencies (Johnston 1991, Stumm and Morgan 1996).

For the micronutrient model, we assigned a high rating to nonacidic wetland soils with high organic matter or clay contents (with high CEC), and low to moderate runoff potential (**Table 5**). A low rating was assigned to wetlands that had acidic conditions, little to no soil, or were low in organic matter or clay.

Table 5. Model component that describes the conditions influencing micronutrient fixing processes in wetland soils.

Micronutrient Fixing Activity	Organic Matter Content	Clay Content	Soil Thickness	Soil Runoff	pH
High	High	Any	Moderate or High	Low or Moderate	Moderate or High
High	Any	High	Moderate or High	Low or Moderate	Moderate or High
Moderate	Conditions other than those found in "low" or "high" micronutrient fixing activity				
Low	Low	Low	Any	Any	Any
Low	Any	Any	Low	Any	Any
Low	Any	Any	Any	Any	Low

Heavy Metals Fixing to Soil Particles

Heavy metals (e.g., mercury, cadmium, lead) reach the soil from a variety of sources including fertilizer impurities, tire dust, cement production, wastewater, urban runoff, and combustion products of fossil fuels, wood, and urban organic trash. The dispersion of heavy metals into the atmosphere, both as particles and as vapors, has resulted in mobilizations of these elements exceeding natural releases (Stumm and Morgan 1996). It has been demonstrated that heavy metals from auto emissions accumulate in roadside soils (Reinirkens 1996, Ward 1990). Emissions of various types are likely to contain lead, cadmium, or mercury because of their relatively high volatility. Heavy metals at trace concentrations generally pose little ecological threat and can be safely complexed and retained within wetland soils. However, in some areas concentrations are increasing due to anthropogenic activities. This has resulted in elevated risks to some organisms, especially those that bioaccumulate heavy metals or feed on organisms that do.

As with the micronutrients, soil pH and the presence of organic matter or clay influences the ability of wetlands to reduce heavy metal concentrations. Liming leads to precipitation of heavy metals as the highly insoluble carbonates, sulfates, or phosphates. The ability of soil organic matter to form stable complexes with metal ions has been well established. For the heavy metals model, we assigned a high rating to nonacidic soils with high organic matter or clay contents, and low to moderate runoff potential (**Table 6**). A low rating was assigned to wetlands that had acidic conditions, little to no soil, or were low in organic matter or clay.

Table 6. Model component that describes the conditions influencing heavy metals fixing processes in wetland soils.

Heavy Metals Fixing Activity	Organic Matter Content	Clay Content	Soil Thickness	Soil Runoff	pH
High	High	Any	Moderate or High	Low or Moderate	Moderate or High
High	Any	High	Moderate or High	Low or Moderate	Moderate or High
Moderate	Conditions other than those found in “low” or “high” micronutrient fixing activity				
Low	Low	Low	Any	Any	Any
Low	Any	Any	Low	Any	Any
Low	Any	Any	Any	Any	Low

Long-Term Uptake and Storage of Nutrients in Plants

Generally, when discussing pollution uptake directly by wetland plants, we are addressing only the nutritive pollutants. Wetland nutrient uptake and storage dynamics can vary significantly from site to site, as a function of the community species composition. Wetlands dominated by floating plants, such as water lettuce (*Pistia stratiotes* L.) and water hyacinth [*Eichhornia crassipes* (Mart.) Solms] characteristically have rapid uptake rates (Wolverton and McDonald 1979, Reddy and Smith 1987). Nonvegetated wetlands often are dominated by algal mats. For example, Everglades sloughs are seasonally covered in calcareous algal mats that have rapid P uptake rates (Vaithiyanathan et al. 1997) and are able to precipitate insoluble calcium phosphate from the water column (see **Equation 10**). Those wetlands that are dominated by floating plants or calcareous algal mats have several important characteristics relative to water quality improvements. The precipitation of calcium phosphate leads to the formation of calcitic mud or marl, a permanent form of P storage (Gleason and Spackman 1974, Swift 1981). Also, since these communities absorb nutrients directly from the water column, they provide a buffer against pulsed nutrient input events by quickly returning the surface water concentrations to background levels (Vaithiyanathan et al. 1997). In fact, so efficient are these communities for removal of nutrients, that they are often employed in alternative wastewater treatment technologies when effective nutrient reduction is a criterion (McNabb 1976, Reddy and DeBusk 1985, Jamil 1990, Gumbricht 1993a, 1993b; Kadlec and Knight 1996).

Emergent-dominated wetlands in South Florida are often composed of species such as sawgrass (*Cladium mariscus* var. *jamaicense* Crantz), cattail (*Typha* spp.), and pickerelweed (*Pontederia cordata* L.). Emergent-dominated wetlands have demonstrated high nutrient removal potentials and productivity that can be affected by nutrient loading (Wetzel 1979, Reddy and DeBusk 1985, Kadlec and Knight 1996). Most nutrient uptake is from the soil, although some species absorb directly from the water column (Chen and

Barko 1988, Johnston 1993). The accretion rates of organic matter in these systems, a mechanism of nutrient storage, can be substantial and is often a result of prolonged hydroperiod, which promotes anoxia (thus retarding decomposition) at the soil-surface water interface (Reddy et al. 1993, Craft and Richardson 1993, DeLaune et al. 1978). Furthermore, the submersed portion of the emergent macrophytes can provide colonization sites for epiphytic algae and bacteria that can be extremely effective in removing inorganic nutrients and can demonstrate productivities exceeding those of the macrophytes (Wetzel 1975).

Conversely, shrubby and forested wetlands contain plant species, such as bald cypress (*Taxodium* spp.) and swamp willow (*Salix caroliniana* Michx.), with abundant woody tissues that very slowly decompose. These plants offer a greater potential for long-term storage of nutrients both within the living tissue and the soil. However they have slow rates of nutrient uptake compared with emergent wetlands (Prentki et al. 1978, Mitsch et al. 1979, Dolan et al. 1981, Deghi and Ewel 1984, Johnston 1993). The standing biomass, or total nutrient storage in living tissues, is much higher in wetland forests than that in other wetland types (Johnston 1991, 1993). Due to the relatively long life of woody species, turnover times for nutrients are very long, often on the order of decades to centuries. Roots, or belowground biomass, can also constitute a significant long-term storage compartment for some nutrients, although this can vary by species and age. Several authors note that belowground nutrient standing stocks were two to three times higher than aboveground standing stocks in three marshes in the southeastern United States (Johnston 1993, Dolan et al. 1981, Boyd 1969, Zoltec et al. 1978).

The model for potential removal of nutrients is shown in **Table 7**. The model assigns a rating based on the vegetation type and water retention characteristics (i.e., leaching and runoff potentials) of the site. Vegetated nonforested wetlands that are permanently flooded and do not have high leaching or runoff potentials offer the best conditions for nutrient removal by the plant community and for peat accretion. Nonvegetated wetlands with a high runoff potential offer the poorest conditions for nutrient uptake.

Table 7. Potential nutrient removal capability of wetlands based on vegetation type and water retention.

Plant Community Nutrient Removal	Plant Community Type	Soil Leaching	Soil Runoff	Hydroperiod
High	Vegetated wetlands	Low or Moderate	Low or Moderate	High
High	Vegetated nonforested wetlands	Low	Low	Any
Moderate	Conditions other than those found in “low” or “high” plant community nutrient removal			
Low	Nonvegetated	Any	Any	Any

Suspended Particulates and Pathogenic Organism Reduction Mechanisms

Sedimentation is the process by which particulates materials are permanently deposited on or within the wetland soil. This process is facilitated by several possible mechanisms. In soils with a high leaching potential and low runoff potential, sediment-laden water is readily filtered through the soil matrix. In other situations, surface water can flow into a wetland and be retained for an extended period of time, allowing particulates to settle out of the water column. In vegetated wetlands, plants can effectively reduce sediment loads from upland runoff by reducing flow rates (Kadlec and Knight 1996, Pearce et al. 1997). Sediment deposition in wetlands benefits downstream water quality by reducing the turbidity and suspended solids concentration, and by retaining phosphorus and other contaminants that are sorbed to the sediments (Johnston 1991, 1993). Lake and wetland sediments can serve as more or less permanent sinks. For example, P that is permanently bound to particulates, can settle to the benthic substrate and become incorporated into the sediment (Johnston et al. 1984). Sediment deposition can result in large fluxes of nutrients, particularly P, from surface waters to wetland soils and is often highest during flooding events, especially in wetlands closest to rivers, canals, and sediment sources (Johnston 1993). If sufficient accumulation occurs, then the P will eventually be buried too deep (below the root zone of plants) to be recycled. By this mechanism, P can be permanently stored in soils.

Another component that is often associated with suspended solids is the pathogen removal efficiencies of wetlands. Disease-causing bacteria (e.g., fecal coliform and streptococci), protozoans (e.g., Entamoeba and Giardia), helminth eggs, and viruses are some of the organisms that can be introduced into wetlands from sewage, livestock lots, or wildlife. Generally, natural wetlands offer environments that are hostile to these organisms, which often depend on the host environment for survival (Kadlec and Knight 1996). Wetlands have been shown to greatly reduce most pathogenic agents, with significantly decreasing numbers associated with extended retention times (Rivera et al. 1994, Krishnan and Smith 1987).

Input of suspended solids and pathogens is a function of flow velocities and proximity to the source. Low water velocities coupled with the presence of vegetation or large-textured soils promotes settling-out and filtration of these pollutants. Trapping of sediments in the litter layer or open spaces between large soil particles prevents resuspension (Kadlec and Knight 1996). Various studies of constructed and natural wetlands indicate high (maximum of 85% to 98%) reduction of total suspended sediments from wastewater or stormwater sources (Knight et al. 1993, WEF 1992, Bavor et al. 1988). Similar reductions of some types of pathogens have been reported (Krishnan and Smith 1987, Hendry et al. 1979, CH2M Hill 1991, Scheuerman et al. 1989, Casson et al. 1992).

Table 8 shows the model we used to describe the mechanism of removal of suspended particulates and pathogenic organisms from surface water.

Table 8. Potential of various wetlands to reduce suspended particulate and pathogen concentrations.

Particulate and Pathogen Removal	Plant Community Type	Soil Runoff
High	Vegetated nonforested wetlands	Any
High	Wetland forests	Low or Moderate
Moderate	Wetland forests	High
Moderate	Nonvegetated wetlands	Low or Moderate
Low	Nonvegetated wetlands	High

Pesticide Retention and Mobilization

Pesticides are defined as any substance intended to prevent, destroy, repel, or mitigate any pest (Ecobichon 1991). These are divided into several classes based on the intended target. Herbicides are used to kill vegetation and are applied in the highest quantities, accounting for approximately 75% of agricultural pesticides use in the United States (Wauchope et al. 1994). Insecticides, fungicides, and algicides are other types of pesticides used throughout Florida. Pesticides can enter the wetland environment through aerosol drift during application, chemical spills, accidental releases, sorbed components of particulates, and surface runoff from application sites.

Once a pesticide has entered a wetland it can undergo transport, degradation, or can be retained by a number of pathways. The fate of pesticides in the environment depends largely on several properties. The ability of a pesticide to be mobilized from the site of application is influenced by its persistence and solubility. Pesticide persistence refers to the stability of the substance in the environment. Most modern pesticides degrade as a result of environmental factors such as sunlight exposure, volatilization, and microbiological and chemical reactions in soils. The half-lives (that is, the time needed for half of the original amount of the substance to degrade) of the most commonly used pesticides varies from days to months.

Other important factors that govern the risk to surface and ground water is the ability of the pesticide to move through the environment. This depends on the runoff and leaching potential of the site (Rao et al. 1983), as well as the compostion of the soils of the site. Soils high in organic matter or clays are able to bind pesticides to them, providing a stable retention site until degradation occurs. Soils low in organic matter or clays present a higher risk to leaching to ground water, since there is negligible binding potential.

The model that describes the risk of ground water and surface water quality degradation due to pesticides is based on the ability of the pesticide to move through the environment. Because of the great multitude of pesticides in use with a variety of characteristics, consideration of the individual risk of a specific pesticide may be necessary for more specific application. However, general movement of pesticides is governed by the organic matter or clay content of the soil, plus the runoff and leaching potential of the site. These elements are included in the model below (**Table 9**)

Table 9. Model component that describes the conditions influencing pesticide mobilization processes in wetlands.

Pesticide Removal Rating	Soil Organic Matter Content	Soil Clay Content	Soil Thickness	Soil Runoff Potential	Soil Leaching Potential
High	High	Any	Moderate or High	Low	Low
High	Any	High	Moderate or High	Low	Low
Moderate	Conditions other than those found in “low” or “high” pesticide removal ratings				
Low	Low	Low	Any	Any	Moderate or High
Low	Low	Low	Any	Moderate or High	Any
Low	Any	Any	Low	Any	Any

Wetland Pollution Risk as a Function of Land Use

This analysis is used to derive a qualitative rating for pollution risk to wetlands based upon the surrounding land use and the relative pollution risk associated with that land use type (**Figure 4**). This method is useful in determining which wetlands may be at highest risk for receiving pollution and, therefore, may have degraded water quality. The products from this analysis are qualitative ratings, rather than numerical values. The

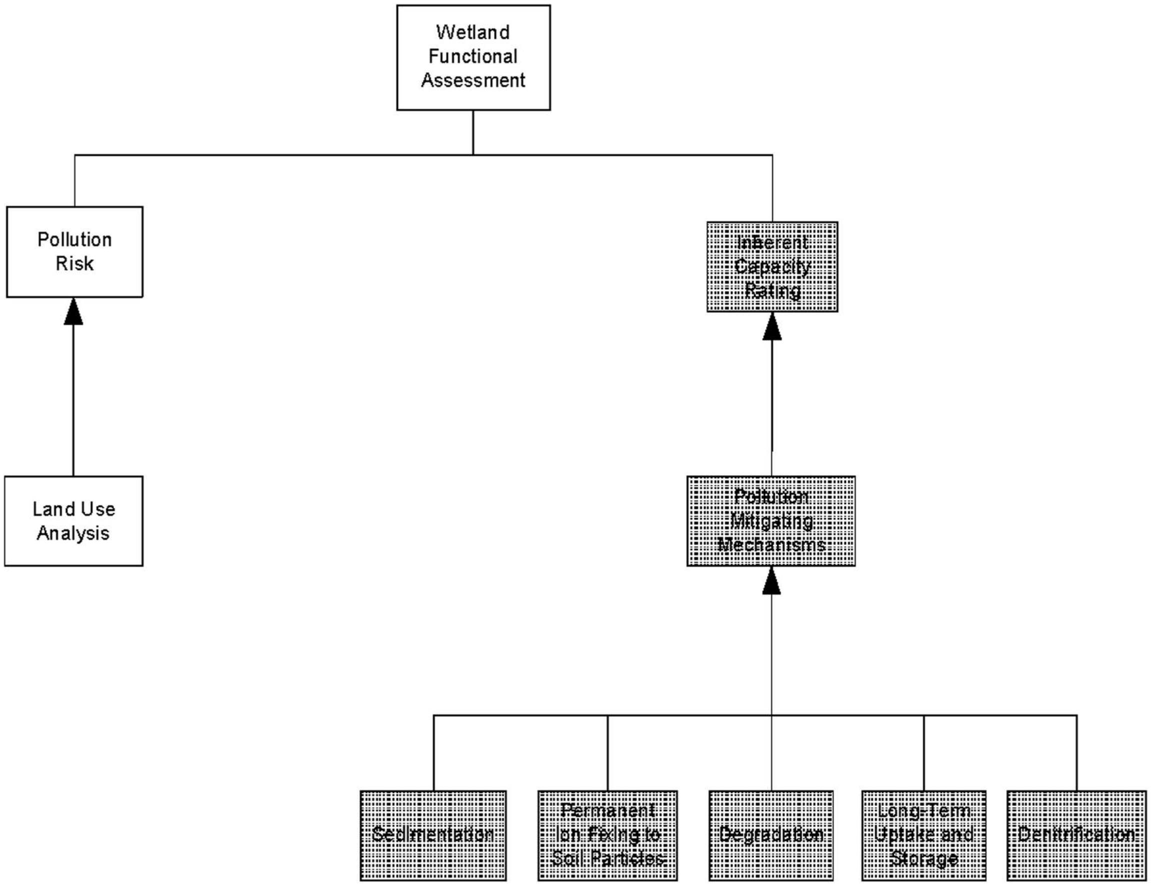


Figure 4. The white boxes of the flowchart are the general components of the pollution risk analysis.

definitions of these ratings are outlined in **Table 10**. It is recognized that water flow into a wetland from surrounding land use is different from one site to another due to drainage characteristics of the buffer zone around the wetland. In some cases, surface water inputs may originate from sheetflow and others from canals. This analysis does not take into consideration these variations in flow dynamics. Rather, it is a screening tool to identify wetlands that are most likely at risk for pollutant based upon surrounding land use.

Table 10. Definitions for ratings used in the pollution risk analysis.

Rating	Implied Definition
Low	Surrounding land uses pose little or no risk as a pollution source
Moderate	Surrounding land uses pose some or moderate risk as a pollution source
High	Surrounding land uses pose a high risk as a pollution source

It has been well documented that certain land uses are sources of specific pollutants (Harper 1992, 1994; Izuno et al. 1991). For instance, nutrient pollutants are commonly associated with agricultural runoff. Pathogenic organisms (such as fecal coliform bacteria) are usual components of feedlot and sewage runoff. Runoff from high-density commercial, residential, or industrial land uses generally contains high amounts of pollutants. Runoff from natural and undeveloped land offers the least risk of pollution runoff.

Adamus and Bergman (1995) developed a method for estimating nonpoint source pollution loads based on a GIS screening model. Their model calculates the average annual runoff from a particular land use based on average annual rainfall, area of the particular land use, and the runoff potential of the soil (**Figures 5** and **6**).

Land use categories and coverages were taken from the SFWMD's Florida Land Use, Cover, and Forms Classification System (FLUCCS) 1995 update. These FLUCCS codes were assigned to more simplified land use categories (**Table 11**). A complete list of FLUCCS codes and the respective land use categories is provided in **Appendix C**. An average annual loading is calculated based on the expected mean pollution concentration and the amount of runoff that is expected to occur from that land use. The pollution runoff loads were calculated by Adamus and Bergman (1995) based on a number of studies conducted in South and Central Florida between 1977 and 1989 (Harper 1992, Izuno et al. 1991) and are shown in **Table 12**. Rainfall volumes were converted to runoff volumes by the use of a runoff coefficients (**Table 13**). Hydrological groups for the wetland polygons were taken from the SSURGO COMP table. In order to account for nonpoint treatment methods that are now required, we selected all land uses that have been developed since 1972 and reduced the average annual load by a removal efficiency factor (**Table 14**).

Both the mean pollution concentration in runoff and the removal efficiency factors were developed by Adamus and Bergman (1995) based on scientific studies conducted on nonpoint pollution treatment methods (Harper 1992, 1994; Izuno et. al. 1991). Average annual rainfall totals within the SFWMD were calculated from long-term data records

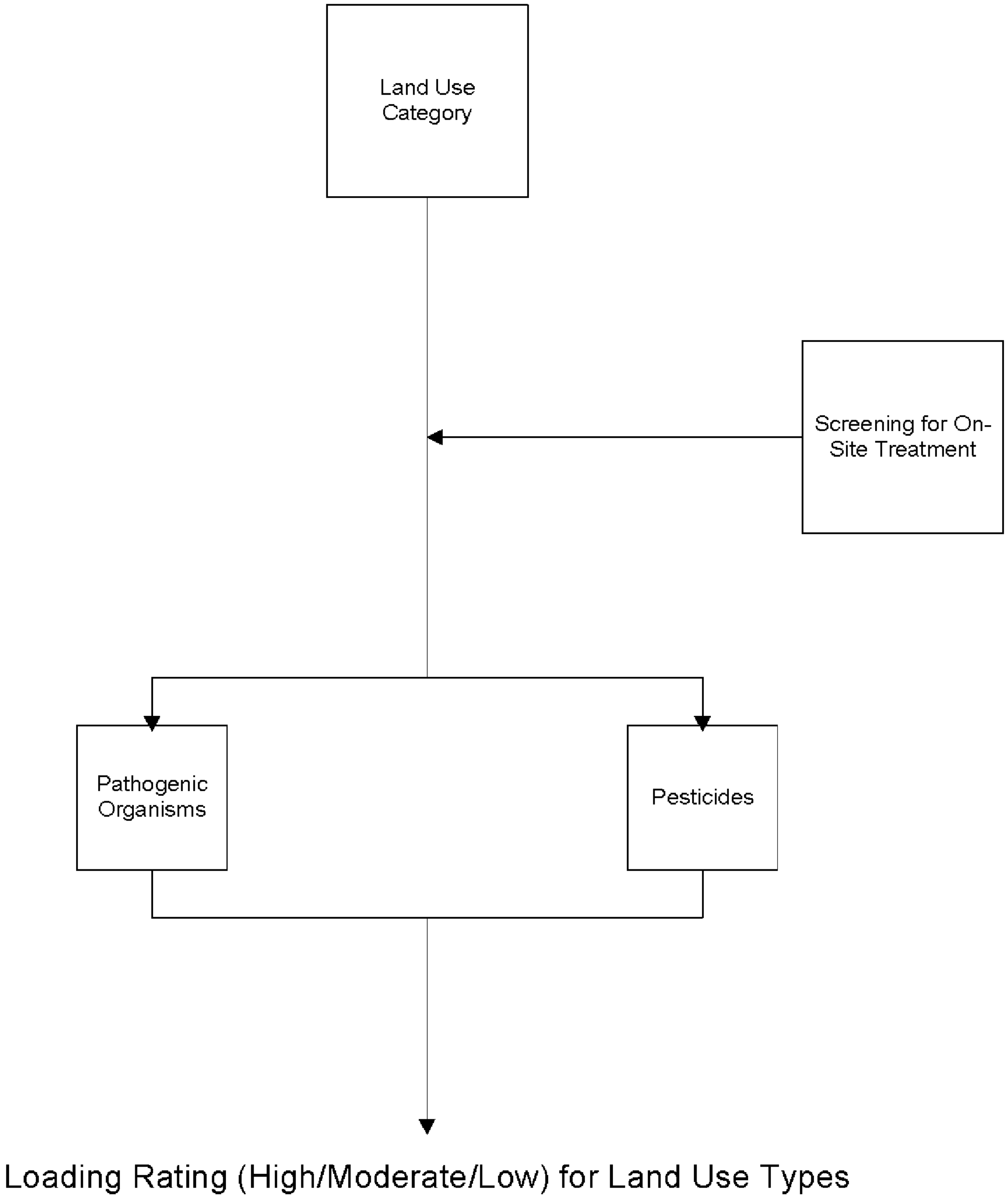
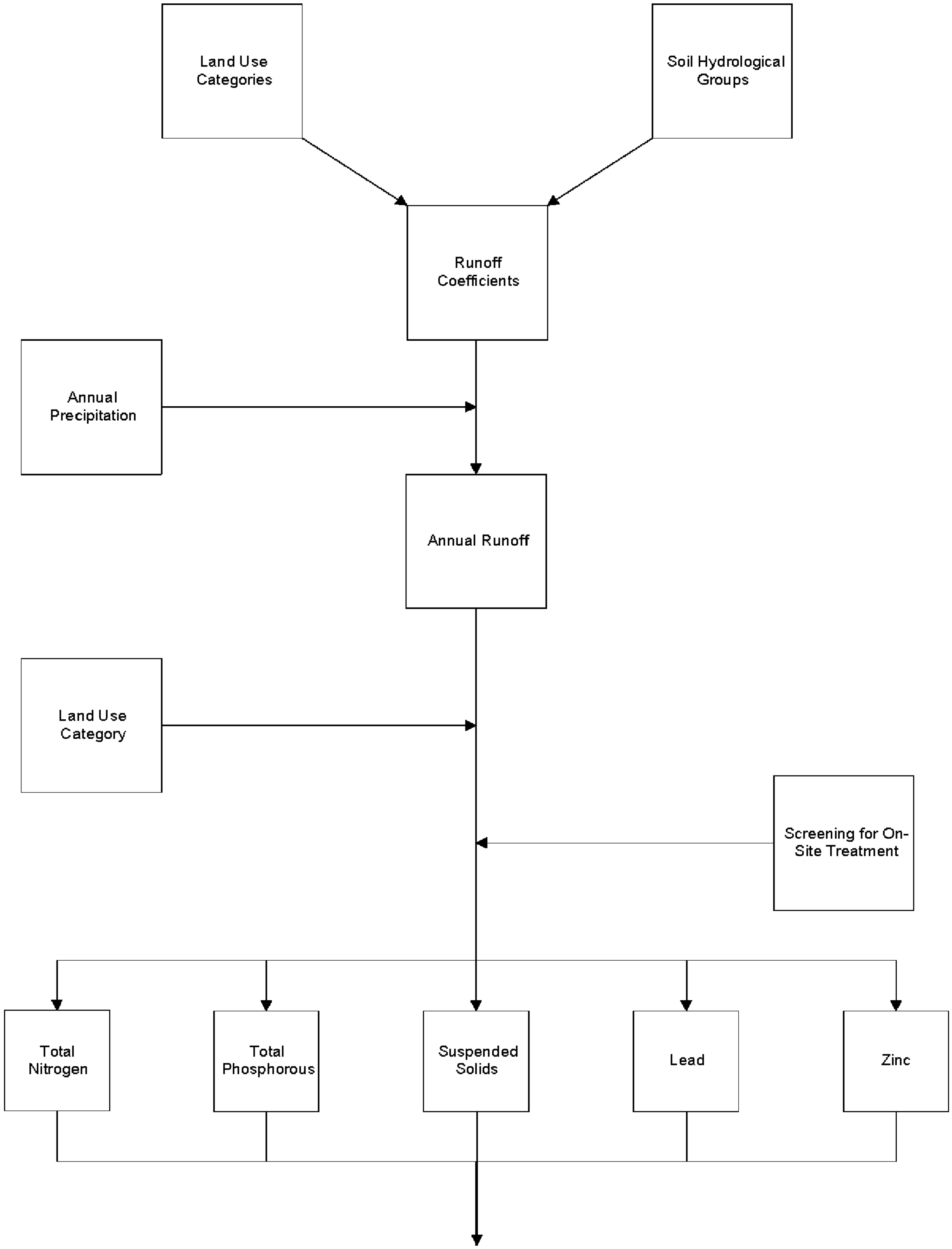


Figure 5. The pollution load screening model for pathogenic organisms and pesticides (based on Adamus and Bergman, 1995).



Annual load (g/m^2) for land use types

Figure 6. The pollution load screening model for total nitrogen, total phosphorous, lead, zinc, and suspended solids (based on Adamus and Bergman, 1995).

Table 11. Land use categories (from Adamus and Bergman 1995).

Category	Definition
Low Density Residential	Less than or equal to one dwelling unit per acre
Medium Density Residential	More than one and less than or equal to five dwelling units per acre
High Density Residential	More than five dwelling units per acre
Low Intensity Commercial	Institutional, governmental, professional services
High Intensity Commercial	Shopping areas, urban centers
Industrial	Industrial
Agriculture-Pasture	Improved and unimproved pastures
Agriculture-Crops	Row crops, field crops, mixed crops
Agriculture-Citrus	Citrus
Agriculture-Other	Other agriculture
Mining	Mining
Recreation, Open Space, Range	Recreation, open space, rangeland
Natural Areas	Upland forest, wetlands, water bodies

Table 12. Mean runoff concentrations from selected land use types (from Adamus and Bergman 1995).

	Pollutant (milligrams per liter (mg/L)				
Land Use Category	Total Nitrogen	Total Phosphorus	Suspended Solids	Zinc	Lead
Low Density Residential	1.77	0.18	19.1	0.032	0.058
Medium Density Residential	2.29	0.30	27.0	0.057	0.091
High Density Residential	2.22	0.47	71.0	0.055	0.091
Low Intensity Commercial	1.18	0.15	81.0	0.111	0.158
High Intensity Commercial	2.83	0.43	94.3	0.170	0.214
Industrial	1.79	0.31	93.9	0.122	0.202
Agriculture-Pasture	2.48	0.48	55.3	0.028	0.025
Agriculture-Crops	2.68	0.42	55.3	0.028	0.025
Agriculture-Citrus	2.05	0.14	55.3	0.028	0.025
Agriculture-Other	2.32	0.34	55.3	0.028	0.025
Mining	1.18	0.15	93.9	0.122	0.202
Recreation, Open Space, Range	1.25	0.05	11.1	0.006	0.025
Natural Areas	0.00[a]	0.00[a]	0.0[a]	0.000[a]	0.000[a]

a. These numbers were set to zero to indicate no additional pollution loading originating from natural lands.

Table 13. Runoff coefficients by land use and soil hydrological group (from Adamus and Bergman 1995).

Land Use Category	Soil Hydrological Group			
	A	B	C	D
Low Density Residential	0.25	0.30	0.35	0.40
Medium Density Residential	0.30	0.37	0.43	0.50
High Density Residential	0.50	0.57	0.63	0.70
Low Intensity Commercial	0.60	0.70	0.80	0.90
High Intensity Commercial	0.65	0.75	0.85	0.95
Industrial	0.60	0.70	0.80	0.90
Agriculture (all types)	0.15	0.23	0.32	0.40
Mining	0.20	0.30	0.40	0.50
Recreation, Open Space, Range	0.10	0.17	0.23	0.30

Table 14. Stormwater treatment systems efficiencies (from Adamus and Bergman 1995).

Pollutant	Removal Efficiency
Nitrogen	30%
Phosphorus	50%
Lead	80%
Zinc	80%
Suspended Solids	55%

stored in the SFWMD's DBHYDRO database from a variety of rain gauging stations within the region. Information about the DBHYDRO data used, including the period of record, can be found in **Appendix D**.

We also considered two other pollutants in the loading and risk analyses: pathogenic organisms and pesticides. These were processed differently since no annual loading data is available for these pollutants. Instead of loading data, we used ratings of "high", "moderate", and "low" risk assigned to land use types. The ratings associated with land use types are shown in **Appendix E**. The processing followed the same method used for the other pollutants, except that values of 1 for "low", 2 for "moderate", and 3 for "high" were used.

The processing of the potential pollution loading analysis was handled by an Arc/Info™ AML program written for this specific application. The program script for this module is shown in **Appendix F**, with annotations to describe the general process method.

After the loading risk assessment was completed, we assigned the loading risk back to the wetlands to determine pollution risks for individual wetlands (pollution risk analysis). We summed the area of polluting land uses within a buffer zone of 300 meters from a wetland, then summed the pollution loading within this buffer. **Figure 7** shows the general process used in this analysis. The processing of the wetland risk analysis was handled by an Arc/Info™ AML program written for this specific application. The program script for this module is shown in **Appendix G**, with annotations to describe the general process method.

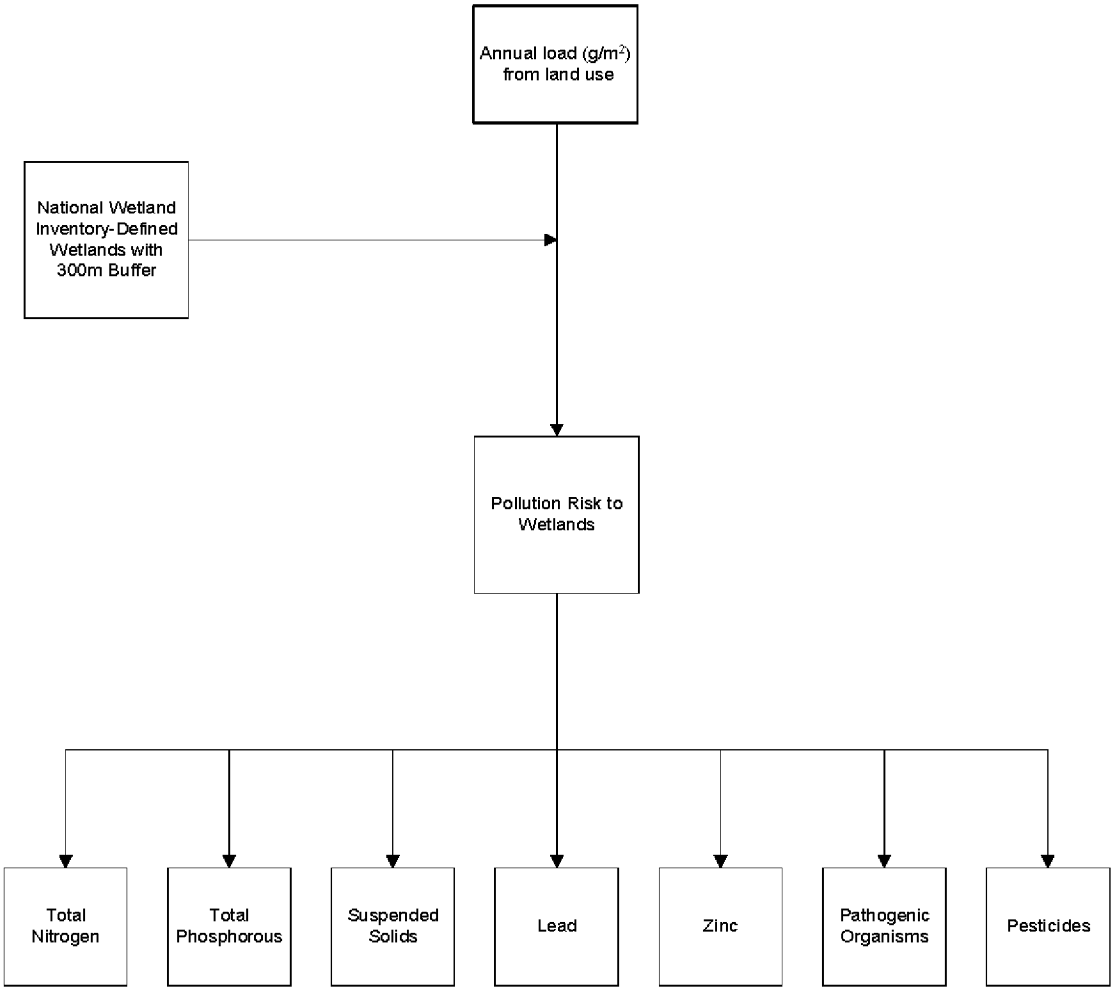


Figure 7. Process used to calculate pollution risk to wetlands.

The estimated risk to Okeechobee County wetlands for nitrogen pollution was selected as a representative figure displaying results of the wetland pollution risk analysis (**Figure 8**). Blue areas indicate land uses for which there are insufficient data to analyze. Green areas indicate wetlands that have no risk of pollution from surrounding land uses. These are wetlands that are surrounded by natural areas, preserves, or vacant land. The scale of nitrogen pollution risk corresponds to a gradient of color from white to deep red. Wetlands that are white to light red in color have lower risks for receiving nitrogen pollutants. Wetlands that are red to deep red have the highest risk. Okeechobee County and nitrogen were selected as a representative county and pollutant to display for this document, but the results for all counties and pollutants within the SFWMD can be found on the compact disk provided with this document and on the Wetlands Conservation Strategy web site.

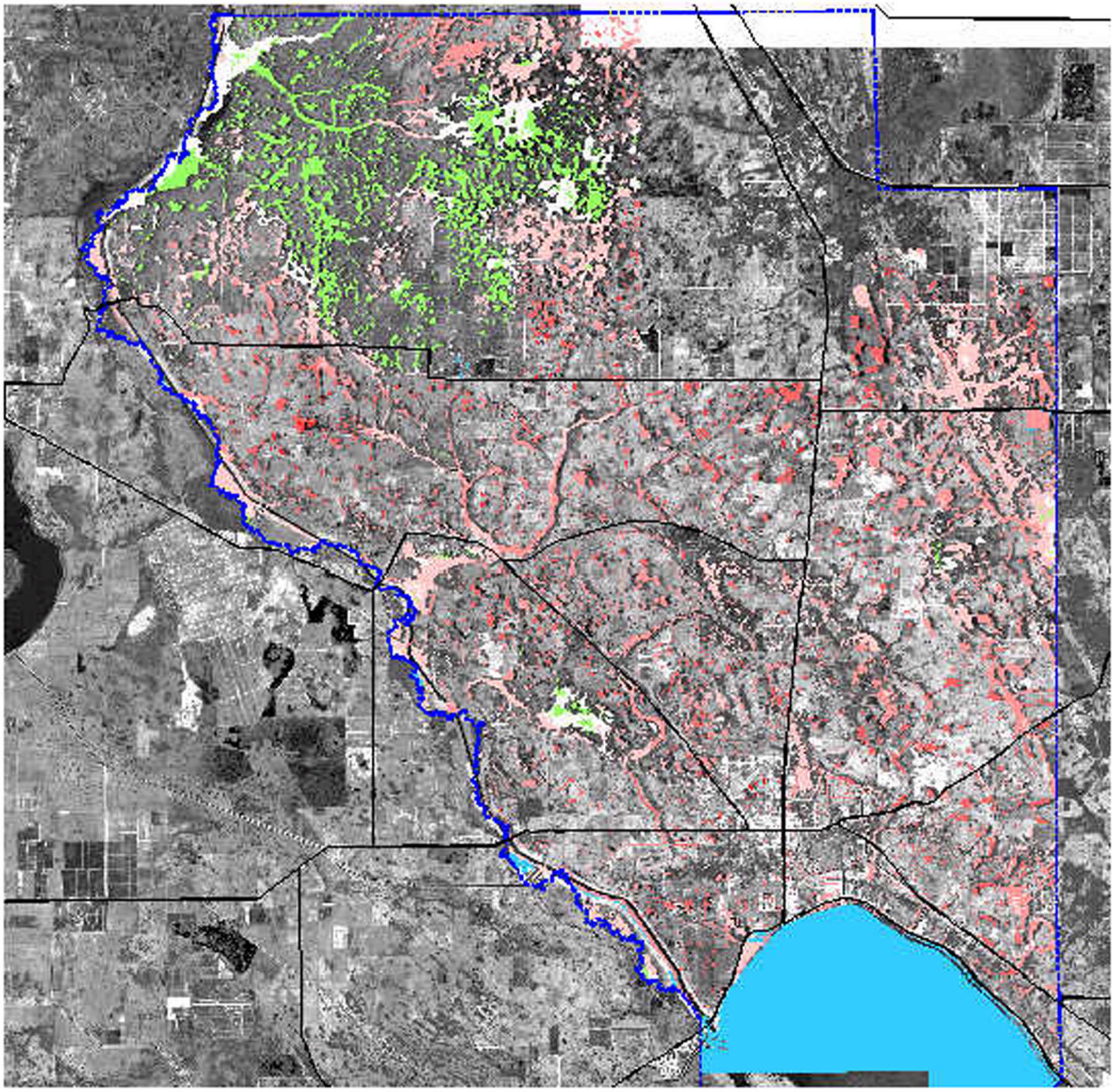


Figure 8. Estimated risk to Okeechobee County wetlands for nitrogen (total nitrogen) pollution based upon surrounding land use.

RUNOFF AND POLLUTION LOADING ESTIMATES

The model that we have developed to calculate runoff and pollution loading is based upon the landscape-level screening model developed by Adamus and Bergman (1995). However, we have added more components in order to adapt it for quantitative application. Verification of the results of the runoff portion of the model is accomplished using the South Florida Water Management Model (SFWMM), a coarser scale resolution hydrological model that is being applied in many regional projects (e.g., CERP, Water Preserve Area Feasibility Study, Lower East Coast regional water supply planning). Verification of the results of the pollution loading portion of the model is left to the user to obtain field data to compare with model output for the specific area of interest.

Other water quality screening models that are currently being used to address water quality needs in South Florida projects include Walker's model for reservoirs and stormwater treatment areas (STAs) (Walker 1999), the Dade County load estimation model (CH2M Hill 1994), and the EUTROMOD (Rechow et al. 1992). These models have been used to size STA components and to compute pollution loading and concentrations from STAs, reservoirs, and best management practice (BMP) elements. However, these models differ from our proposed method in that they are unable to calculate runoff, are steady-state yearly time step models, and cannot be used to determine spatial distribution of pollution. The use of our proposed method would allow us to create a more spatially and temporally accurate characterization of water quality variations within the Water Preserve Area (WPA) basins, investigate changes to water quality relative to predicted changes in future land use, determine the location of pollution "hot spots", and compare runoff values from the screening model with those of the regional SFWMM model output.

Model input consists of spatial data layers produced by a previous analysis of pollution risk to South Florida wetlands (see the **Wetland Pollution Risk as a Function of Land Use** section on page 19), runoff coefficients, mean runoff concentrations, stormwater treatment efficiencies, land use coverages (1972, 1995, and future), and defined WPA component basin boundaries. The analysis is roughly divided into two parts: the calculation of runoff volume from a WPA basin and the calculation of pollution loading.

Calculation of Drainage Basin Runoff

The calculation of potential basin runoff volumes is accomplished in two steps. First, a raw runoff number is obtained from the rainfall volume and runoff coefficient for a land use polygon. This raw runoff volume is further reduced if there is an on-site pollution treatment/runoff retention system present.

The raw runoff volume is calculated by multiplying rainfall (from the desired time period, in the appropriate units) by the area of the land use. This yields a rainfall volume for that specific land use. This rainfall volume is then reduced by the appropriate runoff coefficient to yield an estimate of runoff volume. This is calculated for each land use polygon within a drainage basin as follows:

$$\text{Raw Basin Runoff} = [(\text{rainfall volume}_{LU1})(\text{runoff coefficient}_{LU1})], \quad (11)$$
$$[(\text{rainfall volume}_{LU2})(\text{runoff coefficient}_{LU2})], \ldots$$

Land use type and soil hydrological group are used to determine a runoff coefficient for a land use polygon. These coefficients were derived from a standard reference (Chow 1964) and from more recent Florida studies (Harper 1992, 1994). The runoff coefficients used in this method are shown in **Table 13**.

In order to account for runoff reduction by nonpoint treatment systems that are now required in all development permitted since the mid-1970s, we selected all land use types that have been developed between 1972 (the only land use map available from that era) and 1995 (our most recent land use map). Raw runoff volumes for land uses that were developed before 1972 were not changed (i.e., no on-site treatment system is in place). Raw runoff volumes for the land uses that have been developed after 1972 were reduced by 70% (treatment coefficient of 0.3) (**Equation 12**). This runoff reduction factor was used to simulate the effect of on-site treatment systems that are generally designed to retain the first inch of rainfall runoff.

$$\text{Final Basin Runoff} = (\text{Runoff}_{LU1})(\text{Treatment Coefficient}) + (\text{Runoff}_{LU2})(\text{Treatment Coefficient}) + \ldots \quad (12)$$

In order to compare the output from this method with output from other models, we selected nine canal basins defined within Alternative 3 of the Water Preserve Area Feasibility Study model simulations of the SFWMM (SFWMD, 1999). For the same geographical extent of these nine canal basins, defined in the SFWMM as 2-mile by 2-mile grid cells, runoff was calculated for both the method presented here (based on land use) and the SFWMM. These locations are shown in **Figure 9**. Historical rainfall data for 1988 were used in both calculations. For comparison, **Figure 10** shows the results of the calculated runoff for these canal basins with both models

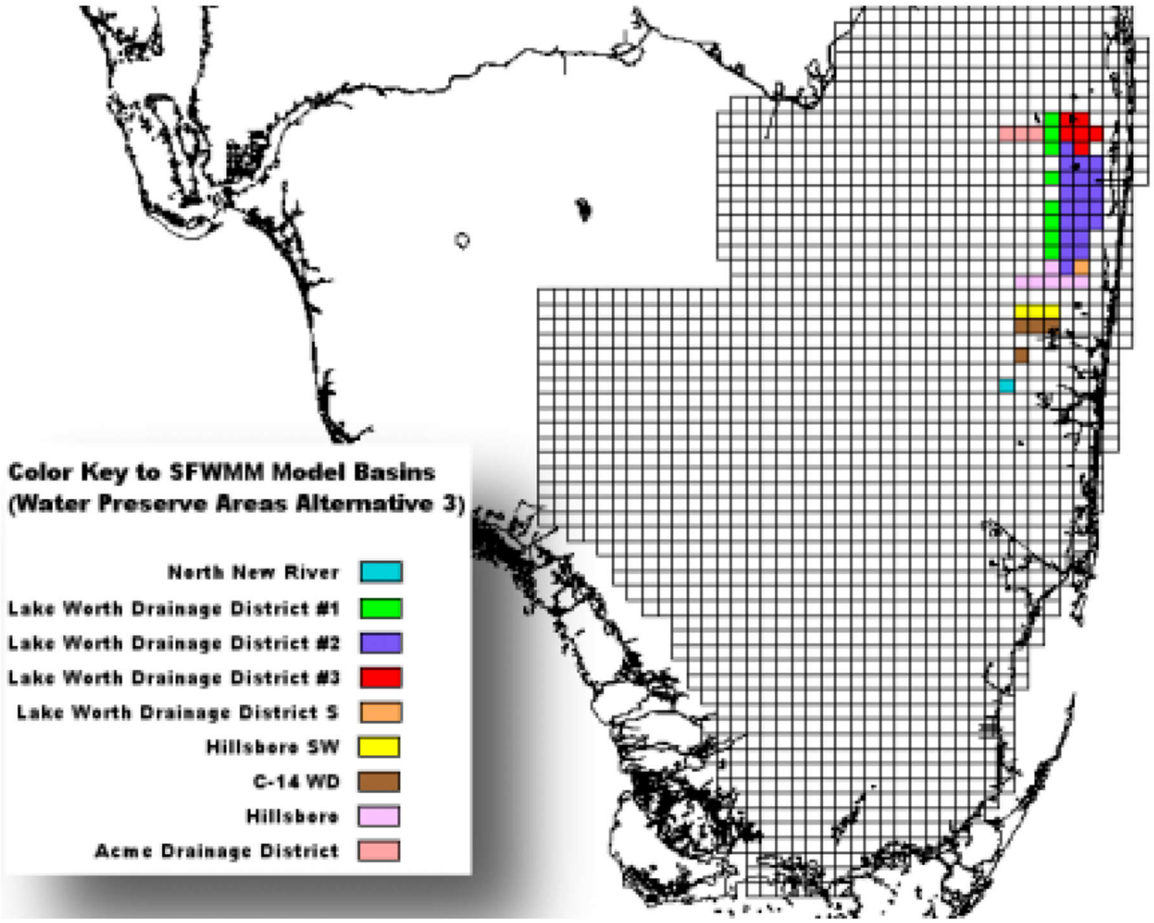


Figure 9. Locations of nine selected canal basins from the South Florida Water Management Model used for comparison with the land use-based model.

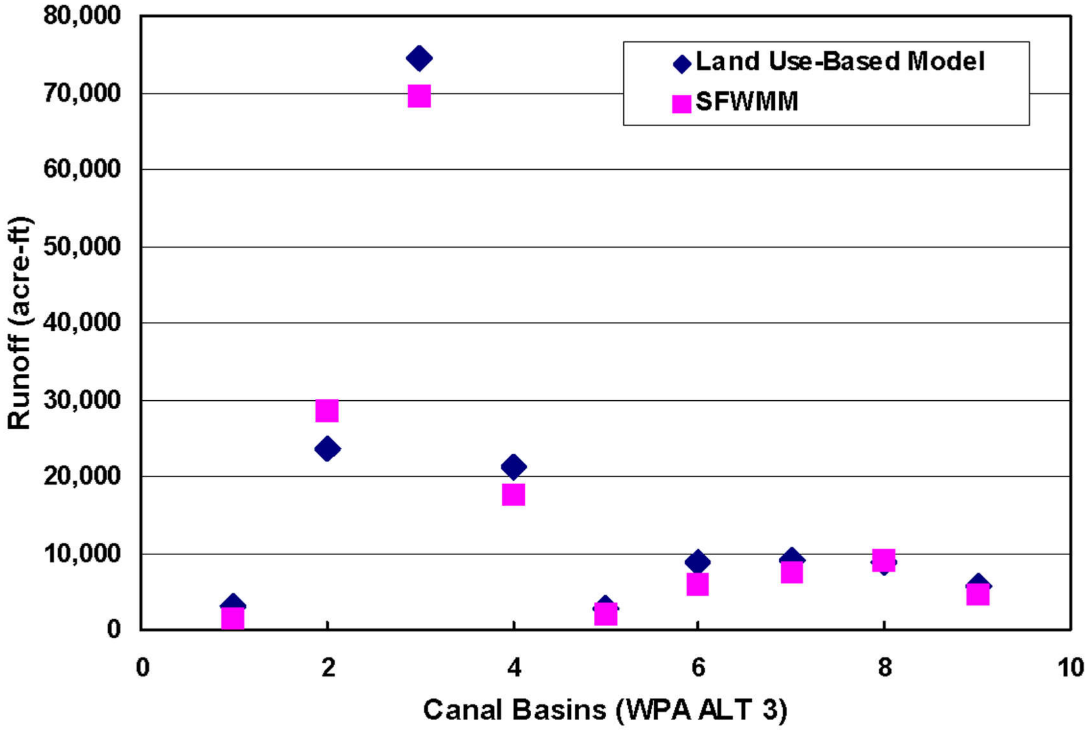


Figure 10. Runoff values (annual runoff for 1988) from the land use-based model and the South Florida Water Management Model.

The results from this land use-based method compare well with those of the SFWMM. Similar trends are observed within both models. Differences seem to be larger with greater area. The SFWMM has been used widely in water supply planning modeling (e.g., Lower East Coast regional water supply planning, Water Preserve Area Feasibility Study). Given its wide use and relatively coarse spatial resolution, a model that yields comparable results with a greater spatial resolution would be a valuable tool in areas that do not correspond well to the large grid cells found in the SFWMM. This land use-based model is capable of offering a much smaller scale of resolution (limited by the land use coverage used; for 1995 this is 2 acres) and may offer more reliable runoff values for relatively small drainage basins.

Pollution Loading and Concentration Calculations

Using estimated runoff, potential pollution loading is calculated using values for mean runoff concentrations for different land use categories. These concentrations were developed using the results of studies conducted in South and Central Florida between 1977 and 1989 (Harper 1992, 1994; Izuno et al. 1991). The mean annual runoff concentrations for all land use types are listed in **Table 12** and potential loading is calculated as follows:

$$\text{Raw Pollution Loading}_{LU1}=[(\text{Runoff}_{LU1})(\text{Pollution Concentration})] \qquad (13)$$

In order to account for nonpoint pollution treatment that is now required in all development permitted since the mid-1970s, we selected all land uses that have been developed since 1972 (the only land use map available from that era) and reduced potential pollution loads by a treatment coefficient (**Table 14**). This calculation is as follows:

$$\text{Final Pollution Loading}_{LU1}=(\text{Raw Pollution Loading}_{LU1})(\text{Treatment Coefficient}) \qquad (14)$$

This pollution reduction factor accounts for the reduction in pollution loads that result from the presence of on-site treatment in land uses that have been developed since pollution treatment systems have been required for new development. Pollutants considered include total nitrogen (TN), total phosphorus (TP), lead, zinc, suspended solids, and biological oxygen demand (BOD).

After determination of the potential loading for each land use polygon, these can be summed for a drainage basin or area of interest. Pollution concentrations can be calculated using runoff numbers derived in a previous step. Using this method, it is possible to not only calculate the annual, monthly, or weekly loading and concentrations for an area, but also to simulate pollution concentration variations resulting from periods of no rainfall.

To model daily variations in pollution loading (and concentration), the amount of loading for each rainfall event is calculated by adding up the number of days since the previous rainfall event and multiplying this by the mean daily loading for each land use. The result is the amount of "accumulated" loading that would be carried off of the land in the next rain event. This accumulated loading is then used to calculate a concentration for the runoff event. This method allows us to determine the variation in concentrations expected through time and model the "first flush" of pollutants following an extended period of time with no rainfall. This process is outlined in **Figure 11**.

A table of runoff volume, outflow loading, and concentrations for daily, weekly, monthly, quarterly, and annual time periods can be generated to allow comparison to water quality samples collected in the field. These data will be useful in the calibration of model output specific for each basin. It is advised that, when applying this method to an area, local field data be used to verify the model results for the sampled location. The degree of certainty between the results of this model and those of the field data can then be established and considered when applying the model results.

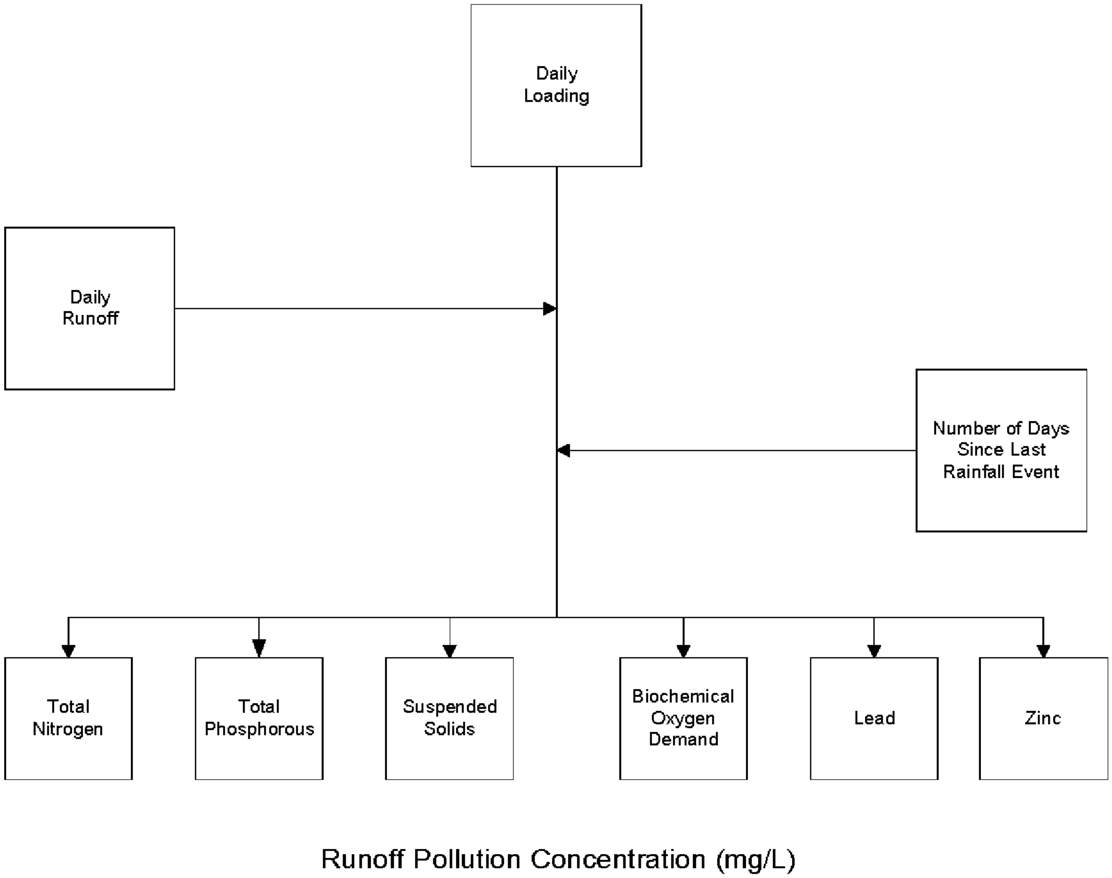


Figure 11. Generalized method used to model runoff pollution concentrations.

APPLICATION OF ANALYSIS RESULTS

The analytical products available from this project include an assessment of the functional capacity of wetlands with respect to different pollutants, an analysis of the risk to wetlands for receiving pollution from surrounding land use, and a quantitative analysis of runoff and pollution loading. The data are in electronic format and can be used to generate maps or GIS coverages. A web site with some products is also available at http://www.sfwmd.gov/org/pld/proj/wetcons. The data and maps are arranged by county and are easily viewable with most internet browsers.

When using the products from this analysis, one should realize that the strength of these data was in their use on a landscape-level application. Our process has not improved on the accuracy of the data sets used, only provided a synthesis of available information. Because of inherent errors and imprecision in the data sets used, the analysis can only give indications of what to expect in an area of interest, and can not provide definitive answers of what occurs at specific sites. This analysis cannot replace site specific assessments. However, it can be used to guide decisions of where load efforts should be concentrated.

These methods of wetland assessment represent only one way to view wetland function. It is not the best or only method and other assessment methods should be considered for comparison. When selecting a methodology for wetland analysis this approach should be evaluated in concert with other assessment tools, such as the WRAP (Miller and Gunsalus 1997) or HGM (Brinson 1996), that may provide complementary or competing results.

Because of the method that was applied in the qualitative wetland pollution risk analysis, one should remember that smaller polygons will generally have a more reliable risk assessment than larger ones. This is due to the fact that a buffer area was examined. In larger wetlands, a potential high risk to one portion of a large wetland system could be masked by the presence of a larger area with low risk. Another important consideration is the number of categories that are set in the rating scale. More categories can yield a more refined map of the degrees of risk. This will also help to untangle clusters of risk (where most of the wetlands tend to be grouped in one region of the scale). In this analysis the scale is relative and not absolute. The data are most useful if comparisons are made against wetlands in natural or unimpacted systems.

These programs have other potential research and planning applications that we have not explored. The assessment method could be applied to projected future and past land use maps to estimate historical and future conditions. The programs can also be used to determine suitability of proposed projects, such as a stormwater treatment wetland or mitigation project. By looking at different scenarios of management and wetland type, differences in functional capacity can emerge. This information may yield designs that better meet the goals of the project.

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APPENDIX A
CONVERSION OF QUANTITATIVE DATA TO QUALITATIVE DATA

In rating wetlands for the capacity to mitigate pollutants, a number of attributes were used to supply the various models with the appropriate input data. The attributes used to supply soil information were provided by the COMP and LAYER tables in the SSURGO database. The attributes from these tables used were clay content, organic matter content, and pH. The classification of attribute data as "low", "moderate", and "high" are discussed below.

Soil Clay Content

The functionality of some pollution mitigating mechanisms was dependant on soil clay content. Clay, by definition, is composed of very fine particles with a very high surface area per volume ratio. These particles have thousands of times more surface area per unit than silt particles and nearly a million times more surface area than very coarse sand particles. For this reason, clay particles are the most chemically and physically active part of mineral soil (USDA 1993). These properties are important with respect to the soil's ability to bind pollutants to the surface. A clay soil with a high CEC has a high ability to sorb pollutants (e.g. ammonium, phosphate, micronutrients, and heavy metals). Conversely, large-textured soils have significantly lower surface area and are much less active. In considering the ratings for a soil's activity, the amount of clay (hence a measure of the relative amount of reactive surface area) and CEC (a property of the soil chemistry) are not considered separately.

In order to rank the soil layers into groups of "low", "moderate", and "high" clay content, we used the surface texture (SURFTEX) attribute data from the SSURGO COMP table. The conventional definitions for soil textural classes of clay (material below 0.002 millimeter [mm]), silt (between 0.002 to 0.05 mm), and sand (0.05 to 2.0 mm) are used to define the different soil types (USDA 1993). Those surface textures with clay as the primary component were rated as high in clay content. Those surface textures with no clay, silt, or loam content were rated as low in clay content. Those surface textures that had clay as a secondary component, or were composed of silt or loam, were rated as moderate in clay content.

Soil Organic Matter Content

The organic matter content of a soil influences its physical and chemical properties in several important ways. Soils that contain some organic matter have increased porosity, lower bulk density, higher water retention and infiltration, and a high-cation adsorption capacity many times greater than mineral particles (USDA 1993). The presence of organic matter is important in denitrification, and in sorption of micronutrients and heavy metals. It can also interfere with ammonium fixing processes. The organic matter content of a soil is measured by oxidizing the organic carbon with potassium dichromate in acid and results are given as the percent organic matter in dry soil (of soil material less than 2 mm in diameter).

In order to rank the soil layers into groups of "low", "moderate", and "high" organic matter content, we used the surface texture (SURFTEX) attribute data from the

SSURGO COMP table. Those soils that are classified as "organic soils" (Histosols) have a very high organic carbon content, and are considered to be organic rather than mineral soils. These soils were rated as "high" in organic matter content. Soils that are classified as mineral soils have a very high mineral material and low organic matter content, usually less than a few percent. Any soil layer that is "sand", "loam", "clay", or a mixture of these with a low organic matter content is rated "low". Other soil textures that are mixtures of an organic soil with another taxonomic class are rated as "moderate".

Soil pH

Soil pH is a numerical expression of the relative acidity or alkalinity of a soil. One important aspect of a soil's pH value is its influence on water quality and sorption mechanisms. Many pollutants are most soluble (available for plant uptake, if a nutrient) in acidic conditions. In nonacidic soils, calcium and magnesium, which are abundant in most South Florida wetlands, will readily form insoluble precipitates with many pollutants, especially micronutrients and phosphorus.

The descriptive classes of soil pH found in the USDA Soil Survey Manual (USDA 1993) were used to rank the soil layers are "low" for acidic, "moderate" for circumneutral, and "high" for basic soils (**Table A-1**).

Table A-1. Soil pH classes, associated pH values, and ratings used for our model.

Soil pH Class	Soil pH range[a]	Model pH Rating
Ultra acid	< 3.5	Low
Extremely acid	3.5 – 4.4	Low
Very strongly acid	4.5 – 5.0	Low
Strongly acid	5.1 – 5.5	Low
Moderately acid	5.6 – 6.0	Low
Slightly acid	6.1 – 6.5	Medium
Neutral	6.6 – 7.3	Medium
Slightly alkaline	7.4 – 7.8	Medium
Moderately alkaline	7.9 – 8.4	High
Strongly alkaline	8.5 – 9.0	High
Very strongly alkaline	> 9.0	High

a. From the *National Soil Survey Handbook* (USDA 1993).

Spodic Soils

Iron, manganese, and aluminum concentrations in soils can affect the sorption of phosphorus, especially in acidic conditions. Our databases do not contain direct data on the concentrations of these elements, however they may be inferred from the soil type. By definition, spodic soils have a “spodic” layer which is high in manganese, aluminum, and/ or iron (Tan, 1982). Dissolved phosphate moving through a spodic layer is bound to these metals, especially under acidic conditions. Because of this, we have used a designation “yes” or “no” to indicate soil types which contain a spodic layer within 40 inches of the surface, as defined in soil taxonomy conventions.

Soil Runoff Potential

In order to determine the relative potential of water to runoff of a site, we used the SOILRUN data table from the FOTG (SCS 1992). This entry, designated by FOTG as “low”, “moderate”, or “high”, indicates the potential of a particular chemical to leave the application site with runoff water and/or detached soil particles.

Soil Leaching Potential

The risk of ground water contamination is an important consideration with respect to some pollutants. We have used the SOILEACH data from the FOTG table (SCS 1992), designated as “low”, “moderate”, or “high”, to indicate both the relative risk of ground water contamination and the ability of surface water to move horizontally through the soil matrix.

Hydroperiod

The ponding of water on a site has implications for several mechanisms that control water quality. Among them are the redox potential of surface soil layers and water retention time relative to plant uptake processes. If surface water is present in a wetland (ponded or flooded) for most of the year, then the soils will be predominantly anaerobic. If surface water is absent from a wetland for most of the year, the surface soils will be predominantly aerobic. Wetlands that are inundated for a significant portion, but not all, of the year fluctuate between these conditions and are defined as having “wet-dry” hydroperiods. All of these conditions are found throughout the South Florida landscape. We used the ponding rating in our model as a surrogate for soil reducing properties. In our ratings of wetland ponding with respect to reducing conditions, we used the general assumption that if a site was flooded for three months or less annually, then the surface soils were predominantly aerobic. If the site was flooded for four to eight months annually, then the site had a “wet-dry” hydroperiod of alternating aerobic-anaerobic surface soil conditions. If the site was flooded for nine months or more annually, then we assumed that the soils were predominantly anaerobic.

Prolonged inundation of a site (with low runoff potential) also assumes a longer surface water retention time, which increases the uptake of nutrient pollutants by the resident plant community, reduction of suspended sediments and pathogens, and decomposition of unstable pesticides.

Short hydroperiod wetlands (three months or less inundation) were rated as “low” and long hydroperiod wetlands (nine months or more inundation) were rated as “high.” Wetlands with inundation from three to nine months are rated as “moderate.”

Soil Thickness

The volume of soil that is available to influence water quality was quantified by a rating method that assigned higher potential function values to sites with thicker soils. We restricted our definition of available soil thickness to the layers which had at least moderate or high permeabilities and were above a flow restricting layer. We defined a confining layer as that layer which is a hard substratum (low permeable bedrock or hardpan). Any soil strata below this confining layer would not significantly influence water quality and was not considered further. Soil substratum of less than 12 inches above the first confining layer were rated as “low” (= thin soil). Soil substratum of 12 or more, but less than 40 inches above the first confining layer were rated as “moderate”. Those sites with 40 inches or more were rated as “high” (= thick soil).

APPENDIX B
WETLAND CAPACITY PROGRAM

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/** Inherent characteristics processing
_/**   calculates wetlands inherent characteristics for improving
/**   or maintaining water quality
/**  Intersects soils and nwi coverages and through cursor
/**    summarizes ratings for each NWI polygon.  Ratings are then
/**    analyzed to determine overall score for each process model.
/**  local path: d:\data\di10\inherent\inherent.aml
/**  120199 ksaari initial coding
/**  031899 ksaari added county argument
/**  033099 ksaari move nwi to central storage, saves resolve table
/**  040899 ksaari added modelscripts added post routine
/**  042299 ksaari modified cursor and models not to run uplands
/** inputs
/**   nwi coverage
/**   ssurgo coverage
/**   ratings database from ratingscomp.xls from John
&args county
&if [null %county%] &then &do
  &messages &on
  &type Usage: inherent <county>
  &type co, le, ma, pb, sl, ...
  &return runs in current workspace
&end
&messages &off
&call setup /** Sets paths to base coverages
&call preprocess /** Prepares base coverages for processing
&call process /** Bulk of intersection processing
&call analyze /** Summarizes soil characteristics for each NWI poly
&call model /** Calculates overall score for each process model
&call cleanup /** Clean up
&call post /** Post results to server
&messages &on
&return end of program

&routine setup /** set variables ************************
  &type Setting up variables for %county%...
  &s nwistore d:\data\di10\covs
  &if [exists \\gis1\pcovs\nwi\%county%\%county%-nwi90 -cover] &then
    &s nwi \\gis1\pcovs\nwi\%county%\%county%-nwi90
  &else &s nwi \\gis1\pcovs\nwi\%county%\%county%-nwi84
  &s soil \\gis1\pcovs\soils\ssurgo\data\%county%-ssur
  &s ratings d:\data\di10\inherent\anal\ratingsmod.dat
  &if [quote %county%] = 'le' &then
    &s nwi \\gis1\pcovs\nwi\%county%\%county%-nwi95
  &s parmlist ph_rate spodic_rate om_rate hydro_rate clay_rate
depth_rate leach_rate run_rate
&return /** end setup
```

```
&routine preprocess /** preprocess pcovs ****************
&type Preprocessing NWI for %county%...
/** nwi
copy %nwi% nwiraw
/** pullitems to leave behind inconsistent garbage
pullitems nwiraw.pat nwiraw.pat
   area
   perimeter
   nwiraw#
   nwiraw-id
   attrib
   sys
   subs
   class1
   class2
   subc1
   subc2
   h2o
   chem
   mod
end
/** get rid of quad boundaries
dissolve nwiraw nwidis #all
kill nwiraw all
/** eliminate wetlands less than two acres
eliminate nwidis nwi
   reselect area < 87120
   [unquote ' ']
   n
   n
kill nwidis
/** create nwinum as unique identifier of nwi polygons
additem nwi.pat nwi.pat nwinum 4 5 b
&data ARC INFO
   ARC
   SELECT NWI.PAT
   CALC NWINUM = NWI# - 1
   Q STOP
&end

/** soils
&type Preprocessing soils for %county%...
/** remove unwanted boundaries
dissolve %soil% soildis muid
/** eliminate less than two acres
eliminate soildis soil
   reselect area < 87120
   [unquote ' ']
   n
```

```
   n
kill soildis
joinitem soil.pat %ratings% soil.pat muid
&return /** end preprocess

&routine process /** bulk of intersection processing **********
&type Intersection processing for %county%...
/** create the intersection coverage
/**   this creates the cross refernce table
intersect nwi soil nwisoil poly
statistics nwisoil.pat nwirate.dat nwinum
   sum area
end
pullitems nwi.pat nwisys.dat nwinum sys class1
joinitem nwirate.dat nwisys.dat nwirate.dat nwinum

/** create place to store parameters in nwisum stats file
&do parm &list %parmlist%
   additem nwirate.dat nwirate.dat nwi%parm% 4 12 f 3
&end
/** generate table of all unique occurances of soil and nwi
/**   this reduces overall number of records to process
frequency nwisoil.pat nwisoil.sta
   nwinum
   muid
   ph_rate
   spodic_rate
   om_rate
   hydro_rate
   clay_rate
   depth_rate
   leach_rate
   run_rate
end
   area
end
&return /** end process ***************************************

&routine analyze /** analyze statistics table
&type Analyzing intersection for %county%...
/** use arcplot to access multiple cursors
arcplot
   /** select out universe polygon and uplands
   /**   this can also be used to subset data for testing
   /**   i.e.  nwinum lt 100
   reselect nwirate.dat info nwinum ne 0 and sys ne 'U'
   /** this is the main cursor for looping through nwi polys
   cursor nwicur declare nwirate.dat info rw
   cursor nwicur open
```

```
   &s count = 1
      &do &while %:nwicur.aml$next%
         /** clear from previous selection
         /**   obviously not necessary for first iteration
         clearselect nwisoil.sta info
         /** this gets at the real data
         /**   all soil polys for a nwi wetland
         reselect nwisoil.sta info nwinum = %:nwicur.nwinum%
         &type Processing %count% of %:nwicur.aml$nsel% to process for
%county%
         /** open cursor for soil polys in nwi wetland
         cursor nscur declare nwisoil.sta info ro
         cursor nscur open
         /** initialize tmp values for each parameter and
         /**   and variable for sum area nodata
         &do parm &list %parmlist%
            &s tmp%parm% 0
            &s %parm%-9999 0
         &end
         /** this is internal loop for soils polys in nwi wetland
         &do &while %:nscur.aml$next%
            &do parm &list %parmlist%
               &if [value :nscur.%parm%] <> -9999 &then
                  /** calculate area weighted average of parameter
                  &s tmp%parm% = [value tmp%parm%] + ( [value
:nscur.%parm%] * %:nscur.area% )
               &else
                  /** or sum nodata area
                  &s %parm%-9999 = [value %parm%-9999] + %:nscur.area%
            &end
            /** loop back for next soil poly
            cursor nscur next
         &end
         /** close soil cursor for nwi wetland
         cursor nscur close
         cursor nscur remove
      &do parm &list %parmlist%
         /** look for at least 70% data
         &if [value %parm%-9999] < %:nwicur.sum-area% * 0.30 &then
            /** calculate average (not counting nodata)
            &s nwi%parm% = [value tmp%parm%] / ( %:nwicur.sum-area% -
[value %parm%-9999] )
         &else
            /** or set nodata
            &s nwi%parm% = -9999
         calc nwirate.dat info nwi%parm% = [value nwi%parm%]
         /** reset temp parm values to zero
         &s tmp%parm% 0
         &s %parm%-9999 0
```

```
      &end
      &s count = %count% + 1
      cursor nwicur next
    &end /** nwi loop
  cursor nwicur remove
quit /** from arcplot
&return /** end routine analyze ****************************

&routine model ********************************************
&type Running models %county%...
  &s parmlist = denit nh4 phos micro plant part pest
  ae
    edit nwirate.dat info
    &do parm &list %parmlist%
      additem %parm% 4 12 f 3
      select all
      calc %parm% = -9999
    &end

    /** Denitrification Model
    /** Wetland rating is = 2 when...
    select sys ne 'U'
    resel Nwiom_rate >= 0.5 and ~
           Nwiph_rate >= 0.5 and ~
           Nwidepth_rate >= 0.5
    &if [show number selected] gt 0 &then
      calc denit = 2
    /** Wetland rating is = 1 when...
    select sys ne 'U'
    resel ( ( Nwiom_rate >= 0.5 and ~
               Nwihydro_rate >= 1.5 and ~
               Nwiph_rate >= 0.5 ) and ~
             ( Nwidepth_rate >= 0.5 and ~
               nwirun_rate >= 1.5 ) ) or ~
           ( ( Nwiom_rate < 0.5 and nwiom_rate >= 0 and ~
               Nwiph_rate >= 0.5 ) and ~
             ( Nwidepth_rate >= 0.5 ) )
    &if [show number selected] gt 0 &then
      calc denit = 1
     /** Wetland rating is = 0 when...
    select sys ne 'U'
    resel ( Nwiph_rate < 0.5 and nwiph_rate >= 0 ) or ~
           ( Nwidepth_rate < 0.5 and nwidepth_rate >= 0 )
    &if [show number selected] gt 0 &then
      calc denit = 0

    /** NH4+ Sorption Model
    /** Wetland rating is = 2 when...
    select sys ne 'U'
```

```
resel Nwiom_rate < 0.5 and Nwiom_rate >= 0 and ~
       Nwiclay_rate  >= 1.5 and ~
       Nwidepth_rate >= 0.5 and ~
       Nwiph_rate    >= 0.5 and ~
       Nwihydro_rate < 1.5 and Nwihydro_rate >= 0 and ~
       nwirun_rate      < 1.5 and nwirun_rate >= 0
&if [show number selected] gt 0 &then
  calc nh4 = 2
/** Wetland rating is = 0 when...
select sys ne 'U'
resel ( Nwiclay_rate < 0.5 and nwiclay_rate >= 0 ) or ~
       Nwiom_rate >= 0.5 or ~
       ( Nwidepth_rate < 0.5 and nwidepth_rate >= 0 ) or ~
       Nwiph_rate < 0.5
&if [show number selected] gt 0 &then
  calc nh4 = 0
/** Wetland rating is = 1 for other cases
select sys ne 'U'
resel nh4 = -9999
reselect (!nwiom_rate ~
           nwiclay_rate ~
           nwidepth_rate ~
           nwiph_rate ~
           nwihydro_rate ~
           nwirun_rate!) <> -9999
&if [show number selected] gt 0 &then
  calc nh4 = 1

/** Phosphate Sorption Model
/** Wetland rating is = 2 when...
select sys ne 'U'
resel ( Nwiph_rate >= 1.5 and ~
         Nwidepth_rate < 0.5 and nwidepth_rate >= 0 and ~
         nwirun_rate < 1.5 and nwirun_rate >= 0 ) or ~
       ( Nwiclay_rate >= 0.5 and ~
         Nwispodic_rate >= 0.5 and ~
         Nwidepth_rate >= 0.5 and ~
         Nwiph_rate < 0.5 and nwiph_rate >= 0 and ~
        ( ( Nwihydro_rate < 0.5 and nwihydro_rate >= 0 ) or ~
            Nwihydro_rate >= 1.5 ) and ~
         nwirun_rate < 1.5 and nwirun_rate >= 0 )
&if [show number selected] gt 0 &then
  calc phos = 2
/** Wetland rating is = 0 when...
select sys ne 'U'
resel ( Nwiph_rate < 0.5 and nwiph_rate >= 0 and ~
         Nwispodic_rate < 0.5 and nwispodic_rate >= 0 ) or ~
       ( Nwidepth_rate < 0.5 and nwidepth_rate >= 0 and ~
         Nwiph_rate < 0.5 and nwiph_rate >= 0 )
```

```
&if [show number selected] gt 0 &then
  calc phos = 0
/** Wetland rating is = 1 for other cases
select sys ne 'U'
resel phos = -9999
reselect (!nwiph_rate ~
           nwidepth_rate ~
           nwirun_rate ~
           nwiclay_rate ~
           nwispodic_rate ~
           nwiph_rate ~
           nwihydro_rate!) <> -9999
&if [show number selected] gt 0 &then
  calc phos = 1

/** Micronutrients/Heavy Metals Sorption Model
/** Wetland rating is = 2 when...
select sys ne 'U'
resel ( Nwiom_rate >= 1.5 and ~
         Nwidepth_rate >= 0.5 and ~
         Nwiph_rate >= 0.5 and ~
         nwirun_rate < 1.5 and nwirun_rate >= 0 ) or ~
       ( Nwiclay_rate >= 1.5 and ~
         Nwidepth_rate >= 0.5 and ~
         Nwiph_rate >= 0.5 and ~
         nwirun_rate < 1.5 and nwirun_rate >= 0 )
&if [show number selected] gt 0 &then
  calc micro = 2
/** Wetland rating is = 0 when...
select sys ne 'U'
resel ( Nwidepth_rate < 0.5 and nwidepth_rate >= 0 ) or ~
       ( Nwiph_rate < 0.5 and nwiph_rate >= 0 ) or ~
       ( Nwiom_rate < 0.5 and nwiom_rate >= 0 and ~
          Nwiclay_rate < 0.5 and nwiclay_rate >= 0 )
&if [show number selected] gt 0 &then
  calc micro = 0
/** Wetland rating is = 1 for other cases
select sys ne 'U'
resel micro = -9999
reselect (!nwiom_rate ~
           nwidepth_rate ~
           nwiph_rate ~
           nwirun_rate ~
           nwiclay_rate!) <> -9999
&if [show number selected] gt 0 &then
  calc micro = 1

/** Plant Community Removal Model
/*? WHAT IS NWI CLASS ML, SB, RS?
```

```
/** Wetland rating is = 2 when...
select sys ne 'U'
resel ( Nwihydro_rate >= 1.5 and ~
           nwileach_rate < 1.5 and nwileach_rate >= 0 and ~
           nwirun_rate < 1.5 and nwirun_rate >= 0 ) and ~
        ( CLASS1 in {'EM', 'AB', 'SS', 'FO', 'ML'} ) /** or ~
/** asel replaces or, 'More than twenty expressions in a list'
asel    ( nwileach_rate < 0.5 and nwileach_rate >= 0 and ~
          nwirun_rate < 0.5 and nwirun_rate >= 0 ) and ~
        ( CLASS1 in {'EM', 'AB', 'SS', 'FO', 'ML'} )
&if [show number selected] gt 0 &then
   calc plant = 2
/** Wetland rating is = 0 when...
select sys ne 'U'
resel CLASS1 in {'RB', 'UB', 'SB', 'RS', 'US', 'OW', 'RF'}
&if [show number selected] gt 0 &then
  calc plant = 0
/** Wetland rating is = 1 for other cases
select sys ne 'U'
resel plant = -9999
reselect class1 ne ''
reselect (!nwihydro_rate ~
           nwileach_rate ~
           nwirun_rate!) <> -9999
&if [show number selected] gt 0 &then
  calc plant = 1

/** Particulate/Pathogen Removal Model
/** Wetland rating is = 2 when...
select sys ne 'U'
resel CLASS1 in {'AB', 'EM', 'SS', 'ML'} or ~
      ( CLASS1 = 'FO' and ~
        nwirun_rate < 1.5 and nwirun_rate >= 0 )
&if [show number selected] gt 0 &then
  calc part = 2
/** Wetland rating is = 1 when...
select sys ne 'U'
resel ( CLASS1 = 'FO' and ~
         nwirun_rate >= 1.5 ) or ~
        ( CLASS1 in {'RB', 'UB', 'US', 'OW', 'RS', 'SB', 'RF'} and ~
          nwirun_rate < 1.5 and nwirun_rate >= 0 )
&if [show number selected] gt 0 &then
  calc part = 1
/** Wetland rating is = 0 when...
select sys ne 'U'
resel CLASS1 in {'RB', 'UB', 'US', 'OW', 'RS', 'SB', 'RF'} and ~
       nwirun_rate >= 1.5
&if [show number selected] gt 0 &then
  calc part = 0
```

```
    /** Pesticide Removal Rating
    /** Wetland rating is = 2 when...
    select sys ne 'U'
    resel ( Nwiom_rate >= 1.5 and ~
             Nwidepth_rate >= 0.5 and ~
             nwirun_rate < 0.5 and nwirun_rate >= 0 and ~
             nwileach_rate < 0.5 and nwileach_rate >= 0 ) or ~
             ( Nwiclay_rate >= 1.5 and ~
               Nwidepth_rate >= 0.5 and ~
               nwirun_rate < 0.5 and nwirun_rate >= 0 and ~
               nwileach_rate < 0.5 and nwileach_rate >= 0 )
    &if [show number selected] gt 0 &then
      calc pest = 2
    /** Wetland rating is = 0 when...
    select sys ne 'U'
    resel ( Nwiom_rate < 0.5 and nwiom_rate >= 0 and ~
             Nwiclay_rate < 0.5 and nwiclay_rate >= 0 and ~
             nwileach_rate >= 0.5 ) or ~
           ( Nwiom_rate < 0.5 and nwiom_rate >= 0 and ~
             Nwiclay_rate < 0.5 and nwiclay_rate >= 0 and ~
             nwirun_rate >= 0.5 ) or ~
           ( Nwidepth_rate < 0.5 and nwidepth_rate >= 0 )
    &if [show number selected] gt 0 &then
      calc pest = 0
    /** Wetland rating is = 1 for other cases
    select sys ne 'U'
    resel pest = -9999
    reselect (!nwiom_rate ~
               nwiclay_rate ~
               nwileach_rate ~
               nwirun_rate ~
               nwidepth_rate!) <> -9999
    &if [show number selected] gt 0 &then
      calc pest = 1
    save
    quit
  dropitem nwirate.dat nwirate.dat
    sys
    class1
    end
&return /** end model

&routine cleanup /** kill off unnecessary files *************
  &type Cleaning up %county%...
  kill soil
  kill nwisoil
  &type [delete nwiclass.dat -info]
  &type [delete nwisys.dat -info]
```

```
  &if [exists %nwistore%\%county%-nwinum -cover] &then
    kill %nwistore%\%county%-nwinum
  copy nwi %nwistore%\%county%-nwinum
  /* kill nwi
&return /** end cleanup *************************************
&routine post
 &type Posting %county% results to IS server...
 &if [exists r:\di10\kurt\covs\%county%-nwinum -cover] &then
   kill r:\di10\kurt\covs\%county%-nwinum
 copy nwi r:\di10\kurt\covs\%county%-nwinum
 &if [exists r:\di10\wetcons\kurt\inherent\%county%-nwirate.dat -info]
&then
    &type [delete r:\di10\wetcons\kurt\inherent\%county%-nwirate.dat -
info]
  copyinfo nwirate.dat r:\di10\wetcons\kurt\inherent\%county%-
nwirate.dat
&return
```

APPENDIX C
LAND USE CODES AND ASSOCIATED LAND USE CATEGORIES

FLUCCS Code	Land Use Category	FLUCCS Description	Land Use Category Description
1009	3	Mobile home units-any density	High density residential
111	1	Fixed single family homes	Low density residential
113	1	Mixed units (fixed and mobile homes)	Low density residential
119	1	Low density under construction	Low density residential
121	2	Fixed single family units	Medium density residential
123	2	Mixed units (fixed and mobile homes)	Medium density residential
129	2	Medium density under construction	Medium density residential
131	3	Fixed single family units	High density residential
133	3	Multiple dwelling units-low rise	High density residential
134	3	Multiple dwelling units-high rise	High density residential
135	3	Mixed units (fixed and mobile homes)	High density residential
139	3	High density under construction	High density residential
141	5	Retail sales and services	High intensity commercial
1411	5	Shopping centers	High intensity commercial
142	5	Wholesale sales and services	High intensity commercial
1423	5	Junk yards	High intensity commercial
143	3	Professional services	High density residential
144	5	Cultural and entertainment	High intensity commercial
145	5	Tourist services	High intensity commercial
146	6	Oil and gas storage	Industrial
147	5	Mixed commercial and services	High intensity commercial
148	1	Cemeteries	Low density residential
149	5	Commercial and services under construction	High intensity commercial
151	6	Food processing	Industrial
152	6	Timber processing	Industrial
153	6	Mineral processing	Industrial
154	6	Oil and gas processing	Industrial
155	6	Other light industrial	Industrial
156	6	Other heavy industrial	Industrial
159	6	Industrial under construction	Industrial
161	11	Strip mines	Mining
162	11	Sand and gravel pits	Mining
163	11	Rock quarries	Mining
164	13	Oil and gas fields	Natural
165	13	Reclaimed land	Natural
166	11	Holding ponds	Mining
171	5	Education facilities	High intensity commercial
172	4	Religious	Low intensity commercial
173	6	Military	Industrial
174	5	Medical and health care	High intensity commercial
175	5	Governmental	High intensity commercial
176	5	Correctional	High intensity commercial
177	4	Other institutional	Low intensity commercial
178	5	Commercial child care	High intensity commercial
179	5	Institutional under construction	High intensity commercial
181	12	Swimming beach	Recreational/open range

FLUCCS Code	Land Use Category	FLUCCS Description	Land Use Category Description
182	2	Golf courses	Medium density residential
183	2	Race tracks	Medium density residential
184	6	Marinas and fish camps	Industrial
185	2	Parks and zoos	Medium density residential
186	2	Community recreation facilities	Medium density residential
187	2	Stadiums	Medium density residential
188	12	Historical sites	Recreational/open range
189	2	Other recreational	Medium density residential
191	13	Undeveloped land within urban areas	Natural
192	12	Inactive land with street pattern	Recreational/open range
193	12	Urban land in transition	Recreational/open range
194	13	Other open land	Natural
211	7	Improved pastures	Pasture
212	7	Unimproved pastures	Pasture
213	7	Woodland pastures	Pasture
214	8	Row crops	Crops
215	8	Field crops	Crops
2156	8	Sugarcane	Crops
221	9	Citrus groves	Citrus
222	10	Fruit orchards	Other agriculture
223	10	Other groves	Other agriculture
231	10	Cattle feeding operations	Other agriculture
232	10	Poultry feeding operations	Other agriculture
233	10	Swine feeding operations	Other agriculture
241	10	Tree farms	Other agriculture
242	10	Sod farms	Other agriculture
243	10	Ornamentals	Other agriculture
244	10	Vineyards	Other agriculture
245	10	Floriculture	Other agriculture
246	10	Timber nursery	Other agriculture
251	7	Horse farms	Pasture
252	7	Dairies	Pasture
253	7	Kennels	Pasture
254	7	Aquaculture	Pasture
259	7	Other	Pasture
261	10	Fallow crop land	Other agriculture
310	13	Herbaceous	Natural
321	13	Palmetto prairies	Natural
322	13	Coastal scrub	Natural
329	13	Other shrubs and brush	Natural
411	13	Pine flatwoods	Natural
4119	13	Pine flatwoods-melaleuca infested	Natural
412	13	Longleaf pine-xeric oak	Natural
413	13	Sand pine	Natural
414	13	Pine-mesic oak	Natural
419	13	Other pines	Natural

FLUCCS Code	Land Use Category	FLUCCS Description	Land Use Category Description
421	13	Xeric oak	Natural
422	13	Brazilian pepper	Natural
423	13	Oak-pine-hickory	Natural
424	13	Melaleuca	Natural
425	13	Temperate hardwood	Natural
426	13	Tropical hardwoods	Natural
427	13	Live oak	Natural
428	13	Cabbage palm	Natural
4289	13	Cabbage palm-melaleuca infested	Natural
429	13	Wax myrtle-willow	Natural
431	13	Beech-magnolia	Natural
432	13	Sand live oak	Natural
433	13	Western Everglades hardwoods	Natural
434	13	Hardwood conifer mixed	Natural
435	13	Dead trees	Natural
437	13	Australian pine	Natural
438	13	Mixed hardwoods	Natural
439	13	Other hardwoods	Natural
441	13	Coniferous plantations	Natural
442	13	Hardwood plantations	Natural
443	13	Forest regeneration areas	Natural
444	13	Experimental tree plots	Natural
445	13	Seed plantations	Natural
521	13	Lakes larger than 500 acres	Natural
522	13	Lakes larger than 100 acres and less than 500 acres	Natural
523	13	Lakes larger than 10 acres and less than 100 acres	Natural
524	13	Lakes less than 10 acres	Natural
531	13	Reservoirs larger than 500 acres	Natural
532	13	Reservoirs larger than 100 acres and less than 500 acres	Natural
533	13	Reservoirs larger than 10 acres and less than 100 acres	Natural
534	13	Reservoirs less than 10 acres	Natural
541	13	Embayments opening	Natural
542	13	Embayments not opening	Natural
550	13	Major springs	Natural
560	13	Slough waters	Natural
611	13	Bay swamps	Natural
612	13	Mangrove swamps	Natural
613	13	Gum swamps	Natural
614	13	Titi swamps	Natural
615	13	Stream and lake swamps	Natural
616	13	Inland ponds and sloughs	Natural
617	13	Mixed wetland hardwoods	Natural
6171	13	Mixed wetland hardwoods-willows	Natural
6172	13	Mixed wetland hardwoods-mixed shrubs	Natural
621	13	Cypress	Natural
6218	13	Cypress-melaleuca infested	Natural

FLUCCS Code	Land Use Category	FLUCCS Description	Land Use Category Description
6219	13	Cypress with wet prairies	Natural
622	13	Pond pine	Natural
623	13	Atlantic white cedar	Natural
624	13	Cypress-pine-cabbage palm	Natural
630	13	Wetland forested mixed	Natural
641	13	Freshwater marshes	Natural
6411	13	Freshwater marshes-sawgrass	Natural
6412	13	Freshwater marshes-cattail	Natural
642	13	Saltwater marshes	Natural
643	13	Wet prairies	Natural
6439	13	Wet prairies with pine	Natural
644	13	Emergent aquatic vegetation	Natural
645	13	Submergent aquatic vegetation	Natural
651	13	Tidal flats	Natural
652	13	Shorelines	Natural
653	13	Intermittent ponds	Natural
654	13	Oyster bars	Natural
710	13	Beaches other than swimming beaches	Natural
720	13	Sand other than beaches	Natural
730	13	Exposed rock	Natural
731	13	Exposed rock with marsh grasses	Natural
741	12	Rural land in transition	Recreational/open range
742	12	Borrow areas	Recreational/open range
743	12	Spoil areas	Recreational/open range
744	12	Fill areas	Recreational/open range
745	13	Burned areas	Natural
811	6	Airports	Industrial
812	6	Railroads	Industrial
813	6	Bus and truck terminals	Industrial
814	2	Roads and highways	Medium density residential
815	6	Port facilities	Industrial
816	4	Canals and locks	Low intensity commercial
817	6	Oil, water, or gas transmission line	Industrial
818	2	Auto parking facilities	Medium density residential
819	6	Transportation facilities under construction	Industrial
821	4	Transmission towers	Low intensity commercial
822	4	Communication facilities	Low intensity commercial
829	4	Communication facilities under construction	Low intensity commercial
831	6	Electrical power facilities	Industrial
832	4	Electrical power transmission lines	Low intensity commercial
833	6	Water supply plants	Industrial
834	6	Sewage treatment	Industrial
835	6	Solid waste disposal	Industrial
839	6	Utilities under construction	Industrial

APPENDIX D
DBHYDRO DATA USED IN RAINFALL ANALYSIS

DBKEY	Station	Alternate DBKEYs	Years Removed	Period of Record	Number of Years	Annual Average Rainfall
06399	ARCADIA_R	06849	1909-13 1915-19 1921-22 1994	1908-1997	77	
06205	ARCHBO 2_R	06094 06238	1932-40 1942 1944-45 1947 1993	1929-1997	55	48.1
06136	AVON PRK_R	05853 06095 05989	1909-14 1925 1933-34 1936 1944 1951 1967	1902-1997	84	52.2[a]
06207	BELLE GL_R	NA[b]	1928-29	1925-1997	71	54.6
05813	BROOKS P_R	NA	1981 1987 1988	1963-1995	30	48.9[a]
06155	HGS2_R (Clewiston)	06240 06219		1949-1994	46	47.4
05848	COW CREE_R	NA		1970-1996	28	45.6[a]
05953	DEVILS_R	06083		1956-1997	42	52.4
06161	EVERGL 2_R	06089		1940-1997	58	52.8
06141	FORT DRU_R	05866 05844		1956-1998	41	51.3[a]
06177	FORT LAU_R	NA	1937 1944-46 1950-51 1960 1962-63	1914-1997	75	62.6
06151	FORT PIE_R	06116	1905 1907 1909-13	1901-1997	90	52.2
06193	FT MEYER_R	06081		1940-1997	58	53.1
06124	HGS1_R (Moore)	05883 05879		1940-1998	59	47.6
06175	HIALEAH_R	NA	1942 1969 1971-74 1985	1941-1997	50	62
06211	HOMES.ES_R	NA	1922 1924-27 1929-30 1982 1987	1916-1988	64	61.4

a. Average; otherwise 1-in-2

b. NA = Not available

DBKEY	Station	Alternate DBKEYs	Years Removed	Period of Record	Number of Years	Annual Average Rainfall
06180	HYPOLUXO_R	06298	1909-13 1924 1928 1935 1938 1943	1900-1997	88	59.1
06195	IMMOKA 3_R	06082		1960-1997	38	49.7
05888	JUPITER_R	06216 06121	1909-20 1922 1927 1929-60 1974-76 1978 1980 1984-89	1900-1928 1961-1997	35	60.6
06162 06163	KEY WEST	NA	1909-13 1947 1959 1963	1902-1997	88	37.6
06146 06147	KISS_R	06234 05859 06021	1909 1919-21 1924-29	1901-1997	83	48.6
06150 06137	L PLACI2_R	06137	1950 1969-70 1975 1982	1933-1997	52	49.4[a]
06158	LA BELLE_R	05952		1940-1997	58	52.7
06181	LOXAHATC_R	05947		1941-1998	48	61.4
06401	MELBOURN_R	05894 06142 06097	1993	1938-1997	59	
06249	MIAMI CI_R	NA	1909-13 1962 1969-70 1975 1977-82	1902-1983	67	55.3
06134	MOUNTIN_R	06108 06135		1935-1997	63	50.1
06160	NAPLES_R	06090		1942-1997	56	51.6
06196 06152 06070 06020	OKEE F 2_R	06073	1924-29	1922-1997	69	47.4
06185	ORLAN AP_R	06214 06104		1900-1997	91	51.3
06179	POMPANOB_R	NA	1965 1971-73 1977 1983 1989 1994	1941-1997	49	58.8
06122	PRATT AN_R	NA		1957-1998	42	66.2[a]

a. Average; otherwise 1-in-2

b. NA = Not available

DBKEY	Station	Alternate DBKEYs	Years Removed	Period of Record	Number of Years	Annual Average Rainfall
06139	PUNTA G4_R	NA	1975 1981 1985	1968-1997	27	50.2
05846	S140 SPW_R	NA		1973-1996	24	43.8
06239	S308_R	06119		1940-1993	54	45.6[a]
05940	S65_R	05878 06200		1965-1997	33	51.2[a]
06237 06075 16416	S80_R	NA	1944-45 1947 1988	1941-1998	54	54.3
06187	STUART 1_R	NA	1995	1936-1997	61	55.5
06166	TAMITR40_R	NA	1952-53 1957 1970-71 1982-84 1995	1941-1997	48	53.3
06262	VERO 4W_R	06192		1965-1997	33	52.9[a]
06182	WPB AIRP_R	05947	1940 1993-94	1939-1997	56	59.9

a. Average; otherwise 1-in-2

b. NA = Not available

APPENDIX E
PATHOGENIC ORGANISM AND PESTICIDE RISK BY LAND USE

FLUCCS Code	Land Use Description	Pathogenic Organism Risk	Pesticide Risk
119	Low density under construction	Moderate	Moderate
121	Fixed single family units	Moderate	Moderate
123	Mixed units (fixed and mobile homes)	Moderate	Moderate
129	Medium density under construction	Moderate	Moderate
131	Fixed single family units	Moderate	Moderate
133	Multiple dwelling units-low rise	Moderate	Moderate
134	Multiple dwelling units-high rise	Moderate	Moderate
135	Mixed units (fixed and mobile homes)	Moderate	Moderate
139	High density under construction	Moderate	Moderate
141	Retail sales and services	Moderate	Moderate
1411	Shopping centers	Moderate	Moderate
142	Wholesale sales and services	Moderate	Moderate
1423	Junk yards	Low	Moderate
143	Professional services	Low	Moderate
144	Cultural and entertainment	Low	Moderate
145	Tourist services	Moderate	Moderate
146	Oil and gas storage	Low	Moderate
147	Mixed commercial and services	Moderate	Moderate
148	Cemeteries	Low	Moderate
149	Commercial and services under construction	Moderate	Moderate
151	Food processing	High	Moderate
152	Timber processing	Low	Moderate
153	Mineral processing	Low	Moderate
154	Oil and gas processing	Low	Moderate
155	Other light industrial	Low	Moderate
156	Other heavy industrial	Low	Moderate
159	Industrial under construction	Low	Moderate
161	Strip mines	Low	Low
162	Sand and gravel pits	Low	Low
163	Rock quarries	Low	Low
164	Oil and gas fields	Low	Low
165	Reclaimed land	Low	Low
166	Holding ponds	Low	Low
171	Education facilities	Low	Moderate
172	Religious	Low	Moderate
173	Military	Low	Moderate
174	Medical and health care	Moderate	Moderate
175	Governmental	Low	Moderate
176	Correctional	Low	Moderate
177	Other institutional	Low	Moderate
178	Commercial child care	Low	Moderate
179	Institutional under construction	Low	Moderate
181	Swimming beach	Low	Low
182	Golf courses	Low	High
183	Race tracks	Moderate	Low

FLUCCS Code	Land Use Description	Pathogenic Organism Risk	Pesticide Risk
184	Marinas and fish camps	Moderate	Low
185	Parks and zoos	High	Low
186	Community recreation facilities	Low	High
187	Stadiums	Low	Low
188	Historical sites	Low	Low
189	Other recreational	Low	Moderate
191	Undeveloped land within urban areas	Low	Low
192	Inactive land with street pattern	Low	Low
193	Urban land in transition	Low	Low
194	Other open land	Low	Low
211	Improved pastures	Moderate	High
212	Unimproved pastures	Moderate	High
213	Woodland pastures	Moderate	High
214	Row crops	Low	High
215	Field crops	Low	High
2156	Sugarcane	Low	High
221	Citrus groves	Low	High
222	Fruit orchards	Low	High
223	Other groves	Low	High
231	Cattle feeding operations	High	Moderate
232	Poultry feeding operations	High	Moderate
233	Swine feeding operations	High	Moderate
241	Tree farms	Low	High
242	Sod farms	Low	High
243	Ornamentals	Low	High
244	Vineyards	Low	High
245	Floriculture	Low	High
246	Timber nursery	Low	High
251	Horse farms	High	High
252	Dairies	High	High
253	Kennels	High	High
254	Aquaculture	High	High
259	Other	High	High
261	Fallow crop land	Low	Low
310	Herbaceous	Low	Low
321	Palmetto prairies	Low	Low
322	Coastal scrub	Low	Low
329	Other shrubs and brush	Low	Low
411	Pine flatwoods	Low	Low
4119	Pine flatwoods-melaleuca infested	Low	Low
412	Longleaf pine-xeric oak	Low	Low
413	Sand pine	Low	Low
414	Pine-mesic oak	Low	Low
419	Other pines	Low	Low
421	Xeric oak	Low	Low

FLUCCS Code	Land Use Description	Pathogenic Organism Risk	Pesticide Risk
422	Brazilian pepper	Low	Low
423	Oak-pine-hickory	Low	Low
424	Melaleuca	Low	Low
425	Temperate hardwood	Low	Low
426	Tropical hardwoods	Low	Low
427	Live oak	Low	Low
428	Cabbage palm	Low	Low
4289	Cabbage palm-melaleuca infested	Low	Low
429	Wax myrtle-willow	Low	Low
431	Beech-magnolia	Low	Low
432	Sand live oak	Low	Low
433	Western Everglades hardwoods	Low	Low
434	Hardwood conifer mixed	Low	Low
435	Dead trees	Low	Low
437	Australian pine	Low	Low
438	Mixed hardwoods	Low	Low
439	Other hardwoods	Low	Low
441	Coniferous plantations	Low	Low
442	Hardwood plantations	Low	Low
443	Forest regeneration areas	Low	Low
444	Experimental tree plots	Low	Low
445	Seed plantations	Low	Low
521	Lakes larger than 500 acres	Low	Low
522	Lakes larger than 100 acres and less than 500 acres	Low	Low
523	Lakes larger than 10 acres and less than 100 acres	Low	Low
524	Lakes less than 10 acres	Low	Low
531	Reservoirs larger than 500 acres	Low	Low
532	Reservoirs larger than 100 acres and less than 500 acres	Low	Low
533	Reservoirs larger than 10 acres and less than 100 acres	Low	Low
534	Reservoirs less than 10 acres	Low	Low
541	Embayments opening	Low	Low
542	Embayments not opening	Low	Low
550	Major springs	Low	Low
560	Slough waters	Low	Low
611	Bay swamps	Low	Low
612	Mangrove swamps	Low	Low
613	Gum swamps	Low	Low
614	Titi swamps	Low	Low
615	Stream and lake swamps	Low	Low
616	Inland ponds and sloughs	Low	Low
617	Mixed wetland hardwoods	Low	Low
6171	Mixed wetland hardwoods-willows	Low	Low
6172	Mixed wetland hardwoods-mixed shrubs	Low	Low
621	Cypress	Low	Low
6218	Cypress-melaleuca infested	Low	Low

FLUCCS Code	Land Use Description	Pathogenic Organism Risk	Pesticide Risk
6219	Cypress with wet prairies	Low	Low
622	Pond pine	Low	Low
623	Atlantic white cedar	Low	Low
624	Cypress-pine-cabbage palm	Low	Low
630	Wetland forested mixed	Low	Low
641	Freshwater marshes	Low	Low
6411	Freshwater marshes-sawgrass	Low	Low
6412	Freshwater marshes-cattail	Low	Low
642	Saltwater marshes	Low	Low
643	Wet prairies	Low	Low
6439	Wet prairies with pine	Low	Low
644	Emergent aquatic vegetation	Low	Low
645	Submergent aquatic vegetation	Low	Low
651	Tidal flats	Low	Low
652	Shorelines	Low	Low
653	Intermittent ponds	Low	Low
654	Oyster bars	Low	Low
710	Beaches other than swimming beaches	Low	Low
720	Sand other than beaches	Low	Low
730	Exposed rock	Low	Low
731	Exposed rock with marsh grasses	Low	Low
741	Rural land in transition	Low	Low
742	Borrow areas	Low	Low
743	Spoil areas	Low	Low
744	Fill areas	Low	Low
745	Burned areas	Low	Low
811	Airports	Low	Low
812	Railroads	Low	Low
813	Bus and truck terminals	Low	Low
814	Roads and highways	Low	Moderate
815	Port facilities	Low	Low
816	Canals and locks	Low	Low
817	Oil, water, or gas transmission line	Low	Low
818	Auto parking facilities	Low	Low
819	Transportation facilities under construction	Low	Low
821	Transmission towers	Low	Low
822	Communication facilities	Low	Low
829	Communication facilities under construction	Low	Low
831	Electrical power facilities	Low	Low
832	Electrical power transmission lines	Low	Low
833	Water supply plants	Low	Low
834	Sewage treatment	High	Low
835	Solid waste disposal	High	Low
839	Utilities under construction	Low	Low

APPENDIX F
POTENTIAL ANNUAL POLLUTION LOADING PROGRAM

```
/** Calculate pollutant runoff loads based on landuse, historic
/**   landuse, rainfall and soils hydrologic group.
/** Generally, follows methodology by Adamus and Bergman.  Uses 1972
/**   landuse as to determine areas without on-site treatment.  Pesti-
cides
/**   and pathogen analysis is based solely on landuse look up table.
/** Uses:
/**   Pre-permit landuse: lulc72
/**   Existing landuse: lulc95
/**   Soil hydric groups: ssurgo.hydgrp
/**   Rainfall: rainthie
/**   Landuse categories: lucat.dat (info file)
/**   Runoff coefficients: runcoef.dat (info file)
/**   Runoff concentrations: runconc.dat (info file)
/**   Treatment efficinecies: treateff.dat (info file)
/**   Pesticide and pathogen ratings: f_pestpath.dat (info file)
/**  ksaari 12/1/98 Initial coding
/**  ksaari 2/27/98 County independence
/**  ksaari 6/17/99 Add pesticides and pathogens
/**                 Performance enhancements

&args co
&if [null %co%] &then
  &return Usage: ANNLOAD <county>
&watch %co%/annload-%co%.wat
&call setup /** Set paths
&call preprocess  /** Preprocess 72 landuse and soils
&call process /** Intersection processing
&call postprocess /** Calculate runoff and loadings
&call cleanup /** Clean up and post
&watch &off
&return

&routine setup /** Use drive letters due to network troubles
  &s pcovs J:
  &s scovs N:
  &s data R:\di10\wetcons\kurt\annload
  &s pollist tn tp ss zn pb  /** List of pollutants to process
  w %co%
&return

&routine preprocess /** Preprocess ****************************
  /** Build county based lulc72
  &select [translate %co%]
    &when BR
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\miami
%scovs%\lulc\luda1972\wplm_bch
```

```
        end
      &end
    &when CH
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\char_har
%scovs%\lulc\luda1972\ft_pierc
%scovs%\lulc\luda1972\wplm_bch
        end
      &end
    &when CO
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\miami
%scovs%\lulc\luda1972\wplm_bch
        end
      &end
    &when DA
      copy %scovs%\lulc\luda1972\miami lulc72all
    &when GL
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\ft_pierc
%scovs%\lulc\luda1972\wplm_bch
        end
      &end
    &when HE
      copy %scovs%\lulc\luda1972\wplm_bch lulc72all
    &when HI
      copy %scovs%\lulc\luda1972\ft_pierc lulc72all
    &when LE
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\char_har
%scovs%\lulc\luda1972\wplm_bch
        end
      &end
    &when MA
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\ft_pierc
%scovs%\lulc\luda1972\wplm_bch
        end
      &end
    &when MO
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\ky_west
%scovs%\lulc\luda1972\miami
```

```
%scovs%\lulc\luda1972\wky_west
        end
      &end

    &when OK
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\ft_pierc
%scovs%\lulc\luda1972\wplm_bch
        end
      &end

    &when OR
      copy %scovs%\lulc\luda1972\orlando lulc72all

    &when OS
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\orlando
%scovs%\lulc\luda1972\ft_pierc
        end
      &end

    &when PB
      copy %scovs%\lulc\luda1972\wplm_bch lulc72all

    &when PO
      &do
        mapjoin lulc72all
%scovs%\lulc\luda1972\ft_pierc
%scovs%\lulc\luda1972\orlando
        end
      &end

    &when SL
      copy %scovs%\lulc\luda1972\ft_pierc lulc72all

  &end /** End select county code

  clip lulc72all %pcovs%\boundary\counties\%co%-bnd lulc72

  /** Existing landuse
  copy %pcovs%/landuse/lu1995/%co%-lu95 lulc95
  /*Xcopy %pcovs%/landuse/lu1995/md-lu95 lulc95
  joinitem lulc95.pat ../f_pestpath.dat lulc95.pat flucs_lev3

  /** Soils
  copy %pcovs%/soils/ssurgo/data/%co%-ssur soils
  joinitem soils.pat ../ssurgo.hydgrp soils.pat muid
```

```
  pullitems soils.pat soils.pat
    area
    perimeter
    soils#
    soils-id
    drained
    undrained
  end

  /** Rainfall
  copy ../rainthie rainthie
&return /** End of preprocess *********************************

&routine process
  /** find preexisting development.  no treatment on-site
  /**lulc72 contains usgs 1972 landuse
  dissolve lulc72 lu72code1 lu1-code poly

  /** lulc95 contains 1995 sfwmd landuse
  intersect lulc95 lu72code1 lu9572 poly

  additem lu9572.pat lu9572.pat treatment 2 2 i

 /** calc treatment if 72 not developed and 95 developed
  arcedit
    edit lu9572
    editf label
    sel all
    calc treatment = -1
    sel lu1-code = 2
    resel flucs_lev1 in {'100' '800'}
    &if [show number selected] > 0 &then
      calc treatment = 1 /** for ag in 72 and "developed" in 95
    sel lu1-code in {3 4 6 7}
    resel flucs_lev1 in {'100' '200' '800'}
    &if [show number selected] > 0 &then
     calc treatment = 1 /** for natural in 72 and "developed" (including
ag) in 95
    save
  quit

  dropitem lu9572.pat lu9572.pat lu1-code

  /** lucatall.dat stores cross-reference table for flucs_lev3 and lu
categories
  joinitem lu9572.pat ../lucatall.dat lu9572.pat flucs_lev3 flucs_lev3
  dropitem lu9572.pat lu9572.pat
    flucs_lev1
    flucs_lev2
```

```
  flucs_lev3
  lucatname
  flucs_desc
end

dissolve lu9572 lucattreat #all poly

dissolve soils hydgrp #ALL poly

/** combine soils with landuse data (inlcuding treatment)
intersect lucattreat hydgrp lucattreats poly

dissolve rainthie rainfall avg_ann poly
intersect rainfall lucattreats allcovs poly
additem allcovs.pat allcovs.pat hydgrp 3 3 c
  ae
    editc allcovs
    editf label
    sel undrained = ' '
    &if [show number selected] > 0 &then
      calc undrained = 'X'
    sel lucat ge 12
    resel undrained ne 'X'
    &if [show number selected] > 0 &then
      calc hydgrp = undrained
    nsel
    &if [show number selected] > 0 &then
      calc hydgrp = drained
    save
  quit
/** need to reorder items to put lucat next to hydgrp for redefine
pullitems allcovs.pat allcovs.pat
  area
  perimeter
  allcovs#
  allcovs-id
  lucat
  hydgrp
  treatment
  avg_ann
  pestrate
  pathrate
end
   /** create landuse hydgroup (luhg) with redefine
    &data arc info
      ARC
      SEL ALLCOVS.PAT
      REDEFINE
      25
```

```
        LUHG
        5
        5
        C
        [unquote '']
      Q STOP
    &end
  joinitem allcovs.pat ../runcoef.dat allcovs.pat luhg
  joinitem allcovs.pat ../runconc.dat allcovs.pat lucat
  joinitem allcovs.pat ../treateff.dat allcovs.pat treatment
  dissolve allcovs annload #ALL
  additem annload.pat annload.pat runoff 4 12 f 3
  &do cnt &list tn tp ss zn pb
    additem annload.pat annload.pat %cnt%load 4 12 f 3
  &end
&return

&routine postprocess
  arcedit
    edit annload
    editf label
    /** calculate runoff
    sel all
    sel hydgrp ne 'X'
    &if [show number selected] > 0 &then
      calc runoff = avg_ann * 0.0254 * coef
    /** -9 for no soil data records
    sel hydgrp = 'X'
    &if [show number selected] > 0 &then
      calc RUNOFF = -9
    sel all
    sel runoff ne -9
    resel tneff ne 0
    /** load = (avg_ann * 0.0254) * runoff coef * concentration * removal
effieciency
    /** * 1000 (to convert to mg/m2
    /** With treatment
    &if [show number selected] > 0 &then
      &do
        &do cnt &list tn tp ss zn pb
          calc %cnt%load = runoff * %cnt%  * ( 1 - %cnt%eff ) * 1000
        &end
      &end
    /** Without treatment
    sel runoff ne -9
    resel tneff = 0
    &if [show number selected] > 0 &then
      &do
        &do cnt &list tn tp ss zn pb
```

```
          calc %cnt%load = runoff * %cnt% * 1000
        &end
    /** -9 for no soil data records
    sel hydgrp = 'X'
    &if [show number selected] > 0 &then
      &do
        &do cnt &list tn tp ss zn pb
          calc %cnt%load = -9
        &end
      &end
    save
  quit
&return /** End of postprocess

&routine cleanup
  &if [exists %data%\%co%-annld -cover] &then
    kill %data%\%co%-annld all
  copy annload %data%\%co%-annld
  &if [exists %data%\%co%-annld -cover] &then
    &do
      &do cov &list allcovs lu72code1 lu9572 lucattreat lucattreats ~
                   lulc72all rainfall hydgrp lulc72 lulc95 rainthie soils
        kill %cov%
      &end
    &end
  w ..
&return /** End cleanup
```

APPENDIX G
WETLAND POLLUTION RISK PROGRAM

```
/** d:\data\di10\risksum\anal\risksum.aml
_/** Calculate risk to wetlands
_/** Summarize risk to wetlands within 1000' buffer around each NWI
_/**   wetland.  Uses nwi coverage preprocessed for inherent
/**   characteristics and annual loading coverage from annload
/**   coverages.
/** kurt 8/10/99 initial coding
/** inputs:
/**   annload
/**   nwi
/** outputs:
/**   %co%-risk.dat (use nwinum to link to wetlands)

&args co
&echo &on
&watch %co%-risk.wat
&if [null %co%] &then
  &return Usage: RISKSUM <county_abbrev>
copy d:\data\di10\inherent\anal\%co%/nwi nwi
/** Few pest and path rates missing from look up table
/**   happen to all be low, saves reprocessing loads
ae
  editc d:\data\di10/annload\anal\%co%\annload
  editf label
  sel pestrate = ''
  &if [show number selected] > 0 &then
    calc pestrate = 'L'
  sel pathrate = ''
  &if [show number selected] > 0 &then
    calc pathrate = 'L'
  save
q
copy d:\data\di10/annload\anal\%co%\annload annload

/** Path and pest rates are character, reset to numeric
additem annload.pat annload.pat peload 3 3 i
additem annload.pat annload.pat paload 3 3 i
ae
  editc annload
  editf label
  sel pestrate = 'L'
  &if [show number selected] > 0 &then
    calc peload = 1
  sel pestrate = 'M'
  &if [show number selected] > 0 &then
    calc peload = 2
  sel pestrate = 'H'
  &if [show number selected] > 0 &then
    calc peload = 3
```

```
  sel pathrate = 'L'
  &if [show number selected] > 0 &then
    calc paload = 1
  sel pathrate = 'M'
  &if [show number selected] > 0 &then
    calc paload = 2
  sel pathrate = 'H'
  &if [show number selected] > 0 &then
    calc paload = 3
  save
quit

ap
  reselect nwi poly sys ne 'U'
  writesel nwi.sel
q
/** Build buffers as regions for wetlands, uplands only
regionbuffer nwi reg reg # # 1000 # poly # # nwi.sel # nwinum
&data ARC INFO
  ARC
  SEL REG.PATREG
  ALTER NWINUM,NWINUM-REG,,,,,,,,
  Q STOP
&end

/** Need to be able to remove actual wetland from buffer
/**   in processing
intersect reg nwi regnwi

/** Combine nwi buffers and loading
intersect regnwi annload all poly
regionquery all risk risk # # nwinum reg.nwinum-reg ~
    tnload tpload ssload znload pbload peload paload
  res nwinum ne 0
  [unquote '']
  n
  n
pullitems nwi.pat nwiarea.dat nwinum
ap
  /** reselect out nwi poly from buffer and sum area in buffer
  reselect risk.patrisk info nwinum ne nwinum-reg
  statistics risk.patrisk info nwinum-reg bufarea.dat
    sum area
    end
  /** reselect valicd data only, removes missing data
  reselect risk.patrisk info tnload ge 0
  statistics risk.patrisk info nwinum-reg vdarea.dat
    sum area
    end
```

```
 q
/** Set names to match for joins, could redefine
&data ARC INFO
  ARC
  SEL BUFAREA.DAT
  ALTER SUM-AREA,BUF-AREA,,,,,,,,
  ALTER NWINUM-REG,NWINUM,,,,,,,,
  SEL VDAREA.DAT
  ALTER SUM-AREA,VD-AREA,,,,,,,,
  ALTER NWINUM-REG,NWINUM,,,,,,,,
  Q STOP
&end

/** Join data to nwi table
joinitem nwiarea.dat bufarea.dat nwiarea.dat nwinum
joinitem nwiarea.dat vdarea.dat nwiarea.dat nwinum

/** Calculate percent of valid data
additem nwiarea.dat nwiarea.dat vd-pcnt 4 12 f 3
ap
  reselect nwiarea.dat info buf-area gt 0
  calculate nwiarea.dat info vd-pcnt = vd-area / buf-area
q

/** Reset names
&data ARC INFO
  ARC
  SEL NWIAREA.DAT
  ALTER NWINUM,NWINUM-REG,,,,,,,,
  Q STOP
&end
joinitem risk.patrisk nwiarea.dat risk.patrisk nwinum-reg
/** Again set names
&data ARC INFO
  ARC
  SEL NWIAREA.DAT
  ALTER NWINUM-REG,NWINUM,,,,,,,,
  Q STOP
&end

/** Must have at least 80% data
/** Don't evaluate wetland itself, only buffer
/** Calculate mean loading
ap
  reselect risk.patrisk info vd-pcnt ge 0.80
  reselect risk.patrisk info nwinum <> nwinum-reg
  statistics risk.patrisk info nwinum-reg risk.dat
    mean tnload area
    mean tpload area
```

```
    mean ssload area
    mean znload area
    mean pbload area
    mean peload area
    mean paload area
    sum area
    end

/** Normalize all numeric ratings by area (not pest or path)
  arc additem risk.dat risk.dat tn_nwirisk 4 12 f 3
  arc additem risk.dat risk.dat tp_nwirisk 4 12 f 3
  arc additem risk.dat risk.dat ss_nwirisk 4 12 f 3
  arc additem risk.dat risk.dat zn_nwirisk 4 12 f 3
  arc additem risk.dat risk.dat pb_nwirisk 4 12 f 3
  arc additem risk.dat risk.dat pe_nwirisk 4 12 f 3
  arc additem risk.dat risk.dat pa_nwirisk 4 12 f 3

  calculate risk.dat info tn_nwirisk = mean-w-tnload * 0.0929
  calculate risk.dat info tp_nwirisk = mean-w-tpload * 0.0929
  calculate risk.dat info ss_nwirisk = mean-w-ssload * 0.0929
  calculate risk.dat info zn_nwirisk = mean-w-znload * 0.0929
  calculate risk.dat info pb_nwirisk = mean-w-pbload * 0.0929
  calculate risk.dat info pe_nwirisk = mean-w-peload
  calculate risk.dat info pa_nwirisk = mean-w-paload

q
/** Back to set names for join
&data ARC INFO
  ARC
  SEL RISK.DAT
  ALTER NWINUM-REG,NWINUM,,,,,,,,
  Q STOP
&end

joinitem nwiarea.dat risk.dat nwiarea.dat nwinum
/** Must have 80% valid data
ap
  reselect nwiarea.dat info vd-pcnt < 0.80
  calculate nwiarea.dat info tn_nwirisk = -9
  calculate nwiarea.dat info tp_nwirisk = -9
  calculate nwiarea.dat info ss_nwirisk = -9
  calculate nwiarea.dat info zn_nwirisk = -9
  calculate nwiarea.dat info pb_nwirisk = -9
q
/** Rename
copyinfo nwiarea.dat %co%-risk.dat
/** Clean unnecessary items
dropitem %co%-risk.dat %co%-risk.dat frequency buf-area vd-area ~
  vd-pcnt mean-w-tnload mean-w-tpload mean-w-ssload mean-w-znload ~
```

```
  mean-w-pbload mean-w-peload mean-w-paload sum-area
/** Post to server
copyinfo %co%-risk.dat r:\di10\wetcons\kurt\risksum\%co%-risk.dat

/** Clean workspace
kill all all
kill annload all
kill nwi all
kill reg all
kill regnwi all
kill risk all
&type [delete vdarea.dat -info]
&type [delete bufarea.dat -info]

&watch &off
&return
```