Chapter 2

Introduction to Water Resource Models

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Introduction to Water Resource Models

INTRODUCTION

The Nation's water resource policies affect many domestic problems in the United States today—energy, the environment, food production, regional economic development, and even the international balance of trade. As the country grows, excess water supplies diminish, and it becomes increasingly important to manage existing supplies with the greatest possible efficiency. Americans are demanding more water—and cleaner water—for households, industry, agriculture, energy development, recreational use, and aquatic life. For many areas of the country, the availability of adequate water supplies is a limiting factor in residential construction, agricultural production, and economic development in general.

As the Nation approaches full utilization of its water resources, water resource management is becoming more complex. Different kinds of uses, and user groups, increasingly compete for limited supplies. Moreover, interconnections among virtually all aspects of water systems are increasingly apparent— stream flows affect underground reservoirs, for example, while manmade civil works, laws, and relations have profound consequences for the hydrologic balances of entire regions.

Thus, the ability to manage and plan the use of America's water resources—and determine the consequences of resource decisionmaking-becomes increasingly important and increasingly difficult as well. In recent years, successful management and planning has increasingly been based on the results of mathematical models. The information provided by these tools is used to help make such decisions as funding flood control structures, planning pollution control programs, or operating water supply reservoirs.

Leaving aside the mystique of computers and complex mathematics, mathematical models are simply tools used to help understand water resources and water resource management activities. Before the dams and sewage treatment plants are built, before actions are taken to comply with regulations, problems must be analyzed to determine an appropriate way to proceed.

This part of water resource management, though not as apparent as the reservoirs, pipes and sewers, is a vital component in meeting the Nations water resource needs. As the desire for more and cleaner water grows, careful analysis becomes more important. Today, wasting water reduces the amounts available for others. Over-building dams or sewage treatment plants wastes money that could be available for other purposes.

Sophisticated analysis, through the use of models, can improve our understanding of water resources and water resource activities, and help prevent wasting both water and money.

This assessment of water resource models is therefore not an assessment of mathematical equations or computers, but of the Nation's ability to use models to more efficiently and effectively analyze and solve water resource problems. The assessment considers not only the usefulness of the technology-the models—but the ability of Federal and State water resource agencies to effectively use these analytic tools.

Models have been available to assist water resources management, planning, and policy for several decades. In 1959, the former Senate Select Committee on National Water Resources made one of the earliest uses of models for policy purposes. The committee investigated the importance of water resources to the national interest, and considered the Federal activities required to provide the desired quantity and quality of water. To aid in its investigations, the committee called on Resources for the Future to develop a model of water supply and projected use for 1980 and 2000.[1]

During the 1950's and early 1960's, many water resource professionals began to realize the poten-

[1]U.S. Senate Select Committee on National Water Resources, Committee Print No. 32. (Washington, D.C : U.S. Government Printing Office, 1960).

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tial of models for improving management and planning—but were overly optimistic about the ease with which these tools could be developed and adopted for general use. During the 1970's, as computers became more readily available and the cost of computation decreased, model development flourished. However, as often occurs, the technology outstripped the capability of the institutions—the State and Federal agencies—to support it. Today, model use is increasing the efficiency and lowering the cost of water resource management, but the potential for further improvement remains great.

The following section of this chapter outlines the basic principles and functions of water resource models, and briefly describes the major types and classifications of the models. A further section introduces the 33 major water resource issues (table 1) for which model use was analyzed and surveyed. The chapter concludes with a case study that illustrates how models were used to deal with a variety of water resource problems in the Riverhead-Peconic area of Long Island, N.Y.

Table I.—Specific Water Resource Issues Addressed in Report

Surface water flow and supply
- Hydrology:
  - Flood forecasting and control
  - Drought and low-flow river forecasting
  - Streamflow regulation (including reservoirs)
  - Instream flow needs (fish and wildlife, recreation, hydroelectricity, etc.
- Use:
  - Domestic water supply
  - Irrigated agriculture
  - Off stream use (other than domestic and agriculture)
  - Water use efficiency and conservation

Surface water quality
- Nonpoint source pollution and land use:
  - Urban runoff
  - Erosion and sedimentation
  - Salinity
  - Agricultural runoff (other than erosion and salinity)
  - Airborne pollutants
- Water quality (other than nonpoint source and land use):
  - Wasteload allocation (point source discharges)
  - Thermal pollution
  - Toxic materials
  - Drinking water quality
  - Water quality impacts on aquatic life (including eutrophication)

Ground water—quality and quantity
- Quantity:
  - Available supplies and safe yields
  - Conjunctive use of ground and surface waters
- Quality:
  - Accidental (and preexisting) contamination of ground water for drinking water (including toxic substances)
  - Agricultural pollutants to ground water
  - Movement of pollutants into and through ground waters from waste disposal (landfill siting, injection, etc.)
  - Saltwater intrusion

Economic and social
- Economic:
  - Effects of water pricing on use
  - Economic costs of pollution control by industrial sector
  - Benefit/cost analysis
  - Regional economic development implications of water resource policy
- Social and integrative:
  - Forecasting water use
  - Social impact analysis
  - Risk/benefit analysis
  - Competitive water use demands (by region, by sector and water quality objectives
  - Unified river basin planning and management

SOURCE: Office of Technology Assessment

INTRODUCTION TO WATER RESOURCE MODELS

What are water resource models? Briefly, they are analytical tools used to determine the consequences of proposed actions or forecast the quantity or quality of the water in the Nation's rivers, lakes, or ground waters. These models, which range in sophistication from simple work with a desk calculator to complex computer programs, are the scientific community's way of understanding and predicting the workings of a water system. Models are used to synthesize and analyze the substantial amounts of water quality, quantity, and societal information needed for effective planning and management, Effective models condense large amounts of data, simulate the physical and biological dynamics within a water body, or suggest solutions that are most equitable to competing water users.

A model is a "numerical representation' of how the real world or some part of it—a lake, a dam, or a community—works. More precisely, a model uses numbers or symbols to represent *relationships* among the *components* of these real-world systems. A river basin, for example, is composed of water flowing in natural (and manmade) channels, and may have dams that generate electricity and create water impoundments. The river's waters are often used by domestic, industrial, and agricultural consumers within the basin. The basin normally contains a wide variety of aquatic and related wildlife, and may attract numerous users of recreation and recreational facilities. All of these may be considered components of a river basin system; if they can be meaningfuhy quantified, they can be included in a mathematical representation, or model, of the river basin.

Models deal with the interrelationships among the components of a system. For example, the decision to store water behind a dam will increase (or maintain) the size of a lake behind the dam, and decrease the amount of water flowing below the dam and the amount of electricity generated at the site. The action may increase the number of fish in the lake, attracting more fishing enthusiasts, and reduce the level of water in a marsh downstream, inducing birds and other wildlife to migrate elsewhere. Models are simply series of equations that express such relationships in mathematical form.

Photo credit: @ Ted Spiegel, 19S2

In addition to generating hydropower, this dam helps to control streamflow on the lower reaches of the river, and assure adequate water supplies in time of drought. Achieving the multiple objectives involved in reservoir management can be significantly improved and simplified through the use of management-related mathematical models

To take the illustration a step further, if a model accurately represents a system, it can be highly useful in analyzing conflicts among different objectives for managing that system, or ways in which management objectives are complementary. For ensuring adequate water supplies in times of drought, reservoirs must retain as much water as possible. But to control floods, unused storage capacities of reservoirs must be available to receive excess flows. Mathematical expressions are used to represent the quantity of flood waters that can be stored when a given amount of water is being held in reserve for water supplies.

A model is necessarily a simplification of the system it describes. It would not be possible to construct a model that accounted for all the minute interactions of a complex system—but perhaps more important, it would not be useful to do so, either. A model's value as an analytical tool lies in its ability to reduce the number of factors to be considered to a manageable size, selecting the most significant interactions in a system, and assuming that other factors have negligible effects.

Models of how pollutants are transported in a river are good examples of the need for simplifying assumptions. In reality, the flow of a river is three dimensional-the river moves and pollutants are dispersed in all directions. It is often prohibitively complex to represent three-dimensional pollutant transport, however; most river models are designed to describe the transport of pollutants in only one direction—downstream —and ignore vertical or across-channel flow. For purposes of predicting the concentration of pollutants at a location far downstream, i.e., at a drinking water intake pipe, at a specific time, these influences on pollutant transport are negligible.

To determine if model assumptions—like those made for pollutant transport—are valid, model results are tested against actual measurements. For example, if the model's forecast of the time of arrival and the concentration of pollutants at the downstream intake pipe is close to the concentration actually measured at that time, it would appear that it is valid to make these assumptions, at least under these conditions. Usually, in *validating* a model, as this process is called, the model is compared with actual measurements under a variety of conditions.

If a model is found to be a reasonable representation of the real system, it can serve a number of functions. First, it can be used *descriptively* to aid analysts in understanding how the real system works. By way of illustration, when a landfill leaks pollutants into ground water reserves, a model can be used to show how far the contamination has spread, and to estimate pollution levels in a given area. Since these factors can only be *measured* by time-consuming drilling of test wells, the model provides the quickest indication of the extent and seriousness of the problem. The insights gained from the model can then be used to determine the probable location of the most contaminated sites, so that detailed field calculations can be made in those areas.

Models can also be used as *Predictive* tools. In a river, for instance, dissolved oxygen levels depend to a large degree on levels of bacterial activity, because as organic matter bacterially decomposes, the bacteria consume dissolved oxygen. Dissolved oxygen concentrations also depend on the exchange of oxygen between the river and the atmosphere, algal photosynthesis and respiration, temperature, sunlight, and many other interactions. Experiments to determine the direct effects of pollution on dissolved oxygen levels would require inducing many different levels of pollution into the river, attempting to keep all the other factors constant, and measuring the result. The experiment would be time-consuming, costly, and difficult to control; moreover, it may be highly undesirable to run such an experiment in the real world. Because equations that represent the major factors in determining oxygen levels can be easily manipulated, models can predict the direct effects of various pollution levels. These models can be used to determine what levels of sewage treatment will be necessary for meeting water quality standards before a sewage treatment plant is built.

Often, however, it is not sufficient to predict the consequences of a single event or series of actions. Preventing floods on a river system, for example, involves opening the floodgates of a dam to a particular position in order to release the greatest possible amount of water without flooding downstream areas. Yet if a river system had 10 floodgates, and each floodgate had only 10 positions, a river manager would be faced with 10 billion (10^{10}) possible choices (or combinations) of floodgate settings to choose from in the event of a flood. Assuming that a computer model can predict the amount of water that will be released by a particular combination, and the impact of the release downstream, in about half a minute, evaluating all the possible floodgate settings would require approximately 10,000 years. However, models can also be designed as optimizing tools that use mathematical logic to determine the best available choice of settings that satisfies the requirements.

The models analyzed in this report address a wide range of water-related issues. These issues can be organized into four broad categories: surface water flow and supply, surface water quality, ground water quality and quantity, and economic and social.

The category of surface *water flow and supply* includes surface hydrology and water use. Hydrology refers to physical factors that influence the movement of water in rivers and streams. Use, in this case, means water that is withdrawn from a stream for a specific purpose.

Surface water quality issues are divided into point sources (e. g., discharges from a factory) and nonpoint sources (e. g., agricultural runoff).

The third category contains issues pertaining to *ground water,* including available supply and quality with respect to intended use. Also included in this grouping are factors relating to the possible interactions between ground and surface water resources.

Economic, social, and interrelated factors fall into the fourth and final category. Included are the economic and/or social factors that might influence, either directly or indirectly, the availability, quality, or demand for water resources.

In further categorizing models, it is often useful to distinguish between two major benefits that models can provide: 1) delivering information more efficiently than was previously possible; and 2) integrating data to create information that would not otherwise be available. Models that perform the first function rely on established methodologies (e. g., traditional engineering formulae) but use the computer to speed calculation. Models that produce otherwise unavailable information incorporate methodologies that require computer assistance for their execution.

Water resources models can also be characterized by the purpose for which they are used. These include: 1) operations and management; 2) planning; 3) policy development; 4) regulation; and 5) data management.

Models for *operations and management* are used to support short-term managerial decisions. These models might be used to control the operation of a sewage treatment plant or to regulate waterflows through a system of reservoirs within a river basin.

Models that support *Planning activities* are often broader in scope than operations and management models, as they are used as an aid to medium-range decisionmaking. Planning models might be used to evaluate alternatives for future expansion of a treatment plant or to study the impact of the proposed development of a water-consuming industry along a river or stream.

Models used for long-range planning would fall under the class of policy development models. Policy models might be used to estimate the effects of energy development on western U.S. water resources.

Models for regulation are those used in direct support of enforcement or promulgation of standards or in the issuance of permits. For example, a regulation model might be used to determine the allowable discharge level for a sewage treatment facility prior to the issuance of a permit for facility expansion.

Some models are developed solely for data *management*-organizing and accessing data. These models usually are supported by extensive monitoring and reporting networks, and may include data for a wide range of water-related issues.

Yet another method to classify models is by their technical characteristics. Two of the technical categories most germane to this report are: 1) prescriptive v. descriptive models; and 2) deterministic v. probabilistic models.

Descriptive, or simulation, models "describe" how a system operates, and are used to determine changes resulting from a specific course of action.

They are often used to test alternative plans until a satisfactory option is found.

Prescriptive, or optimization, models, on the other hand, "prescribe" a course of action that best meets a specified objective (e. g., least cost or ***greatest*** water yield). If more than one objective is specified, these models can be used to describe the tradeoffs among best solutions for the various objectives.

In deterministic models, the results of an event or series of events are given as a single number or data series, without indication of extent of possible error in the resulting calculations. The quantitative relationships among the parts of the system are fixed—results are completely "determined' by the model and the data provided.

Probabilistic, or stochastic, models produce data that are expressed as a range of probable results. Such models take into account the fact that many events appear to occur randomly. For example, the intensity and timing of any particular rainfall event cannot be precisely predicted, but must be described as a probability of occurrence.

WATER RESOURCE ISSUES

A broad spectrum of activities is involved in managing water resources. Networks for receiving, routing, and using rainfall—both manmade facilities and alterations to natural systems—must be planned, built, and operated. The quality of various water supplies must be analyzed, regulated, and, if necessary, improved through treatment and other management practices. Supplies and qualities of ground water reserves must be determined, and responsible planning provided for their continued use. Perhaps most importantly, effective and efficient strategies must be designed for aiding users to get the greatest possible benefit from the water they consume—in agriculture, residential uses, and industry, as well as for recreational purposes and the protection of natural environments.

Professionals have found modeling useful in virtually all aspects of these activities. Chapter 6, "Modeling and Water Resource Issues, " presents 32 of the 33 specific issue areas in water resource management listed in table 1, and details the manner and extent of current model use for each. A broad and more general overview is provided below, to introduce the reader to the kinds of activities involved in model-aided water resource analysis and management. Italicized words or phrases represent issues specifically analyzed for this report, and addressed in chapter 6.

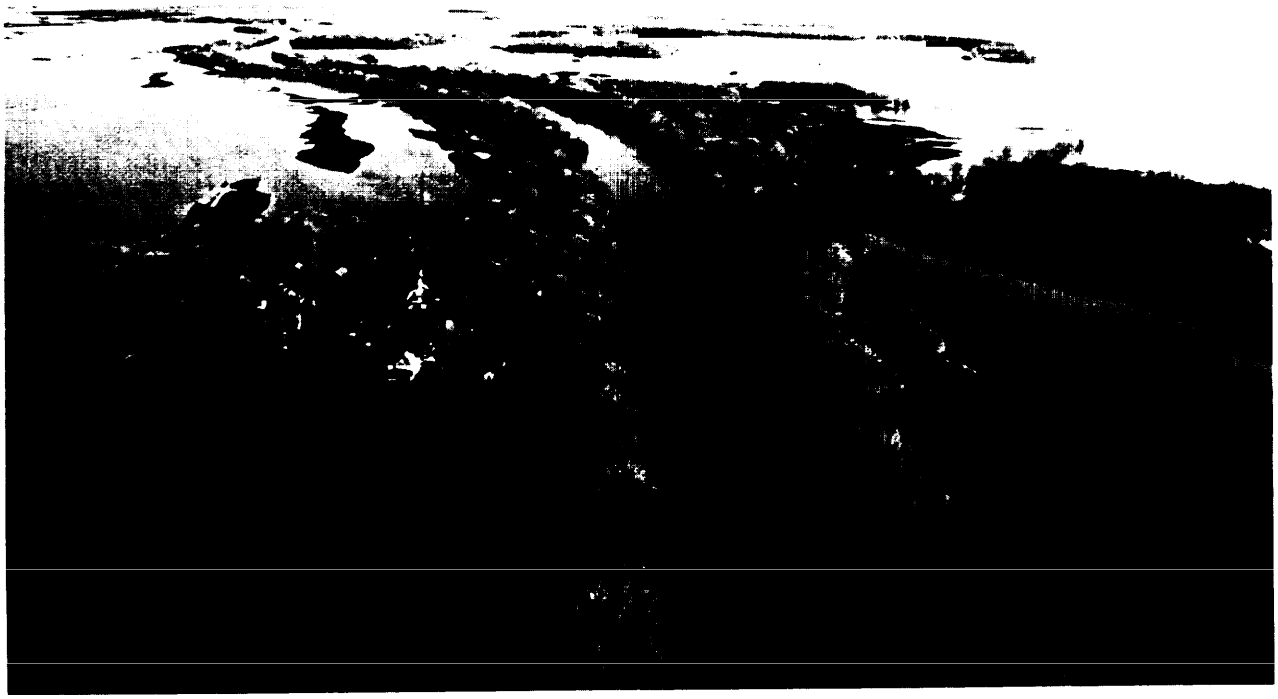
Perhaps the most striking example of man's interaction with the hydrologic cycle is flooding. In addition to the natural potential from spring rains, hurricanes, and the like, urbanization and other land-use activities can aggravate flooding problems. In 1975 alone, 107 lives were lost and $3.4 billion in property damage resulted from flooding. At the same time, $13 billion has been spent on flood management and control since 1936.[2]

To a degree, man has learned to manage floods. Dams have been constructed that can store floodwaters, releasing them gradually. Stream channels have been straightened and dredged to transport floodwaters more efficiently. More recently, nonstructural alternatives, including flood forecasting, restrictions on building in flood plains, and floodproofing, have received attention. Models have been widely used to assist in both structural and nonstructural flood management, including the design and operation of dams and other structural controls, the delineation of flood-prone lands, and advanced warnings of floods.

While some areas of the country are plagued with too much water, other regions may be troubled by a lack of it. Low rates of precipitation, both regionally and seasonally, can result in both *drought and low stream flows.* The Water Resources Council has identified 17 out of 106 water resource subregions that either have serious water deficiencies at present or are projected to have them by the year 2000.[3] Figure 1 illustrates the regions projected

'U. S Water Resources Council, *The Nation Water Resources 1975-2000,* (Washington, D. C.: U.S. Government Printing Office, 1978). (Hereafter: WRC,1978).

'Ibid.



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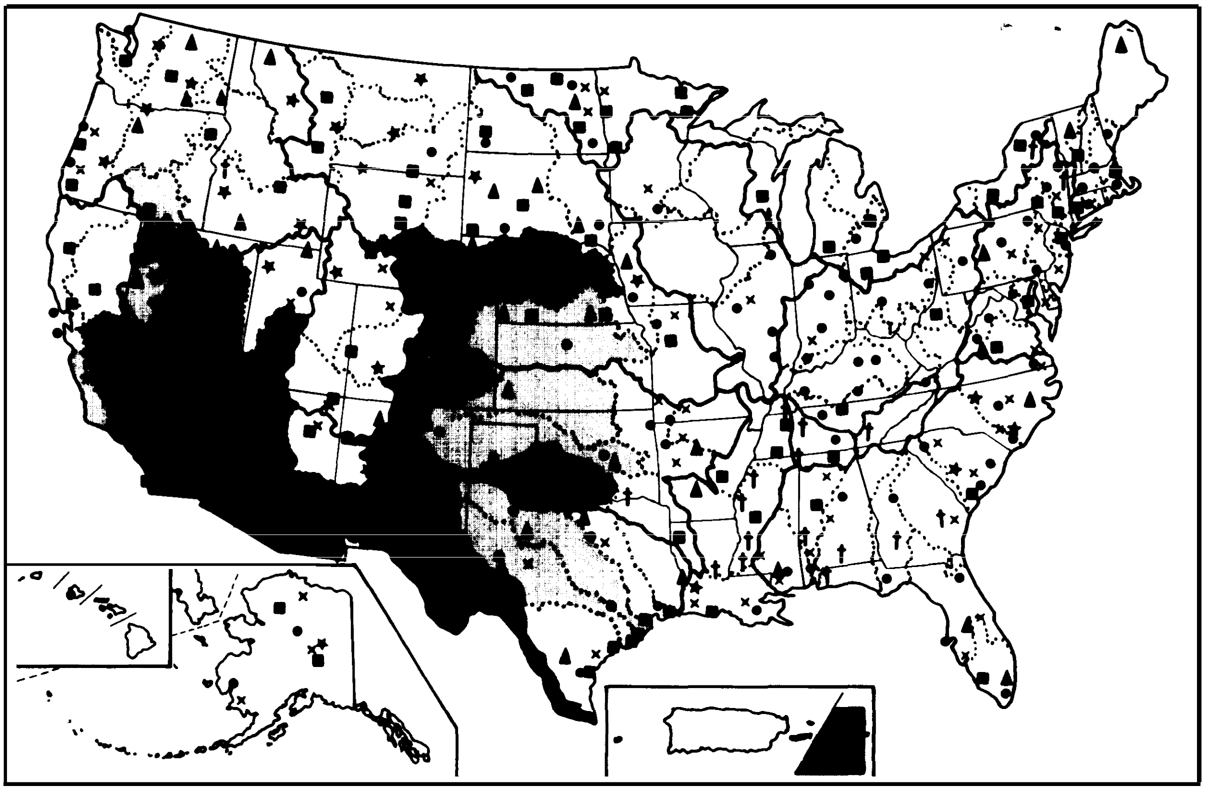
to experience surface water supply and related problems through 2000.

Models similar to those used for flood forecasting and control can estimate the frequency, timing, and extent of droughts or low flows. This information can assist reservoir managers in preparing for potential conditions of limited water or in instituting appropriate conservation measures prior to periods of water shortage.

Streamflow regulation is often associated with tradeoffs among competing objectives. For example, storing reservoir water for droughts may reduce the availability of water for downstream fish and wildlife habitats. Reservoirs must be operated to meet often-conflicting multiple objectives. Models can help evaluate the tradeoffs among these objectives, so that managers can determine an equitable strategy for operating reservoirs.

Conflicting objectives for water are not limited to reservoir operation; intense competition between instream and offstream uses also exists. *Instreamj70w needs* include adequate water for fish and wildlife habitat, recreation, navigation, and the generation of hydroelectricity. *Offjstream uses* include *irrigated agriculture; domestic water supply;* and water for manufacturing, minerals, and energy production. When water is withdrawn from streams in the United States, about two-thirds is returned; the one-third not returned is termed "consumptive use. Among offstream uses, by far the greatest consumptive user of water is agriculture. In 1975, agriculture accounted for over 80 percent of the total U.S. water consumption.

Figure 1 .—Inadequate Surface Water Supply and Related Problems



Explanation

Subregion with Inadequate streamflow (1975-2000)

■ 70 percent depleted in average year

□ 70 percent depleted in dry year

U Less than 70 percent depleted

Specific problems as *Identified by Federa/ and State/Regkvra/ Study Teams*

* Conflict between off stream uses

Inadequate supply of fresh surface water to support—

OfLstream use

● Central (municipal) and noncentral (rural) domestic use

X Industry or energy resource development

A Crop irrigation

Instream use

● Fish and wildlife habitat or outdoor recreation

t Hydroelectric generation or navigation

Boundaries

— **Water resources region**

"-...".''... Subregion

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000, Volume 1: Summary,* **December 1978.**

Total withdrawal of water for offstream use is expected to decline slightly by 2000 due to improvements in water use efficiency and conservation. Significant improvements in the efficiency of irrigation practices have been made through model-based analyses, resulting in major financial and energy-related savings, and alleviating demands on scarce ground and surface water reserves. However, while withdrawals are expected to decline by 2000, it is predicted that the annual consumption of water will increase by 27 percent over the same period.[4] This increase in consumptive use will aggravate the conflicts between instream and offstream water uses.

Decisionmakers at all levels of government are responsible for balancing these competing uses; a wide variety of models is available to assist the decisionmaker with this charge. Models can assist in allocating streamflow among conflicting users, and help forecast future water needs for formulating current policies, long-range planning, and management practices.

Despite the progress made over the last decade, the effects of municipal and industrial point source waste discharges on water quality are still widespread. About 90 and 65 percent of the Nation's river basins are affected by municipal and industrial discharges, respectively.[5] Figure 2 illustrates the regions of the country exposed to point-source surface water pollution problems. Models can estimate the ability of streams to assimilate pollutants from these various point sources so as to meet receiving water quality standards. Such *wasteload allocation* models are extensively relied on for planning purposes.

Therma/ additions from electric power generation and manufacturing sources elevate stream temperatures, and can significantly affect aquatic life if the temperature rise or rate of change is great enough. Models are routinely employed to estimate the effects of thermal wastes from existing and planned facilities.

Dispersed nonpoint pollution sources are equally significant contributors of contaminants to the Nation's waterways, and are significantly more difficult to analyze and control than point sources. Figure 3 illustrates the areas of the country exposed to nonpoint pollution problems. An Environmental Protection Agency inventory estimates that about one-third of the oxygen-demanding loads, two-thirds of the phosphorous, and three-quarters of the nitrogen discharged to streams comes from *nonpoint agricultural sources.* Agricultural runoff, the most widespread nonpoint source problem, affects 70 percent of the country's major river basins.[6]

Runoff and irrigation return flows contribute high concentrations of fertilizers, pesticides, herbicides, sediment, salts, and minerals. Excessive *salinity,* due to the leaching of salts from the soil by irrigation water, may affect receiving waters to the extent that they cannot be used for irrigation downstream. Models can be used to help farmers design ' 'best management practices' to minimize nonpoint source agricultural pollutants.

Although erosion, and the resulting *sedimentation* in waterways, are natural processes, human activities— in particular, agriculture—have accelerated natural rates of soil loss. Sediments from erosion clog waterways and build up in the slower reaches of streams, lakes, and reservoirs. Sediments also carry such pollutants as phosphates and pesticides. Models are widely used to evaluate land-use management practices for minimizing soil erosion, as well as to assess the transport and deposition of sediments for river management.

Storm *runoff from urban* areas—containing oil and grease, lawn fertilizer, garbage, and soil from construction sites— affects half of the Nations river basins. Models of urban runoff can be used to simulate the quantity and quality of pollutants from a particular area and to compare the effectiveness of alternative control strategies.

Airborne pollution is also a source of nonpoint contaminants. For example, the combustion of fossil fuels produces sulfur and nitrogen oxides, which have been linked to the phenomenon of "acid rain. While the ultimate effects of airborne pollutants are not certain, increased rainfall acidity has led to such effects as the loss of fish in sensitive lakes. Models that deal with acid rain and other airborne pollution to water are currently being developed.

Water pollution from both point and nonpoint sources can have harmful *effects on aquatic life.* Excessive concentrations of nutrients can cause explosive growth of aquatic plants. organic wastes, such as sewage, can reduce oxygen levels in lakes and streams, adversely affecting fish. Models can be used to assist biologists in determining the effects of various pollutants on aquatic life.

Toxic pollution of drinking water is one of the most serious water quality problems facing the Nat ion today. The magnitude of the problem is large—

[4] *Ibid*

[5] *U.S. E.P.A National Water Quality Inventory — 1977 Report to Congress,* EPA-440/4-78-001

[6] Ibid

Photo cred/t: G Ted Spiegel, 1932

Fry at left have been raised with only 20 percent of the normal oxygen level of freshwater. The EPA laboratory in Duluth, Minn., performs experiments like these to determine what conditions are necessary to assure that offspring develop normally, like those on the right. Models that estimate oxygen levels in water bodies, when combined with laboratoty data, can be used for estimating effects of actual conditions in rivers, lakes, and streams on aquatic life

30,000 chemicals identified as toxic to humans are presently produced commercially. Many toxicants are difficult to detect and remove using present technologies. Extensive potential exists for using models to trace the transport and fate of toxicants through the environment, and to test different management approaches for preventing toxicants from reaching water supplies.

Other agents of water-borne disease also pose threats to *drinking water quality,* including bacteria and viruses. Over 4,000 cases of water-related illnesses are reported each year, primarily from bacterial and viral sources. [7] While surface waters are extensively treated before distribution to users, ground water, which serves up to 40 percent of the population, is frequently consumed untreated from individual wells. Toxicology models, which relate concentrations of hazardous substances to human health, are used to aid in setting standards.

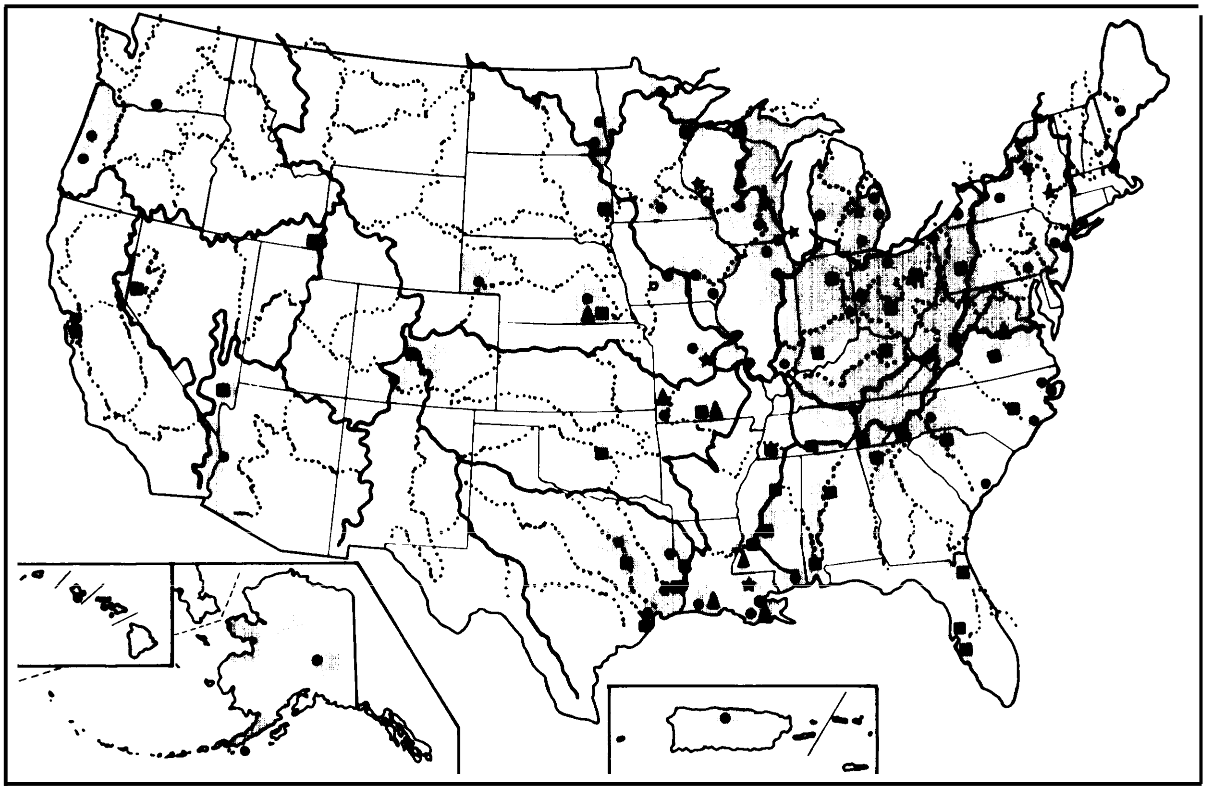
Stored underground in the Nation's ground water reserves is an amount of water equal to 35 years of surface water runoff. Nonetheless, ground water resources are exhaustible. Aquifers—water-bearing soil or rock—can be overexploited if ground water is removed faster than it can be recharged. Ground water "overdraft' can result in increased water pumping costs, declines in streamflow, land subsidence, and saltwater intrusion. Figure 4 illustrates the regions of the country experiencing significant ground water overdraft. Assessing *avail-*

[7] WRC, 1978.

Photo credit: C Ted Spiege/, 1982

A soil scientist examines damage to cotton crop caused by excess salinity in the San Joaquin Valley, Calif.

Figure 2.—Surface Water Pollution Problems From Point Sources **(municipai and industrial waste)**
(as **identified by Federai and State/Regionai study teams)**



Explanation

Area problem

Area in which significant surface water pollution from point sources is occurring

Unshaded area may not be problem-free, but the problem was not considered major

Specific types of point source pollutants

- ● Coliform bacteria from municipal waste or feedlot drainage
- ★ PCB (polychlorinated biphenyls), PBB (polybromated biphenyls, PVC (polyvinyl chloride), and related industrial chemicals
- ▲ Heavy metals (e.g., mercury, zinc, copper, cadmium, lead)
- ■ Nutrients from municipal and industrial discharges
- ○ Heat from manufacturing and power generation

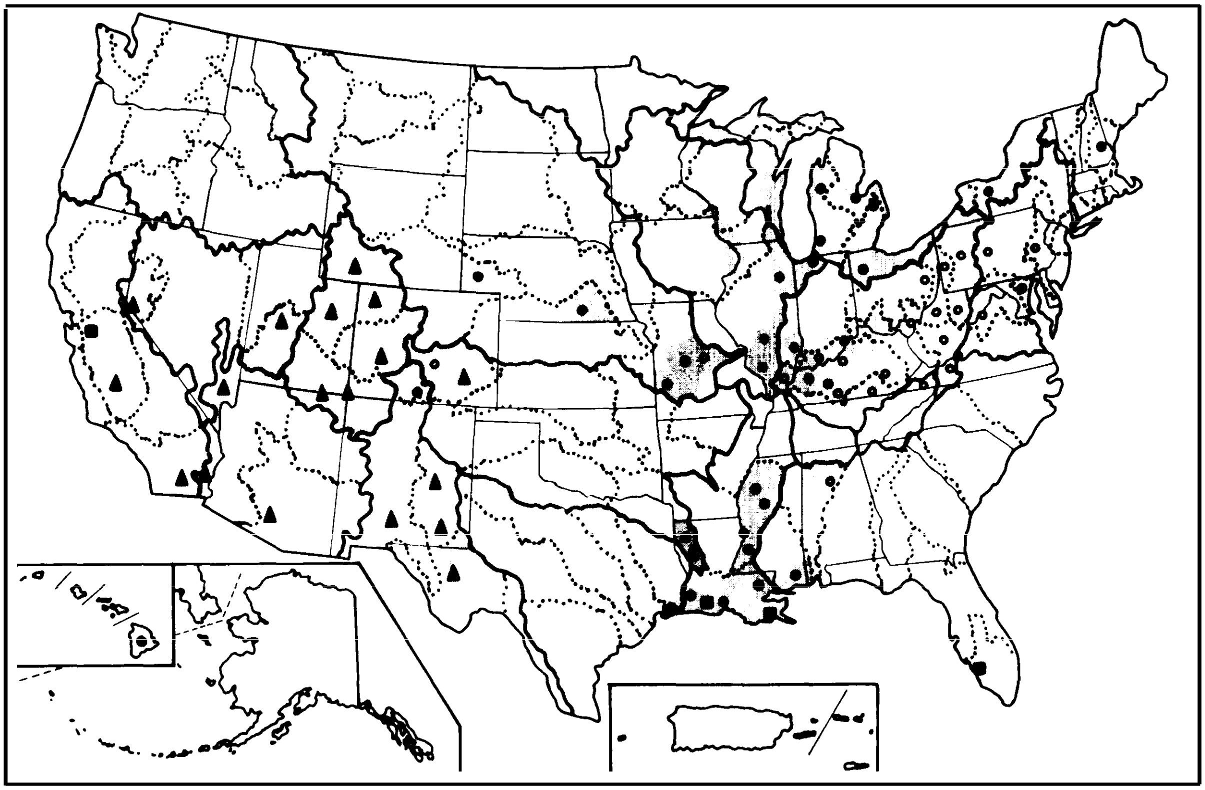
Boundaries

— Water resources region

- - - **Subregion**

SOURCE: US. Water Resources Council, The Nation's Water *Resources, 1975-2000, Volume 1: Summary,* **December 1978.**

Figure 3.—Surface Water Pollution Problems From Nonpoint Sources



Explanation

Area problem

Area in **which significant surface water pollution from nonpoint sources is occurring**

Unshaded area may not be problem-free, but the problem was not considered major

Specific types of nonpoint source pollutants

● **Herbicides, pesticides, and other agricultural chemicals**

Irrigation return flows with high concentration of dissolved solids

● **Seawater intrusion**

0 **Mine drainage**

Boundaries

— Water resources region

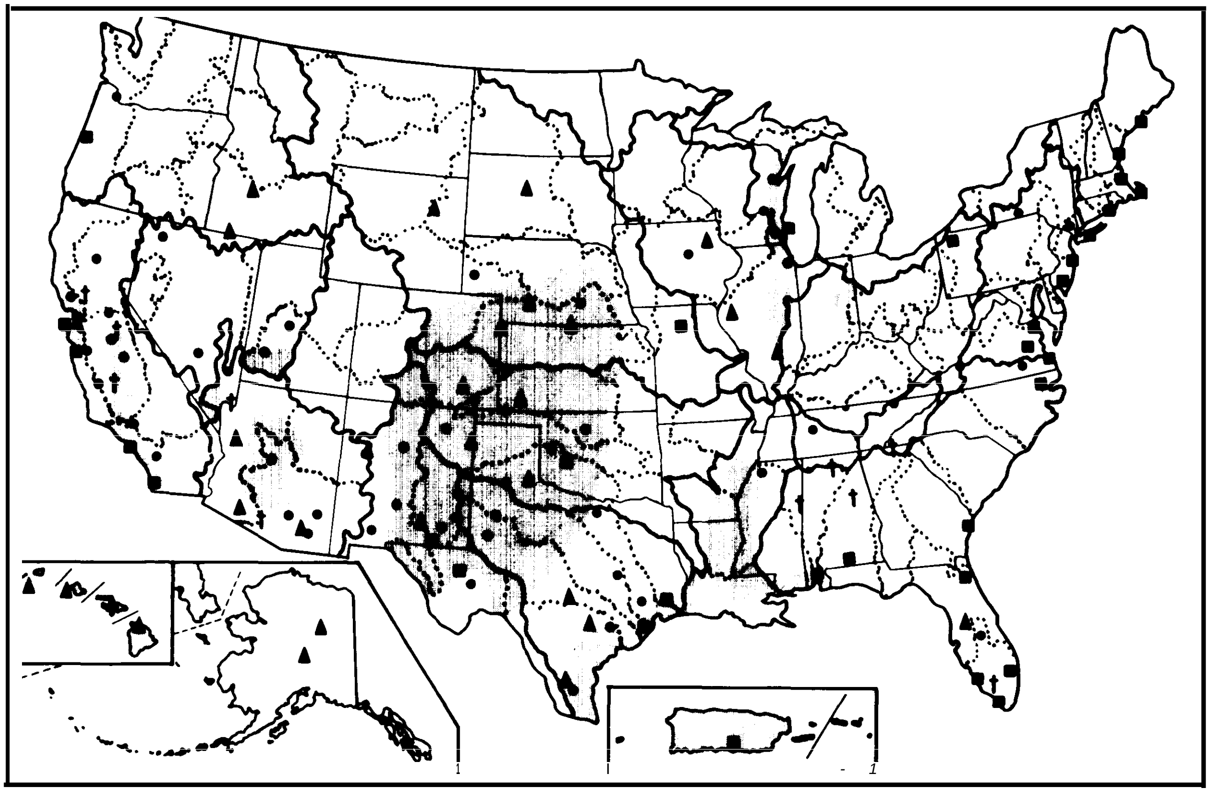
•“-..... Subregion

SOURCE: U.S. Water Resources CounciL The Nation’s Water Resources, 197fKW00, WMume 1: *Summary,* **December 1978**

able supplies and aquifer yields from individual aquifers is a pressing need; models are widely used tools for managing, regulating, and planning the use of ground water. Models can be used to design a well field for greatest efficiency, to assess the extent of usable supplies, and to predict water-level declines resulting from alternative development schemes.

In some areas, however, the excessive use of ground water has stopped too late. Major drops in ground water levels have caused the land to settle or subside, damaging buildings, roads, and railroads, and causing flooding in coastal areas. *Saltwater* intrusion-penetration of underlying saltwaters into the freshwater layer—has also been caused in

Figure 4.—Ground Water Overdraft and Reiated Probiems



Explanation

Area problem

- Area in which significant groundwater overdraft is occurring
- Unshaded area may not be problem-free, but the problem was not considered major

Specific problems *(as identified by Federal and State/Regional*

- ● Declining groundwater levels
- ▲ Diminished springflow and streamflow
- † Formation of fissures and subsidence
- ■ Saline-water intrusion into freshwater aquifers

Boundaries

- —— Water resources region
- ---- Subregion

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources, 1975 -2(W0, Volume 1: Summary,* **December 1978.**

coastal areas by excessive pumping. Similarly, ground water overdrafting may draw poor quality ground water near the land surface into deeper, high-quality ground water reservoirs. The likelihood of encountering these problems in a particular community or region can be assessed with models. Models can also help to evaluate management strategies to minimize the risk of such occurrences.

Many ground water users are now attempting to manage the *conjunctiue use of ground and surface waters* to assure adequate water supplies. When available, surface waters are used to meet demands, while ground water is relied on primarily during dry periods. Ground water aquifers are often hydrologically connected to surface lakes and streams; models can be used to analyze their interaction and aid in their combined management, providing information about both quantity and quality aspects of ground and surface water interrelationships.

In the past, ground water was generally considered to be a reliable source of high-quality water. Yet pollutants from many sources enter the ground water system, though the extent and seriousness of contamination has only recently been recognized. Moreover, the ability of aquifers to rid themselves of pollutants is limited by the slow movement of ground water.

Accidental ground water pollution frequently went unnoticed due to the ubiquitous nature of contamination—from road salt, oil and gasoline, and other chemical spills and leaks. Waste *disposal* has also been a major source of ground water contamination. Wastes are sometimes injected into deep wells, which, if improperly designed, can contaminate drinking water. Toxic chemicals have found their way into ground water from municipal and industrial landfills and dumps. Seepage from septic tanks has for many years been recognized as a major source of bacterial contamination of ground water. In addition, *agricultural pollution of ground water* can occur from pesticides, fertilizers, and salts leached from the soil by irrigation waters. Once contamination occurs, the time and cost of reversing the process can far exceed the cost of preventing it. Models can be used to estimate the infiltration of these pollutants into ground water and the movement of contaminated water through an aquifer. They also have potential for aiding the design of waste-disposal landfills and injection wells to minimize the potential for polluting ground water.

Shortages of water, poor water quality, and flooding have obvious effects on society. Perhaps less obvious are the indirect economic and social effects that result from efforts to ensure or enhance water supplies and quality. The construction of a multipurpose reservoir, for instance, will bring an influx of construction workers from outside the local community. A part of the salaries these workers receive will be spent within the community, thus stimulating the local economy. An increased population, however, may also tax the local community's ability to provide adequate services such as education or police protection.

Part of the need to consider the *social impacts* of many water resource programs and projects stems from the uneven distribution of benefits and differing perceptions of the effects by various groups. Models can assist the decisionmaker by both organizing information on the social implications of a project and determining what social effects may occur and who may be affected.

Closely associated with social impacts are the *regional economic development implications* of water resource policies and projects. A new reservoir might stimulate increased recreational activities that subsequently attract new businesses to an area, or make a region more desirable for siting industries or utilities. Models have been developed that project changes in the level of local or regional economic activities resulting from water resource programs and projects.

The desirability of a project or policy may often be studied using a *benefit/cost analysis,* which attempts to assess relative economic efficiencies, weighing the monetary benefits of a project against economic costs. Models can be used both to assist in measuring the benefits and costs and to undertake the benefit/cost analysis itself.

The costs to industry of pollution control can also have economic implications that affect such factors as industry location and national inflation levels. Models are used to determine the impacts of these costs on economic indicators like the Consumer Price Index and the gross national product, as well as to determine the impact of these costs on specific industries.

Since the economic and social effects of water-related development extend beyond a project's immediate location, it is often important to analyze these effects on a regional basis. Water resource strategies can be developed through *unified river basin planning and management,* in which projected water use demands, water quality objectives, and numerous secondary considerations, including desired levels of economic development, are balanced and coordinated. Models are useful in many aspects of such planning.

Another analysis that is often necessary in the project-planning process is the consideration of uncertainty. Risk/benefit analysis weighs the probability of some outcome—a flood or drought—against the benefit that would potentially be derived, for instance, if a reservoir were built to mitigate the impacts of these floods or droughts. Models can help evaluate both the risks and benefits involved in projects to aid decisionmakers in determining acceptable levels of risk.

One influence on present use of water is price; raising the cost of water can reduce demand in some sectors, especially agriculture. This economic approach to conservation is particularly important because it can alleviate both the need for construction of expensive, large-capacity structural supply systems and the necessity for regulating water use. Models can determine the effects *of water pricing on use* by analyzing consumer response to price.

For regional and national analyses, *forecasting water use* requires an evaluation of population and economic growth, employment, industrial expansion, etc. to project future water needs. Models can estimate future levels of water use both by projecting past economic and demographic trends and by simulating the relationships between these factors and water use.

CASE STUDY OF MODEL USE: WATER RESOURCES IN LONG ISLAND, N.Y.

On Long Island, N. Y., water is a critical resource. Ground water is the sole source of drinking water for the island's 3 million residents and is endangered by contaminants from leakage of septic tanks, landfills, and other sources. Along Long Island's coast, rapid overdrafting of ground water has caused the intrusion of saltwater into freshwater aquifers. In addition, Long Island's rivers, bays, and estuaries, foundations of a fishing and tourist-based economy, are threatened by domestic and industrial wastes. In the past, contamination from these wastes has resulted in bans on fishing and the closing of public beaches.

In 1970, the Nassau-Suffolk Regional Planning Board found that the most obvious limit to future growth on Long Island was the availability of potable water. The board developed a Comprehensive Land Use Plan, which recommended seeking additional funds to conduct water quality studies on Long Island, and provided an impetus for more rational management of the island's water resources. Soon after, section 208 of the Federal Water Pollution Control Act of 1972 became the vehicle for undertaking these further studies and developing a regional strategy for treating and disposing of domestic and industrial waste. The

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Nassau-Suffolk Regional Planning Commission was designated as the local agency responsible for carrying out this investigation.

In designing a waste management strategy, the commission relied heavily on models to provide a quantitative framework for making management decisions. [a] While water quality conditions were directly measured whenever possible, the geographic scope of the island and the expense of drilling test wells to analyze groundwater conditions precluded extensive direct measurement. The executive director of the Nassau-Suffolk section 208 study noted that a wide variety of models was necessary to provide information for evaluating alternative waste management strategies and plans:

> Long Island's $5.2 million 208 study could not have been completed without the application of management, physical, chemical, analogue and hydrogeological models. These models were necessary to help replicate a 1,200 square mile, geologically complex area. [8]

The nature of the management decisions facing Long Island also favored the use of models. To minimize the environmental impact of a wastewater treatment plant, for example, it is necessary to evaluate many alternative sites to determine its optimum location. The time and resources available for measurement limits the number of alternatives that can be evaluated. Models can help eliminate less desirable alternatives, focusing time and resources for detailed field testing on the most feasible sites.

Several options, for example, were available for managing the wastes of the Riverhead-Peconic area of Long Island (fig. 5). One or more regional, subregional, or local sewage treatment plants could be constructed to handle domestic wastes; alternatively, wastes could be diverted to the existing Riverhead plant. One factor in the decision was the relative impact of waste discharges from the various treatment alternatives. Several options were again available: dispose of the wastewater in Flander's Bay, discharge it into the Peconic River, or inject it or allow it to infiltrate into the aquifer. The commission also considered nonpoint sources of wastes and alternative means of controlling them—zoning, street cleaning, special agricultural practices, etc.

The commission had to use several models to evaluate the various alternatives. First, to determine the quantity of water and the amount of pollutants originating from nonpoint sources, the commission utilized a water *budget model.* For a given quantity of precipitation, this model projects the amount of water that will infiltrate the aquifer; return to the atmosphere via evaporation or plant transpiration; or reach rivers and streams overland. Changes in land-use practices—particularly the construction of impervious surfaces, like parking lots, and the removal of vegetation—alter the proportions of ground water infiltration, evapotranspiration, and runoff. The water budget model can respond to actual or hypothetical changes in land use by estimating changes in the proportional distribution of precipitation. In most cases, with increasing development, recharge to the aquifer decreases, while runoff normally increases.

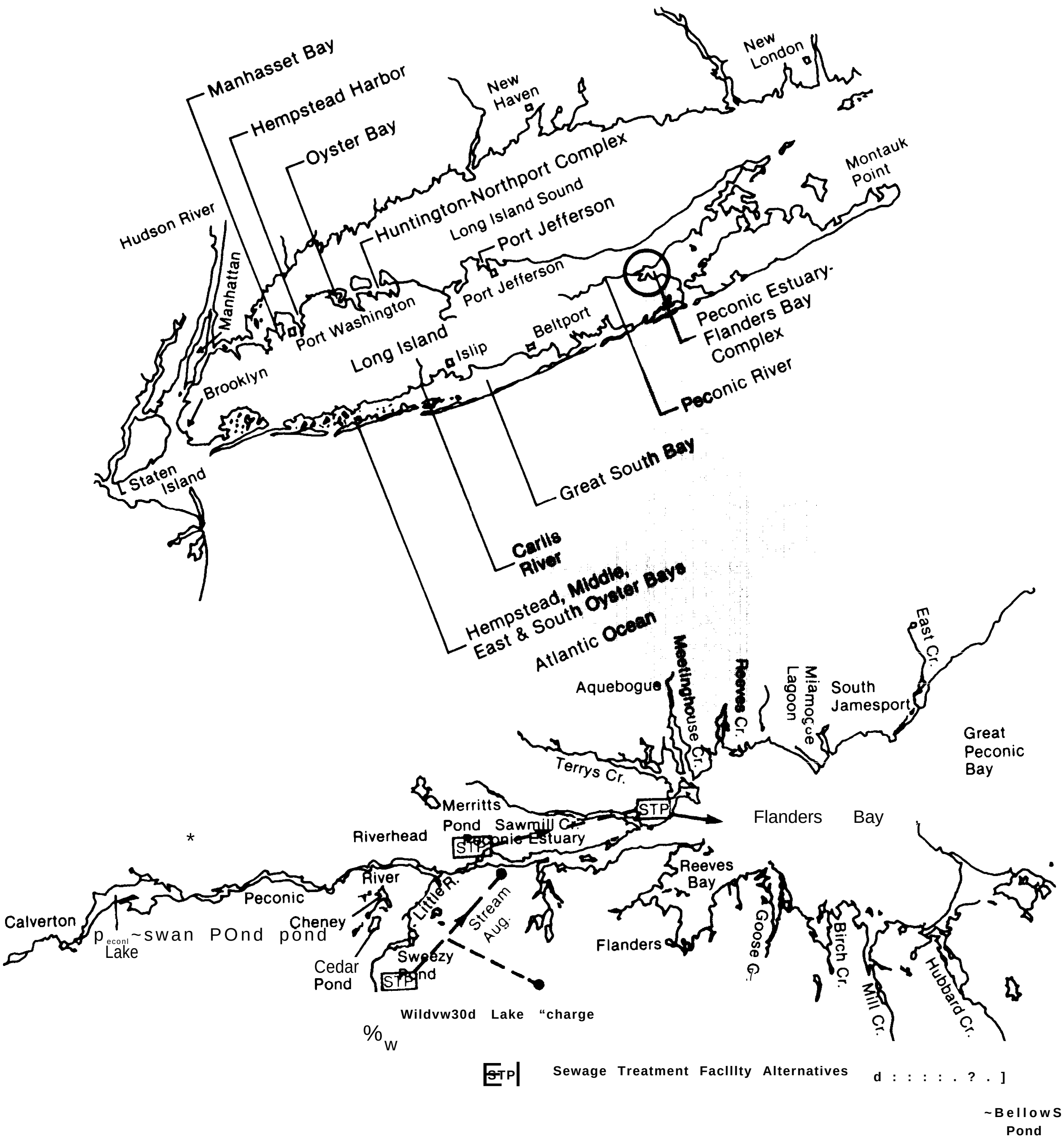
An increase in overland runoff tends to increase the load of pollutants discharged—e. g., sediment from construction areas, grease from urban streets, and fertilizers from agricultural land. Runoff can thus contribute a major source of contaminants to water bodies such as the Peconic River and Flanders Bay. The water budget model can be extended to estimate the load of nutrients contained in urban runoff and the total input of these nutrients to the bay. Thus, as a planning tool, the water budget model can be used to: 1) estimate the effects of altering land-use practices to reduce excess runoff and ensure recharge of ground water; 2) estimate the effects of altering land-use practices to reduce sources of nonpoint source contaminants; and 3) determine the relative amounts of total bay and river system contamination contributed by nonpoint sources.

Other models are used to predict the impact of waste discharges from point sources on the Peconic River and Flanders Bay. These models simulate the currents and circulation patterns of these water bodies and project the transport and fate of pollutants once discharged. Different models must be used for the river and the bay because of differences

[8] *The Long Island Comprehensive Waste Treatment Management Plan,* Volume 1 : Summary Plan; Volume 2: Summary Documentation (Hauppauge, N. Y.: Nassau-Suffolk Regional Planning Board, 1978),

[a] Lee H Koppelman, personal communication to OTA staff, No\, 24, 198]

Figure 5.—Riverhead-Peconic Area, Long Island, N.Y.



SOURCE: *The Long Island Comprehensive Waste Treatment Management Plan, vol. 2,* **figs. 7-27, 7-28.**

in their currents and circulation patterns. Not all areas of a bay or river disperse pollutants equally; e.g., some sections of Flander's Bay are isolated from its primary circulation patterns. Since nutrients stimulate algal growth, which can severely affect water quality, it is advantageous to rapidly disperse wastewater discharges to the bay. The river and estuary models can assist in determining an acceptable location for wastewater disposal.

The river and bay models assume that the growth of algae in these water bodies depends primarily on the concentration of nutrients from waste discharge, However, other factors like "grazing' of the algae by herbivorous zooplankton and recycling of nutrients from decomposing organic matter also influence algal populations. To account for these factors, the commission used an ecological model that simulates algal growth more accurately, The ecological model more fully explores the impacts of both point and nonpoint source discharges on the bay ecosystem.

An alternative to discharging wastewater to the bay or river is to discharge treated effluents by either injecting them directly into the ground water or allowing them to slowly percolate into the aquifer. These approaches have the potential advantage of recharging declining ground water levels; however, they could also contaminate the ground water. Several different models were used to assess the impact of recharging ground water with wastewater in the Riverhead-Peconic area. One model type projects the effect of recharge on the height of the water table and the flow and distribution of recharge water in the aquifer.

A second model describes the way in which pollutants are transported with ground water flow. This type of model is used to estimate how a leaking septic tank, an injection well, or a recharge basin will affect ground water quality.

It is important to note that these models are not designed to make management decisions themselves. Many qualitative and quantitative considerations that affect management decisions are not within the scope of the models' analyses. For example, while a model may help to guide the selection of an adequate location for releasing treated sewage outflows in terms of water quality considerations, it does not consider many other factors, like a site's recreation or habitat potential, which are necessary aspects of the decisionmaking process. Models are virtually indispensable, however, for their ability to both describe and project, in a quantitative framework, the effects of alternative management decisions.

Photo credit: O Ted Spkge/, 1982

Construction crews prepare a wastewater injection well on Long Island. Wastewater will be pumped directly into the ground water table to prevent saltwater intrusion. Prior to construction, models were used to assess the injection well's potential to recharge (elevate) ground water levels, as well as to assess the possibility that wastewater could contaminate ground water supplies