EVALUATING PC-BASED WATER QUALITY MODELS AS TOOLS FOR LAND USE PLANNING

by

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ABSTRACT

This thesis identifies PC-based water quality models that address nonpoint source pollution (NPS) concerns and determines which of these tools, if any, improve the ability of planners to make land use decisions consistent with water quality objectives. More specifically, this thesis addresses three questions: (1) Under what circumstances are water quality models useful for making land use decisions? (2) Are current PC-based water quality models useful for making land use decisions, and, if so, how? (3) What is the future of water quality model use in land use planning?

A literature search served as a foundation to identify materials and models explicitly addressing the relationship between NPS water quality concerns and land use planning. Environmental quality, environmental assessment, and planning issues relevant to water quality modeling were analyzed, and specific NPS water quality models were identified and analyzed. This information was used to develop a checklist of important model characteristics, including the descriptive and subjective characteristics which were applied to the selected models.

As planners use a variety of intuitive and analytical tools to help communities manage development, they play an important role in environmental protection. With proper application, several currently available PC-based water quality models could be used to enhance planners' abilities to forecast and monitor the effects of land use changes on water quality.

Generalizing about a model's usefulness is complicated; for every planning action, the set of needs and resources available to address water quality issues differs. However, the models reviewed in this thesis demonstrate the potential for integrating PC-based NPS water quality models with land use planning, and can help estimate contamination generated from urban, non-urban, and mixed land use/load sources.

Thesis Supervisor: Philip B. Herr, Professor, City Planning

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TABLE OF CONTENTS

CHAPTER 5

CHAPTER 6

LIST OF FIGURES AND TABLES

FIGURES

TABLES

CHAPTER 1

INTRODUCTION

Environmental concerns have moved to the forefront of public consciousness. As the effects of past actions on the water, air, and land become more apparent, citizens and the government have begun to clean up the past and plan for the future. As planners more frequently address environmental concerns, they will need more technical planning tools. This thesis focuses on evaluating personal computer-based (PC-based) modeling tools used to address nonpoint source (NPS) water quality concerns.

The environmental movement generally has focused on national issues and national problems. Yet in many cases, local environmental problems affect the daily lives of citizens more than do national concerns. Examples range from the acutely obvious (contaminated drinking water supplies or inability to dispose of solid waste) to the less obvious (topsoil runoff or destruction of species' habitats).

Traditionally, environmental protection has been guided by the U.S. Environmental Protection Agency (USEPA); state departments of environmental protection; and state, county, and local public health agencies. However, as planners help communities manage development, they too play an important role in environmental protection by influencing the extent to which land use planning remains consistent with water quality objectives.

Planners currently use a variety of intuitive and analytical tools to perform their duties. PCs have increased the number of analytical tools available to planners. PC-based models provide one option for addressing water quality concerns. However, it is unlikely that planners will ever wholly rely upon PC-based water quality models for two reasons. First, models tend to be too technical and research-oriented for the more policy-driven needs of planners. Second, water quality models are not appropriate for addressing all water quality concerns. Other tools such as rough calculations, mapping, or rules of thumb may be more appropriate. Nonetheless, with proper application, several currently available PC-based water quality models could be used to enhance planners' abilities to forecast and monitor the effects of land use changes on water quality.

The over-arching research question of this thesis is: are current PC-based NPS water quality models useful for planners making land use decisions? Evaluating a model's usefulness is complicated, because for every planning action, the set of needs and resources available to address water quality issues differs. The following set of questions can help planners decide whether to use standard computer models (as opposed to simple calculations or ad hoc models) in their assessment of a planning action. First, could the planning action have water quality impacts? Second, does the planning action require at least a screening analysis of land use change impacts on water quality? Third, is a standard computer model appropriate, or are site visits or simple calculations adequate for decision making? Fourth, is there an existing or foreseeable computer modeling procedure that will answer the planner's questions? Fifth, is utilizing the model within the planner's resources, expertise, and time constraints? Sixth, if feasible, is the model practical for a particular planning action?

In a 1976 report evaluating models for water quality and water resources planners and managers, Grimsrud, Finnemore, and Owen summarized the need to view water quality models as part of a larger framework. They suggested:

> Water quality models are tools for accomplishing one portion of the planning process. Their effective use demands more than the technical expertise to select, prepare, execute and interpret the results of whatever model may be used. It is imperative that the use of such analytical tools and the analyses performed be properly and thoroughly integrated with the numerous other portions of the planning process. Adequate integration of activities does not occur automatically (Grimsrud, Finnemore, and Owen, p. 105).

Models are one of many tools available to planners looking at the relationship between land use decision making and water quality concerns. This thesis, however, only addresses the applicability of PC-based models to planners. This focus is not a carte blanche endorsement of model use.

In fact, models must be selected, run, and utilized very carefully. The phrase "easy to use, easy to abuse" is said repeatedly about water quality models and should be taken seriously.

A. RESEARCH OBJECTIVE

This thesis will identify PC-based water quality models addressing NPS pollution concerns and determine which of these tools, if any, improve the ability of planners to make land use decisions consistent with water quality objectives.

More specifically, three questions will be addressed:

1. Under what circumstances are water quality models useful for making land use decisions?
2. Are current PC-based water quality models useful for making land use decisions, and, if so, how?
    - What PC-based water quality models can be identified through a literature search?
    - What are the characteristics of these models?
    - Could and should these models be used by planners?
    - What needs do planners have that can (or cannot) be met with the identified water quality models?
3. What is the future of water quality model use in land use planning?

B. RESEARCH DESIGN

A literature search served as a foundation to identify materials and models explicitly addressing the relationship between NPS water quality concerns and land use planning. The information gathered from the literature search helped shape the descriptive and subjective criteria and characteristics used in evaluating the models. Models selected for review were applied to the descriptive and subjective framework.

C. EXPECTED SIGNIFICANCE OF RESEARCH

Traditionally, water quality research and modeling has been done by and for scientists, engineers, and other individuals trained in math and water quality theory. However, with the advent of PC-based model and geographic information system (GIS) applications, individuals not formally trained in math and water quality theory use models with greater frequency. The primary audience of this thesis is "potential" model users who are not technically-trained. This group likely includes many planners and policy makers.[1]

For planners interested in water quality models, this thesis describes the relevance of PC-based models. This analysis includes an evaluation of how, when, where, and which models should be used. The models reviewed in this thesis provide examples of potential uses and explore

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[1] "Planners" will be used generically to describe this group of non-technically trained individuals. Although some planners may have extensive technical training, many planners interested in water quality have no formal training in this area.

appropriate and effective applications.

For scientists, engineers, and other technically-trained individuals developing models, this thesis examines how water quality models apply to planning actions. Most of the models reviewed in this thesis were created by scientists and engineers for use by scientists and engineers. This thesis presents planners as an additional and important user group for water quality models. Scientists and engineers concerned with the proactive use of their work may want to use this thesis to re-evaluate the applicability of their models to the needs of planners.

For policy makers, this thesis highlights suggested uses and applications of models by planners. Knowledge of how planners use models may help policy makers to set enforceable policies and guidelines, such as compliance standards. Such knowledge may also help policy makers understand the need to fund additional work in this area.

D. OVERVIEW

In this thesis, much of the descriptive information on scientific processes and modeling components has been synthesized from other NPS water quality model and literature reviews. Unlike other model surveys and reviews, this thesis focuses on the planner. As a planner-to-be, conducting research on water quality was initially intimidating. The work of a few scientists and engineers framed the issues relevant to water quality modeling in a way that seemed applicable to planning.[2]

Chapter 2 provides background and definitions for much of the thesis. The topics reviewed include environmental quality, environmental assessment, and planning. Chapter 3 explores different environmental assessment methods, with an emphasis on forecasting methods, and establishes criteria for important modeling characteristics. Chapter 4 provides an overview of water quality and water quality modeling theories. Chapter 5 explains the model identification and selection processes and outlines model characteristics. Chapter 6 reviews and analyzes the identified models. Chapter 7 explores the future of computer use in land use/water quality planning and explores legislative alternatives. Finally, Chapter 8 offers conclusions and recommendations about the role of PC-based water quality models and their applicability to land use planning.

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[2] The writings of these authors--primarily Robert B. Ambrose, Jr.; Thomas O. Barnwell, Jr.; Anthony S. Donigian, Jr.; James P. Heaney; Wayne C. Huber; Daniel P. Loucks; Leonard Ortolano; and William W. Walker, Jr.--helped frame the research questions, theoretical basis, and model reviews for this thesis.

CHAPTER 2

REVIEW OF CONTEMPORARY PERSPECTIVES ON WATER QUALITY AND LAND USE ISSUES

A. ENVIRONMENTAL QUALITY ISSUES

Extensive research and writings address the scientific, policy, and planning aspects of environmental quality issues. This thesis, however, focuses only on the relationship between water quality and land use. This chapter reviews general water quality issues, environmental assessment, and planning procedures as they relate to water quality and land use.

A.1 Relationship Between Water Quality and Land Use

Everyday activities testify to the importance of water quality for life-sustaining purposes as well as industrial, transportation, recreation, religious, and aesthetic reasons. Although it is possible to write extensively about the importance of water quality, the focus of this research is on the problems jeopardizing water quality and the potential solutions available to planners.

Water quality is a relative definition at best; different water uses require different quality standards (Dzurik, p. 163). However, water quality can be broadly defined to mean "those characteristics that are distinctive to a particular supply or body of water in relation to some use such as drinking, manufacturing, agriculture, recreation, or propagation of fish and wildlife" (Dzurik, p. 163).

Natural physical, chemical, and biological processes directly affect water quality, and also react with sources of water pollution. Water pollution is typically categorized as either point source or NPS pollution. Point source pollution is that pollution discharged from a single locus into a water body (e.g., industrial discharges from a pipe into a water body or a leaking underground storage tank leaching into groundwater). In contrast, NPS pollution comes from relatively diffuse sources.

Sources of NPS pollution are broader than those of point source pollution, and are more difficult to identify and characterize. Surface NPS pollution is primarily transported by rainfall and snowmelt; underground NPS pollution typically travels with groundwater. The most common sources of NPS pollution typically are agriculture, silviculture, mining, construction/urban runoff, and other sources (e.g., on-site septic systems, landfills, and hazardous waste sites) (Hansen, Babcock, and Clark, pp. 19-23).

NPS pollution threatens both surface and groundwater quality. Several land usage factors influence the extent to which NPS pollution impacts water quality: type of land use, proximity of land use to water body, amount and duration of precipitation, and other natural features (e.g., soil types, terrain) (Huber and Heaney, pp. 125-126; Hansen, Babcock, and Clark, p. 19). NPS contaminants threatening surface water and groundwater and their respective land uses are identified in Table 2.1. Table 2.2 indicates the effects and descriptions of principal water pollutants and water quality indicators.[3]

Significant reasons for environmental degradation in natural and developed areas include the common practice of addressing land, water, and air resources independently and the difficulty of intergovernmental coordination (Viessman, p. 321). Federal programs currently control most water quality and water resource programs, and local governments typically issue land use regulations (Dzurik, p. 180). The stronger the relationship between land use planning and water quality, the greater the need to formally coordinate problem solving between federal, state, and local governments (Viessman, p. 323).

The Land Management Project (LMP), a non-regulatory Rhode Island organization assisting Rhode Island communities evaluate the impacts of land use on water quality, aptly summarizes some of the conflicts between maintaining water quality and land use:

> Nonpoint source pollution is inseparably related to the use of land. **Sprawling, poorly planned development** generates more road surface (with its associated

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[3] For more information on NPS pollution impacts and their relationship to planning issues, see Hansen, Babcock, and Clark (1988); Jaffe and DiNovo (1987), and Schueler (1987).

TABLE 2.1

Land Use and Potential Contaminants

This matrix identifies what contaminants may be associated with certain land uses. Not all land uses have necessarily resulted in demonstrated contamination problems from all pollutants listed. Sources of information are listed below.

Key: ▒ = threat to surface water ▦ = threat to groundwater ■ = threat to surface and groundwater

	Acids	Bases	Chlorides	Iron/Manganese	Metals	Nitrogen	Oxygen demand	Pathogens	Pesticides	Petroleum products	Phenols	Phosphorus	Sediment	Sodium	Solvents	Surfactants/det.	Thermal polln.	Key Pollutants
Agriculture - cropland						■			■			■	▒					Nitr, phos, pest, sed
Ag.- pasture/hay land						■	▒	▒				■	▒					Nitr, phos, pest
Ag.- feedlots, manure pits						■	▒	■				■	▒	▒				Nitr, phos, ox, path
Airports			■		■	▒		▒	■	■		▒	▒	■			▒	Petr, solv
Aquaculture						▒	▒					▒						Nitr, phos
Asphalt plants, storage										■								Petr
Auto: car washes			■		■					■				■	■	■		Surfac, petr
Auto salvage	▦			■	■					■					▦	■		Metals
Auto service shops					■					■					▦	■		Solv, petr
Beauty parlors		▦			▦										▦	▦		Surfac
Boat use & maintenance					▒	▒	▒	▒		▒		▒					■	Path, petr
Boat yards/builders					■					■	■				▦			Petr, solv
Cemeteries						■			■			■						Nitr, phos
Chemical mfrs.	■	■	■	■	■	■			■	■	■			■	▦	■		Various
Combined sewer lines			■	■	■	■	▒	■		▒		■	▒	■	▦	■	▒	Nitr,phos,path,&other
Construction										▒			▒				▒	Sed
Dry cleaners															▦			Solv
Furniture stripping	■	■			■										▦			Solv
Golf courses						■			■			▒	▒				▒	Nitr, phos
Hazardous mat. stor/trans.	■	■	■	■	■	■		■	■	■	■	■		■	■	■		Any haz. material
Household haz. wastes					■				■	■					▦			Solv, surf, petr
Household lawn/garden						■			■			■						Nitr, phos, pest
Hydrologic modifications						▒	▒					▒	▒				▒	Sed, therm
Infiltration wells/basins			▦			▦				▦		▦		▦				Petr, sod, chlor
Jewelry, metal plating	■	■		■	■					■				■	▦	■		Metals, acids, bases
Landfills, dumping grounds	■	■	■	■	■	■	■	■	■	■	■	■	▒	■	■		▒	Any
Laundromats								■							▦	■		Surf, path, solv
Machine & metal shops	■	■			■					■					▦	■		Metals,acid,base,solv
Manufacturing: misc.	■	■	■	■	■	■	▒	■	■	■	■	■	▒	■	▦	■	▒	Various
Printing, photography	▦	▦			■										▦	■		Metals,acid,base,solv
Research labs, hospitals	▦	▦		■	■	■		■	■	■	▦	■			▦	■		Various
Road de-icing			■										▒	■				Sodium, chlor, sed
Road maint. depots			■						■	■				■	▦			Sodium, chlor, petr
Road runoff			■		■	▒	▒	■		■		▒	▒	■	▦		▒	Sod,chl,petr,met,ther
Road/bridge construction			■		▒				▒	■			▒	■			■	Sed, petr
Sand & gravel operations										■			▒		▦		▒	Sed
Septic systems (ISDS)			▦	▦	▦	■		■	▦			■		▦	▦	▦		Nitr, phos, path
Sewer lines & plants			▦	▦	▦	■	▒	■				■		▦	▦	▦		Nitr,phos,path,&other
Silviculuture							▒		▒				▒				▒	Sed
Sludge disposal sites	▒	▒	■	■	■	■	▒	■	■	▒		■	▒	■	▦	■		Various
Stormwater drains/lines			■		■	▒	▒	■	▦	■		▒	▒	■	▦			Sod,chl,petr,met,ther
Underground storage tanks					▦				▦	▦					▦			Petr
Urban runoff			■		▦	■	▒	▒	■	▦		■	▒	■			▒	Petr, metals, others
Waste lagoons, pits	■	■	■	■	■	■	▒	■	■	■	■		▒	■	▦	■	■	Various
Wood preserving					■					■	■				▦	▦		Phenols, metals

Source: The Land Management Project (Undated B).

TABLE 2.2

Principal Water Pollutants and Water Quality Indicators

a. Water Pollutants

POLLUTANT	SOURCE	EFFECT
Phosphorus (P)	Fertilizer, treated[a] and untreated sewage, detergents	Occurs predominantly as phosphate (PO_4) and serves as a plant nutrient which can lead to eutrophication (a process of overfertilization and overproduction of water plants) which, in turn, can produce algal blooms and other nuisance conditions.
Nitrogen (N)	Fertilizer, treated[a] and untreated sewage, the atmosphere	As dissolved nitrogen (N_2)—and like many dissolved gases at high concentrations—it is toxic to fish. As ammonia (NH_3), it interferes with drinking water chlorination. As nitrite (NO_2) and nitrate (NO_3), it is a plant nutrient and thus can lead to eutrophication. As NO_3 it can be toxic to humans, especially infants, causing methemoglobinemia.
Suspended solids (SS)	Soil, street debris, sewage	Can reduce sunlight penetration and clog animal and plant surfaces thus reducing biological activity; high levels will also cause water bodies to have a brown or muddy appearance.
Heat[b]	Nuclear generators, industrial plants	Can be toxic to fish at high levels while at lower levels, it can increase their susceptibility to disease and stress. Decreases dissolved oxygen (see Table 2-1-b).
Bacteria	Sewage, effluents with high BOD content can induce bacterial multiplication (see below)	Some forms are disease-causing in man; many cause reduction in dissolved oxygen levels through biological degradation of waste (see Table 2-1-b).
Other (e.g., metals, chlorinated compounds, exotic materials)	Industrial effluent, sewage additives from treatment plants, stormwater runoff from agricultural lands, etc.	Some are cancer-causing or otherwise toxic to man. Polychlorinated biphenyls are generally toxic to animals, especially fish and waterfoul.

b. Water Quality Indicators (In addition to pollutant levels)

INDICATOR	DESCRIPTION/COMMENTS
Biological oxygen demand (BOD)	BOD is a descriptor of effluent content. It is the amount of oxygen required to completely oxidize a quantity of organic matter by biological processes.[c] If the organic matter is being discharged into a body of water, then this is the amount of dissolved oxygen which will be depleted from the stream.
Dissolved oxygen (DO)	Water bodies with high DO levels will have abundant plant and animal life (assuming that other necessary conditions exist). Low DO levels are often the result of the discharge of effluents with high BOD levels.[d]
Turbidity	This is a measure of suspended solids (SS) concentration. High levels indicate high concentrations of SS and, thus, low light penetration.
pH	This is a measure of acidity. High quality water can display a range of values depending on natural conditions. However, very acidic or very alkaline water will not support much life.

[a] Treated at the primary or secondary level.

[b] This is obviously a physical state of water rather than a pollutant. However, heat can be considered a pollutant in terms of its production and effects.

[c] BOD is usually expressed as BOD_5 or the amount of oxygen consumed by the decomposition of the organic matter during a five-day period. However, laboratory methods are now available to measure total oxygen demand (TOD) or ultimate BOD without having to wait long periods of time for bacterial decomposition to take place.

[d] Sewage treatment plants using ozone (O_3) as a disinfective sometimes supersaturate the receiving water with DO; this can lead to fish kills.

Source: Keyes (1976), p. 53.

> polluted runoff), creates more fertilized lawn area, requires more de-icing, and causes significant changes in natural flood storage capacity. Sprawl consumes land and frequently compromises the functioning of natural resource systems, intruding on wetlands, groundwater recharge areas, and other sensitive interconnected habitats. This type of development can quickly rob a community of its historical and cultural character--its "sense of place," while imposing significantly higher costs on taxpayers for road maintenance, utilities, mass transit, and other public services (Land Management Project, Undated A, p. 1).

The interrelationships between water quality and land use is recognized at all levels of government. However, the extent to which NPS pollution is addressed varies.

A.2 Environmental Legislation for Water Quality

Federal, state, and local legislation addresses water resources, water quality in particular. Federal water legislation has encompassed two different water resource objectives. Early legislation, such as the Rivers and Harbors Act of 1899, protected water as a commercial and economic resource. Subsequent legislation, such as the Clean Water Act of 1977, addressed water quality (Dzurik, p. 52). Table 2.3 from Dzurik (1990) highlights selected federal water legislation.

Since states manage the federal water programs, state agencies and water legislation typically reflect the policies of federal legislation (Dzurik, pp. 68-69). Examples from Dzurik demonstrate the range of state activity in water resource planning:

TABLE 2.3

Selected Federal Water Legislation: 1899-1987

Year	*Legislation*
1899	Rivers and Harbors Act
1902	Reclamation Act
1914	Reclamation Extension Act
1920	Federal Water Power Act
1948	Federal Water Pollution Control Act
1965	Water Resources Planning Act
1968	Wild and Scenic Rivers Act
1968	National Flood Insurance Act
1969	National Environmental Policy Act
1972	Federal Water Pollution Control Act Amendments
1973	Endangered Species Act
1974	Safe Drinking Water Act
1976	Resources Conservation and Recovery Act
1976	Toxic Substances Control Act
1977	Clean Water Act
1980	Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
1982	Reclamation Reform Act
1984	Resources Conservation and Recovery Act Amendments
1986	Superfund Amendment and Reauthorization Act
1986	Water Resources Act
1986	Federal Safe Drinking Water Amendments
1987	Water Quality Act

Source: Dzurik (1990), p. 68.

> Two states, Delaware and Florida, require statewide comprehensive water resources planning and management under the direction of a single state agency. Other states require either continuous comprehensive water planning (fourteen states); static comprehensive planning (seven states); or continuous comprehensive planning with static water plan (four states) (Dzurik, p. 69).

At the local level, municipal and county water authorities or districts implement legislation dealing with drainage, water supply, and wastewater treatment (Dzurik, p. 69). The nature of local legislation and management typically depends on specific water resource needs (Dzurik, pp. 69-70). As would be expected, areas with critical water problems or water bodies that are vital to the economic health of a locality tend to have more legislation protecting water.

One major piece of federal legislation affecting water quality is the National Environmental Policy Act (NEPA) of 1969. Under NEPA, federal agencies must evaluate how proposed major actions will affect environmental quality, including water quality.

B. ENVIRONMENTAL ASSESSMENT ISSUES

Much has been written about NEPA and state NEPAs[4], the significance of environmental impact reviews (EIR), and processes for conducting EIRs. For purposes of this thesis, a general understanding of environmental assessment is

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[4] Several states have adopted legislation similar to NEPA, thereby requiring the evaluation of state actions.

helpful for the analysis of water quality.[5]

Environmental impact assessments are project, development, or action specific (Rau and Wooten, eds., p. 1-26). Some of the environmental impacts reviewed when applicable are:

> air quality and air pollution control; weather modification; energy development, conservation, generation, and transmission; toxic materials; pesticides and herbicides; transportation and handling of hazardous materials; aesthetics; coastal area; historic and archaeological sites; flood plains and watersheds; mineral land reclamation; parks, forests and outdoor recreation; soil and plant life, sedimentation, erosion, and hydrologic conditions; noise control and abatement; chemical contamination of food products; food additive and food sanitation; microbiological contamination; radiation and radiological rodent control; water quality and water pollution control; marine pollution; river and canal regulation and stream channelization; and wildlife preservation (Rau and Wooten, eds., p. 1-26 to 1-27).

Processes for evaluating environmental impacts are similar across impact types. A typical EIS process would operate following step similar to these:

1. Perform a preliminary review of the existing environment and proposed project[;]
2. Select environmental indicators to be used for describing the environment and gauging the effects of the project[;]
3. Describe the existing environment by providing quantitative descriptions of each indicator, using existing data sources[;]
4. Conduct field sampling programs to complete the description of the environmental setting[;]
5. Make predictions of the effects of the proposed project on the environment (impact assessment)[;]
6. Propose modifications which could minimize adverse impacts resulting from the project[;]

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[5] In this section, Rau and Wooten, editors (1981) are cited because of the concise nature in which their handbook addresses issues relevant here. For additional sources, see Bibliography.

7. Prepare the appropriate sections dealing with water quality for the environmental impacts statement or report (Rau and Wooten, eds., 6-2 to 6-3).

The techniques used for addressing water quality impacts will be discussed in Chapter 3.

C. PLANNING ISSUES

The planning profession must interact with other professions as well as with many levels of government. As the general planning literature explains, a planner needs to be a "jack-of-all-trades," capable of working within a multi-party and intergovernmental network and capable of addressing plans, policies, and regulations (So and Getzels, eds., 1988, p. 16). Understanding how to comply with the law, address financial situations, and participate in managing planning programs are also planning responsibilities (So and Getzels, eds., 1988, p. 16). Additionally, planners must consider the environment as an integral part of the planning practice.

When water quality problems are severe, planners tend explicitly to incorporate water quality considerations into their land use decisions. As more surface and groundwater supplies are threatened, planners will increasingly consider water-related environmental impacts when making decisions. Planners, however, should not wait until significant problems arise, but should take preventative measures to protect water quality. Even though the nature of planning is to anticipate future impacts, current land use planning procedures do not require systematic consideration of the environment. More must be done by explicitly coordinating water quality planning, land use, transportation, housing, industrial development, and the like (Viessman, p. 323).

The measures needed for effective and integrated planning go beyond what can be done at the local level. Ideally, these efforts should occur at the watershed level (McCullough and Crew, p. 2389). However, in the absence of integrative planning at the watershed level, local governments should take the initiative.

Three general approaches address water quality concerns: legislation and policy, analytical methods, and management strategies. Legislation and policies typically set an overall agenda for addressing water quality or regulating specific steps that must be taken to address water quality. Analytical methods include the tools used to assess current or potential water quality problems. Best management practices strive to reduce NPS pollution though a variety of measures including structural methods (physical) and nonstructural methods (e.g., density restrictions). These three approaches will be reviewed in more detail below.

For many years, legislative and policy actions have been used to address water quality issues. Examples of this include the Federal Clean Water Act and Safe Drinking Water Act, both aimed at protecting and improving water quality. In recent years, the focus of legislative actions has enhanced the recognition of NPS pollution as a major contributor to the degradation of water quality. The 1987 reauthorization of the Clean Water Act is a prime example. Section 319 requires each state to identify: (1) water bodies unable to meet water quality standards without NPS protection, sources of NPS pollution, and processes for selecting appropriate best management practices (BMPs)[6] to reduce NPS pollution, and (2) BMPs and programs to implement the BMPs.

Additional legislation at the state level has also emerged to protect natural resources. The state growth management programs of the early 1970s and their counterparts of the middle and late 1980s focused on the coordination of development and land use planning standards with natural resources, economic development, and other social and economic goals. Many of these states seek to manage the course of development so that the natural beauty

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[6] According to the LMP, "[b]est management practices (BMP) are nonstructural and low-structural practices or combinations of practices that are determined to be the most effective, practical means of preventing or reducing pollution inputs from nonpoint sources (e.g. stormwater runoff, pesticide and nutrient leaching, and construction and development practices) in order to achieve water quality goals. Improving quality and controlling the quantity of runoff to receiving groundwater and surface water is a common purpose among these primarily **preventative** practices" (Land Management Project, Sept. 1990, p.1).

and environmental integrity will not be compromised.

Regional programs and plans have also been used to protect natural resources. For example, Maryland's Chesapeake Bay Critical Area Protection Program was put into law in 1984. This program "was developed in response to intense conflict between environmental concerns and growth in land use development activities within the Chesapeake Bay region" (Salin, p. 208). The program seeks improvement of water quality and protection of fish and wildlife, and requires local protection programs to address similar goals (Salin, p. 211). A more recent regional undertaking is that of the Cape Cod Commission (CCC). One of the major purposes of the Act was natural resource protection. According to the 1991 Draft Plan:

> No subject arouses more concern in this regard than water resources. The quality and quantity of the Cape's groundwater is of critical importance as it is the only source of drinking water for most of Cape Cod. Of equal concern is the health and productivity of both marine and freshwater bodies on the Cape. These resource areas provide a wealth of economic and recreational opportunities, not to mention their aesthetic appeal (Cape Cod Commission, p. 10).

The CCC plan establishes a series of planning goals and policies indicating specific methods for taking measures to protect water quality.

Localities typically respond to and act in accordance with federal, state, and regional regulations. Additional local legislation often augments other legislation or seeks to protect specific local environmental resources. Two examples of local legislation include aquifer and watershed controls and non-zoning resource controls. Aquifer and watershed controls typically use land use controls (zoning overlays or special districts) to regulate activities endangering water quality. Non-zoning resource controls, enacted under the general powers of the locality, are designed to protect local environmental resources. Examples include wetlands protection controls, wellhead protection controls, hazardous materials storage and transport controls, dredge and fill controls, pesticide management controls, and fertilizer management controls.

The analytical methods used to assess the interrelationship between land use and water quality include site visits, physical models, simple calculations, and computer models. Levels of specificity, resource requirements, technical requirements, and general applicability vary among models. Proper selection and use require careful consideration of these aspects.

Computer-based models can assist planners in understanding quantitative and qualitative aspects of existing water quality problems or the potential impacts of land use decisions on water quality. Although setting up and using models can be costly, time consuming, and difficult, computer models are a tremendous resource for planners. Computer models are currently being used for evaluating proposed (or actual) development and impacts from proposed (or actual) BMPs, analyzing hydrology and water quality conditions, assisting regulatory compliance, and identifying problems.

Best management practices incorporate controls designed to prevent NPS water quality problems. These controls represent the "coordinated, judicious timing of activities and use of vegetation and materials (including some structures), as components within a total land management system" (USEPA, p. 33). Specific controls differ based on land uses and project specifics. Major BMPs can be divided between agriculture, construction/urban runoff, silviculture, and mining land uses (USEPA, p. 33). Table 2.4 highlights BMP activities by land use categories.

Legislation, analytical tools, and best management practices influence planning as well as have direct bearing on water quality. Because of these interrelationships, the role of planners should be explicitly considered in conjunction existing and future water quality modeling.

TABLE 2.4

Best Management Practice Activity Matrix

BMP	NUTRIENT REDUCTION	STRUCTURAL CONTROL	NONSTRUCTURAL CONTROL	AGRICULTURE	SILVICULTURE	CONSTRUCTION	RUNOFF
AGRICULTURE							
Conservation tillage			●	●			
Contouring			●	●			
Contour strip cropping			●	●			
Cover crops			●	●			
Integrated pest management	●			●	●		
Range and pasture management	●			●	●		
Sod-based rotations	●		●	●			
Terraces		●		●		●	●
Waste management practices	●	●		●			
CONSTRUCTION & URBAN RUNOFF							
Structural control practices	●	●			●	●	●
Nonvegetative soil stablization	●	●	●		●	●	●
Porous pavements	●	●					●
Runoff detention/retention	●	●		●	●	●	●
Street cleaning	●		●			●	●
Surface roughening			●			●	
SILVICULTURE							
Limiting disturbed areas	●		●		●	●	
Log removal techniques	●	●			●		
Ground cover			●		●	●	
Removal of debris			●		●		
Proper handling of haul roads			●		●		
MINING							
Water diversion	●	●					
Underdrains	●	●					
Block-cut or haul-back	●		●				
MULTICATEGORY							
Buffer Strips		●	●	●	●	●	●
Grassed waterway	●	●	●	●		●	
Devices to encourage infiltration	●	●		●		●	●
Interception/diversion	●	●		●	●	●	●
Material ground cover	●	●		●	●	●	●
Sediment traps		●		●	●	●	●
Vegetative stabilization/mulching			●	●	●	●	●

Source: U.S. Environmental Protection Agency (1987), p. 34.

CHAPTER 3

ENVIRONMENTAL IMPACT ASSESSMENT METHODS

This chapter reviews environmental impact assessment methods and proposes criteria for evaluating the usefulness of water quality models in making planning decisions. This discussion provides contextual information helpful for evaluating the usefulness of NPS water quality models.

A. ENVIRONMENTAL IMPACT ASSESSMENT METHODS

The environmental impact assessment methods used by researchers and practitioners can be divided into three broad categories: identification, forecasting, and evaluation of environmental impacts. Specific techniques for applying these methods are presented below.

A.1 Identification of Environmental Impacts

At the preliminary stages of environmental impact assessment, environmental planners[7] identify potential environmental impacts from proposed actions (Ortolano, p. 159-160; So and Hand, eds., 1986, p. 247; and Rau and Wooten, eds., p. 8-1). This process typically yields suggestions for future investigations of the impact(s). Techniques and processes for identification include:

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[7] In this thesis, "environmental planners" refers to government officials and professional and private individuals working to protect and plan for the environment.

- checklists of impacts (Ortolano, p. 160; So and Hand, eds., 1986, p. 243; Rau and Wooten, eds., p. 8-4 to 8-6);
- matrices combining checklists and relationships of impacts (So and Hand, eds., 1986, p. 244; Rau and Wooten, eds., p. 8-6 to 8-16);
- networks diagraming related impact components (So and Hand, eds., 1986, p. 244; Rau and Wooten, eds., p. 8-25 to 8-29);
- literature reviews by project types (Ortolano, p. 160).

A.2 Forecasting Environmental Impacts

Forecasting[8] provides a basis for analysis, comparison, and evaluation of potential environmental impacts (Ortolano, p. 159; So and Hand, eds., 1986, p. 247; Rau and Wooten, eds., p. 8-1). A variety of approaches--including judgmental and intuitive techniques, physical models, and mathematical models--are effective forecasting tools.

Judgmental and intuitive techniques utilize the experience and advice of others for the purpose of guiding environmental planning decisions. These techniques can be used across environmental impact categories (e.g. water, air, noise). Expert opinions, impacts of past projects, the Delphi Method, networks, and workshops are examples of these techniques (Ortolano, pp. 160-162; So and Hand, eds., 1986, p. 245).

Physical models provide three-dimensional

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[8] Forecasting is also called predicting or extrapolating.

representations of "reality" (Ortolano, p. 162). These models tend to be specific to environmental impact categories. Examples of physical models include modeling visual impacts, water bodies, and transport of air-borne residuals (Ortolano, pp. 162-164).

Mathematical models, or quantitative models, combine algebraic and/or differential equation with scientific and/or statistical analyses (Ortolano, p. 165). Mathematical models tend to be specific to environmental impact categories. However, many air and water quality models use mass-balance equations based upon the theory of conservation of mass and energy, where the outflow of a substance equals the inflow of the substance, plus any production, and minus any decay or change in storage (Ortolano, p. 165).

A.3 Evaluating and Interpreting Forecasted Environmental Impacts

In the final phase of environmental impact assessment, the forecasted impacts are used to compare, evaluate, and rank the impacts from alternative plans as well as to select a final plan (Ortolano, p. 159; So and Hand, eds., 1986, p. 247; Rau and Wooten, eds., p. 8-1). This process combines the technical evaluation of environmental impacts with socio-economic and other policy concerns. Examples of evaluation techniques include:

- cost-benefit analysis (Ortolano, p. 185-187);
- tabular displays and weighing procedures (Ortolano, p. 187-193; So and Hand, eds., 1986, p. 245; Rau and Wooten, eds., p. 8-18 to 8-25);
- public evaluation (Ortolano, p. 193-199);
- direct display for directly comparing alternatives (So and Hand, eds., 1986, p. 245);
- constraint setting, e.g. suitability analysis (So and Hand, eds., 1986, p. 245; Rau and Wooten, eds., p. 8-2).

A.4 The Importance of Forecasting Environmental Impacts

Environmental impact assessment methods provide a basis for understanding and balancing the environmental effects of proposed planning actions. This thesis focuses on using mathematical models to forecast environmental impacts. Forecasting methods are the "central element" of environmental impact assessment: they provide the major source of information used for evaluation of environmental impacts and decision making (So and Hand, eds., 1986, p. 244). One of the most useful forecasting methods is mathematical modeling. Keyes (1976) states: "Quantitative estimates of end impacts on man appear to provide the most useful information to the decision maker. At the same time it is important to use recognized standards or other reference points in interpreting the quantified and often technically specified estimates in several of the impact categories" (p. xii).

Forecasting, particularly with mathematical models, provides a more solid basis for most environmental impact assessment. For years, mathematical and statistical models have been used by scientists and engineers to research, monitor, and predict physical, chemical, and biological processes. Generally, the models developed have incorporated theoretical considerations and other technical "parameters" for appropriate representation of physical conditions. Many of the models used for environmental impact assessment purposes have facilitated the evaluation and comparison of alternatives planning actions.

Computers have assisted many of these modeling efforts. When properly used, computer-assisted modeling can be faster, more accurate, and more detailed compared to unassisted modeling. Advances in computer technology, especially with PCs, have made computer use even more integral to modeling.

Much has been written about computer-assisted modeling for scientific and engineering applications. Little, however, has been written about how "traditional" planners can utilize computer-assisted modeling for environmental impact assessment. The planning literature addressing computer use is general and typically limited to information on setting up computer systems, using major software programs, and adapting general modeling concepts. However, in one book, Computer Models in Environmental Planning, Gordon (1985) identifies available mainframe-based computer models that can be employed by planners and engineers to analyze environment impacts in a variety of fields. Although the issues raised by Gordon are relevant today, the specific examples are somewhat outdated; many of the models described have been revised and reworked as PC models.

A.5 Forecasting and Water Quality

Water quality, water quantity, and flooding impacts rank among the most important environmental effects that environmental planners must consider in evaluating planning actions. Public health and safety is the primary concern of these impacts. Fish and wildlife, wetlands, navigation, recreation, and hydroelectric power are additional water concerns (Dzurik, pp. 257-273).[9]

In order to ensure that planning objectives and statutory standards will be met, environmental planners must forecast a planning action's impact on water. Different forecasting methods are used for water quality, water quantity, and flooding assessment. The thesis addresses mathematical models for water quality forecasting.

Although water quality forecasting methods can be categorized in many ways, one simple breakdown distinguishes

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[9] See Dzurik (1990) and Keyes (1976) for overview of water resource problems.

loading models and receiving water models.[10] In this context, loading models estimate pollutant loads from point sources or NPS.[11] NPS pollutant loading models estimate loads from surface runoff to surface receiving waters and from water infiltration or recharge into groundwater. Surface and subsurface receiving water models estimate the effects of the physical, chemical, and biological processes on the quality of the receiving water. For relatively simple models, these distinctions tend to be exclusive, but for more complex models, both load sources and receiving water quality are evaluated.

B. CRITERIA FOR ENVIRONMENTAL ASSESSMENT

The model characteristics discussed in this section affect how useful a PC-based NPS water quality model can be for planners. This section presents a checklist of those criteria, explains the methodology for choosing the criteria, and discusses how the criteria should be interpreted by a potential model user. Chapters 5 and 6 summarize these subjective criteria, but also discuss the more descriptive characteristics relevant to models.

The checklist was developed using three basis

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[10] The models reviewed in Chapter 6 are categorized as NPS pollutant load models or receiving water models. Loading model include simple calculations as well as detailed simulations models used to assess NPS loads.

[11] Only NPS pollutant loading models are reviewed in this thesis.

procedures. First, a general literature review on environmental quality, environmental impact assessment, and planning was conducted (see Chapter 2). Next, planning, engineering, and scientific literature was reviewed for information about characteristics of good models and criteria for models. Finally, the background information and model criteria information were synthesized to develop a checklist of important model characteristics.

Scientists, engineers, and planners use similar criteria for defining "good" models. Most researchers believe that models should be reliable, effective, documented, and capable of being used by others. Those interested in planning also tended to focus on the use of models by non-technically trained individuals.

The model checklist (Table 3.1) is divided between model development, model use, and model application. The model development section identifies how the model was developed and whether or not the model development, as well as its inputs and outputs, can be understood by planners. The model use section focuses on the experience of planners trying to use the models. The model application section explores how the models can be applied for planning actions.

TABLE 3.1

Summary of Important Model Characteristics
(Numbers in () refer to literature referenced below.)

Model Development

- Are model outputs/results realistic? reliable? verifiable? appropriate? (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15)
- Does the model have predictive capabilities? (e.g., 12)
- Are the model's data requirements reasonable? Is the data required typically available? (e.g., 2, 4, 5, 6, 8, 14, 16)
- Are the variables used comprehensible? (e.g., 8)
- Is the model output clear? (e.g., 8)

Use of Model

- Is the model easy to acquire? (e.g., 4, 7, 9, 13)
- Is the cost of model adaptation and use reasonable? (e.g., 4, 7, 12, 13)
- Are the user, data, and system requirements for running the model reasonable? (e.g., 4, 6, 7, 8, 14)
- Is the model easy to use and understand? (e.g., 4, 6, 8, 10, 11, 14, 16)
- Is the documentation adequate? (e.g., 1, 2, 3, 4, 5, 6, 8, 13, 14, 15)
- What is the model's degree of acceptance and application by other users? (e.g., 1, 3, 5, 6, 15)
- Is the model support adequate? (e.g., 5, 6, 10, 14)
- Is the output clear? (e.g., 4, 8)

Application of Model Results

- Is the model applicable to more than one situation? Is it transportable? (e.g., 7, 8, 10, 16)
- Does the model facilitate comparing alternative scenarios? (e.g., 8)
- Is the model effective? (e.g., 1, 3, 6, 15)
- Is the model useful? (e.g., 1, 3, 6, 15)
- Are policy choices visible and changeable? (e.g., 8, 13)
- Is the model capable of affecting policy choices? (e.g., 12, 14)
- Does the model output match planning needs? (e.g., 12)

Literature used to develop summary of important model characteristics:

1	Ambrose, 1989
2	ASCE, 1990
3	Barnwell, 1987
4	Basta, 1982
5	Donigian, 1985
6	Donigian, in press
7	Gordon, 1985
8	Herr, 1988
9	Lima, 1984
10	Loucks, 1985
11	McCutcheon, 1989
12	Reckhow, 1985
13	Sterman, 1988
14	US EPA, 1987
15	US EPA, no date (CEAM)
16	Walker, 1989 (memo)

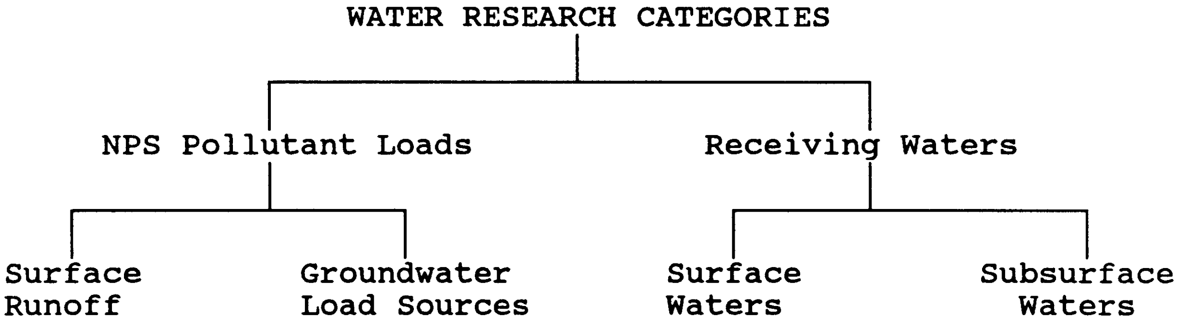
CHAPTER 4

OVERVIEW OF WATER QUALITY AND WATER QUALITY MODELING THEORY

As background for understanding the model reviews, this chapter will provide a theoretical overview of the basic terminology and concepts used in water quality theory and water quality modeling techniques. For NPS pollutant loading and receiving water models, major water quality problems and physical, chemical, and biological processes will be reviewed. The techniques used for modeling these waters will be identified and reviewed. The structure of this chapter is diagramed in Figure 4.1.

Figure 4.1

Diagram of Water Quality Elements in Chapter 4



Water Quality Theory Section: For the specific NPS pollutant load and receiving water categories, major water quality problems and physical, chemical, and biological processes are reviewed.

Water Quality Modeling Techniques Section: For the specific NPS pollutant load and receiving water categories, major water quality modeling techniques are reviewed.

A. OVERVIEW OF WATER QUALITY THEORY

This section provides a brief introduction to water quality science and focuses on the major water quality problems and processes of loading and receiving waters. Most of the factual information was taken from Hinson and Basta (1982), Huber and Heaney (1982), and Jaffe and DiNovo (1987).[12]

A.1 NPS Pollution Load Sources

As discussed in Chapter 2, NPS pollution generated from land use enters receiving waters as a function of the hydrologic cycle. Rainfall and snowfall transport NPS pollutants into surface receiving waters, and recharge processes transport NPS pollutants into groundwaters.[13] These definitions, while simplistic accounts of the hydrologic cycle, appropriately describe the relationship between land use and NPS loads.

NPS pollutants generated and discharged from all land

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[12] Although there are numerous sources on NPS pollution and water quality, these writings clearly and concisely identify relevant information and present it in a format understandable by non-technical readers. For additional sources, see Bibliography.

[13] The definition of recharge processes is: "Groundwater is comprised of the portion of rainfall that does not run off to streams and rivers and that does not evaporate or transpire from plants. This water percolates down through the soil until it reaches the saturated zone of an aquifer. This process is called *aquifer recharge*. Percolating water may reach the aquifer at any point, but aquifer recharge takes place principally in defined areas called *aquifer recharge areas*. These areas occur where the aquifer is overlain by highly permeable material and groundwater flow is mostly downward into the aquifer" (Jaffe and DiNovo, p. 9).

use activities vary depending upon the type of land use activity, amount of water moving over and into the land surface, and types of contaminants being carried with the water (Huber and Heaney, pp. 125-126). This section describes water quality issues and processes applicable to surface runoff and groundwater load sources.

A.1.1 Surface runoff waters

The natural systems models (NSMs) used to analyze NPS entering surface waters are called runoff models.[14] Runoff models are: "NSMs which estimate the temporal and spatial distribution of water and associated residuals that run off the land surface due to precipitation, and enter [surface] receiving water bodies" (Huber and Heaney, p. 126).[15]

The relevant features of runoff models are (Basta and Moreau, p. 34):

- "They typically describe the interrelationships among precipitation events (rainfall and snowmelt), surface hydrodynamics, erosion mechanics, and material transport for a given surface area."
- "Many of these models also include components which route water flows in channels and pipeline networks before discharge into a [surface] receiving water body."

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[14] Runoff models, also called surface runoff water quality models, will be referred to as runoff models for the rest of the thesis.

[15] Huber and Heaney (1982) use "residuals" to describe pollutants in the context of economic costs and values (Bower and Basta, pp. 2-3).

- "Runoff models have been developed to analyze residuals generation and discharge from land surfaces with varying characteristics, as reflected principally by size of surface area (catchment), type of land use, soil characteristics, and frequency, duration, and types of precipitation."
- Runoff models are often divided between predominantly urban land surfaces[16] and predominantly non-urban land surfaces[17].

Major runoff water quality problems

The effects of urban and non-urban runoff impact the interrelated problems of quality and quantity. The primary quality aspects are "the effect on ambient [surface] receiving water quality of the addition of residuals washed off the land surface" (Huber and Heaney, p. 129). The quantity aspects are "the effect of man's use of water and man's activities on the volume of water which runs off the land surface..." (p. 129). Although quality and quantity are never totally separate, this distinction helps identify the problems and analytical approaches (Huber and Heaney, p. 129).

The linkages between quality and quantity begin with

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[16] Urban runoff, according to Huber and Heaney (1983) (p. 130), "refers to runoff from areas of relatively high population density, areas which are relatively impervious--do not absorb water--because of the amount of land area covered by roads, sidewalks, parking lots, and buildings."

[17] Non-urban runoff, according to Huber and Heaney (1982) (p. 130), "refers to runoff from all land areas other than urban. Nonurban includes many types of land use activities such as: park land; agricultural land in crops; orchards or pasture; range land; forest land; mining areas."

the fact that most water quality models require knowledge of quantity aspects (Huber and Heaney, p. 135). For example, to estimate pollutant concentrations and loads, the water flows must have been estimated (Huber and Heaney, p. 135). Second, mitigation of quantity and quality problems are often complementary (Huber and Heaney, p. 135).

The major concerns with water quality relate to surface receiving water quality, not the quality of the water before it reaches the target water body (Huber and Heaney, p. 132). The "[r]esiduals concentrations in water moving over the land surface are important only in so far as that information is needed to estimate residuals concentrations in runoff as the runoff enters a [surface] receiving water body, or for analyzing residuals discharge reduction measures" (Huber and Heaney, p. 200).

Runoff analysis determines NPS inputs to surface receiving waters as well as the intensity and time patterns of these NPS discharges (Huber and Heaney, p. 133). Most frequently, NPS problems relate to erosion and sedimentation. Other residuals considered by runoff models include biochemical oxygen demand (BOD), organic materials, nitrogen (N), phosphorus (P), bacteria, metals, pesticides, and many forms of solids (Huber and Heaney, p. 134).

The major water quantity problems include flooding and water supply (Huber and Heaney, pp. 131-2). This thesis examines water quantity only as it relates to water quality.

Runoff water: physical, chemical, physicochemical, biochemical, and ecological processes

Physical, chemical, physicochemical, biochemical, and ecological processes identify and describe the natural processes affecting the movement of water and the transport of residuals over land surfaces (Huber and Heaney, p. 128). Attention to these processes varies on a model by model basis (Huber and Heaney, p. 136). Table 4.1 briefly describes these processes and how they are applicable to runoff models.

TABLE 4.1

Runoff Water: Physical, Chemical, Physicochemical, Biochemical, and Ecological Process

Physical Processes

Defined: Relative to runoff from land surfaces, physical transport processes are those processes which affect the movement of water, and the movement of materials in water over the land surface and in conveyance systems (e.g., pipes, canals, channels, ditches) before entering surface receiving water bodies (p. 136).

Hydrological Cycle: The net amount of water which runs off the land surface depends on many factors, all of which relate to the hydrologic cycle. The hydrologic cycle is the cycle of water movement from the atmosphere to the earth and its return to the atmosphere through various processes (p. 136).

Accounting for the Hydrological Cycle in Runoff Models: Even though the hydrologic cycle is the starting point for any analysis of runoff, the extent to which models include specific aspects of the cycle varies. In many models simplifying assumptions are adopted. However, accurate representation of the hydrologic cycle is a prerequisite for accurate estimation of runoff (p. 139).

Conservative and Nonconservative Residuals: Physical processes of runoff account only for the movement of conservative and nonconservative residuals within water and not the transformation of nonconservative residuals (p. 142). A conservative residual is a residual which does not decay during the process of transport; a nonconservative residual decays during transport (p. 200).

Chemical, Physicochemical, Biochemical Processes

Defined: Chemical, physicochemical, and biochemical processes account for the transformation of nonconservative chemicals. However, because of the short period of time for rainfall to wash residuals off land surfaces, little or no transformation occurs before residuals are discharged into surface receiving waters or into holding basins from which discharge eventually occurs into surface receiving waters (p. 142).

Accounting for Chemical and Biochemical Processes in Runoff Models: Few models explicitly consider chemical and biochemical processes, because the extent of transformation during runoff is negligible compared with transformation in surface receiving waters (p. 142).

Accounting for Physicochemical Processes in Runoff Models: Physicochemical processes have an important effect on ambient concentrations of residuals in runoff, regardless of the short time frame involved. The most important physicochemical processes are adsorption, desorption and absorption. Adsorption is the adhesion of a substance to the surface of a solid or liquid. Adsorption is important because many residuals, such as nitrogen, phosphorus, various pesticides, and heavy metals, attach themselves to sediment particles and are in turn transported with the particles in runoff. Desorption is when the adsorption process is reversed, i.e., the residuals detach from the sediment particles. Absorption is the penetration of a substance into or through another substance. Absorption usually takes place at the air-water interface where gases, e.g., oxygen, are absorbed into water. Although a certain amount of absorption does take place during runoff, the overall effect is negligible compared to the residuals collected off the land surface and carried in the runoff (pp. 142-3).

Ecological Processes

Defined: Ecological processes relate to the linkages between and among living organisms. These linkages typically involve the consumption of one species or organism by another which is higher in the food chain, and the consumption of that species by another, and so on (p. 143).

Accounting for Ecological Processes in Runoff Models: Some ecological processes do affect residuals discharges from the land surfaces, however, these processes are generally not considered in runoff models (p. 143).

Source: All information taken from Huber and Heaney (1982) with little editing. Any misrepresentations are mine.

A.1.2 Groundwater NPS pollution load sources

Groundwater contamination is a serious problem, difficult and complicated to remediate even with the help of natural and technological processes. Little dilution or attenuation of pollutants in groundwater and the slow rate of groundwater movement (a few feet to a few inches per day) contribute to the difficulties of groundwater cleanup (Jaffe and DiNovo, p. 1). Although much has been written about groundwater contamination, this section only addresses groundwater quality as it relates to the NPS pollutants introduced to groundwater via recharge processes.

In general, the greatest risk to groundwater quality is the pollution introduced to groundwater as a result of human activities (Jaffe and DiNovo, p. 17). Examples of point source pollution affecting groundwater include underground injection of waste into groundwater and pollutants leaking from underground storage tanks. The recharge of NPS pollution to groundwater is another major threat.[18]

Common groundwater contaminants include bacteria, minerals, and inorganic or organic chemicals (Jaffe and DiNovo, p. 22). Additional contaminants and their generating land uses are displayed in Table 2.1.

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[18] Recharge is not the only source of NPS pollution in groundwater. Additional NPS pollutants from below-ground activities (e.g., septic tanks and leaching of landfills) also degrade groundwater. If these pollutants are introduced above the groundwater level, they are transported by recharge waters. Otherwise, they are transported by groundwater flow.

For the most part, the natural processes most likely to influence groundwater recharge are physical processes. These involve the transport of pollutants from the load sources into the groundwater. The attenuation of pollutants in transport includes physical, chemical, and biological processes that will be described in the subsurface receiving water section.

A.2 Surface and Subsurface Receiving Waters

NPS pollutants generated from land sources are transported eventually to surface or subsurface receiving waters. For receiving waters, in-water processes are of primary concern, and load sources are only considered as they related to pollutant delivery.

A.2.1 Surface receiving waters

Surface receiving water systems are "surface water bodies into which residuals are directly or indirectly discharged" (Hinson and Basta, p. 249). Streams, rivers, lakes, ponds, reservoirs, estuaries, and offshore marine systems are surface water systems (Hinson and Basta, p. 249).

While surface receiving water models typically are not developed specifically for NPS pollution, they can simulate the effects of NPS pollution on receiving waters (EPA, p. 9). In order to better understand how surface receiving waters relate to NPS pollutants, this section reviews important surface receiving water features, as described by Hinson and Basta (1982).

Surface receiving water models "estimate the temporal and spatial distribution of ambient water quality which results from the discharge of residuals into surface receiving waters" (Basta and Moreau, p. 34). The context of the analysis determines the study boundaries, which could include a single pond, a section of a river, or an entire watershed (Basta and Moreau, p. 34). In some cases these models are site or water body specific, whereas other models are more general and can be applied more easily to different types of water bodies (Hinson and Basta, p. 322).

Major surface receiving water ambient water quality problems

Problems resulting from NPS discharges into surface receiving waters cause "decreased propagation of fish and wildlife; transmission of disease to humans; reduced aesthetic properties; and reduced utility of water for beneficial uses other than fish and wildlife" (Hinson and Basta, p. 251). These problems result from natural processes and human activities which accelerate natural processes. The major water quality problems are temperature, salinity, sedimentation, dissolved oxygen, eutrophication, toxic substances, and biological effects

(Hinson and Basta, p. 252). Although not all water quality problems fall under these headings, these provide a framework for surface receiving water quality analysis (Hinson and Basta, p. 261). These problems are summarized in Table 4.2.

TABLE 4.2

Major Surface Receiving Water Quality Problems

Temperature measures the ambient thermal condition of surface receiving water bodies. Temperature in surface receiving water bodies is a function of variables such as solar heat inputs and hydrodynamic properties of the water body. Temperature affects (a) obvious changes in state of water (like freezing or evaporation), (b) viscosity of water and the series of changes occurring from this, (c) physicochemical reactions, (d) biochemical reactions, (e) biological processes, and (f) behavioral patterns of organisms (p. 252).

Salinity problems are usually associated with high concentrations of total dissolved solids, which are mostly inorganic salts and some organic material. Salinity is a problem because of its effects on organisms in surface receiving water bodies and because of its effects on the uses of the water withdrawn from the water bodies (e.g., drinking, irrigation, or industrial activities) (p. 253).

Sedimentation is the process by which sediment settles or deposits, under the force of gravity, on the floor of a surface receiving water body. Sediment which has settled may be resuspended in the water as a result of flood flows, tidal action, or vessel passage. Suspended solids in flowing water can adversely affect many uses of water and many aquatic organisms. Some of the specific problems related to sedimentation include: diminishing light penetration; inhibiting photosynthesis by aquatic organisms; settling and smothering life on the bottom of surface receiving waters; carrying attached nutrients, pesticides, and heavy metals (all with various affects on water quality) into the surface receiving water (pp. 254-256).

Dissolved oxygen (DO) is a measure of the concentration of oxygen in a surface receiving water body. A substantial amount of DO must be maintained in a surface receiving water body for many organisms to survive and sustain aerobic decomposition of organic matter and oxidation of chemical compounds. The amount of oxygen able to dissolve in water depends primarily on the percent of oxygen saturation of the surface receiving water body, water temperature, and atmospheric conditions of temperature and pressure. The primary demand of oxygen in a surface receiving water body results from the demand for oxygen to decompose organic material discharged into the water body (pp. 256-7).

Eutrophication is the normally slow aging process by which a lake evolves into a bog or marsh and ultimately is entirely filled in. During eutrophication, a lake becomes so rich in nutrient compounds that algae and other plant life grow until they literally begin to choke or "dry up" the lake. The principal nutrients affecting eutrophication are nitrogen and phosphorus. Usually the effects of eutrophication are undesirable. Two examples include the decline in aesthetic and recreational value of surface receiving water bodies and hinderance the increased algae causes to water treatment plant operations (pp. 257-259).

Toxic substances that come into contact with organisms--fish, animals, people--will over time cause some degree of morbidity or mortality. The toxic substance problem in surface receiving water involves analyzing the movement, transformation, and effects of such substances in surface receiving water. However, little is known about the behavior and temporal effects of most chemical compounds discharged into surface receiving waters (p. 259).

Biological effects relate to impact of residuals discharges on resident aquatic organisms or on terrestrial animals which directly utilize surface receiving water bodies. (Adverse biological effects are closely related to the other water quality problems.) Types of biological effects include: transmission of pathogenic bacteria and viruses to man or other terrestrial animals via direct contact or drinking water; chronic toxicity effect; decreased productivity of autotrophic organisms; and changes in competition, feeding, and reproductive patterns (pp. 260-261).

Source: These problems were described in Hinson and Basta (1982), and are summarized here with little editing. Any misrepresentations are mine.

Surface Water: physical, chemical, physicochemical, biochemical, and ecological processes

Physical, chemical, physicochemical, biochemical, and ecological processes identify and describe natural processes affecting the movement and transformation of residuals in surface receiving water bodies, both of which result in the water quality problems described above (Hinson and Basta, p.250). Table 4.3 briefly describes the processes and how they are applicable to surface receiving water models.

TABLE 4.3

Surface Water: Physical, Chemical, Physicochemical, Biochemical, and Ecological Process

Physical Processes

Defined: The movement of water is the primary mechanism which transports material and energy into, within, and out of a surface receiving water body. Physical (hydraulic) transport processes bring about: (1) the movement of water through a surface receiving water body; and (2) the movement of material and energy within the water moving through the surface receiving water body. These process account for the movement of both conservative and nonconservative substances in surface receiving waters, but they have little or no effect on the transformations of nonconservative substances which take place in surface receiving water (pp. 262-265).

Chemical, Physicochemical, Biochemical Processes

Chemical Processes Defined: They involve the reaction of two or more compounds with each other to form one or more different compounds. The principal chemical processes affecting chemical reactions in water bodies are oxidation-reduction processes and ionic dissociation (p. 265).

Physicochemical Processes Defined: They involve both the chemistry and physics of molecules as they interact in their surroundings. Principal physicochemical processes affecting either the transformation of substances or the movement of substances in water bodies are: adsorption, desorption, absorption, and gravity settling (p. 266).

Biochemical Processes Defined: This is the process in which a chemical reaction takes place as a result of living organisms in the biological cycle. Two phases exist in the biological cycle, regardless of whether the system under scrutiny be on land or in surface receiving waters. These two phases are growth and decay, both of which are always simultaneously occurring in natural systems. Examples of the biochemical process include photosynthesis and bacterial decomposition (p. 268).

Ecological Processes

Defined: Ecological processes are closely related to biochemical processes. However, whereas biochemical processes such as photosynthesis and bacterial decomposition involve direct linkages to substances in water, ecological processes relate to direct linkages among different species. Ecological linkages involve the consumption of one species or organism by another species higher in the food chain, and so on (p. 270).

SOURCE: All information taken from Hinson and Basta (1982) with little editing. Any misrepresentations are mine.

A.2.2 Subsurface receiving waters

Subsurface receiving waters, or groundwaters, are generally defined as "[t]he supply of freshwater under the earth's surface in an aquifer or soil that forms a natural reservoir" (Tourbier, p. 172). Groundwater is an important source of water used for drinking, industrial purposes, power generation, and irrigation for many communities (Jaffe and DiNovo, p. 5).

Subsurface, or groundwater, models address water quantity and quality. Groundwater models estimate water flow and transport of constituents "into, through, and within various subsurface soil and rock strata" (Basta and Moreau, p. 35). These estimation procedures also incorporate process parameters and information about the area and conditions to be studied.

The three major modeling problems of groundwater movement are: "ground water flow, multiphase flow (e.g., soil, water, and air; water and gasoline; or water and a dense nonaqueous liquid (NAPL)), and the flow the flow of contaminants dissolved in ground water" (National Research Council, p. 28). For purposes of this thesis, only groundwater quality issues are reviewed.

Many load-source models and surface receiving water models make assumptions about groundwater (Basta and Moreau, p. 35). Unless these models explicitly address water flow and transport of constituents, they are not considered groundwater models in this thesis.

Major subsurface water quality problems include the NPS pollution generated from land use. These pollutants (e.g, bacteria, nutrients, chemicals) are described in the preceding groundwater load source section.

The degree to which physical, chemical, and biological processes attenuate groundwater contaminants varies with respect to several conditions. Depending on where the contaminant is introduced to the hydrologic system (ground surface, unsaturated zone, or above the aquifer), potential factors influencing attenuation include geological materials, environmental conditions, and distance and time the contaminants travel through unsaturated materials (Jaffe and DiNovo, p. 25). Examples of NPS contaminants introduced at the ground surface level include pesticides and storm water; contaminants introduced in the unsaturated and saturated zones include septic systems and landfill leachate (Jaffe and DiNovo, p. 25). Table 4.4, reproduced from National Research Council (1990) details the complex physical, chemical, and biological processes influencing the transport of groundwater contaminants.

Water quality problems and natural processes affecting load source and receiving waters are modeled in a variety of ways. The techniques used for modeling are presented in the following section.

TABLE 4.4

A Summary of the Processes Important in Dissolved Contaminant Transport and Their Impact on Contaminant Spreading

Process	Definition	Impact on Transport
Mass transport		
1. Advection	Movement of mass as a consequence of ground water flow.	Most important way of transporting mass away from source.
2. Diffusion	Mass spreading due to molecular diffusion in response to concentration gradients.	An attenuation mechanism of second order in most flow systems where advection and dispersion dominate.
3. Dispersion	Fluid mixing due to effects of unresolved heterogeneities in the permeability distribution.	An attenuation mechanism that reduces contaminant concentration in the plume. However, it spreads to a greater extent than predicted by advection alone.
Chemical mass transfer		
4. Radioactive decay	Irreversible decline in the activity of a radionuclide through a nuclear reaction.	An important mechanism for contaminant attenuation when the half-life for decay is comparable to or less than the residence time of the flow system. Also adds complexity in production of daughter products.
5. Sorption	Partitioning of a contaminant between the ground water and mineral or organic solids in the aquifer.	An important mechanism that reduces the rate at which the contaminants are apparently moving. Makes it more difficult to remove contamination at a site.
6. Dissolution/precipitation	The process of adding contaminants to, or removing them from, solution by reactions dissolving or creating various solids.	Contaminant precipitation is an important attenuation mechanism that can control the concentration of contaminant in solution. Solution concentration is mainly controlled either at the source or at a reaction front.
7. Acid/base reactions	Reactions involving a transfer of protons (H^+).	Mainly an indirect control on contaminant transport by controlling the pH of ground water.
8. Complexation	Combination of cations and anions to form a more complex ion.	An important mechanism resulting in increased solubility of metals in ground water, if adsorption is not enhanced. Major ion complexation will increase the quantity of a solid dissolved in solution.
9. Hydrolysis/substitution	Reaction of a halogenated organic compound with water or a component ion of water (hydrolysis) or with another anion (substitution).	Often hydrolysis/substitution reactions make an organic compound more susceptible to biodegradation and more soluble.
10. Redox reactions (biodegradation)	Reactions that involve a transfer of electrons and include elements with more than one oxidation state.	An extremely important family of reactions in retarding contaminant spread through the precipitation of metals.
Biologically mediated mass transfer		
11. Biological transformations	Reactions involving the degradation of organic compounds, whose rate is controlled by the abundance of the microorganisms and redox conditions.	Important mechanism for contaminant reduction, but can lead to undesirable daughter products.

Source: National Research Council (1990), pp. 38-39.

B. OVERVIEW OF WATER QUALITY MODELING TECHNIQUES

Not all water quality questions can be answered with the use of models (Donigian and Huber, p. 1). However, for those efforts requiring modeling, the following descriptions identify modeling techniques for load sources and receiving waters. The following discussion, much like the one on water quality theory, closely follows the organization and theories included in Donigian and Huber (in press), Hinson and Basta (1982), and the National Research Council (1990).

The five general modeling objectives presented in Donigian and Huber (in press) provide a useful introduction to modeling technique theory. These objectives were written for runoff modeling but also generally apply to groundwater load source and receiving water modeling. The first two characterize the magnitude of the problem; the second through fifth relate to the analysis and solution of the problem under investigation (Donigian and Huber, p.1). Their suggested objectives (Donigian and Huber, p. 1) are:

1. Characterize runoff quantity and quality as to temporal and spatial detail, concentration/load ranges, etc.
2. Provide input to a [surface] receiving water quality analysis, e.g., drive a [surface] receiving water quality model.
3. Determine effects, magnitudes, location, combinations, etc. of control options.
4. Perform frequency analysis on quality parameters, e.g., to determine return periods of concentrations/loads.
5. Provide input to cost-benefit analyses.

The ability of runoff models to address these issues varies based on model design. Donigian and Huber (in press) point out that computer models make feasible certain types of analysis, such as frequency analysis, that would rarely be performed without the computer (Donigian and Huber, p. 1).

Donigian and Huber (in press) also highlight six modeling fundamentals found in the literature, and use these to summarize modeling caveats and introductory information. Again, these were written for runoff modeling, but generally apply to groundwater load source and receiving water modeling. The modeling fundamentals are (Donigian and Huber, p. 3):

1. Have a clear statement of project objectives. Verify the need for quality modeling. (Perhaps the objectives can be satisfied without quality modeling.)
2. Use the simplest model that will satisfy the project objectives. Often a screening model, e.g., regression or statistical, can determine whether more complex simulation models are needed.
3. To the extent possible, utilize a quality prediction method consistent with available data. This would ordinarily rule against buildup-washoff formulations, although these might still be useful for detailed simulation, especially if calibration data exist.
4. Only predict the quality parameters of interest and only over a suitable time scale. That is, storm event loads and EMCs will usually be the most detailed prediction necessary, and seasonal or annual loads will sometimes be all that is required. Do not attempt to simulate intra-storm variations in quality unless it is necessary.
5. Perform a sensitivity analysis on the selected model and familiarize yourself with the model characteristics.

6. If possible, calibrate and verify the model results. Use one set of data for calibration and another independent set for verification. If no such data exist for the application site, perhaps they exist for a similar catchment nearby.

The following sections identify classes of models typically used in load source and receiving water analysis. The models reviewed in Chapter 6 apply these techniques.

B.1 Load Source Models

B.1.1 Runoff models

For urban and non-urban modeling of NPS pollutants, the techniques range from annual loading models to detailed simulation process models (Donigian and Huber, p. 10). The nature of human activities on the land is crucial to estimating NPS pollution loads (Donigian and Huber, p. 10). Even though the same physical, chemical, and ecological processes that affect NPS pollutant loads occur on all land surfaces, the nature of land use strongly affects the magnitude of each of these processes (Donigian and Huber, p. 10).

Donigian and Huber (in press) define modeling techniques differently for urban modeling and non-urban modeling. The five principal techniques suggested for urban modelling are listed in order of increasing complexity. These techniques should be available and understandable to engineers familiar with water quality modeling.

Urban modeling methods include: (1) constant concentration, (2) spreadsheet[19], (3) statistical, (4) rating curve or regression, and (5) buildup/washoff methods (Donigian and Huber, p. 5). Constant concentration or unit load models assume a constant concentration for a given pollutant. This constant can be used to produce annual runoff loads (Donigian and Huber, p. 5). Spreadsheets on PCs can "automate and extend" the constant concentration method (Donigian and Huber, pp. 5-6). "The EPA Statistical Method utilizes the fact that EMCs are not constant but tend to exhibit a lognormal frequency distribution. When coupled with an assumed distribution of runoff volumes (also lognormal), the distribution of runoff loads may be derived. When coupled with an assumed distribution of streamflow, an approximate (lognormal) probability distribution of in-stream concentrations may be derived..." (Donigian and Huber, p. 6). The regression, or rating curve approach, "has been performed to try to relate loads and EMCs to catchment demographic and hydrologic characteristics..." (Donigian and Huber, p. 7). Buildup and washoff methods refer to the idea that buildup processes "lead to an accumulation of solids and perhaps other pollutants that are then 'washed off' during storm events" (Donigian and Huber, p. 8). Buildup processes are "the complex spectrum of dry-

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[19] Donigian and Huber (in press) consider spreadsheets a modeling method. However, I believe it is also appropriate to consider spreadsheets an "environment" for performing modeling methods, rather than a distinct modeling technique.

weather processes that occur between storms, including deposition, wind erosion, street cleaning, etc." (Donigian and Huber, p. 8). Table 4.5 is taken from Donigian and Huber; it identifies the data needs for various runoff quality prediction methods.

For non-urban areas, Donigian and Huber (in press) focussed on loading functions and simulation techniques. The loading function method "describe[s] simple calculational procedures usually [used] for estimating the *average annual load*, and sometimes the storm event load, of a pollutant from an individual land use category" (Donigian and Huber, p. 10). The most widely used of these procedures is the EPA Screening Procedure. The simplified nature of these procedures limits their utility, especially for evaluation of management practice impacts (Donigian and Huber, p. 11). Simulation models use temporal and spatial detail and more refined representations of processes than do loading models (Donigian and Huber, p. 12). More specifically,

> [T]he added detail of most simulation models requires a computer code, computer facilities, and significantly more input data, such as daily rainfall and possibly other meteorological timeseries. These models are most often computerized procedures that perform hydrologic (runoff), sediment erosion, and pollutant (chemical/biological) calculations on short time intervals, usually ranging from one hour to one day, for many years. The resulting values for each time interval, e.g., runoff, sediment, pollutant load or concentration, can be analyzed statistically and/or aggregated to daily, monthly, or annual values for estimates of nonpoint loadings under the conditions simulated (Donigian and Huber, p. 12).

TABLE 4.5

Data Needs for Various Quality Prediction Methods

Method	Data	Potential Source
Unit Load	Mass per time per unit tributary area.	Derive from constant concentration and runoff. Literature values.
Constant Concentration	Runoff prediction mechanism (simple to complex).	Existing model; runoff coefficient or simple method.
	Constant concentration for each constituent.	NURP; local monitoring.
Spreadsheet	Simple runoff prediction mechanism.	e.g., runoff coefficient, perhaps as function of land use.
	Constant concentration or concentration range.	NURP; local monitoring.
	Removal fractions for controls.	NURP; Schueler (1987); local and state publications.
Statistical	Rainfall statistics.	NURP; Driscoll et al. (1989); Woodward-Clyde (1989); EPA SYNOP model.
	Area, imperviousness. Pollutant median and CV.	NURP; Driscoll (1986); Driscoll et al. (1989); local monitoring.
	Receiving water characteristics and statistics.	Local or generalized data.
Regression	Storm rainfall, area, imperviousness, land use.	Local data.
Rating Curve	Measured flow rates/volumes and quality EMCs/loads.	NURP; local data.
Buildup	Loading rates and rate constants.	Literature values*.
	Street cleaning removals.	Literature values.
Washoff	Power relationship with runoff.	Literature values.*.

*Usually must be calibrated using end-of-pipe monitored quality data.

Source: Donigian and Huber (in press), p. 9.

B.1.2 Groundwater load source models

The methods for groundwater load source modeling are similar to those of runoff waters. However, the literature describing these loading and recharge processes is somewhat limited, because often these methods are addressed as one step in a larger groundwater modeling effort.

However, the most common modeling efforts, as identified by the models researched for this thesis, include constant concentration or unit load models and spreadsheet automation. These techniques evaluate total NPS pollutant loads estimated in conjunction with total water recharged in an area.

B.2 Receiving Water Models

B.2.1 Surface receiving water models

Hinson and Basta (1982) described two modeling approaches for surface receiving water models, conservation of mass and energy methods (mass-balance equations) and statistical methods. The context of the analysis (e.g., type of water body, flow condition, the problem context, problem assumptions) determines the way in which the conservation of mass and energy method is used (Hinson and Basta, pp. 273-274). Depending on the analysis, at least two of the four building blocks of the mass and energy method are use as needed. The blocks include the hydraulic block, physical transport block, chemical reaction block, and ecological block. (Hinson and Basta, p. 274). According to Hinson and Basta (1982), the principle "is to account for the movement of mass, or energy, or of both into and out of each volume into which a surface receiving water body may be divided" (p. 274). A schematic representation of the blocks is shown in Figure 4.2.

Statistical methods have been widely used in analysis of surface receiving water bodies. Statistical modeling is, however, unable to explain causal relationships in surface receiving waters, and the use of the model is limited to the sample range.[20] Therefore, as researchers learn more about water quality problems and natural processes affecting them, the use for statistical methods is declining. Use of statistical modeling is limited to first cut analysis or situations where complex conservation of mass and energy models are not available but analysis is nonetheless essential. (All information from Hinson and Basta, pp. 297-298.)

B.2.2 Subsurface receiving water models

The subsurface environment is neither easily observed nor assessable (National Research Council, p. 22) Groundwater models are used to understand groundwater systems and simulate and predict groundwater system behavior

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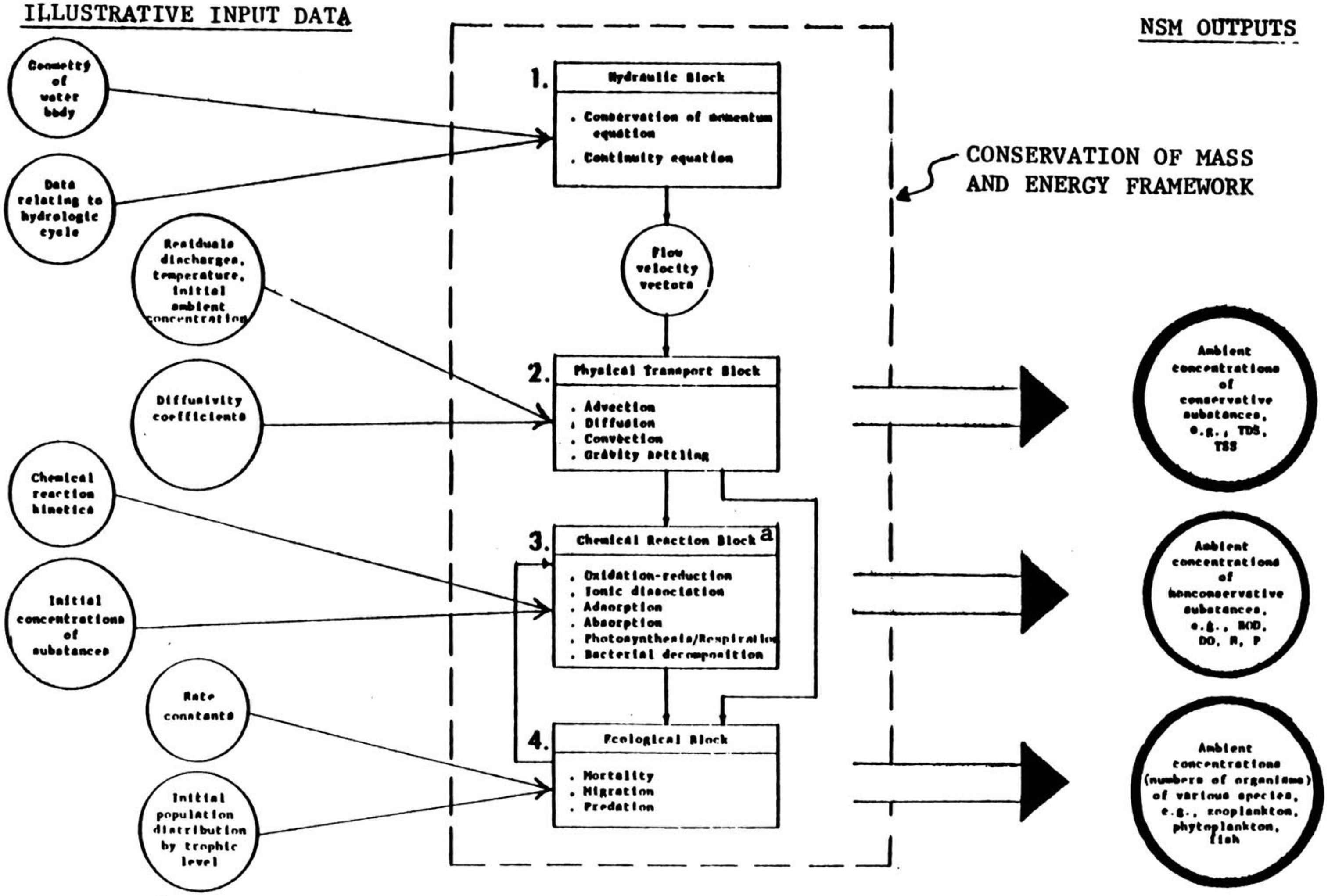
[20] For example, if data is limited to a specific catchment, only conclusions about that catchment could be drawn; inferences could not be applied properly to other catchments.

FIGURE 4.2
Schematic of Receiving Water NSM Based on Conservation of Mass and Energy



[a] Includes chemical, biochemical, and physicochemical reactions.

(National Research Council, p. 22).

Groundwater flow, multiphase flow, and contaminant transport are typically modeled using <u>mathematical equations</u> (National Research Council, p. 28). Different mathematical equations and input parameters are used to represent the natural processes governing each of these areas (National Research Council, p. 53). Addition information needed for all three areas include: "(1) the size and shape of the region of interest, (2) the boundary and initial conditions for that region, and (3) the physical and chemical properties that describe and control the processes in the system" (National Research Council, p. 64).

As concern for water quality has grown, more modeling efforts have begun addressing water quality and the transport of contaminants. Regardless, groundwater modeling processes are very complex, and "[f]ew flow and transport problems are modeled with confidence" (National Research Council, p. 2). Limited understanding of the underlying scientific and modeling concepts makes it difficult to design and use models with confidence (National Research Council, p. 2). Groundwater flow is the easiest of the three areas to characterize and understand, and is modeled with the most confidence (National Research Council, pp. 2 and 29). Contaminant models are the most complex and difficult of the three areas to understand and model; the ability to model is largely dependent upon the "chemical species and phase of interest" (National Research Council, pp. 2 and 4).

According to the National Research Council (1990), when properly applied, groundwater models are "useful" tools for research and scientific reasons as well as for assisting evaluation of specific problems or strategies (p. 9). The accuracy of model applications, however, should not be confused with the accuracy of a model; it is one element of the overall model assessment (National Research Council, p. 250).

The need for and importance of water quality models will increase as more water systems are threatened and become contaminated. Additional demand for these models may result from the from the fact that compliance with federal and state legislation may require modeling efforts.

CHAPTER 5

MODEL IDENTIFICATION, SELECTION, AND REVIEW PROCESSES

This chapter provides background information on the model review processes. The methodology used to select and identify the models is outlined. Also, the framework for the model review is presented.

A. MODEL IDENTIFICATION AND SELECTION PROCESSES

The models reviewed in this thesis were identified through a literature search. These models were selected from hundreds of model write-ups because they met two broad criteria: (1) usable on PCs; and (2) address NPS water quality concerns. A discussion of the model identification and model selection processes follows.

A.1 Model Identification Process

The PC-based NPS water quality models used for this thesis were identified primarily through a literature search. One of the overall objectives of the thesis was to identify models available to planners. For planners without personal contacts in the area of water quality, a literature search would be a logical starting point. Also, the literature search was intended to be broad based. If the search had relied upon the models suggested by individuals working with NPS water quality models, it is likely that many of these models normally would not be accessible to a wide spectrum of planners (e.g., proprietary models used for in-house or client purposes). With this in mind, a literature search was conducted in the fall of 1990 using the sources detailed in Table 5.1.

TABLE 5.1

Locating PC-Based Water Quality Models and Information

Key Word Searches:

Key word searches were conducted using NTIS, Compendex, Barton (MIT's library computer system), and the EPA Region 1 library system.

Variations of the following key words were used: nonpoint source pollution, land use, models, computers, personal computers, planning, water quality, groundwater, surface water.

Journals and Professional Magazines Reviewed:

Manual review of articles in the following journals and magazines was conducted.

- American Planning Association (APA) Journal, 1985 on
- APA's Planning, 1985 on
- APA's, PAS Memos, 1985 on
- APA's PAS Reports, 1985 on
- Water Resources Bulletin, 1985 on
- Water Resources Journal, 1985 on

American Society of Civil Engineers (ASCE) Publications Reviewed:

For all relevant ASCE conference proceeding and notes identified and available at MIT, table of contents and indexes were reviewed.

Land Management Project Library Holdings Reviewed:

The Land Management Project was contacted during the literature search process. Relevant water quality information used by the organization was reviewed, and the sources identified in their abstract of nutrient loading and contamination transport models and methods was used.

Individuals Consulted for Assistance for Help with the Literature Search:

A few individuals were consulted during the literature review. They were: MIT staff librarians, EPA staff librarians, Phil Herr (thesis advisor), Lyna Wiggins (thesis reader), Jennie Myers (Director, Land Management Project), and Terry Whelan (Land Management Project).

Additional Step:

During the literature search processes, the bibliographies of relevant sources were used to identify additional information.

Toward the end of the literature search process, several individuals were contacted for more information about specific writings or to confirm the results of the search. The contacts included two people from USEPA's Center for Exposure Modeling, five planning and engineering academics, and two engineers. See Appendix A for list of contacts.

Although the model identification process used for this thesis yielded a wide a range of literature, several weaknesses of this process should be noted. First, work in progress and soon to be published information could not be identified.[21] Second, almost all of the writings were from scientists and engineers. Planners do work with water quality models, but as a whole, the planning community has published much less on this subject than have scientists and engineers. Third, the information used in the thesis partly depended on which identified sources could be obtained. The majority of the identified sources were obtained quickly from MIT, EPA, and Land Management Project holdings. Finally, the sources identified in the literature review are a function of the author's understanding of the topic, which increased dramatically during the year. It is possible, therefore, that relevant sources identified in the early stages of the research were inadvertently omitted.

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[21] One exception to this is the Donigian and Huber (in press) report sent to me by Thomas Barnwell, Jr., USEPA.

A.2 Model Selection Process

Of the models identified, only seventeen were selected for review in this thesis. Because the literature search was quite broad, hundreds of model write-ups were identified and reviewed. Many of these write-ups described very technical, research-oriented processes. However, several others described models, processes, regulations, and model applications that would be of interest to planners looking for more general water quality materials. Unfortunately, most of this information did not address the thesis research questions.

The models selected for review were PC-based models explicitly considering NPS pollution water quality impacts. The focus of this research was computer-based tools for addressing water quality. PC-based models were chosen to limit the model search to technology that is likely to be accessible to planners. Although mainframe-models might offer additional modeling capabilities, it is unlikely that many planners have access to mainframes. NPS pollution was selected as the core of this analysis for two reasons. First, NPS water quality pollution is a major concern for many communities and a growing concern for many more. Second, NPS pollution is directly tied to land use, and land use planning is central to the planning profession.

These criteria are more general than those used in most model reviews. However, they appropriately narrow the topic to the needs of planners. Many model reviews require the reviewed models to be "operational." The characteristics of operational models include sufficient documentation of the model, user support of the model, and experience (or proven track record) (Donigian and Huber, p. 3).

The models reviewed in this thesis were not required to meet this operational definition. The information used was not always sufficient to determine whether or not the models were operational. However, for each selected model, documentation, user support, and experience were examined. A more comprehensive discussion about how these models were reviewed follows.

B. DESCRIPTION OF MODEL CHARACTERISTICS

The framework used for this model review adapted frameworks used for other model reviews and oriented the relevant components toward the analytical needs of planners. The template used to highlight descriptive characteristics comes primarily from Huber and Heaney (1982) and Donigian and Beyerlein (1985). The subjective characteristics template reflects the criteria developed in Chapter 3. The detailed model reviews were adopted from the framework used in Basta and Bower (1982) and Donigian and Huber (in press).

The <u>descriptive characteristics</u>, annotated in Table 5.2, represent significant features applicable to both load sources and receiving water models. Although some of the

TABLE 5.2

Descriptive Characteristics and Capabilities of Selected Water Quality Models

(Definitions and Explanations)

Model Description	
NPS Pollutant Load Models	estimate NPS loads from runoff and groundwater recharge and simulate hydrologic changes
Receiving Water Models	estimate physical, chemical, and biological processes occuring in receiving waters
Land Use/Load Sources	
Urban	primary land use category
Agriculture	primary land use category
Forest/Natural	primary land use category
Mining	primary land use category
Wetlands	primary land use category
Precipitation	potential pollutant sources
Chemical Application	potential pollutant sources
Individual Sewage Disposal System	potential pollutant sources
Hydrology, Water Body & Flow Conditions	
Hydrological Conditions	
Surface Runoff	rainfall runoff from land surfaces into surface waters
Snowmelt	runoff from snowmelt into surface waters
Subsurface Processes	recharge, seepage, infiltration
Surface Water Body	
Rivers/Streams	
Lakes/Impoundments	
Estuaries	
Flow Conditions	
Confined Flow	
Drainage/Control Structures	
Water Quality	
Sources of Pollution	
Point Source Discharges	concentrations or conditions
Temperature	conditions
Erosion & Sedimentation	concentrations/conditions or loads
Nutrients	concentrations/conditions or loads
Pesticides/Organics/Toxics/Metals	concentrations/conditions or loads
Indicators of Water Quality	
D.O./BOD/NBOD	concentrations or conditions
Biological Conditions	concentrations or conditions
Time Scale & Conditions	
Average Conditions	prediction of average annual, seasonal, monthly, or daily loads
Event Loads	analysis of single event, typically storm event
Continuous Simulation	simulates output for extended period of time using time steps typically ranging from a few minutes to one day (Donigian and Beyerlein, p. 9)
Space Scale	
Segmented/Multiple Catchments	segmentation of an area into multiple catchments and land use categories (Donigian & Beyerlein, p. 10)
Lumped/Single Catchment	single land use catchments with uniform (or lumped) characteristics (Donigian and Beyerlein, p. 10)
Computer Program	Fortran, Basic, Lotus 1-2-3, etc.

differences between loading and receiving water models are significant, a single list of characteristics was used to highlight information relevant planners. However, the template is oriented somewhat more toward features of load source models which address NPS pollution more directly and are often more useful for the types of questions planners answer. For example, land use/load sources are inherent to load source modeling and less important for receiving water modeling. The information on descriptive characteristics was taken from the literature.

The <u>subjective characteristics</u> of the model represent a synthesis of the criteria presented in Chapter 3. Table 5.3 annotates the specific areas of interest. The responses to the subjective characteristics were my interpretations of how the models might be used by planners.

The <u>detailed model descriptions</u> were based on the literature. Table 5.4 is an annotated version of the format used for the model descriptions found in Appendix B. In order to ensure the most accurate representation of these models, the descriptions from the literature were incorporated with little editing. The information sources are noted on the model descriptions. Any of my interpretations were noted.

TABLE 5.3

Subjective Characteristics and Capabilities of Selected Water Quality Models

(Classifications)

MODEL DEVELOPMENT		
RESULTS:	Realistic	Y=yes; N=no
	Verifiable	Y=yes; N=no
DATA:	Requirements	L=low; M=moderate; H=high
	Easy to obtain	Y=yes; N=no; S=somewhat
VARIABLES:	Understandable	Y=yes; N=no
OUTPUT:	Clear	Y=yes; N=no
USE OF MODEL		
EASY TO ACQUIRE		Y=yes; N=no
COST:	Adaptation	L=low; M=moderate; H=high
	Use	L=low; M=moderate; H=high
SYSTEM SETUP REQUIREMENTS		L=low; M=moderate; H=high
TECHNICAL KNOWLEDGE		L=low; M=moderate; H=high
EASY TO USE & UNDERSTAND		Y=yes; N=no; S=somewhat
DOCUMENTATION		A=available; DK=don't know
MODEL SUPPORT		A=available; DK=don't know
APPLICATION OF MODEL RESULTS		
APPLICABLE:	Site-level	Y=yes; N=no
	Water body	Y=yes; N=no
	Watershed	Y=yes; N=no
TRANSFERABLE:	Region	Y=yes; N=no
	Nation	Y=yes; N=no
POLICY CHOICES:	Visible	Y=yes; N=no
	Changeable	Y=yes; N=no
	Ability to compare	Y=yes; N=no

TABLE 5.4

MODEL DESCRIPTION FORMAT

Name: Name and commonly used acronym

Type of Method: Identification of overall model effort (NPS pollutant loads and receiving waters)

Purpose: General description of model purpose. (Ex.: Predict runoff processes in urban areas.)

Land Drainage Area: Identification of land area considered for modeling (urban or non-urban). For NPS pollutant load models, specific land areas/land uses identified (e.g., Non-urban agricultural uses (crops and pasture).

Time Properties: Description of temporal variation used in model. The most common time sequences include (a) average conditions, (b) single/storm event loads, and (c) continuous simulations.

Space Properties: Identification of spatial variations incorporated in models: single/lumped catchment or multiple/segmented catchment. For NPS pollutant load models, the number, size, and dimensions of catchments are considered. For receiving models, the spatial dimension are identified as well as the as the ability to look at discrete areas of the water body.

Method & Techniques: Description of theoretical basis for model and identification of significant techniques employed in addressing model questions (i.e., physical, chemical, and biological processes).

Data Needs: Description of data inputs needed to run the model.

Output: Description of output of the assessment.

Limitations: Identification of major model constraints and problems.

Computer Hardware & Software: Description of programming language, hardware, and software required to run the model.

Linkage to Other Models: Description of linkages between different models.

Level of Effort: Description of requirements for data, personal, system setup, and assessment.

Experience/Validation: Description of where model has been used successfully. Description of model validation and review process.

Contact: Information about where to purchase and/or receive more information about the model.

Other: Description of miscellaneous issues.

References: Identification of model references, and sources most heavily relied upon for model summary information.

Source: Categories and definitions are simplifications of those used in Basta and Bower (1982); Basta and Moreau (1982); Huber and Heaney (1982); Hinson and Basta (1982); and Donigian and Huber (in press).

CHAPTER 6

MODEL SUMMARIES AND ANALYSIS

This chapter includes the model summaries and model analysis. The model summary section includes brief model summaries as well as the templates containing the descriptive and subjective model characteristics. Longer template "model descriptions" are given in Appendix B. In the model analysis section, both descriptive and subjective model characteristics are assessed.

A. MODEL SUMMARIES

This chapter provides summary information on the seventeen models reviewed. In Section A.1, the models are highlighted in one paragraph summaries, including developer, purpose, history, methods, land areas, time properties, space properties, experience, validation, and overall impressions. In Section A.2, the two templates addressing descriptive and subjective model characteristics are presented.

A.1 Model Summaries

For the following model summaries, all factual information was taken from model documentation and reviews. Any subjective information reflects my opinions.

A.1.1 AGNPS (Agricultural Nonpoint Source Pollution Model)

Released in 1986 by Young and the U.S. Department of Agriculture-Agriculture Research Service, AGNPS is a runoff model designed to provide accurate information on runoff; it also allows the user to compare the effects of different BMPs within an agricultural watershed. The model simulates runoff, sediment, and nutrient transport for a single storm event or for continuous simulation. The model divides the watershed into cells (e.g., 1 acre), and model computations are done at the cell level. The output for analysis of one cell is the input for analysis of an adjacent cell. Modeling procedures predict runoff volumes, watershed flow, soil erosion, and nitrogen and phosphorus concentrations. The model can also include point source loads from feedlots, wastewater treatment plants, and user-defined stream banks and gully erosion. Use of AGNPS has been limited primarily to the Midwest. Although it has limited demonstrated experience, the model has been validated using data from several Midwestern agricultural watersheds. The overall requirements for model setup, use, and assessment appear to be moderate.

A.1.2 ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation)

ANSWERS was released in 1981 by its developers, Beasley and Huggins of Purdue University. It is primarily a runoff and sediment model for agricultural watersheds and can be used to evaluate BMPs. Model simulations are done on an event basis, usually a single storm. ANSWERS uses a distributed space scale where the watershed is divided into square grids, and within the grids the model simulates processes of interception, infiltration, surface storage, surface flow, subsurface drainage, sediment drainage, and sediment detachment, transport, and deposition. The output from one grid cell is then used as input for the adjacent grid cell. Other modeling procedures include nutrient simulation of nitrogen and phosphorus based on simple correlations between concentration and sediment yield/runoff volume. Model use has been limited primarily the Midwest, and it has been validated by its developers. The setup, personnel, and assessment requirements appear to be moderate, but the data demands seem to be high.

A.1.3 BURBS: A Simulation of the Nitrogen Impact of Residential Development on Groundwater

BURBS was developed by Hughes and Pacenka (1985) at the Center for Environmental Research at Cornell University. BURBS is a load-source model designed to compute the potential nitrogen concentrations that would be recharged to groundwater as a result of residential development as well as the amount of nitrogen that would be leached into groundwater. Eighteen user-defined parameters (e.g., major types of land coverage) characterize the development.

Suggested parameter values are provided. Model calculations incorporate annual load estimates for a single catchment. BURBS was designed as a planning tool for assessing the impacts of a development before it is built. Model validation and use are unknown. (The suggested parameter values come from work done on Long Island, NY.) Presumably, the model could be adapted for use throughout the U.S. This Lotus 1-2-3 model appears to be easy to setup and use, and data and personnel requirements are minimal.

A.1.4 Cape Cod Aquifer Management Project (CCAMP)--A Mass-Balance Nitrate Model for Predicting the Effects of Land Use on Groundwater Quality in Municipal Wellhead Protection Areas

The CCAMP Nitrate Model was developed in 1988 by Frimpter, Donohue, and Rapacz for use by the Cape Cod Aquifer Management Project. To predict nitrate concentrations at the municipal wellhead, this model compares the total nitrogen loads from development and land use within the zone of contribution to a wellhead with the total volume of water entering the zone of contribution to the wellhead. Calculations can also be done for the land surface through and over which water drains into the zone of contribution. Nitrate concentrations associated with different land uses are provided. The calculated level of nitrate concentration can be used to assess the relative effects of different types and levels of development on water quality and to plan development accordingly. The level of nitrate concentration can also be used to evaluate the potential for exceeding nitrate concentration health limits or planning goals. Model use and validation are unknown. This Lotus 1-2-3 model appears to be relatively easy to setup and use, and data and personnel requirements are minimal.

A.1.5 CHEM II

CHEM II, developed by Ffolliott, Guertin, and Fogel (1990), simulates concentrations of dissolved chemicals in snowmelt-runoff from forested watersheds in Arizona. Applications for this runoff model include: simulating the effects of watershed management practices on dissolved chemical concentrations; identifying watershed management practices that are "safe" with regard to water quality standards; and estimating nutrient loads from forested watersheds with specified conditions. Model calculations for the watershed are done on a single streamflow event basis where concentrations of dissolved chemicals are represented as a function of discharge, and discharge is represented as a function of time. The predictive equations allow instantaneous concentrations of dissolved chemicals in streamflows from snowmelt-runoff. Model use and validation are unknown. Overall demands for model setup, use, data, and personnel appear to be moderate.

A.1.6 CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems)

Since its release in 1980, CREAMS (developed by the U.S. Department of Agriculture-Agricultural Research Service) has been validated and applied to multiple agricultural sites with a variety of hydrologic settings, mostly in the south and midwest. CREAMS is an agricultural runoff model designed to analyze BMPs for pollution control. For field-sized areas, the model simulates agricultural runoff and erosion as well as land surface and soil processes that determine fate and transport of pesticides and nutrients. The model can also simulate user-defined management activities such as aerial spraying. The output includes calculations for runoff volume, peak flow, infiltration, evapotranspiration, soil water content, percolation, erosion and sediment yield, and nutrient and pesticide concentrations. The model simulates continuously but can also consider event loads. The model is based on submodels for hydrology, erosion, and chemistry. The overall requirements for setup, data, personnel, and use are high. CREAMS has a companion model, GLEAMS, that analyzes chemical movement to groundwater, with special emphasis on unsaturated zone processes. GLEAMS is discussed below in A.8.

A.1.7 EXAMS (Exposure Analysis Modeling System)

EXAMS-II, released by USEPA in 1985, is a steady-state and dynamic receiving water model designed to evaluate the behavior of synthetic organic chemicals in lakes, rivers, and estuaries. EXAMS divides the water body into segments or zones. The model uses a series of mass balance equations to account for the physical, chemical, and biological processes governing the fate and transport of the compounds. The chemical mass entering and leaving the system, the transport process exporting compounds from the system, and the chemical transformation processes are represented in a set of mass balance equations. The output consists of the resulting chemical exposure, fate, and persistence. EXAMS has been validated with field data and model experiments, and has been used in a wide range of regulatory applications for USEPA. Typically, model demands for setup, use, data, and personnel are high. However, the model can be run with reduced data sets.

A.1.8 GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)

GLEAMS, a companion model to CREAMS, was development by the U.S. Department of Agriculture-Agricultural Research Service (1986). It is an agricultural runoff model designed to utilize the BMP orientation of CREAMS and analyze the vertical flux of pesticides in the root zone. Like CREAMS, it can continuously simulate or use event simulation for field-sized areas. The modeling procedures include: hydrology, erosion/sediment yield, and pesticide components, where precipitation is partitioned between surface runoff and infiltration and water balance computations are calculated daily. The overall demands for model use are unclear, but assumed to be like the demands for CREAMS, high.

A.1.9 HSPF (Hydrological Simulation Program - Fortran)

HSPF (1980) represents the culmination of a series of modeling efforts[22] conducted by USEPA. HSPF is currently in its ninth release. HSPF addresses the behavior of point and NPS loads in surface runoff and receiving waters. (Only NPS components are discussed in this thesis.) According to USEPA HSPF "is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions" (Ambrose and Barnwell, p. 4). Contributions of sediment, pesticides, and nutrients from urban and non-urban areas are simulated for multiple catchments. The output is a time history of water quantity and quality at any place in the watershed as well as a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations. HSPF has been validated with field data and model experiments and used for a wide variety of hydrologic and water quality studies in the U.S. and Canada. The overall

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[22] Earlier models included PTR, ARM, NPS, and WEST.

demands for model use are high.

A.1.10 MINLEAP (Minnesota Lake Eutrophication Analysis Procedure)

MINLEAP, developed by Wilson and Walker (1989), assists efforts in Minnesota for developing lake management strategies. It was designed for use by county and regional lake resource managers. MINLEAP uses an ecoregion data set collected by the Minnesota Pollution Control Agency to predict eutrophication indices in Minnesota lakes. The analysis formulates water and phosphorus balances and uses empirical models to predict lake phosphorus, chlorophyll a, and transparency levels. The results are intended to be used as a screening tool for estimating lake conditions and for identifying problem lakes. MINLEAP uses average load conditions for calculations of lake quality. Although adapted from work done in Vermont, according to the authors, MINLEAP should be adaptable to other ecoregions in the country. Model verification and use are unknown. Given the existence of the ecoregion data, the overall demands for model use are modest.

A.1.11 P8 Urban Catchment Model

P8 Urban Catchment Model (or Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds) was developed in 1989 for the Narragansett Bay Project by William W. Walker, Jr. and IEP, Inc. P8 is a runoff model designed to predict the generation and transport of storm water runoff pollutants in small, well defined, urban catchments. It was developed to provide Rhode Island local and state land use planners and engineers with an easy to use tool for designing and evaluating runoff treatment schemes. More specifically, primary uses of P8 include evaluating site plans for compliance with treatment objectives and selecting and sizing BMPs to achieve a given treatment objective. The model can also be used to make "absolute" predictions (e.g., predicting runoff water quality and loads). The model relies upon USEPA's Nationwide Urban Runoff Program (NURP) data for calibration of certain water quality parameters, and requires little additional data. Modeling procedures include continuous water-balance and mass-balance calculations for user-defined systems consisting of watersheds, devices, particle classes, and water quality components. P8, developed for Rhode Island, is being adapted for use in North Carolina and Minnesota. The demands for model setup, use, and data are low. However, the model users need a moderate level of knowledge to use this model.

A.1.12 Revised Phosphorus Loading Model Adopted by Rhode Island's Nonpoint Source Pollution Management Program

The revised phosphorus loading model was developed by Carlson and Scott (1989) for Rhode Island Department of

Environmental Management. This runoff model was designed to estimate phosphorus loads, concentrations, and trophic state of a lake or pond. The outputs for development scenarios include "high" and "low" estimates based on usage of high and low phosphorus loading coefficients and an indicator of trophic state. According to the authors, "[t]he model provides local officials with a tool which can be used in conjunction with other data to assess existing water quality conditions, define realistic water quality goals, and assess the potential response of waterbodies to various land use decisions." Model use and validation is unknown. The setup, use, data, and personnel demands for this IBM compatible spreadsheet model appear to be modest.

A.1.13 SWMM (Storm Water Management Model)

SWMM, originally developed for USEPA between 1969 and 1971, is now in its fourth version. SWMM is a comprehensive model designed to analyze water quality and quantity problems resulting from urban runoff. Continuous and single-event simulations are possible throughout the model. Simulations include: all aspects of the urban hydrologic and quality cycle (e.g., rainfall, snowmelt, surface and subsurface runoff), flow routing through drainage networks, storage, and treatment. SWMM processes are segmented into blocks--Runoff, Transport, Extran, Storage/Treatment, and Statistics--for rainfall-runoff, routing, and statistical computations. All blocks, but Extran, simulate water quality; EXTRAN is used for hydraulic analysis. SWMM can be used for single catchments or multiple catchments. SWMM has been calibrated, verified, and used for many cities through the U.S. and Canada, as well as some application world-wide. Typically, the overall demands for model use are high. However, it is possible to use SWMM for more simplistic configurations.

A.1.14 SWRRB (Simulator for Water Resources in Rural Basins)

SWRRB, released by Williams, Nicks, and Arnold in 1985, is a continuous simulation runoff model designed to evaluate water quality for large agricultural watersheds. This model simulates weather, hydrology, crop growth, sedimentation, and nitrogen, phosphorus, and pesticide movement on a daily time step basis. Modeling procedures include dividing the basin into multiple segments. SWRRB is used by the Exposure Assessment Branch, Hazard Evaluation Division and the Office of Pesticide Programs at USEPA. The model was tested on watersheds throughout the U.S., and results show that SWRRB simulation outputs are realistic for a variety of soils, climates, land-uses, topographies, and management systems. According to Donigian and Huber (in press), the nitrate capabilities of the model are still being tested. Several aspects of this model are modifications of CREAMS. The overall demands for model use range from moderate to extensive.

A.1.15 VirGIS: Annual Estimation of Nitrogen in Agricultural Runoff Using VirGIS (Virginia Geographic Information System)

This is a surface runoff procedure developed by Yagow, Shanholtz, Kleene, and Flagg (1990). The model uses inputs from an existing raster GIS database to estimate annual nitrogen loads in surface runoff from agricultural watersheds and field-sized areas. Mass-balance calculations for hydrologic and nitrogen loading components are done for this event-based model. The model can be used to estimate the impacts of BMP implementation and nutrient management. Preliminary verification was conducted for watersheds in Virginia. Other experience with this model is unknown. Although this model is designed for use with an existing raster GIS database, it could be used with manual input of data. Data and personnel requirements for the "base" model appear to be moderate. However, setup, maintenance, and personnel requirements for a GIS system are more extensive.

A.1.16 WASP4 (Water Quality Analysis Simulation Program)

WASP4 is a USEPA model currently in its fourth version. WASP4 models contaminant fate and transport in receiving surface waters using a generalized framework. The generalized framework allows WASP4 to be applied to one, two, or three dimensions. This steady-state model treats

NPS pollution loads as point source equivalents. Two models accompany WASP4, TOXI4 and EUTRO4. TOXI4 predicts dissolved and sorbed chemical concentrations in the bed and overlying waters by combining a kinetic structure adapted from EXAMS2 with the transport structure and sediment balance equation used in WASP4. EUTRO4 predicts dissolved oxygen and phytoplankton dynamics affected by nutrients and organic material by combining a kinetic structure adapted from the Potomac Eutrophication Model with the WASP4 transport structure. For all WASP4 operations, the water body is divided and represented as a series of computational elements. The WASP4 models have been used in a wide range of regulatory applications for the USEPA; some of the applications have been verified with field data and model experiments. The overall demands for model use are high.

A.1.17 Williamstown Nitrate Loading Model

The Williamstown Nitrate Loading Model was developed by Phil Herr in 1989 for use by the Williamstown Planning Board. This load-source model is designed to estimate and compare the nitrogen loads generated and recharged on specific-sites and the amount of water being recharged through that site. The result is a loading equivalent that can be compared with health permits or planning goals. Loading equivalents can also be used to compare alternative development plans. Default recharge values based on the literature are provide. The Williamstown model has been adapted for use in other Massachusetts communities and could be adapted for use throughout the U.S. Model validation is unknown. The overall demands for the Lotus 1-2-3 model are modest.

A.2 Descriptive and Subjective Templates

The following templates provide additional information about the models. The descriptive model characteristics, presented in Table 6.1, reflect information taken from model documentation and reviews. The subjective model characteristics, presented in Table 6.2, represent my opinions based upon model documentation and reviews.

B. MODEL ANALYSIS

This chapter summarizes and analyzes the descriptive and subjective characteristics of the seventeen PC-based models reviewed. In the event that PC-based NPS water quality modeling is germane for a specific planning project, these models--when properly applied--are potentially useful to planners.

B.1 Descriptive Review of Seventeen PC-Based Models

The PC-based models reviewed in this thesis offer planners much information about what types of models are currently being used and what these models do. This

TABLE 6.1

Descriptive Characteristics and Capabilities of Selected Water Quality Models

	AGNPS	ANSWERS	BURBS	CCAMP NITRATE	CHEM II	CREAMS	EXAMS	GLEAMS	HSPF	MINLEAP	P8	RIDEM PHOSPHORUS	SWMM	SWRRB	VIRGIS NITRATE	WASP4	WILLIAMSTOWN NITRATE
Model Description																	
NPS Load Models	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X
Receiving Water Models							X		X	X			X			X	
Land Use/Load Sources																	
Urban			X	X					X	X	X	X	X				X
Agriculture	X	X		X		X		X	X	X		X		X	X		
Forest/Natural		X	X	X	X				X	X		X					X
Mining		X							X								
Wetlands										X		X					
Precipitation			X	X					O						X		
Chemical Application			X	X		O			X						X		X
Individual Sewage Disposal System			X	X					X			X					X
Hydrology, Water Body & Flow Conditions																	
Hydrological Conditions																	
Surface Runoff	X	X			X	X	C		X	X	X	X	X	X	X	C	
Snowmelt					X	X			X				X				
Subsurface Processes			X	X				X	C				C	C	C	C	X
Surface Water Body													X				
Rivers/Streams	X			X	X		X		X	X			X		X	X	
Lakes/Impoundments							X		X	X	X	X	X			X	
Estuaries							X						X			X	
Flow Conditions																	
Confined Flow									O		X		X				
Drainage/Control Structures									X		X		X				
Water Quality																	
Sources of Pollution									X								
Point Source Discharges									X				O				
Temperature									X								
Erosion & Sedimentation	X	X				X		X	X		X		X	X	X	X	
Nutrients	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Pesticides/Organics/Toxics/Metals					X	X	X	X	X		X		X	X		X	
Indicators of Water Quality																	
D.O./BOD/NBOD									X				X			X	
Biological Conditions									X	X		X	X			X	
Time Scale & Conditions																	
Average Conditions			X	X						X		X			X		X
Event Loads	X	X			X	X	X	X	X		X		X		X	X	
Continuous Simulation	X					X		X	X		X		X	X			
Space Scale																	
Segmented/Multiple Catchments	X	X				X	X		X				X	X		X	
Lumped/Single Catchment			X	X	X			X		X	X	X	X		X		X
Computer Program	Fortran	Fortran	Lotus	Lotus	Fortran	Fortran	Fortran	Fortran	Fortran	Basic	Fortran	Spreadsheet	Fortran	Fortran	GIS	Fortran	Lotus

X Capability included in model
O Capability not explicitly included but can be user-defined
C Processes considered, but not explicitly modeled

TABLE 6.2

Subjective Characteristics and Capabilities of Selected Water Quality Models

		AGNPS	ANSWERS	BURBS	CCAMP NITRATE	CHEM II	CREAMS	EXAMS	GLEAMS	HSPF	MINLEAP	P8	RIDEM PHOSPHORUS	SWMM	SWRRB	VIRGIS NITRATE	WASP4	WILLIAMSTOWN NITRATE
MODEL DEVELOPMENT																		
RESULTS:	Realistic	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Verifiable	Y	Y				Y	Y	Y	Y		Y		Y	Y		Y	
DATA:	Requirements	M	M	L	L/M	M	H	H	H	H	L	L	L	H	M	L/M	H	L
	Easy to obtain	S	S	Y	Y		N	N	N	S	N/A	Y	Y	S	S	N/A	N	Y
VARIABLES:	Understandable	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
OUTPUT:	Clear			Y	Y						Y	Y	Y					Y
USE OF MODEL																		
EASY TO ACQUIRE		Y	Y				Y	Y	Y	Y			Y	Y	Y		Y	
COST:	Adaptation	M	M	L	L	M	M	M/H	M	M/H	H	M	L	M/H	M	H	M/H	L
	Use	M	M	L	L	M	M	M/H	M	M/H	L	L/M	L	M/H	M	L	M/H	L
SYSTEM SETUP REQUIREMENTS		D/W	D/W	D	D	D/W	D/W	D/W	D/W	D/W	D/W	D	D	D/W	D/W	D/W	DK	D
TECHNICAL KNOWLEDGE		M	M/H	L	L	M	H	H	H	H	L	M	L	H	M	M	H	L
EASY TO USE & UNDERSTAND		S	S	Y	Y	S	N	N	N	N	Y	Y	Y	N	N	S	N	Y
DOCUMENTATION		A	A	A	A	DK	A	A	A	A	DK	A	A	A	DK	DK	A	A
MODEL SUPPORT		A	A	DK	DK	DK	A	A	A	A	DK	DK	A	A	DK	DK	A	DK
APPLICATION OF MODEL RESULTS																		
APPLICABLE:	Site-level			Y	Y		Y		Y			Y				Y		Y
	Water body							Y		Y	Y		Y				Y	
	Watershed	Y	Y		Y	Y				Y	Y	Y	Y	Y	Y	Y		
TRANSFERABLE:	Region	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y
	Nation			Y	Y		Y	Y	Y	Y	Y	Y	Y	Y			Y	Y
POLICY CHOICES:	Visible	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y			Y	Y	Y
	Changeable	Y	Y	Y	Y	Y	Y		Y			Y	Y			Y		Y
	Ability to compare			Y	Y							Y	Y			Y		Y

A=available; DK=don't know
D=days; M=months; W=weeks
L=low; M=moderate; H=high
Y=yes; N=no; S=somewhat

information can be used to help planners identify how their needs relate to existing models.

Model descriptions. Fifteen of the seventeen water quality models reviewed estimate NPS pollutant loads. Of these fifteen, eleven address surface runoff and four address groundwater load sources; three of the eleven runoff models also model surface receiving waters. The remaining two models focus on the physical, chemical, and biological processes occurring within surface receiving waters. The breakdown between the number of NPS loading and receiving water models was heavily influenced by the NPS and water quality focus of this research; by definition, loading models address NPS concerns, whereas receiving water models may or may not.

Land use/load sources. The loading models fell into the categories of urban only, non-urban only, and mixed sources. Two models consider urban load sources only; seven, non-urban only; and six, mixed sources. Many of the models considering urban and non-urban load sources were developed to address pre- and post-development scenarios.

Surface and subsurface water bodies. Thirteen of the seventeen models address either surface runoff or surface receiving waters; the other four models address groundwater load sources. For the most part, the surface water models look at runoff as a loading source for streams, rivers, lakes, ponds, reservoirs, and estuaries. The more urban models also look at confined flows and drainage control structures. The surface receiving water models can be used to analyze similar water bodies. The groundwater models reviewed only consider load sources. The fact that there are no subsurface receiving water models does not indicate that this category of modeling is unable to address NPS water quality concerns. The absence of these models more likely reflects a gap in the model search process. Several of the models consider both surface and subsurface procedures. For the most part, these models do not model groundwater loads sources, and none model groundwater process; instead, most of these models make assumptions about how much precipitation will reach surface waters, and one of the assumptions influencing this is the amount of precipitation recharged into groundwater.

Water quality. Most of the models estimate pollutant loads and levels for more than one pollutant. The most commonly modeled contaminants include nutrients (16), erosion and sedimentation (10), and pesticides, organics, toxics, and metals (9). The water quality indicator of dissolved oxygen was only explicitly modeled by receiving water models. Biological conditions were modeled in receiving water models, but were also considered by some of the surface runoff models that include screening indexes for biological conditions.

Time scale and conditions. Many of the models reviewed are capable of handling data that come from different time scales. Six models use average condition data; eleven, event-based data; and seven, continuous simulation data. Several of the models usable for either event-based or continuous simulation conditions.

Space scale. Eleven of the models are designed for use with lumped or single catchments, and seven make calculations for segmented or multiple catchments. One model was explicitly designed to allow both. The more simple surface water models and all of the subsurface water models reviewed make calculations for a single catchment. The more complicated models, especially the agricultural models, segment the catchments being analyzed.

Computer programs. Most of the models (11) were developed in Fortran. As for the others, one was developed in Basic; one, for use as part of a GIS; and four, for use on IBM-compatible spreadsheets. Although three of the four spreadsheet models considered groundwater load sources, these models do not need to be created using spreadsheets. It is possible that three of the four groundwater load source models are analogous because they were all developed for similar planning purposes in the northeast.

This review of descriptive characteristics captures the essence of the models. These characteristics are, however, by no means exhaustive.

B.2 Subjective Review of Seventeen PC-Based Models

This section provides a subjective component to the model reviews. The caveats of the analysis are presented as well as the analysis of model applications, model requirements, and overall model usefulness. The model evaluations are intended to frame the relevant questions for planners and assist them in making their own evaluations of the models. They are not meant to endorse or criticize specific models or make definitive conclusions about the usefulness of these models.

B.2.1 Model review caveats and limitations

Evaluation of individual models is a difficult and subjective task for several reasons. First, it is difficult to evaluate a model for more than one user and one situation. It would be easier to evaluate the appropriateness of models for use by a specific person for a specific project, rather than to offer generic advice. In this thesis, the understood user of the models is a assumed (1) to be PC-literate, (2) to have no extensive formal technical background, and (3) to be interested in water quality modeling in conjunction with land use planning. This user is the "baseline" planner for whom the subjective evaluations are based. (Note: It is not necessary for planners to use these models alone. Modeling efforts may be more realistic and efficient with the assistance of a technically-trained individual.) Second, this author's ability to review the models plays a significant role in the model evaluations. Because this thesis was used a way for the author to learn about water quality modeling, her ability to understand and interpret relevant water quality and modeling theory evolved throughout the review process. Although careful attention was paid to assessing and documenting the effectiveness of models, the results are the author's interpretations based upon model reviews and model documentation. Third, the information used to review the models varied from extensive model documentation to write-ups published in conference proceedings. The reviews based on model documentation and multiple sources about the model are more substantial. Fourth, the author was unable to independently review methods of model calibration and verification because of her limited knowledge in the area of water quality.

B.2.2 Review of model usefulness

The usefulness of specific models depends on the user's needs and resource constraints. Therefore, the usefulness of specific models should be judged by the prospective user. To assist in this evaluation, several characteristics of the models are summarized. The topics include (1) model applications and uses, and (2) resource requirements of each model. These topics provide a framework that allows planners to determine the relevance of applications as well as compare resource demands against available resources.

Primary Model Applications and Uses

In this section, a primary application or use is identified for each model reviewed. This summary is one tool for matching a model with modeling needs. Of the seventeen models reviewed, eleven of the primary applications related to evaluating proposed (or actual) development or the impacts of proposed (or actual) BMPs. Other applications included comprehensive analyses of hydrology and water quality conditions, regulatory assistance, and problem identification procedures. A list of the primary application or use, by model, follows in Table 6.3.

Model Requirements

This section summarizes subjective impressions of four areas: data requirements, personnel requirements, length of time for system setup, and length of time for conducting model assessments. Based on the information available, these questions were answered with relative confidence. These categories highlight some of the major modeling requirements. Other requirements include budget, time frame, hardware, and software. Donigian and Huber (in

TABLE 6.3

APPLICATIONS OF SELECTED MODELS

AGNPS	BMP evaluation
ANSWERS	BMP evaluation
BURBS	Assess impacts of development
CCAMP Nitrate Model	Assess impacts of development
CHEM II	Watershed management practice evaluation
CREAMS	BMP evaluation
EXAMS	Regulatory applications
GLEAMS	BMP evaluation
HSPF	Comprehensive analysis of watershed hydrology and water quality
MINLEAP	ID problem lakes
P8	Site plan evalution; selecting and sizing BMPs
RIDEM Phosporus Model	Assess impacts of land use changes
SWMM	Comprehensive analysis of hydrology and water quality
SWRRB	Evaluate basin scale water quality
VIRGIS Nitrate Model	BMP evaluation
WASP4	Regulatory applications
Williamstown Nitrate Model	Assess impacts of development

press) analyzed models along similar lines for engineers[23]. Their conclusions were used as a basis for assessing the requirements with planners in mind.

Data and personnel requirements were divided into three categories[24]: low, moderate, and high. These breakdowns were not intended to be absolute or definitive; instead, they are designed to provide a rough indication of model requirements. For data requirements, the distinctions were defined for this thesis:

Low: little data required, easily obtainable (e.g., from site visits, local government, scientific literature).

Moderate: data requirements vary but data demands are not excessive; general data often available from government agencies, however, some data is very specific to cells or elements in a multiple catchment analysis. Models requiring much easily obtainable data are classified as moderate.

High: extensive and complex data required.

For personnel requirements, the distinctions were defined for this thesis:

Low: little or no technical background needed to use the models; a general understanding of the issues required.

Moderate: some technical experience with water quality issues and models necessary; prior experience or knowledge of water quality analysis recommended.

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[23] Donigian and Huber (in press) used the following analytical categories: data and personnel requirements, overall model complexity, system setup, and assessment.

[24] Categories from Donigian and Huber (in press); definitions designed for thesis.

High: extensive training or understanding of water quality issues and models required.

System setup and model assessment were divided between the estimated amount of time required to perform tasks: person days, weeks, months.[25] System setup refers to the process of getting the model up and running. Model assessment refers to the analysis and application of results. The amount of time for setup and assessment was estimated relative to the baseline of the assumed skills outlined in section B.2.1 of this chapter. Of course, the amount of time required to perform a task depends on the individual as well as the circumstances of the project.

Table 6.4 summarizes estimated data and personnel requirements and setup and assessment times for the models reviewed.

Overall Model Complexity

Ultimately, the overall usefulness of a particular model applied to a particular situation can only be decided by the planner. Donigian and Huber (in press) highlight the tradeoffs between models in their descriptions of data requirements and ease of applications. This relationship can be extended to cover personnel requirements. Should a planner with limited technical skills believe that a model

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[25] Categories from Donigian and Huber (in press); definitions for setup and assessment were inferred from Donigian and Huber (in press).

TABLE 6.4

MODELING REQUIREMENTS OF SELECTED MODELS

	Data	Personnel	System Setup	Assessments
AGNPS	Moderate	Moderate	Days/weeks	Weeks/months
ANSWERS	Moderate	Moderate/High	Days/weeks	Weeks/months
BURBS	Low	Low	Days	Days
CCAMP Nitrate Model	Low/Moderate	Low	Days	Days
CHEM II	Moderate	Moderate	Days/weeks	Days/weeks
CREAMS	High	High	Days/weeks	Weeks/Months
EXAMS	High	High	Days/weeks	Weeks/Months
GLEAMS	High	High	Days/weeks	Weeks/Months
HSPF	High	High	Days/weeks	Weeks/Months
MINLEAP	Low	Low	Days/weeks	Days/weeks
P8	Low	Moderate	Days	Days/weeks
RIDEM Phosporus Model	Low	Low	Days	Days
SWMM	High	High	Days/weeks	Weeks/Months
SWRRB	Moderate	Moderate	Days/weeks	Weeks/Months
VIRGIS Nitrate Model	Low/Moderate	Moderate	Days/weeks	Days/weeks
WASP4	High	High	Don't Know	Weeks/Months
Williamstown Nitrate Model	Low	Low	Days	Days

more complicated than he/she is capable of operating is the most appropriate, technical expertise should be sought to help with the process. Often larger research problems and questions will be addressed by more than one or two people, speeding setup and assessment time. Similarly, the rule of thumb models and spreadsheet analyses often could be used successfully by someone who conscientiously adapts the model for a specific planning action.

If the models must be divided by usefulness, there are three simplifying categories: models with low overall requirements, moderate overall requirements, and high overall requirements. These categories reflect the data, personnel, setup, and assessment interpretations. Table 6.5 indicates the models' overall complexity.

Donigian and Huber (in press) summarized the question of usefulness with regard to runoff models. They wrote:

> When properly applied and their assumptions respected, models can be tremendously useful tools in analysis of urban and non-urban runoff quality problems. Methods and models are evolving that utilize the large and currently expanding data base of quality information. As increasing attention is paid to runoff problems in the future, the methods and models can only be expected to improve (Donigian and Huber, p. 30).

Assuming that this analysis holds true for runoff, pollutant loading, and receiving water models, planners should consider water quality models a viable tool for addressing NPS water quality problems today and in the future.

TABLE 6.5

OVERALL REQUIREMENTS OF SELECTED MODELS

AGNPS	Moderate
ANSWERS	Moderate/High
BURBS	Low
CCAMP Nitrate Model	Low
CHEM II	Moderate
CREAMS	High
EXAMS	High
GLEAMS	High
HSPF	High
MINLEAP	Moderate
P8	Moderate
RIDEM Phosporus Model	Low
SWMM	High
SWRRB	Moderate/High
VIRGIS Nitrate Model	Moderate
WASP4	High
Williamstown Nitrate Model	Low

CHAPTER 7

FUTURE OF WATER QUALITY MODELS IN LAND USE PLANNING

Although it is difficult to determine the usefulness of specific NPS water quality models, it is appropriate to recognize the general and overall usefulness of these models. Continuing methodological and conceptual advances in modeling will make them even more valuable for integrating land use decisions and water quality objectives.

Factors likely to influence the future of water quality planning are geographic information systems (GIS) and legislation and policy addressing the relationship between land use and water quality. Examples of potential uses of GIS and legislation are offered in this chapter.

A. GIS AND WATER QUALITY PLANNING

GIS is part of a larger body of computer-related tools available to planners. Among these tools--CAD environments, spreadsheets, and database managers--GIS offers superior opportunities for planners to relate environmental information with the spatial aspects of water bodies and land use. GIS can integrate the locations of inherently spatial items (like wellheads or lakes) with information about the characteristics of these specific points. For example, in a system with information about wellheads, land use, and pollutant discharges, a GIS could be used determine which land uses in a designated area around the wellhead contribute nitrate loads.

A.1 Background

GIS modeling technology is essentially an outgrowth of a planning method developed by Ian McHarg called "suitability analysis" (Males, p. 101). Much like suitability analysis, GIS technology performs analysis across different layers of attributes (Males, pp. 101-102). For water resource applications, the data layers often include land use, land cover, geology, soils, steams, water distribution systems, sewer systems, terrain, and surface information (Males, p. 103).

Currently, GIS technology may be unable to meet some of the tasks needed for complex water resource analysis. The current technology used to perform water resource applications was developed by and for the general planning community, and is frequently inadequate for more engineering-oriented water resource applications, such as hydrologic modeling and surface and groundwater interaction (Grayman, p. 111).

Grayman, a consulting engineer on GIS and water issues, predicts that GIS will be integrated with other computer-based tools to provide capabilities for spatially based analysis and display systems (Grayman, p. 112). He believes these advances will have synergistic effects on water resource modeling (Grayman, p. 113). The combination of new technology and greater availability of data may result in "renewed development" of models designed to use spatial data (Grayman, p. 113). Improvements among a broad spectrum of water quality models may occur, including "groundwater and groundwater - surface water models, non point source models, stream hydraulic and water quality models, sewer and water system analysis and design models" (Grayman, p. 113).

If this is true, the development and usage of water resource-related GIS applications will be divided among general planners and water resource planners and engineers. This division already exists, but would likely be more distinct with even greater divergence in the complexity of modeling. This poses interesting questions about accessibility and the usefulness of engineering models for planners.

A.2 Examples of GIS Applications

Of the models reviewed in this thesis, one of the models (the VirGIS nitrate model) was designed to use a GIS. In addition, several of the other models have (or soon will have) the ability to link to GIS (e.g., AGNPS, RIDEM, P8, WASP4). In an analysis of WASP4/GIS linkage, Dilks and Slawecki (1990) determined that current effective GIS use was limited to data input preparation and output display (pp. 646-648). This observation is likely true for the other observed models, with the exception of VirGIS, which uses the GIS as a modeling tool.

Application of GIS for input/output assistance and modeling can be useful. Today, much GIS work includes input/output assistance. However, as data availability increases and technology improves, GIS will be used more and more as a modeling tool.

Of the GIS information reviewed for this thesis, the most examples were from the VirGIS program.[26] Although the full scope of the VirGIS Project is unclear, much has been written about Virginia's efforts to use GIS and water quality models as state-level NPS pollution control management tools.[27] The integration of GIS, database and management tracking, and modeling programs has become a framework from which additional tools for addressing NPS pollution control efforts can be developed using mainframe computers and PCs. These general program areas are highlighted below.

<u>GIS:</u> VirGIS was begun in 1985 to provide spatially-referenced digital information. The data coverages include

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[26] This information was given to me by Thomas Van Buren, MIT MCP student. He obtained this information through personal correspondence with Vernon O. Shanholtz, Director of the Information Support Systems Laboratory at Virginia Tech, Blacksburg, Virginia.

[27] This effort is part of Virginia's comprehensive NPS pollution control program. Key objectives include: effective NPS pollution problem identification, prioritization, targeting, and assessment of off-site benefits (Flagg, et. al, p. 1). The Virginia agency leading these efforts is the Department of Conservation and Recreation, Division of Soil and Water Conservation.

soil type, elevation, agricultural land use, surface drainage, political boundaries, and watersheds. According to Flagg, Hession, and Shanholtz (no date), VirGIS attributes and abilities include:

--support of government agencies,

--improved detailed modeling algorithms,

--improved model interfaces for water quality models,

--coordination of basic resource information (e.g. soils and land use),

--enhanced ability for government agency to make detailed, timely evaluations for management decisions,

--assistance for mapping and data summaries (for government agencies, research, and consulting interests not directly involved) (Flagg, Hession, and Shanholtz, p. 3).

<u>Database Management and Tracking:</u> HYDROMAN is Virginia's PC-based software program for hydrologic unit management. It allows users to store, query, and display spatially referenced NPS water quality assessment information (Flagg, Hession, and Shanholtz, p. 4). Menu-driven functions allow users to access extensive spatial and non-spatial databases for reporting, analysis, screen mapping, and output functions. The HYDROMAN database includes spatial and nonspatial layers. For the spatial layers, there are 492 unique watershed elements, 136 unique political subdivisions, roads, and streams (Flagg, Hession, and Shanholtz, p. 4). Non-spatial information for water quality criteria is proposed, and will include data for water quality standards violations at monitoring stations,

designated/non-designated nutrient enriched water bodies, identified toxic or other water quality problems, etc. (Flagg et al., p. 3) Other proposed non-spatial databases for quantitative NPS water quality assessment will include major NPS categories (agriculture, forestry, etc.), acreage by watershed, and percentages of agricultural cropland and pasture land by watershed (Flagg, Hession, and Shanholtz, pp. 4-5). HYDROMAN-compatible databases are also used for tracking NPS pollution reductions. Tracked information includes BMPs under state BMP cost-sharing program and nutrient management program (Flagg, Hession, and Shanholtz, pp. 4-5).

Water Quality Modeling integrates three types of data: (1) VirGIS database information on land-based resources, (2) pollution abatement information from the NPS control tracking program, and (3) monitoring data for control and assumption checks (Flagg, Hession, and Shanholtz, p. 5). Current water quality and quantity modeling efforts are being done in conjunction with AGNPS, HSPF, and VirGIS models (Flagg, Hession, and Shanholtz, p. 5).

The integrated use of GIS, database and management tracking, and water quality modeling for Virginia provides an example of the types of analysis possible for basin, state, regional, county and local analyses.[28] Although these analytical efforts are structurally different from the

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[28] For specific VirGIS projects, see Bibliography.

models reviewed Chapter 6 planners considering the advantages of integrated GIS efforts should consider the criteria suggested in Chapter 3 and the subjective evaluations used in Chapter 6.

Another GIS example, from Haness, Warwick, and Dickey (1990), addresses GIS/water quality linkage with respect to storm water quality modeling.[29] This analysis responds to the Water Quality Act of 1987 which requires formal regulation of urban storm water runoff in cities of at least 100,000 people by the early 1990s. Under the proposed EPA regulations, applicable storm water outfalls must be permitted under the National Pollutant Discharge Elimination System (NPDES). This regulation, while acknowledging the significance of storm water runoff as a major water quality pollutant, creates a very difficult assessment and permitting problem. The system used by Haness, Warwick, and Dickey (1990) integrates GIS with hydrodynamic water quantity and quality models (HEC-1 and HEC-5Q). The system quantifies the water quality impacts of urban storm water runoff and can also "identify municipal outfalls affecting surface water quality, classify watersheds based on sensitivity to storm water inputs, and assist the local community in meeting EPA proposed NPDES permit requirements

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[29] This thesis only addresses the water quality aspects of storm water modeling. This example, a surface water quantity and quantity model, is used because of its water quality component as well as its wide-reaching significance to GIS.

for storm water discharges" (p. 176). Haness, Warwick, and Dickey (1990) assert that this integrated system offers cities interested in assessing storm water impacts and proposed mitigation projects an "effective, affordable planning tool" (p. 176). If this system functions well, it is conceivable that in order to comply with NPDES permits, planners may be compelled by the regulation to use integrated GIS/water quality analysis.

The VirGIS and storm water quality models demonstrate the relevance of GIS to land use/water quality analysis. Despite the complexity of these examples, not all GIS applications need be so complex. It is possible, as in the case with Virginia, for planners to share the cost of an overall GIS system with other agencies.

B. LEGISLATION AND POLICIES

The previous example showed how legislation can compel development and use of modeling to integrate land use planning and water quality protection. This section discusses two examples of regional and local legislation which explicitly relate water quality and land use planning. As problems with water increase, more extensive federal, state, and local legislation can be expected.

Anne Arundel County, MD, undertook a comprehensive watershed management program designed to preserve and protect the water resources of the county.[30] The program included 11 watershed areas for which existing hydrologic, hydraulic, and environmental conditions were analyzed and used to estimate future conditions based on existing zoning. The analysis identified areas needing immediate attention and areas where significant water quality deterioration is expected in the near future. Several water quality and quantity models and studies were used (e.g., HEC-2, NURP data). Completion of the plan required cooperative efforts between federal, state, and local agencies. Based on the analysis, the authors concluded: "By incorporating information on wildlife, geology, zoning, developmental activities, and hydrologic/hydraulic impacts, a plan can be developed to reduce the adverse consequences of increased runoff and pollutants in the watershed, as well as the loss of wildlife habitat" (Etzel and Ellis, p. 501). The effectiveness of this comprehensive legislation was constrained by time limitations, which caused analyses to be based on insufficient data.

In North Carolina, one approach to water quality planning focuses on local government actions. The North Carolina Division of Coastal Management began a water quality "planning for prevention" outreach program for local

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[30] All information from Etzel and Ellis (1990).

governments in 1985 (McCullough and Crew, p. 2388).[31] Coastal Management staff provided communities "a handbook, public presentations, and one-on-one work with local planners covering coastal ecology, water quality impacts from development, and how to plan for water quality management through local land use planning" (McCullough and Crew, p. 2388). This process included helping localities recognize problems or potential for problems; identifying the necessity of local action; conveying "achievable" solutions; and explaining why such planning was advantageous for the localities (McCullough and Crew, p. 2392).

As part of the overall coastal water quality effort, localities were encouraged to use existing local policies and ordinances to protect coastal water quality. The "hands-on" activities of localities provide opportunities for implementing policies and programs independently of federal and state policies. In North Carolina, where local governments are oriented toward individual property rights, new federal and state regulations and ordinances regarding water quality have been opposed. Therefore, Lynn Phillips (Planning Director for Carteret County) and John Crew (Chief Land Use Planner for North Carolina Natural Resources and Community Development, Division of Coastal Management) believe that "the prevailing strategy must be for stronger

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[31] This program is part of a larger N.C. water quality initiative, including the N.C. Coastal Area Management Act.

protection of water quality standards through existing plans, policies and regulations in place" (Phillips and Crew, p. 2396). They recommend modifying existing policies and ordinances at the local level.

These examples are just two of many innovative programs used in the U.S. to address the interrelationship between land use and water quality. As other regions begin to address water quality problems or the threat of these problems, they too will likely use some form of legislation or policies. In this effort, planners will be called to take increasing roles in protecting and maintaining water resources.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The focus of this thesis was to identify PC-based water quality models addressing NPS pollution concerns and to determine which of these tools, if any, improve the ability of planners to make land use decisions consistent with water quality objectives. To address this question, conditions for appropriate model use, current applications of models, and future model uses were reviewed.

The models reviewed in this thesis demonstrate the potential for integrating PC-based NPS water quality models with land use planning. Current model uses include evaluating the impacts of development and BMPs, analyzing hydrologic and water quality conditions, assisting regulatory processes, and identifying and screening problem areas. Unfortunately, the transferability of specific models to other users is difficult. Appropriate model use depends on the circumstances under which these models will be used as well as the resources available to the model user. Although model documentation might help potential users evaluate the appropriate use of models, the final decision to use a particular model must be made by the user. Undoubtedly, future models will offer planners an even wider range of tools, but these new models must also be selected and used appropriately.

The models reviewed in this thesis also demonstrate the current range of PC-based modeling available for many surface and subsurface circumstances. They can help planners estimate contamination generated from urban, non-urban, and mixed land use/load sources and simulate receiving water processes. The contaminants commonly modeled include nutrients; erosion and sedimentation; and pesticides, organics, toxics, and metals.

Models comprise an important group of tools for water quality analysis. While they predict physical, chemical, and biological processes, they are neither designed nor intended to answer all questions about the relationship between water quality and land use. Models cannot decide some of the important value judgements made regularly by planners. Although models can approximate the physical effects of land use changes, they cannot help planners decide whether these effects are acceptable or appropriate for a given community. Finally, if used inappropriately and without a firm understanding of the issues being modeled, models can actually distort the relationship between land use and water quality.

Few available water quality writings and models specifically address the NPS pollution issues facing planners. Instead, these writings and models tend to address scientific and engineering research issues. One reason why there are few models oriented more directly toward planners is that models are typically designed by and for engineers and scientists. In addition, much of the federal funding for water quality research targets engineering and scientific problems requiring accuracies greater than those needed by planners. The research also tends to be site-specific. In other words, the characteristics of available models may be driven by federal institutional initiatives and funding for research and model development. Until planners, localities, regions, or states are held more accountable for NPS pollution in water, there may never be the impetus to develop models that can be used effectively by planners.

Throughout the model identification process, I searched for the water quality model equivalent to the Soil Conservation Service (SCS) hydrologic model used in water quantity modeling.[32] Ideally this model or set of models would be readily available to planners and capable, when used appropriately, of helping planners to see better the relationship between land use decisions and water quality. However, such a generically applicable model was not found.

If the models identified by the literature review adequately represent the kinds of PC-based water quality models available to planners, there is a definite gap between planners' needs to evaluate and manage land use in

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[32] According to Gordon and Anderson (1989), the SCS model is a widely used and generically applicable storm water quantity model that can be incorporated into a spreadsheet and used by planners with little technical expertise (pp. 92-94).

conjunction with water quality objectives and the available tools. Although the individual models reviewed are valuable in particular circumstances, as a group the models identified are of limited use, at best, for planners. First, many of these models require moderate to extensive levels of technical knowledge and resources, thereby excluding many potential planning-oriented users. Second, the models identified as requiring less knowledge and resources tended to estimate only one of the many land use related problems facing planners: nutrient loads in groundwater or receiving waters.

This gap may be a function of the complexity of water quality analysis, which requires detailed information about the catchment(s) as well as the water body. Additionally, the physical, chemical, and biological processes affecting water quality are complex, difficult to model, and not always well understood. These complexities may render a generic or transferable model inappropriate.

A second reason why water quality models do not address planners' concerns is that planners do not have a common professional or advisory group that researches water quality issues and sets guidelines and standards for water quality models. There appear to be no formal standards for using water quality models in the planning profession. Until planners are aware of the need to model, and are capable of using the models as part of a larger decision making framework, model use will continue to be limited and sporadic.

With ever-increasing technological capabilities and greater understanding of the processes affecting water quality, the universe of water quality models continues to grow. Perhaps the most promising tool for water quality modeling is the application of GIS. The data, spatial, and analytical capabilities of GIS will greatly enhance planners' ability to model NPS pollutants. Unfortunately, GIS is a resource-intensive system to develop, maintain, and use.

In the interim, planners interested in computer-assisted modeling of water resources should consider the appropriateness and usefulness of existing models. The models identified in this thesis may be a good starting place. Planners should also seek funding and technical assistance from agencies already involved with water quality research, such as USEPA, SCS, and U.S. Geological Survey. Finally, planners should also consider ways to work with other planners, engineers, and scientists toward understanding and developing computer-based methods that address NPS water quality concerns.

APPENDIX A

LIST OF ADDITIONAL INDIVIDUALS CONTACTED DURING THESIS RESEARCH

See Chapter 5, Table 5.1 for individuals contacted during literature review.

<u>Contacted for more information about specific writings:</u>

o Bob Ambrose, Director, U.S. EPA Center for Exposure Assessment Modeling Director

o William W. Walker, Jr., environmental engineer

o Ed Ikner, water quality staff at the Cape Cod Commission

<u>Contacted to verify literature search findings:</u>

o Tim Cartwright, York University, Environmental Studies

o Steven Gordon, Professor of City Planning at Ohio State University

o James Heaney, University of Florida, Gainesville

o Richard Klosterman, Associate Professor of Urban Studies at the University of Akron and chair of the APA's Information Technology Division)

o David Marks, Chair of Civil Engineering Department, Massachusetts Institute of Technology

<u>Other individuals contacted during the thesis:</u>

o Thomas Barnwell, Jr., U.S. EPA Assessment Branch, Environmental Research Laboratory, Athens, GA

o Richard Lewis, Water Quality Liaison at the New York State Soil and Water Conservation Committee

o Ted Pratt, Buzzards Bay Commission and Director of Board of Health, Marion, MA

o Robert Pirani, environmental planner at the Regional Plan Association, New York City

APPENDIX B

DETAILED MODEL SUMMARIES

Notes:

1. These summaries are intended to be factual summaries of the literature. The information found in these summaries was taken from the "key" references with little embellishment. Other references were used to verify information and expand explanations.
2. In Reference section, "*" denotes "key" reference.
3. Italics denote my opinions.
4. Limitations, unless otherwise noted, represent the most significant limitations identified in the literature.

Name: Agricultural Nonpoint Source Pollution Model (AGNPS)

Type of Method: 1. Runoff model

Purpose: Predict concentration of contaminants in runoff waters and surface waters.

Land Drainage Area: 1. Non-urban areas (agricultural)

Time Properties: 1. Single storm event simulation 2. Continuous simulation

Space Properties: 1. Multiple catchments for watershed. Watershed is divided into square working areas (cells). Watershed size can range from 2.5 - 23,000 acres.

Method & Techniques: 1. SCS curve number approach is combined with a unit hydrograph routing procedure for predicting flow in watershed. 2. Modified Universal Soil Loss Equation is used for predicting soil erosion. 3. Pollutant transport portion is subdivided for analysis of soluble pollutants and sediment attached pollutants.

Data Needs: 1. Data is needed for two categories: (a) watershed-scale data (e.g., watershed size, number of cells), (b) cell-level data (parameters based on land practices in cells). 2. Data obtainable through (a) visual field operations; (b) maps (topographic and soils); (c) various publications, tables and graphs. 3. Soil and land use data obtainable from local USDA-SCS office. 4. Meteorologic data: daily rainfall needed for hydrology simulation.

Output: 1. Hydrology estimates: runoff volumes, peak runoff rate. 2. Sediment estimates: upland erosion, channel erosion, and sediment yield. 3. Nutrients estimates: pollutant loadings to receiving cells. 4. Graphics option available to plot different variables within watershed.

Limitations: 1. Does not handle pesticides. 2. Pollutant transport component needs further field testing. 3. Nutrient transformations and instream processes are not within model capabilities.

Computer Hardware & Software: 1. Written in FORTRAN/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models: 1. Linkages to GIS under development.

Level of Effort: *1. Data: moderate. 2. Personnel: moderate. 3. System setup: days/weeks. 4. Assessment: weeks/months.*

Experience & Validation: 1. Model is used extensively within U.S. by government agencies and consultants to evaluate NPS pollution. 2. Model has been validated using field data from agricultural watersheds in Minnesota, Iowa, and Nebraska. Model was also validated for an Illinois watershed using the model's single storm option.

Contact:

Dr. Robert Young
USDA-ARS
North Central Research Laboratory
Morris, MN 56267
(612) 589-3411

Other: 1. Additional components under development: (a) unsaturated/saturated zone routines, (b) economic analysis, (c) linkage to GIS. 2. AGNPS provides information and accurate estimates of runoff quality, particularly for nutrient and sediments. It allows users to compare effects of various pollution control practices that could be incorporated into watershed management.

References:

*Donigian and Huber (in press)
IEP, Inc. (undated)
USEPA (1987)
Young and Onstad (1990)

Name: Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS)

Type of Method: 1. Runoff model

Purpose: Predict concentration of contaminants in runoff waters.

Land Drainage Area: 1. Non-urban areas (agricultural)

Time Properties: 1. Storm event

Space Properties: 1. Multiple catchments where watersheds are subdivided into grids of 1-4 hectare squares. Note: Elements must be small enough so that all important parameter values within its boundaries are uniform.

Methods & Techniques: 1. Within each grid of square elements, model simulates process of interception, infiltration, surface storage, surface flow, subsurface drainage, sediment drainage, sediment detachment, transport, and deposition. 2. Output from one element becomes input for adjacent elements. 3. Nutrients are simulated using correlation relationships between chemical concentrations, sediment yield, and runoff volumes.

Data Needs: 1. Requires detailed description of watershed topography, drainage network, soils, and land use. 2. Most data is available from USDA-SCS soil surveys and land use and cropping surveys.

Output: 1. For flow and sediment, output is available for elements or entire watershed. 2. Output includes estimates of interception, infiltration, surface storage, surface flow, subsurface drainage, sediment drainage, sediment detachment, transport, and deposition. 3. Plotting program included.

Limitations: 1. Mainframe computer needed to run ANSWERS for large watershed; PC okay for smaller watersheds. 2. Input data file preparation complex. 3. Snowmelt process and pesticides not simulated. 4. Water quality constituents modeling limited to nitrogen and phosphorus. 5. Transformation of nitrogen and phosphorus not accounted for in model. 6. Soil nutrient process not simulated. 7. Limited to single "design" storms.

Computer Hardware & Software:

1. Written in FORTRAN/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models:

Level of Effort:

1. Data: moderate. 2. Personnel: moderate/high. 3. System setup: days/weeks. 4. Assessment: weeks/months.

Experience & Validation:

1. Successfully applied in Indiana on an agricultural watershed and construction site to evaluate BMPs. 2. Extensively validated for Midwest.

Contact:

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Professor and Head of Department of
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University of Georgia
Coastal Plain Experiment Station
P.O. Box 748
Tifton, GA 31793
(912) 386-3377

Other:

1. Different from most other NPS models. It is an event based, distributed parameter model designed to simulate single storm events and not a continuous, lumped parameter modeling approach. 2. Evaluates alternative erosion control management practices for agricultural land and construction sites.

References:

Donigian and Beyerlein (1985)
*Donigian and Huber (in press)
IEP, Inc. (undated)
USEPA (1987)

Name:	BURBS: A Simulation of the Nitrogen Impact of Residential Development on Groundwater
Type of Method:	1. Groundwater NPS pollutant loading model
Purpose:	Predict concentration of contaminants in recharge to groundwater.
Land Drainage Area:	1. Urban areas (features associated with residential dwellings such as turf, roof area, driveways, roads)
Time Properties:	1. Average conditions: annual average precipitation and pollution
Space Properties:	1. Single catchment for specific site
Method & Techniques:	1. Computes nitrogen concentration in recharge water from residential development. 2. Computes amount of water that would be recharged from residential development and the amount of nitrogen that would be leached. 3. Nitrogen leached is divided by water recharged to estimate nitrogen concentration in recharge. 4. These calculations sum nitrogen loads from land uses and other sources affecting development site.
Data Needs:	1. Data inputs include: % land in turf; % land impervious; avg. persons/dwelling; housing density; precipitation rate; water recharged from turf and natural land; evaporation from impervious surface; runoff from impervious surface; runoff recharged from impervious surface; home water use/per person; nitrogen concentrations in precipitation and in water used; turf fertilization rate; % of nitrogen leached from turf; % waste water nitrogen lost as gas; % wastewater removed by sewer; nitrogen per person in waste water; nitrogen removal rate of natural land
Output:	1. For turf, natural land, waste water,

impervious runoff total: (a) water recharge (in/yr and %); nitrogen leached (lbs/yr and %). 2. Nitrogen concentration in recharge (mg/l).

Limitations: *1. Model makes many simplifying assumptions. Model provides data that is applicable for analysis in relative not absolute sense.*

Computer Hardware & Software: 1. Written for Lotus 1-2-3. 2. Hardware: IBM PC/AT compatible.

Linkage to Other Models:

Level of Effort: *1. Data: low. 2. Personnel: low. 3. System setup: days. 4. Assessment: days.*

Experience & Validation: 1. Model experience and validation not addressed in literature.

Contact:

Center for Environmental Research
Cornell University
Ithica, NY

Other: 1. Model was developed by Henry Hughes and Steven Pacenka at the Center for Environmental Research at Cornell University in 1985. 2. BURBS is a planning tools that assesses the potential nitrate impacts of a development on groundwater quality.

References:

*Hughes and Pacenka (1985)
Land Management Project (undated C)

Name: Cape Cod Aquifer Management Project (CCAMP) Nitrate Model

Type of Method: 1. Groundwater NPS pollutant loading model

Purpose: Predict concentration of contaminants in recharge to groundwater.

Land Drainage Area: 1. Urban (residential, commercial, churches, schools, hospitals, lawns) 2. Non-urban (cranberry bogs, animal feed lots) 3. Note: Model is designed to incorporate all land use with zone of contribution to wellhead. Documentation has detailed tables of nitrogen concentrations associated with different land uses.

Time Properties: 1. Average conditions (calculated as average daily conditions)

Space Properties: 1. Single catchment for the zone of contribution to wellhead

Method & Techniques: 1. Uses mass balance equation where nitrate concentration in well water = (Nitrate load from precipitation + Nitrate load from sources) / (Total volume of water)

Data Needs: 1. Data inputs include: volume of withdrawal from well; nitrate concentration in recharge from precipitation; nitrate loads from individual load sources; nitrate concentrations in individuals sources; volume of water used by each source before discharge to septic system. 2. When well derives part of its yield from a stream, additional data inputs include: volume of induced infiltration from streams; volume of drainage from land surface through and over which water drains (Zone III) to the wellhead zone of contribution (Zone II); nitrate concentration in induced infiltration; nitrate concentration of drainage from Zone III to Zone II.

Output: 1. Total water volume recharged. 2.

Total nitrogen load. 3. Nitrate concentration in well water.

Limitations: 1. Model is not intended to provide stand-alone technical information. Instead, it provides a technical basis for evaluating future alternative development plans and for comparing tradeoffs between various land uses and development proposals in groundwater quality protection areas.

Computer Hardware & Software: 1. Written for Lotus 1-2-3. 2. Hardware: IBM PC/AT compatible.

Linkage to Other Models:

Level of Effort: *1. Data: low/moderate. 2. Personnel: low. 3. System setup: days. 4. Assessment: days.*

Experience & Validation: 1. Experience and validation not addressed in literature. 2. Designed and applied to Cape Cod.

Contact:
Michael H. Frimpter
U.S. Geological Survey
Massachusetts District Office
Water Resources Division

Other: 1. Developed in 1988 for Cape Cod. 2. The goal of the model was to help planners and managers recognize what level of development would violate the nitrate planning goal. This was to serve as a signal to cease further development of nitrate loading activities within the zone of contribution.

References:
*Frimpter, Donohue, and Rapacz (1988)
The Land Management Project (undated C)

Name:	CHEM II
Type of Method:	1. Runoff model
Purpose:	Predict concentration of contaminants in runoff and surface waters.
Land Drainage Area:	1. Non-urban (forested)
Time Properties:	1. Single event simulation of streamflow events
Space Properties:	1. Single catchment
Method & Techniques:	1. Simulates concentrations of dissolved chemicals in snowmelt-runoff from forested watersheds. 2. Estimates magnitude of nutrient flows. 3. Dissolved chemical constituent estimates include: calcium, magnesium, sodium, chloride, sulfate, bicarbonate, fluoride, nitrate, total soluble salts. 4. Modeling options: (a) one or all chemicals can be simulated at one time; (b) discharge can be obtained from direct measurement or simulated output of another model. 5. Change in land management practices reflected in change of discharge. 6. Default value of "best" estimate available if no pH input value.
Data Needs:	1. Inputs vary depending on specific dissolved chemical constituents considered. 2. General inputs include: forest type, geology, watershed area, discharge, pH.
Output:	1. Identification of range of dissolved chemical concentrations in streamflows.
Limitations:	1. Limited to forested watersheds of Arizona.
Computer Hardware & Software:	1. Written in FORTRAN/77. 2. Hardware: IBM PC/AT compatible.
Linkage to Other Models:	
Level of Effort:	*1. Data: moderate. 2. Personnel:*

moderate. 3. System setup: days/weeks. 4. Assessment: days/weeks.

Experience & Validation: 1. Experience and validation not addressed in literature. 2. Designed for and tested in Arizona.

Contact:

Peter F. Ffolliott
Professor
School of Renewable Natural Resources
College of Agriculture
University of Arizona
Tucson, AZ 85721

Other: 1. Authors plan to adapt Chem II to include watersheds in other ecosystems. 2. Uses include: simulating effects of watershed management practices on dissolved chemical concentrations; identifying watershed management practices that are "safe" and adhere to water quality standards; and simulating and estimating dissolved chemical concentrations and nutrient flows.

References: *Ffolliott, Guertin, and Fogel (1990)

Name: Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS)

Type of Method: 1. Runoff model

Purpose: Predict concentration of contaminants in runoff waters.

Land Drainage Area: 1. Non-urban (agricultural)

Time Properties: 1. Continuous simulation. 2. Single event simulation for storm event.

Space Properties: 1. Segmented catchment (field-sized).

Method & Techniques: 1. Separate hydrology, erosion, and chemistry submodels used. 2. Hydrology: runoff volume, peak flow, infiltration, evapotranspiration, soil water content, and percolation are computed daily. 3. Erosion: daily erosion and sediment yields (including particle size distribution) are estimated at edge of field. 4. Plant nutrients and pesticides simulated. 5. Storm load and average concentrations determined for runoff, sediment, and percolation through root zone. 6. User-defined management activities simulated: areal spraying, soil incorporation of pesticides, animal waste management, and agricultural BMPs.

Data Needs: 1. Data needs include: meteorologic (breakpoint precipitation); solar radiation; air temperature; soil type; grown crop information

Output: 1. Output options available for hydrologic and nutrient simulations (including storm, monthly, or annual summary). 2. Output for segments of overland flow or channel elements available from areas in watershed where intense erosion or deposition identified. 3. BMP evaluation.

Limitations: 1. Maximum size for simulation limited to field plots. 2. Limited data management and handling. 3. Cannot simulate instream processes. 4. Concerns about CREAMS' simulation capabilities for snow accumulation, melt, and resulting runoff, and hydrologic impacts of frozen ground conditions.

Computer Hardware & Software: 1. Written in FORTRAN/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models: 1. GLEAMS, groundwater counterpart. 2. Economic model to evaluate effects of conservation practices.

Level of Effort: *1. Data: high. 2. Personnel: high. 3. System setup: days/weeks. 4. Assessment: weeks/months.*

Experience & Validation: 1. Applied in wide variety of hydrologic settings and climactic regions. 2. Hydrology submodel validated at 46 sites in U.S. south and midwest.

Contact:

Dr. Walt Knisel or Frank Davis
USDA-ARS
Southeast Watershed Research Lab
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Other: 1. CREAMS first released in 1980. 2. Developed by the agricultural research community with special emphasis on representing soil profile and field-scale processes at level of detail appropriate for design of field-based agricultural management systems. 3. Models used for analysis of management activities including aerial spraying, soil incorporation of pesticides, animal waste management, and agricultural BMPs.

References:

Donigian and Beyerlein (1985)
*Donigian and Huber (in press)
IEP, Inc. (undated)
USEPA (1987)

Name: Exposure Analysis Modeling System (EXAMS)

Type of Method: 1. Surface receiving water model.

Purpose: Prediction of concentration and behavior of contaminants in surface waters.

Land Drainage Area:

Time Properties: 1. Not clear from information available. Appears to use average conditions and continuous simulation.

Space Properties: 1. Segmented catchment (segmented by distinct zones in the water system)

Method & Techniques: 1. Interactive modeling system. 2. Combines loading, transport, and transformation of chemicals into a set of differential equations using law of conservation of mass as accounting principle. 3. Accounts for all chemical mass entering and leaving system as algebraic sum of (a) external loadings, (b) transport processes that export compounds from system, and (c) transformation processes within system that convert chemicals to daughter products. 4. Mass balances developed for segments. 5. EXAMS includes process models of physical, chemical, and biological phenomena governing transport and fate of compounds.

Data Needs: 1. Data needs vary with complexity of desired model setup. Allows for extensive environmental data. 2. Specific inputs include: (a) set of chemical loadings for each sector of ecosystem, (b) molecular weight, solubility, and ionization constants of compound, (c) sediment-sorption and biosorption parameters, (d) volatilization parameters, (e) photolysis parameters, (f) hydrolysis data, (g) oxidation data, (h) biotransformation data, (i) parameters defining strength and direction of advective and dispersive transport pathways, (j) system geometry and hydrology data.

Output: 1. Twenty summary tables: summary of input data and predictions of chemical exposure, fate, and persistence. 2. Exposure: expected environmental concentrations based on user-specified pattern of chemical loadings. 3. Fate: distribution of chemical in system and relative dominance of each transport and transformation process. 4. Persistence: time required for effective purification of system once chemical loading terminated. 5. Printer-plot of longitudinal and vertical concentration profiles and time-based graphics.

Limitations: 1. Does not simulate solids with which chemicals interacts. 2. Limited use for site-specific analysis. 3. Not designed to fully evaluate transient concentrations (e.g., chemical spills).

Computer Hardware & Software: 1. Written in Fortran/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models:

Level of Effort: *1. Data: high. 2. Personnel: high. 3. System setup: days/weeks. 4. Assessment: weeks/months.*

Experience & Validation: 1. Validated with field data and model experiments. 2. Reviewed by independent experts.

Contact:

Center for Exposure Assessment Modeling
Environmental Research Laboratory
U.S. Environmental Protection Agency
College Station Road
Athens, GA 30613

Other: 1. Used for wide range of regulatory applications for USEPA.

References:

Ambrose (undated)
*Ambrose and Barnwell (1989)

Barnwell, Vandergrift, & Ambrose (1987)
IEP, Inc. (undated)

Name: Groundwater Loading Effects of Agricultural Management Systems (GLEAMS)

Type of Method: 1. Groundwater NPS pollutant loading model

Purpose: Predict concentration of contaminants in groundwaters (unsaturated and root zones)

Land Drainage Area: 1. Non-urban (agricultural)

Time Properties: 1. Continuous simulations. 2. Storm event simulation.

Space Properties: 1. Segmented catchment (field-sized)

Method & Techniques: 1. Precipitation partitioned between surface runoff and infiltration. 2. Water balance computations done on daily basis. 3. Surface runoff estimated using modified SCS Curve Number method. 4. Soil is divided into layers (minimum 3 layers and maximum of 12 layers of variable thicknesses) and used for water and pesticide routing. 5. Component for vertical flux of pesticides in root zone.

Data Needs:

Output:

Limitations: Maximum size for simulations limited to field size.

Computer Hardware & Software: *Assumed same as CREAMS*: 1. Written in FORTRAN/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models: CREAMS

Level of Effort: *Assumed same as CREAMS. 1. Data: high. 2. Personnel: high. 3. System setup: days/weeks. 4. Assessment: weeks/months.*

Experience &

Validation: 1. GLEAMS validated with field data for Fenamiphos and its metabolites.

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(912) 386-3462

Other:
1. Watershed scale under development.
2. Combines management oriented physically based CREAMS with components for vertical flux of pesticides in root zone.

References: *Donigian and Huber (in press)

Name: Hydrological Simulation Program - Fortran (HSPF)

Type of Method: 1. Runoff 2. Surface receiving water

Purpose: Predict concentration of contaminants in runoff waters, surface waters, and groundwaters.

Land Drainage Area: 1. Urban 2. Non-urban

Time Properties: 1. Continuous simulation 2. Single event simulation

Space Properties: 1. Multiple catchments

Method & Techniques: 1. Comprehensive model of watershed hydrology and water quality allowing integrated simulation of land and soil contaminant runoff processes with hydraulic and sediment-chemical interactions. 2. Simulation of three sediment types (sand, silt, clay). 3. Simulation of single organic chemical and transformation products of the chemical. 4. Transfer and reaction processes include: hydrolysis, oxidation, photolysis, biodegradation, volatilization, sorption. 5. Sorption modeled as first-order kinetic process where user must specify desorption rate and an equilibrium partition coefficient for each of the three solid types. 6. Resuspension and setting of silts and clays (cohesive solids): defined in terms of shear stress at sediment-water interface. 7. Sands: capacity of system to transport sand at particular flow calculated; resuspension or settling defined by difference between sand suspension and capacity. 8. Benthic exchange modeled as sorption/desorption and desorption/scour with surficial benthic sediments.

Data Needs: 1. Data needs: (a) continuous rainfall records, (b) evapotranspiration (desirable), (c) temperature (desirable), (d) solar intensity (desirable), (e) land use, (f) BMPs. 2. Some default values provided where reasonable values available. 3. Ability of bypass sections of program where data not available.

Output: 1. Time history: runoff flow rate, sediment load, nutrient and pesticide concentrations. 2. Time history of water quality and quantity at any point in watershed. 3. Evaluation of BMP effectiveness.

Limitations: 1. HSPF assumes Stanford Watershed Model hydrologic model is appropriate for area being modeled. 2. Instream model assumes receiving water body is well-mixed with width and depth, thus limiting usage to well-mixed rivers and reservoirs. 3. Application of model generally requires team effort because of its comprehensive nature.

Computer Hardware & Software: 1. Written in Fortran/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor required, (d) printer required. 3. Also available for DEC/VAX or VMS.

Linkage to Other Models: 1. Incorporates watershed-scale ARM and NPS models into basin-scale analysis framework. 2. Links to a water quality model called STREAM (Stream Transport and Agricultural Runoff for Exposure Assessment Methodology).

Level of Effort: *1. Data: high. 2. Personnel: high. 3. System setup: days/weeks. 4. Assessment: weeks/months.*

Experience & Validation: 1. Extensive use in U.S. and Canada for wide variety of hydrologic and water quality studies. 2. Validated with field data and model experiments. Has been reviewed by independent experts.

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Other: *1. HSPF has point source capabilities not described here.* 2. HSPF considers all streamflow components (surface runoff, interflow, baseflow) and their pollutant contributors. It allows direct linkage of contributors to an instream water quality model.

References:

Ambrose (undated)
Ambrose and Barnwell (1989)
Barnwell, Vandergrift, & Ambrose (1987)
Donigian and Beyerlein (1985)
*Donigian and Huber (in press)
IEP, Inc. (undated)
Smith and Moore (1990)
USEPA (1987)

Name: Minnesota Lake Eutrophication Analysis Program (MINLEAP)

Type of Method: 1. Runoff model 2. Surface receiving water model

Purpose: Prediction of contaminants in runoff waters and surface waters. Prediction of eutrophication indices of lakes based upon area watershed, depth, and ecoregion.

Land Drainage Area: 1. Urban (general and residential) 2. Non-urban (cultivated, pasture, forested) 3. Also includes marsh and water.

Time Properties: 1. Average conditions

Space Properties: 1. Single catchment

Method & Techniques: 1. Lake water outflow estimated. 2. Phosphorus loading estimated. 3. Ecoregion used to predict regional runoff, precipitation, evaporation, stream phosphorus concentration, atmospheric phosphorus deposition. 4. Lake phosphorus concentrations predicted using phosphorus retention function. 5. Chlorophyll *a* and transparency predicted using regression equations developed from statewide lake data set.

Data Needs: 1. Model designed to use ecoregion data set collected by Minnesota Pollution Control Agency (data collected summers 1985-1987). Data collected for four ecoregions: northern central hardwood forests, northern lakes and forests, northern glaciated plains, and western corn belt plains. 2. Ecoregion database includes: (a) number of lakes, (b) land use, (c) watershed area, (d) lake area, (e) mean depth, (f) total phosphorus, (g) chlorophyll *a* (h) Secchi depth, (i) outflow, (j) total phosphorus load, (k) inflow phosphorus concentration, (l) areal phosphorus load, (m) residence time, (n) overflow rate, (o) stream total phosphorus, (p) precipitation, (q) evaporation, (r) runoff, (s) atmospheric load.

Output: 1. Statistical comparisons of observed and predicted phosphorus, chlorophyll *a*, and transparency values; uncertainty estimates. 2. Estimates of chlorophyll *a* interval frequencies for observed and predicted conditions.

Limitations: 1. Not intended to be used for defining detailed water and nutrient balances of lake characteristics.

Computer Hardware & Software: 1. Written in BASIC. 2. Hardware: IBM PC/AT compatible.

Linkage to Other Models:

Level of Effort: *1. Data: low. 2. Personnel: low. 3. System setup: days/weeks. 4. Assessment: days/weeks. (Assumed ecoregion data available.)*

Experience & Validation: 1. Other than case study for southern range of North Central Hardwood Forests ecoregion, model experience and validation not addressed in literature. 2. Based on similar program developed for Vermont. Adaptable to other ecoregions in U.S.

Contact:

C. Bruce Wilson
Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, MN 55155

or

William W. Walker, Jr., Ph.D.
Environmental Engineer
1127 Lowell Road
Concord, MA 01742

Other: 1. Designed for use as a "first cut" analysis of water quality. 2. Screening tool for estimating lake conditions with minimal input data and for identifying "problem" lakes (those with unusually high phosphorus concentrations given their location, morphometry, and hydrology). 3. Lakes in database selected to represent minimally impacted lakes and lakes with land uses typical to their respective ecoregions.

References:	*Wilson and Walker (1989)

Name: Program for Predicting Polluting Particle Passage through Pits, Puddles & Ponds (P8)

Type of Method: 1. Runoff

Purpose: Predict generation and transport of contaminants in runoff waters.

Land Drainage Area: 1. Urban

Time Properties: 1. Continuous simulation

Space Properties: 1. Single catchments (small, well-defined urban catchments)

Method & Techniques: 1. Continuous water-balance and mass-balance calculations performed for user-defined systems of (a) watersheds (NPS area), (b) devices (runoff storage/treatment areas, BMPs), (c) particle classes, (d) water quality components. 2. Predicts water quality components: suspended solids (five size fractions), total phosphorus, total Kjeldahl nitrogen, copper, lead, zinc, and total hydrocarbons. 3. Simulates BMP types: detention ponds (wet, dry, extended), infiltration basins, swales, and buffer strips. 4. Analysis includes: simulation, design functions, sensitivity analysis, and flow calibration.

Data Needs: 1. Data typically available from drainage plans, soil surveys, and other local sources. 2. General inputs include: hourly rainfall, daily air temperature. 3. Watershed inputs: total area, impervious fraction, depression storage, SCS curve number for pervious area, street-sweeping frequency. 4. Device inputs vary with device types. 5. Particle class inputs: accumulation/washoff parameters for impervious areas, fixed runoff concentrations for pervious and/or impervious areas, street-sweeping efficiency, settling velocity, decay rates, filtration efficiency. Default values provided based on EPA NURP results. 6. Water quality inputs: defined based upon weight distribution across particle classes. EPA NURP default calibrations for total suspended solids, total phosphorus, total Kjeldahl nitrogen, lead, copper, zinc, hydrocarbons.

Output: 1. Tabular and graphic output for user-defined systems. 2. Extensive output for simulation results, design functions, sensitivity analysis, and flow calibration.

Limitations: 1. Like many other urban runoff models, uses generalized data sources, whereby limiting model's accuracy and use. 2. Data limitations and site variations in factors controlling runoff quality make model accuracy relative and not absolute.

Computer Hardware & Software: 1. Written in Fortran/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models:

Level of Effort: *1. Data: low. 2. Personnel: moderate. 3. System setup: days. 4. Assessment: days/weeks.*

Experience & Validation: 1. Preliminary calibration to NURP data for median and 90th percentile sites. Can be calibrated to simulate contaminants with first-order settling, first-order decay, and/or second-order decay kinetics. 2. Model designed for use in Hunt-Potowomut watershed. 3. Model tested for device performance, sensitivity analysis, watershed-scale application, and effects of precipitation variations.

Contact:

IEP, Inc.
6 Maple Street
P.O. Box 780
Northborough, MA 01532

or

William W. Walker, Jr., Ph.D.
Environmental Engineer
1127 Lowell Road
Concord, MA 01742

Other: 1. Developed to help engineers and planners design and evaluate runoff treatment schemes for existing or proposed urban developments in the Hunt-Potowomut Watershed, RI. 2. According to Walker, P8 is currently being adopted for use in Minnesota and North Carolina. 3. Primary applications include evaluating site plans for compliance with treatment objectives and, in design mode, selecting and sizing BMP's to achieve a given treatment objective. Other applications include "absolute" predictions of runoff water quality, loads, etc. 4. Consists primarily of algorithms derived from other urban runoff models (e.g., SWMM, STORM, HSPF, D3RM, TR20). 5. Applicable at site or watershed levels.

References:
IEP, Inc. (1990)
The Land Management Project (undated B)
*Walker (1989)

Name: Revised Phosphorus Loading Model Adopted by Rhode Island's Nonpoint Source Pollution Management Program

Type of Method: 1. Runoff

Purpose: 1. Predict concentration of contaminants in runoff waters.

Land Drainage Area: 1. Urban (density of residential use, commercial/industrial). 2. Non-urban (agricultural, forest). 3. Other (wetland)

Time Properties: 1. Average conditions: annual average conditions

Space Properties: 1. Single catchment

Method & Techniques: 1. Uses series of simple equations to estimate (a) total phosphorus loads entering water body from land uses and other sources, (b) current phosphorus concentration for water body, and (c) comparison estimate of phosphorus concentration if watershed all forested. These calculations use inflow and outflow estimates based on the mass-balance premise that total yearly outflow equals total yearly inflow. 2. Uses low and high phosphorus loading coefficients. 3. Uses total phosphorus concentration to provide estimates of what this would mean for trophic state and chlorophyll *a*. For tropic status, range values given for oligotrophic, mesotrophic, and eutrophic states.

Data Needs: 1. Data needs: (a) acreage by land use, (b) lake surface area, (c) lake mean depth 2. Optional inputs: (a) pounds of animal waste, (b) number of waterfowl, (c) number of septic systems, (d) number of people served by sewage treatment plant, (e) total phosphorus from upstream watersheds, (f) inflow from upstream watersheds, (g) other significant phosphorus sources.

Output: 1. Two set of estimates based on low and high phosphorus loading coefficients.

2. Estimates include: total phosphorus outflow from land use and hydrologic information, total phosphorus from upstream, inflow from upstream, current phosphorus concentration, tropic state, chlorophyll *a*.

Limitations: 1. Model does not account for all physical, chemical, or biological processes affecting phosphorus concentrations. 2. Model cannot be used to determine effects of BMPs. 3. Model provides data that is applicable in relative, not absolute, sense.

Computer Hardware & Software: 1. Written for IBM-compatible spreadsheets. 2. Hardware: IBM-PC compatible.

Linkage to Other Models:

Level of Effort: *1. Data: low. 2. Personnel: low. 3. System setup: days. 4. Assessment: days.*

Experience & Validation: Experience and validation not addressed in literature.

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Other: 1. Model designed to be used in conjunction with other data to assess existing water quality conditions, define realistic water quality goals, and assess potential response of waterbodies to land use decisions. 2. Model provides rough indication of phosphorus loads and concentration concentrations under sets of land use/land cover conditions. 3. Model designed to facilitate relative comparisons of difference land use/land cover scenarios.

References: *Carlson and Scott (1989)
The Land Management Project (undated C)

Name: Storm Water Management Model (SWMM)

Type of Method: 1. Runoff 2. Surface receiving waters

Purpose: Predict rainfall, runoff, and quality processes in urban areas. Predict hydrographs and pollutographs (concentration vs. time) in runoff waters, surface waters, and groundwaters.

Land Drainage Area: 1. Urban

Time Properties: 1. Continuous simulation. 2. Single event simulation.

Space Properties: 1. Multiple catchments (for drainage areas 5-2000 hectares)

Method & Techniques: 1. Uses several modules or blocks to simulate most quantity and quality processes in urban hydrologic cycles. Each block uses specific techniques. 2. For water quality, the Runoff Block includes generation of surface runoff constituent loads for several options: (a) buildup of constituents during dry weather and washoff during wet weather, (b) "rating curve" approach where loads are proportional to flow rate to a power, (c) constant concentration (including precipitation loads) and/or (d) Universal Soil Loss Equation.

Data Needs: 1. Data needs vary with model configuration. 2. Minimum data required: information on area, imperviousness, slope, roughness, depression storage, and infiltration characteristics. 3. Channel/pipe data: shapes, dimensions, slopes or invert elevations, roughness, etc. 4. Quantity data usually available on urban municipality's contour maps and drainage plans. 5. Quality (from Runoff Block using buildup/washoff formulation) requires: coefficients for alternative buildup formulations and washoff equations. 6. Precipitation: can use hyetograph information for individual storm events, or long-term or 15-minute precipitation records from National Climatic Data Center.

Output: 1. Time history of flow, stage, and constituent concentration at any point in the watershed. 2. Seasonal and annual summaries. 3. Continuity checks. 4. Other summary output.

Limitations: 1. Quality simulation is weak in representation of true physical, chemical, and biological processes of nature. 2. Simulation of solids transport weak. 3. PC version not user-friendly and lacks good graphics routines.

Computer Hardware & Software: 1. Written in Fortran/77. 2. Hardware: (a) IBM XT/AT compatible, (b) hard disk required, (c) math co-processor usually required, (d) printer required.

Linkage to Other Models: 1. Can be linked to STORM and QUAL-II.

Level of Effort: *1. Data: high. 2. Personnel: high. 3. System setup: days/weeks. 4. Assessment: weeks/months.*

Experience & Validation: 1. Most widely used urban model. 2. Applied in over 100 location in U.S. and Canada during is 20 year history. 3. Validated and calibrated on many independent data sets.

Contact:

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or

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University of Florida
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Other: 1. SWMM is in its fourth version. 2. Suggested that user be knowledgeable in modeling techniques for non-linear reservoirs, kinematic waves, St. Venant equations, and buildup/washoff equations.

References:

Ambrose (undated)
Ambrose and Barnwell (1989)
Barnwell, Vandergrift, & Ambrose (1987)
Donigian and Beyerlein (1985)
*Donigian and Huber (in press)
Hartigan and George (1988)
Huber and Dickinson (1989)
IEP, Inc. (undated)
USEPA (1987)
Walker and IEP, Inc (1989)

Name: Simulator for Water Resources in Rural Basins (SWRRB)

Type of Method: 1. Runoff

Purpose: Predict concentration of contaminants in runoff waters and groundwaters.

Land Drainage Area: 1. Non-urban (agricultural)

Time Properties: 1. Continuous simulation

Space Properties: 1. Multiple catchments (large, complex, rural basins)

Method & Techniques: 1. Operates on daily time step and simulates weather, hydrology, crop growth, sedimentation, nitrogen, phosphorus, and pesticide movement. 2. Surface runoff calculations use SCS Curve Number technique. 3. Sediment yield computed for each basin using modified USLE. 4. Channel and flood plain sediment routing model has two components operating simultaneously (deposition and degradation). 5. Return flow calculated as function of soil water content and return flow time.

Data Needs: 1. Data needs include: (a) meteorologic data: daily precipitation and solar radiation (required for hydrology simulations), (b) soils, (c) land use, (d) fertilizer and pesticide applications. 2. Soil and land use data can be obtained from USDA-SCS soil survey maps.

Output: 1. Predicts: (a) daily runoff volume and peak rate, (b) sediment yield, (c) evapotranspiration, (d) percolation, (e) return flow, (f) pesticide concentration in runoff and sediment

Limitations: 1. Minimal documentation. 2. Snow accumulation not in hydrology component. 3. Model does not account for nutrient transformations and pesticide daughter products.

Computer Hardware

& Software: 1. Written in Fortran/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models: 1. Pesticide Runoff Simulator (PRS) - developed by USEPA Office of Pesticide and Toxic Substances to simulate pesticide runoff and adsorption into soil on small agricultural watershed. Based on SWRRB.

Level of Effort: *1. Data: moderate. 2. Personnel: moderate. 3. System setup: days/weeks. 4. Assessment: weeks/months.*

Experience & Validation: 1. Used by USEPA's Exposure Assessment Branch, Hazard Evaluation Division, and Office of Pesticide Programs. 2. Tested on 11 large watersheds in 8 Agricultural Research Service locations throughout U.S.

Contact:

Nancy Sammons
808 East Blackland Road
Temple, TX 76502
(817) 770-6512

Other: 1. SWRRB modifies the CREAMS daily rainfall hydrology model for application to large, complex rural basins. 2. Different than other NPS models because includes channel process and subsurface flow components, allowing representation of large basin areas.

References: *Donigian and Huber (in press)

Name: Annual Estimation of Nitrogen in Agricultural Runoff Using Virginia Geographic Information System (VirGIS)

Type of Method: 1. Runoff

Purpose: Predict concentration of contaminants in surface runoff and groundwater.

Land Drainage Area: 1. Non-urban (agricultural)

Time Properties: 1. Average loads (annual) 2. Event loads

Space Properties: 1. Single catchment. *Although model utilizes detailed spatial variations of land-based characteristics, it is not clear from the literature whether or not the model does calculations at this level. It is clear that analysis is done for entire small agricultural watershed or field-sized area.*

Method & Techniques: 1. Hydrologic component computes (a) overland flow, (b) infiltration, (c) leachate, and (d) interflow. 2. Loading rate of soluble nitrate runoff computed as result of concentrations for sum of soluble Nitrogen multiplied by hydrologic component. 3. Soluble nitrogen contributing to stream loading is sum of nitrogen from rainfall, runoff extraction, and interflow component.

Data Needs: 1. Model incorporates: (a) VIRGIS raster databases (land use, county and watershed boundaries, soil type, and water quality index); (b) county average values (30 year annual rainfall, rainfall nitrogen concentration, excess nitrogen fertilizer applied); (c) average runoff values. 2. User specified data: (a) annual rainfall for 30 year county mean (or default), (b) nutrient management level, (c) USLE factors.

Output: 1. Estimates include: (a) soluble nitrogen in runoff (sum of components from rainfall, runoff extraction, and interflow); (b) sediment-bound nitrogen

(nitrogen attached to sediment and transported to nearest stream); (c) runoff nitrogen (total nitrogen load runoff)

Limitations: *1. Model concepts transportable, but model not easily adaptable for non-GIS users and vector-based GIS users.*

Computer Hardware & Software: GIS system setup not explicitly addressed in literature. *(Believe to be PC-compatible.)*

Linkage to Other Models: 1. Integrates with existing VirGIS databases.

Level of Effort: *1. Data: low/moderate. 2. Personnel: moderate. 3. System setup: days/weeks. 4. Assessment: days/weeks. (Active GIS and GIS databases assumed.)*

Experience & Validation: 1. Preliminary verification by model developers for watershed and its subshed in Virginia. 2. Calibration done using data with area-lumped soil and cover parameters.

Contact:

E.R. Yagow
Information Support Systems Laboratory
Department of Agricultural Engineering
Virginia Tech
Blacksburg, VA 24061

Other: 1. Model used to estimate impacts of BMP implementation and nutrient management. 2. Model utilizes empirical relationships defined in CREAMS and AGNPS.

References: *Yagow, et al. (1990)

Name: Water Quality Analysis Simulation Program (WASP4)

Type of Method: 1. Surface receiving water

Purpose: Predict concentration and behavior of contaminants in surface water bed and overlying waters.

Land Drainage Area:

Time Properties: 1. Event loads

Space Properties: 1. Segmented catchment

Method & Techniques: 1. Body of water (streams, lakes, estuaries) represented as series of computational elements or segments. (a) Environmental properties and chemical concentrations modeled as spatially constant within segments. (b) Segment volumes and types (surface waters, subsurface water, surface benthic, subsurface benthic) must be specified, and hydraulic coefficients for riverine networks must be specified. 2. Transport described by six mechanisms. Transport fields include: (a) advection and dispersion in water column, (b) advection and dispersion in pore column, (c) settling, resuspension, and sedimentation of up to three classes of solids, (d) evaporation or precipitation. 3. For WASP4, TOXI4, and EUTRO4, series of mass balance equations solved.

Data Needs: 1. Data needs for each state variable: (a) loads, (b) boundary concentrations, (c) initial concentrations, (d) dissolved fractions of each variable for each segment. 2. Data needs for advection: each inflow or circulation pattern requires (a) specification of fraction routed through relevant water column segments, (b) time history of corresponding flow. 3. Data needs for dispersion: (a) specification of cross-sectional areas between model segments, (b) characteristics of mixing lengths, (c) time history of corresponding dispersion coefficient. 4. Specific data needs for TOXI4 and EUTRO4 vary based on catchment, relevant transformation processes, chemicals, and time variable for particular simulation.

Output: 1. In conjunction with TOXI4, predictions include: dissolved and sorbed chemical concentrations in bed and overlying waters. 2. In conjunction with EUTRO4, predictions include: dissolved oxygen, carbonaceous biochemical oxygen demand, phytoplankton, carbon, chlorophyll *a*, ammonia, nitrate, organic nitrogen, and orthophosphate in the bed and overlying waters.

Limitations: 1. For TOXI4, model needs chemical concentrations to be near trace levels; at higher concentrations, assumptions for linear partitioning and transformation begin to break down. 2. For TOXI4, chemical density near source can be important. In the case of a spill, large concentrations can affect environmental characteristics and alter their transformation rates. TOXI4 does not include feedback for these cases.

Computer Hardware & Software: 1. Written in Fortran/77. 2. Hardware: (a) IBM PC/AT compatible, (b) hard disk required, (c) math co-processor recommended.

Linkage to Other Models: 1. TOXI4: toxics WASP model that combines kinetic structure adapted from EXAMS with WASP4 transport structure and simple sediment balance algorithms to predict dissolved and sorbed chemical concentrations in the bed and overlying waters. 2. EUTRO4: dissolved oxygen/eutrophication WASP model that combines a kinetic structure adapted from the Potomac Eutrophication Model with the WASP4 transport structure to predict dissolved oxygen and phytoplankton dynamics affected by

	nutrients and organic materials. 3. WASP4 input and output may be linked to (a) DYNHYD4, a hydrodynamic model; (b) PRZM, a pesticide groundwater exposure model; (c) WASP Food Chain Model; and (d) FGETS, a fish bioaccumulation model.
Level of Effort:	*1. Data: high. 2. Personnel: high. 3. System setup: don't know. 4. Assessment: weeks/months.*
Experience & Validation:	1. Used by USEPA for wide range of regulatory applications. 2. Problems studied include: biochemical oxygen demand, dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and toxic chemical movement. 3. Some applications validated with field data or verified by model experiments and reviewed by independent experts.
Contact:	Center for Exposure Assessment Modeling Environmental Research Laboratory U.S. Environmental Protection Agency College Station Road Athens, GA 30613
Other:	1. WASP4 requires modeling sophistication and appropriate scientific and engineering judgement.
References:	Ambrose (undated) *Ambrose and Barnwell (1989) Barnwell, Vandergrift, & Ambrose (1987)

Name: Williamstown Nitrate Loading Model

Type of Method: 1. Groundwater NPS pollutant loading model

Purpose: Predict concentration of contaminants in recharge to groundwater.

Land Drainage Area: 1. Urban (characteristics of building and site, chemical applications on site). 2. Non-urban (natural areas).

Time Properties: 1. Average conditions: annual loads

Space Properties: 1. Single catchment (site-specific)

Method & Techniques: 1. Puts nitrate loads in uniform annual basis. 2. Makes simple mass-balance calculations where total nitrate loads and total recharge are calculated, and contaminants are divided by recharged waters to estimate nitrate recharge concentration.

Data Needs: 1. Constants: (a) annual rainfall; (b) lawn/garden nitrate; (c) recharge percentages and nitrate load constants for effluent and rainfall via pavement, roofs, fertilized areas, and natural areas. 2. Project analysis: (a) on-site disposal; (b) area analysis (total, pavement, roof, fertilized, natural); (b) other impacts (recharge, nitrates). 3. Defaults exist for all constants but annual rainfall.

Output: 1. Estimates of recharge (mg/yr) and nitrate (lb/yr) for project analysis components and total. 2. Recharged nitrogen concentration (ppm) estimated and compared against USEPA standard.

Limitations: *1. Simplifying assumptions of model make model useful for relative, not absolute, analysis of groundwater quality.*

Computer Hardware & Software: 1. Written for Lotus 1-2-3, release 2 or later. 2. Hardware: IBM PC compatible.

Linkage to Other Models:

Level of Effort: *1. Data: low. 2. Personnel: low. 3. System setup: days. 4. Assessment: days.*

Experience & Validation: 1. Developed for Williamstown, MA, Planning Board. 2. Later adapted for use in other areas of Massachusetts. 3. Validation not addressed in literature.

Contact:

Philip B. Herr
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447 Centre Street
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Other: 1. Model designed to estimate nitrate effects of development on groundwater, and compare this result with USEPA standards for nitrate levels in drinking waters.

References: *Herr (1989)

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Ambrose, Robert B., Jr. (Undated) "Center for Exposure Assessment Modeling." Athens, GA: Center for Exposure Assessment Modeling, Office of Research and Development.

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Ambrose, Robert B, Jr. and Thomas O. Barnwell, Jr. 1989. "Environmental Software at the U.S. Environmental Protection Agency's Center for Exposure Assessment Modeling." Submitted to Environmental Software, February 1989.

"[P]aper reviews the capabilities of 23 environmental simulation models for urban and rural nonpoint sources, conventional and toxic pollution of streams, lakes and estuaries, tidal hydrodynamics, geochemical equilibrium, and aquatic food chain bioaccumulation." (p. 1)

American Society of Civil Engineers Task Committee on Evaluation Criteria for Watershed Models. 1990. "Summary Report: Evaluation Criteria for Watershed Models." Watershed Planning and Analysis in Action, Irrigation and Drainage Conference (1990: Durango, CO). New York, NY: American Society of Civil Engineers: 386-394.

Details the problems with many existing papers, and makes recommendations for what should be included in papers. Focus is on model developers.

Archibugi, F. and P. Nijkamp, eds. 1989. Economy and Ecology: Towards Sustainable Development. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Considers several challenges to sustainable development. Explains the role of environmental assessment and policy making with regard to sustainable development.

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Describes PC models supported by the EPA Center for Water Quality Modeling.

Basta, Daniel J. and Blair T. Bower, eds. 1982. *Analyzing Natural Systems*. Washington, D.C.: Resources for the Future.

Book offers information on how to analyze natural systems. Topics most applicable to thesis include: (1) residuals generation and discharge from urban and non-urban surfaces (runoff), (2) receiving water bodies, and (3) atmospheric systems. The runoff chapter includes the widely cited runoff model evaluation by Huber and Heaney; the receiving water bodies chapter includes a model review by Hinson and Basta.

Basta, Daniel J. and David H. Moreau. 1982. "Introduction to Analyzing Natural Systems." Chapter 2 in: Basta, Daniel J. and Blair T. Bower, eds. 1982. *Analyzing Natural Systems*. Washington, D.C.: Resources for the Future.

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Bugliarello, George. 1987. "Computers and Water Resources Education: A Projection." *Journal of Water Resources Planning and Management*, 113(4): 498-511.

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Burby, Raymond J., Edward J. Kaiser, Todd Miller, and David H. Moreau. 1983. *Drinking Water Supplies: Protection through Watershed Management*. Ann Arbor, MI: Ann Arbor Science.

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Cape Cod Commission. 1991. Draft Regional Policy Plan.

Draft plan includes discussion of issues, goals, and policies related to the importance of water resources, including water quality.

Carlson, L. and E. Scott. 1989. <u>A User's Guide to the Revised Phosphorus Loading Model Adopted by Rhode Island's Nonpoint Source Pollution Management Program</u>. Providence, RI: Rhode Island Department of Environmental Management, Office of Environmental Coordination.

Spreadsheet model estimates phosphorus loadings, concentrations, and tropic status for surface water bodies. Model can be used to evaluate potential phosphorus impacts of development.

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Provides subroutines and programs for many groundwater applications. However, book is written for hydrogeologists, and is directed at specific applications and not general planning applications.

Contant Cheryl K. and Lyna L. Wiggins. Draft 1990. "Toward Defining and Assessing Cumulative Impacts: Practical and Theoretical Considerations."

Article summarizes cumulative impact analysis methods and identifies their difficulties. Authors recommend detailed monitoring, accurate monitoring, and effective management to overcome difficulties.

Da Costa, Steven L. and Karen A. Glatzel. 1987. "Simulating Nonpoint Source Runoff to Coastal Waters." <u>Symposium of Coastal and Ocean Management (5th: 1987: Seattle, WA)</u>. New York, NY: American Society of Civil Engineers: 3902-3916.

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DeCoursey, D.G. and Edward H. Seely. 1988. "Water Quality Modeling Using a Small Watershed Model (SWAM)." <u>Hydraulic Engineering, National Conference (1988: Colorado Springs, CO)</u>. New York, NY: American Society of Civil Engineers: 417-424.

SWAM simulates the movement of water, sediment, and chemicals through a small, mixed land use watershed. Developed to aid planners and others in assessing NPS pollution.

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Leighton, Daniel H. and Craig Von Bargen. 1990. "Beyond Basic Modeling." Optimizing the Resources for Water Management, National Conference (17th: 1990: Fort Worth, TX). New York, NY: American Society of Civil Engineers: 308-311.

"This paper looks at the evolving use of computer technology to do water planning studies, and proposes a revised approach to building analysis environments that go beyond basic modeling." (p. 308) Provides nice outline of the connection between data collection - use - modeling - analysis - mapping. Explains significance of database management and mapping.

Lima, Robert J. 1984. *Planning Software Survey*. Planning Advisory Service Report Number 388. Chicago, IL: American Planning Association.

Software review is outdated, but review categories are relevant.

Loucks, Daniel P. 1981. "Water Quality Models for River Systems" in: Asit K. Biswas, ed. *Models for Water Quality Management*. USA: McGraw-Hill, Inc.: 1-33.

Provides theoretical information on water quality models for river systems.

Loucks, Daniel P., Janusz Kindler, and Kurt Fedra. 1985. "Interactive Water Resources Modeling and Model Use: An Overview." *Water Resources Research*, 21(2): 95-102.

Explains current problems with traditional water quality modeling. Explores alternatives for the future, including improving human-computer-model interaction and communication. Emphasizes the importance of credible, easy to use, easy to understand, and adaptable models. Stresses the importance of developing models that help policy makers make decisions about what to do and how to do it.

Males, Richard M. 1990. "History of Geographic Information Systems, with Applications in Water Resources Planning and Management." *Optimizing the Resources for Water Management, National Conference (17th: 1990: Fort Worth, TX)*. New York, NY: American Society of Civil Engineers: 100-105.

Explains the spatial components of water quality modeling since the middle 1960s; GIS, since the early 1970s. Includes examples of applications.

Marsh, Floyd, Clifford Pomerantz, and Dennis Phinney. 1988. "Computer Based Master Plans Manage Water Resources." *Critical Water Issues and Computer Applications, Water Resources Conference (15th: 1988: Norfolk, VA)*. New York, NY: American Society of Civil Engineers: 341-343.

Describes case of Scottsdale, AZ, where they will use "computer-based master planning models to address impacts of changing land use on water distribution and wastewater collection treatment and reuse." (p. 343)

McCullough, Melissa W. and John C. Crew. 1989. "Selling Water Quality Planning to Local Governments." Symposium on Coastal and Ocean Management (6th: 1989: Charleston, SC). New York, NY: American Society of Civil Engineers: 2388-2394.

Paper addresses why land use planning and water quality are interrelated. Reviews need to train planners and local governments to address these issues.

McCutcheon, Steve C. 1989. Water Quality Modeling. Boca Raton, FL: CRC Press, Inc..

Good water quality modeling reference. Addressees: what is water quality modeling, why use it, what is important, what are the components, what is the process? Also reviews models in use.

Memon, Altaf A., Kenneth A. Bartal, Theodore P. Clista, and R.B. Patel. 1988. "Water Quality Assessment and Management System in Regulatory Environments." Critical Water Issues and Computer Applications, Water Resources Conference (15th: 1988: Norfolk, VA). New York, NY: American Society of Civil Engineers: 77-80.

Describes system used to prioritize problem water bodies and candidates for detailed water quality analysis.

Miller, D.R., M.J. Focazio, M.A. Dickinson, and W.E. Archey. 1988. A User's Guide to a Model for Estimating the Hydrological Effects of Land Use Change. Cooperative Extension Service, University of Connecticut, University of Massachusetts, Northeast Regional Center for Rural Development, and Northeast Regional Climate Center.

Analyzes hydrologic changes resulting from land use changes. Does not model water quality.

Najarian, Tavit O., Thomas T. Griffin, and Vajira K. Gunawardana. 1986. "Development Impacts of Water Quality: A Case Study." Journal of Water Resources Planning and Management, 112(1): 20-35.

Reviews application of modified STORM model, and offers technical descriptions of impacts from different development scenarios. Mainframe model.

National Research Council. 1990. Ground Water Models: Scientific and Regulatory Applications. Washington, D.C.: National Academy Press.

Offers a critical look at current modeling efforts and how they are used in scientific and regulatory applications.

Ortolano, Leonard. 1984. *Environmental Planning and Decision Making*. New York, NY: John Wiley & Sons.

Provides thorough introduction to the multidisciplinary nature of environmental planning. Includes background, theory, practice, and examples of residuals management, environmental impact assessment, land use and the environment, and techniques for assessing impacts.

Phillips, Lynn R. and John Crew. 1989. "Using Existing Local Policies and Ordinances to Protect Coastal Water Quality." *Symposium on Coastal and Ocean Management (6th: 1989: Charleston, SC)*. New York, NY: American Society of Civil Engineers: 2395-2402.

Describes why local governments should take action to protect water quality by modifying existing policies and ordinances.

Rau, John G. and David C. Wooten, eds. 1980. *Environmental Impact Analysis Handbook*. New York: McGraw-Hill Book Company.

Handbook provides background and specific methodologies for addressing environmental impacts. For several impact categories, general issues and key variables/formulas are reviewed. Some models are described.

Reckhow, Kenneth H., Jonathan B. Butcher, and Carlos M. Marin. 1985. "Pollutant Runoff Models: Selection and Use in Decision Making." *Water Resources Bulletin*, 21(2): 185-195.

Offers objectives of NPS pollutant runoff models that should be incorporated into model selection and use. Also proposes alternative approaches to NPS pollutant runoff modeling.

Salin, Stephen L. 1987. "Maryland's Critical Area Program: Saving the Bay." *Symposium of Coastal and Ocean*

Management (5th: 1987: Seattle, WA). New York, NY: American Society of Civil Engineers: 208-221.

Describes water quality protection program driven by legislation. Details protection programs and techniques.

Schueler, Thomas R. 1983. *Nationwide Urban Runoff Program, Washington, D.C. Area Urban Runoff*. Washington, D.C.: Metropolitan Washington Council of Governments, D.C.

Presents documentation of NURP for the Seneca Creek Watershed Management Study. Although they used a mainframe version of HSPF, this program is a good example of why urban runoff must be studied.

Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Washington, D.C.: Metropolitan Washington Council of Governments.

Offers detailed review of impacts of urban runoff and BMPs. Good glossary.

Scott, Jonathan C. 1989. *Computerized Date-Base System for Land-Use and Land-Cover Data Collected at Ground-Water Sampling Sites in the Pilot National Water-Quality Assessment Program*. Oklahoma City, OK: U.S. Geological Survey, Water Resources Division.

Report documents data collection and computerized data-base system. System is designed for storage and retrieval of land-use and land-cover data.

Shanholtz, V.O. and N. Zhang. 1989. "GIS/Hydrologic Model Interface for Local Planning Jurisdictions." Prepared for presentation at the 1989 International Winter Meeting sponsored by The American Society of Agricultural Engineers, New Orleans, LA.

Describes package that uses "GIS technology to meet needs in database management and map display useful in hydrologic modeling." (Abstract)

Shanholtz, V.O., C.J. Desai, N. Zhang, J.W. Kleene, C.D. Metz, J.M. Flagg. 1990. "Hydrologic/Water Quality Modeling in a GIS Environment." Prepared for presentation at the 1990 International Summer Meeting sponsored by The American Society of Agricultural Engineers, Columbus, OH.

Describes how VirGIS can be use to "rank the nonpoint source pollution potential of agricultural land areas, to identify and map resource protection and management areas for use by county jurisdictions for water quality control, to determine and map the pollution potential of concentrated livestock operations, to identify land areas with high erosion potential and to identify and map environmentally sensitive areas." (Abstract)

Smith, Edwin, L., Thanh K. Tran, and G.V. Loganathan. 1984. "Planning Land/Water Interactions for Urban Growth." <u>Modeling and Simulation (15th: 1984: Pittsburgh, PA)</u>. New York, NY: American Society of Civil Engineers: 1363-1367.

Notes importance of interaction between land use planning and water resources planning. Offers a systems dynamics model for analyzing the impacts of land use practices on water pollution.

Smith, Roger H. and Larry W. Moore. 1990. "Modeling Erosion and Effects of Agricultural BMP's on a West Tennessee Watershed." <u>Watershed Planning and Analysis in Action, Irrigation and Drainage Conference (1990: Durango, CO)</u>. New York, NY: American Society of Civil Engineers: 570-579.

Uses HSPF to determine the effects of land management practices on surface water quality.

So, Frank S. and Irving Hand, eds. 1986. <u>The Practice of State and Regional Planning</u>. Chicago, IL: Published in cooperation with International City Management Association by the America Planning Association.

General guide for state and regional planners. Includes chapters on environmental impact assessments and environmental planning.

So, Frank S. and Judith Getzels, eds. 1988. <u>The Practice of Local Government Planning</u>. Washington, D.C.: Published for the ICMA Training Institute by the International City Management Association.

This is a general, yet thorough, guide to local planning.

Environmental planning information provides useful background.

Soil Conservation Service, Engineering Division. 1986. *Urban Hydrology for Small Watersheds, 2nd Edition, Microcomputer Version 1.11, Executable Modules Only (Technical Release Number 55)*. Washington, D.C.: Soil Conservation Services, Engineering Division.

TR-55 looks at water quantity. It is a good example of a simplified model that can be used for planning purposes. It can also be used by engineers to make order of magnitude comparisons with more complex models.

Stakhiv, Eugene Z. 1989. "The Role of the EIS in Water Resources Planning." *Water Resources Planning and Management, Annual Conference (16th: 1989: Sacramento, CA)*. New York, NY: American Society of Civil Engineers: 361-364.

Offers critical look at EIS, including "inadequacy of scientific content," "inappropriate use as the primary decision document," and "inadequate and inconsistent evaluation procedures." (p. 361)

Sterman, John. 1988. "A Skeptic's Guide to Computer Models." *Foresight and National Decisions*. L. Grant, ed. Lanham: University Press of America.

Outlines questions model users should ask but often don't.

Tourbier, J. Toby and Richard Westmacott. 1981. *Water Resources Protection Technology*. Washington, D.C.: Urban Land Institute.

Gives overview of why we need to protect water resources and how this can be done. Details "measures that can be integrated into urban development to prevent, reduce, or ameliorate potential problems which would otherwise adversely affect water resources." (p. v)

Tran, Thanh K., Donald P. Rice, and G.B. Loganathan. 1984. "System Dynamics Approach to Land Use/Water Quality Analysis." *Modeling and Simulation (15th: 1984: Pittsburgh, PA)*. New York, NY: American Society of Civil Engineers: 1357-1361.

Describes simulation model used to evaluate land use impacts on water quantity. The model is designed to incorporate policy changes in land zoning, water supply, and water conservation. Model assess the effects of land use changes on water supply and demand.

U.S. Environmental Protection Agency, Criteria and Standards Division. 1987. *Controlling Nonpoint Source Pollution, a Guide*. Washington, D.C.: U. S. Environmental Protection Agency.

Evaluates modeling and other assessment techniques. Looks at physical and decision-oriented models. Gives steps for selecting models. Includes good section on BMPs.

Viessman, Warren. 1990. "Land-Water Management: Theory and Practice." *Optimizing the Resources for Water Management, National Conference (17th: 1990: Fort Worth, TX)*. New York, NY: American Society of Civil Engineers: 321-325.

Offers critical evaluation of land-water management. Includes Florida examples.

Walker, William W. Jr. and IEP, Inc. 1989. "Design Concepts for a Land-Based Water Quality Model of the Hunt-Potowomut River." Paper prepared for Narragansett Bay Project.

Outlines goals for Narragansett model and reviews existing models (SWMM and HSPF mostly).

Walker, W. W. Jr. 1990. *P8 Urban Catchment Model, Program Documentation*. Northborough, MA: IEP, Inc.

P8 predicts the generation and transport of stormwater runoff pollutants in urban watersheds. Assists in design, selection, and analysis of BMPs. Also predicts water quality and pollutant loads.

Whipple, William Jr. and Daniel J. Van Abs. 1989. "Principles of a Ground Water Strategy." *Water Resources Planning and Management, Annual Conference (16th: 1989: Sacramento, CA)*. New York, NY: American Society of Civil Engineers: 25-28.

Discusses groundwater policy direction of NJ. Does not specify models to be used.

Whipple, William, Jr. 1990. "Nonpoint Source Pollution Control & Land Use." *Optimizing the Resources for Water Management, National Conference (17th: 1990: Fort Worth, TX)*. New York, NY: American Society of Civil Engineers: 237-241.

Describes relationship between land use and NPS pollution. Discusses impacts of clustering.

Wilson, C. Bruce and William W. Walker, Jr. 1989. "Development of Lake Assessment Methods Based Upon the Aquatic Ecoregion Concept." *Lake and Reservoir Management*, 5(2): 11-22.

Describes model used to predict runoff and average stream phosphorus concentration. Model results designed to assist in water quality screening of lakes.

Yagow, E.R., V.O. Shanholtz, J.W. Kleene, and J.M. Flagg. 1990. "Annual Estimation of Nitrogen in Agricultural Runoff." Prepared for presentation at the 1990 International Summer Meeting sponsored by The American Society of Agricultural Engineers, Columbus, OH.

Procedure estimate annual nitrogen loads in surface runoff from agricultural watersheds and field-sized areas. Model uses existing raster-based GIS data.

Young, R.A. and C.A. Onstad. 1990. "AGNPS: A Tool for Watershed Planning." *Watershed Planning and Analysis in Action, Irrigation and Drainage Conference (1990: Durango, CO)*. New York, NY: American Society of Civil Engineers: 453-462.

AGNPS model is a runoff model for agricultural watersheds. Model considers impacts of BMPs.