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HUNTINGTON II Simulation Program – POLUT

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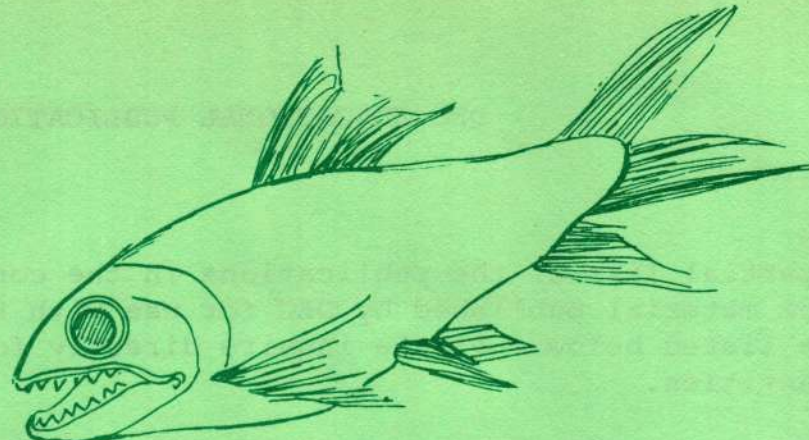
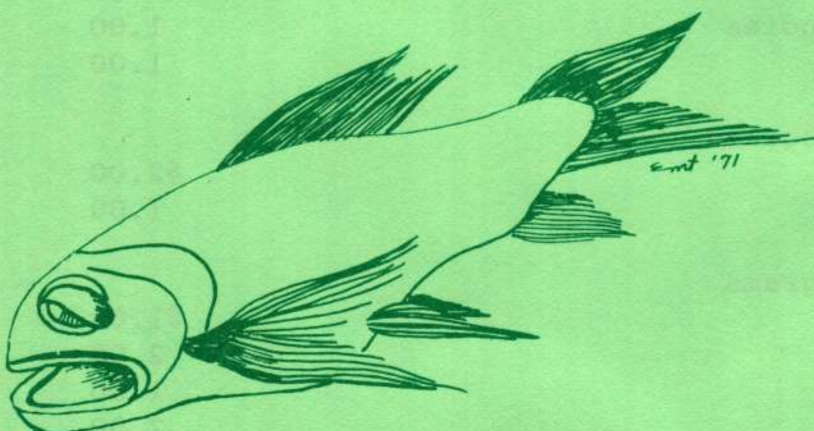


POLUT

R E S O U R C E   H A N D B O O K



HUNTINGTON TWO COMPUTER PROJECT

The work of The Huntington II Project partially supported by The National Science Foundation, Grant GW-5883.

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I. BACKGROUND INFORMATION

INTRODUCTION

Water has always been one of man's most vital and valuable resources. His communities have historically been determined by the locations of rivers, lakes, and springs, and his first great civilizations arose in the valleys of powerful rivers -- the Nile in Egypt, the Tigris and Euphrates in Mesopotamia, the Indus in India and the Hwang Ho in China.

Water has been an essential factor in enhancing the quality of human life. In addition to nourishing man himself, his crops and his animals, water is used in great quantities for cleansing, for carrying away wastes, for industrial processes, and for recreation.

Today, with a world population of 3,616,000,000, and industry and technology at an unprecedented level around the globe, the demand for water is tremendous. Every American uses an average of 70 gallons of water per day, much of which is used for cleansing and carrying away wastes. Every minute spent in a shower uses about 5 gallons of water, an automatic washing machine takes about 30 gallons to run, and 3 gallons are needed to flush a toilet. Industry uses great quantities of water to cool heat-generating machines. You may be surprised to know that it takes about 150 gallons of water to make the paper for one Sunday newspaper.

Despite his dependence on water, man has been carelessly polluting his water sources for many many years, and only recently has come to the realization that his very survival depends on his intentional protection of the quality of his water supplies.

This handbook will give you some background information about the many factors that interrelate in the problem of water pollution. Once you have this basic knowledge, you should be able to use the computer program POLUT to expand your understanding of the problems of water resource management.

THE CHEMICAL AND PHYSICAL PROPERTIES OF WATER

Chemical Composition

Chemically, water is a compound of hydrogen and oxygen, and is represented by the familiar formula H_2O, which indicates that every molecule of water is composed of two atoms of hydrogen and one atom of oxygen. Water is a stable compound; that is, it does not break down easily into its component parts. Thus, in a lake or river, for example, the oxygen component is not available for use by fish or any other aquatic organisms. However, "free" oxygen from the air and from the photosynthetic processes of algae and other aquatic plants can be readily dissolved in the water, and this dissolved oxygen can be used by fish.

Specific Heat and Density

Water has a high specific heat, which means that more energy is required to heat a unit mass of water than to heat most other substances. Water reaches its greatest density, or the point at which it has greatest mass per unit volume, at a temperature of 3.98° C, just above its freezing point. Since water becomes heavier as it gets more dense, when winter approaches and the surface water temperature nears 0° C, the surface water sinks. Then in spring as the surface ice (or water) warms, the "melt-water" will sink and replace the deeper water which has become warmer and lighter. This circulatory action is called "over turn", and it helps the nutrients in the water to redistribute themselves. The sinking surface water carries oxygen down to levels where it has been depleted and the rising lower water brings carbon dioxide and minerals to the sunlit levels where it will be used in food manufacture by green plants.

Solubility of Substances in Water

Many substances, both beneficial and detrimental, are readily soluble in water. Thus some organic materials which dissolve in water can nourish aquatic life and disperse nutrients into the water, whereas some industrial chemicals and some pesticides can have dire effects on the water quality. Water treatment can protect drinking water, but it cannot remove all dissolved chemicals from the water, and the effects of prolonged exposure of life to some of these chemicals is simply unknown.

BODIES OF WATER

Fresh water occurs in a wide variety of forms, some of which are described below.

1) A lake is an inland body of water.

2) A pond is an inland body of water which is smaller than a lake.

3) A river is a stream of water which empties into an ocean, a lake, or another river.

4) A stream is a small river.

5) An estuary is an inlet or arm of the sea, especially the wide mouth of a river, where the tide meets the current.

Since bodies of water replenish their oxygen supply by drawing it from the air, the rougher or more turbulent the surface of the water body is, the more easily the water will "aerate" or take in oxygen. Thus a fast-flowing stream should have a stronger, steadier supply of oxygen than a relatively still pond.

FISH AND THEIR INTERACTION WITH WATER

One major concern in protecting water quality is to preserve the fish which inhabit the waterways. Fish rely on oxygen (from the air or from plants) which has been dissolved in the water. A fish respires by taking in water through its mouth, and passing it through its gill chambers. During this process, the dissolved oxygen in the water is given up to the blood, and the water takes away carbon dioxide.

As the temperature of the water rises, the oxygen consumption of fish increases rapidly. Unfortunately, the ability of oxygen to dissolve in water decreases as the water temperature rises; hence, there will be less available oxygen at higher temperatures. Under conditions of rising water temperature and/or insufficient oxygen supply, fish will exhibit symptoms of respiratory distress. Some types of fish will breathe more rapidly and more deeply, in an attempt to take in enough oxygen. When a fish breathes normally, it is able to use 80% of the dissolved oxygen which passes through the gill chambers; however, rapid respiration decreases the efficiency of its respiratory system, and a fish is only able to use 75% or less of the free oxygen.[2] Some fish will show respiratory distress by an increased tendency to swim in order to find better aerated water or to facilitate the movement of water through the mouth and gill chambers.

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[2] J. R. Jones, Fish and River Pollution (London: Butterworths, 1964) p.7

One important question with respect to water resource management then becomes the determination of the minimum allowable level of oxygen concentration. At any particular temperature, the difference between the amount of oxygen consumed by a fish in full activity and that consumed by a fish at rest is called the "scope for activity". The generally accepted minimum of oxygen concentration is half of the scope when the water is saturated with air. The scope for activity, and hence the minimal oxygen concentration, varies with the type of fish. The speckled trout, for example, needs a minimum of almost 6 parts per million of oxygen when the water is at 10° C.[3] For smaller fish, this minimum rises with the water temperature.

TYPES OF WASTE

Pure water does not occur naturally. Mineral traces are found in the purest mountain streams. However, minerals are not pollutants. Water becomes polluted when nature and man dump their wastes into it. Nature contributes pollutants such as dead fish and animals, leaves and sticks. Man's pollutants come from three primary sources:

1) Sewage. Organic animal and plant wastes can be safely dumped into the water if there is enough dissolved oxygen in the water to allow the bacteria which utilize oxygen (aerobic) to carry on the process of breaking down wastes. When the oxygen supply is insufficient, the waste breakdown will be carried out by organisms which do not utilize oxygen (anaerobic). Although such organisms can carry on waste breakdown at the same rate as those which use oxygen, this anaerobic process can result in the formation of undesirable gases, the accumulation of slime, and the general pollution of the water.

2) Industrial Wastes. Many industrial wastes are pollutants of water. Textile factories, paper mills, slaughterhouses, and vegetables canneries release their wastes into waterways. Factories which produce metal and chemical products dump salts, acids, oils, tars and greases into the water. Tremendous amounts of water are used for cooling purposes in industry, and the resulting discharges of great quantities of hot water causes thermal pollution. This type of pollution occurs as the temperature of the receiving water increases and the water is able to hold less dissolved oxygen, directly affecting the fish present in the water and the ability of the water to treat waste.

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[3] J.R. Jones, Fish and River Pollution (London: Butterworths, 1964) p. 23

3) Agricultural Chemicals. Every year farmers use millions of pounds of weedkillers, pesticides and fertilizers. Rain washes off a certain quantity of these and carries them to the rivers, or they seep into the ground and flow to the rivers. In addition to the obvious harmful effects of herbicides and pesticides on aquatic life, the introduction of fertilizers into water can result in a detrimental increased growth of aquatic plants. As plants multiply, they cover large areas of the water and thereby reduce the water's ability to aerate or gain a constant supply of fresh oxygen.

Wastes are sometimes classified as degradable or nondegradable, although many substances do not strictly fit one of these categories. Degradable wastes are those which can be reduced in quantity by the biological, chemical and physical properties of natural waters. Nondegradable wastes are those which can be diluted and changed in form, but which are not appreciably reduced in weight by the receiving waters. One significant problem presented by nondegradable wastes is the frequent difficulty in identifying them. Sometimes identification is complicated because the content of the waste is expressed in parts per billion, rather than parts per million. In addition, the reactions of some nondegradable wastes with the water are not fully understood. Some nondegradable viruses are deceptive because their environment determines their activity, and while they may appear dormant in water, they can be reactivated under proper conditions.

Bacteria and other organisms in the water utilizing free oxygen will work on the degradable organic waste materials and convert them to stable inorganic materials. If the receiving waters are excessively loaded with wastes, however, the process of degradation cannot keep up with the amount of waste, and the water will begin to exhibit the signs of pollution - undesirable gases will form, slime will accumulate, and the water will look dirty.

IMPROVING THE QUALITY OF WATER BODIES

There are several strategies which can be used to improve the quality of water. One is to treat the waste loads which are discharged into the water. Another is to increase the assimilative capacity of the receiving waters. Thirdly, a combination of these two strategies can be used. Since the computer program POLUT makes available only the first strategy, this method of improving water quality will be the focus of the discussion here.

A basic measure of organic waste load is "biochemical oxygen demand (BOD)" which indicates the amount of oxygen needed in the decomposition process. Waste treatment before discharge can greatly reduce BOD, and in addition can improve the bacteriological quality of the water.

The reduction of the BOD of wastewater can be accomplished in waste treatment plants by the removal of many harmful organisms and other matter from the waste. There are fundamentally two phases to a total waste treatment: primary treatment and secondary treatment.

Primary treatment removes the heavy, solid waste material from the water. The wastewater is passed through a coarse screen which filters out the largest pieces of matter, and is then run into a grit chamber where the heavy inorganic material sinks. The remaining wastewater moves into a primary sedimentation tank and stays there for up to three hours during which time most of the remaining heavy solid matter sinks. After the wastewater has undergone primary treatment, it contains only dissolved materials and very tiny particles and organisms. Such treatment can reduce the BOD by 35-40%.[4]

Secondary treatment destroys harmful organisms and removes some of the remaining dissolved materials. There are two major techniques used in secondary treatment.

1) The trickling filter method uses a filter of crushed stone about five feet deep. As the wastewater passes over the stone beds, the organisms form a film on the stones. The film combines with oxygen and changes harmful substances into solid matter which is then filtered out. The filtered water flows into a final sedimentation tank, where more solid wastes sink. Chlorine is then added and the treated water is then released into a waterway. The sludge which remains is moved to a sludge digestion tank for further treatment. Often it is dried and used for fertilizer.

2) The activated sludge method uses an aeration tank instead of a crushed stone bed. Certain kinds of bacteria are kept in the tank, and when air or oxygen is introduced, the combination of the bacteria and the air destroys the harmful matter in the wastewater.

Primary and secondary treatment combined can usually reduce BOD by 80 to 90%.[5] Fig. 1 illustrates the primary and secondary treatment of wastes, with the trickling filter secondary treatment.

As would be expected, it is more expensive to use both primary and secondary treatment. In fact, as the reduction of BOD reaches 95% and up, costs rise sharply.

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[4]Allen V. Kneese and Blair T. Bow, Managing Water Quality. Economics Technology, Institutions (Baltimore: Resources for the Future, Inc. by the John Hopkins Press, 1968), p. 52.

[5]Ibid., p. 52.

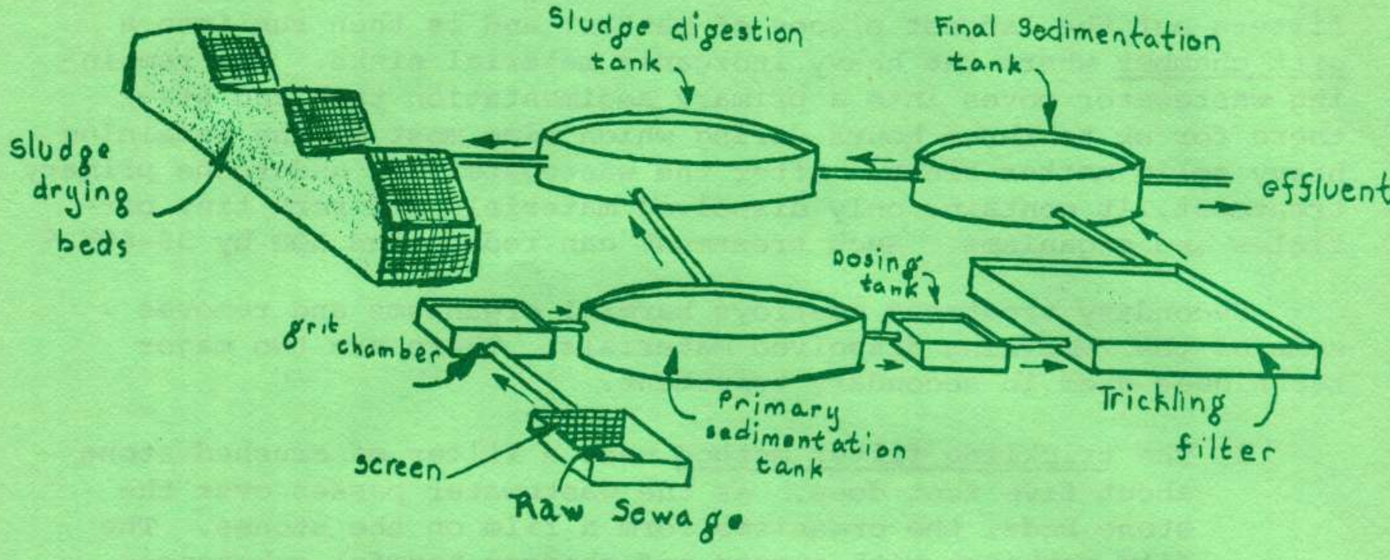

Fig. 1. Primary and secondary treatment of wastes

A Trickling Filter removes organic matter in one type of city treatment system. Raw sewage first passes through a screen into the grit chamber and primary sedimentation tank, where heavy sludge settles. Remaining waste is treated in a sludge digestion tank.
(<u>World Book Encyclopedia</u>, Vol. 17, p. 258)

FURTHER EXPLORATION OF THE PROBLEM

Many American cities get water from sources that are many miles away. Once you are aware of your city's water resources and how they can be affected, you may find yourself taking a more serious interest in the activities which take place near them. The computer program POLUT has been designed to give you a context within which you can explore the effects of certain variables related to the problems of water pollution. A thorough investigation of these and participation in the extensive discussion questions related to them should help you become more familiar with the problem and knowledgeable about possible solutions.

PROJECTS

1. Investigate the relative cost to industries of each type of waste treatment (primary, secondary, none), and prepare a report which discusses the economic feasibility for an industry to use each type of treatment. Include a discussion of the feasibility of each type of treatment if the industry is charged damage costs when it does pollute the environment.

2. Investigate the measures that have been taken by your federal, state, and local officials with regard to the water pollution problem. Include an investigation of the current legal aspects of the question, and prepare a class report.

3. Organize and conduct a debate of the question: "Should private industries be required to assume the total cost of controlling their pollution of waterways?"

4. Prepare a series of "ecology bulletins" and post them in strategic places. (Don't contribute to the paper pollution by distributing a copy to every member of the school community!) Include notes as suggested in projects 5 and 7 below, and notes regarding community, state, and federal activity with respect to water pollution.

5. Investigate the kinds of everyday measures which can be taken by citizens to curb water pollution. These could be included on the ecology bulletin.

6. Many industries have found that materials previously thought of as wastes can be recycled or reused in the manufacture of by-products. Some of these ideas are extremely creative, and it would be interesting to make an investigation and prepare a report on some industrial activity in this area.

7. Try to develop your own "pollution control mechanism" by stopping yourself every time you discard something and asking yourself, "Is there any other possible use for this item?" and "Could I have used something else in place of this item which would not need to be disposed of?" (For example, many containers which are usually thrown away can be recycled, or used in creative projects; paper towels can be replaced by sponges or cloth towels which can be washed and reused.) Record your observations and make a class collection, perhaps to be included in an "ecology bulletin."

8. Investigate the progress which scientist have made in developing degradable containers, paper products, dyes, etc. Prepare a report for the class.

WATER POLLUTION AND THE COMPUTER

The following articles will give you some idea of how the computer is being used on a large scale to help solve the problems of water pollution.

COMPUTERS ATTACK WATER POLLUTION

Man, it is said, can survive four days without water. Of those four days, only the first one is really tolerable - if it can be said that a burning headache and parched mouth, eyes and nasal membranes can be tolerated.

In the last three days of thirsting to death, man reverts totally to the beast and he is aware of the agony of a thirsting death. And with that awareness comes his concern for the manner in which he has wasted that vital ingredient of life: water.

Now thoroughly concerned and perhaps a little frightened, man is using his intellect and his resources in an effort to reobtain what he has always so desperately needed. Data processing has become one of his more important tools.

The National Science Foundation (NSF) reports on an outlined project that is slated to come to the aid of the greatly disturbed Chesapeake Bay area.

Scientists and engineers from Johns Hopkins University, the University of Maryland and the Virginia Institute of Marine Sciences have combined into an interdisciplinary study of the problem, the causes and the solutions of the man-caused troubles of the day.

One ultimate aim of the NSF-funded plan is to create a computerized data bank that can be queried or consulted by scientists and regulatory or legislative decision-makers for information on proposed changes related to the bay or its drainage area.

Detailed Bank

According to NSF, the plans call for a highly detailed bank of literally all entities, processes and characteristics of the region.

The main goal of the project would be the ultimate better management and control of the bay area as a major regional and national resource.

Computers, too, are being used extensively to create simulations. In Appleton, Wis., scientists at the Institute of Paper Chemistry have filled a 360/44 with a river of their own making...mathematically.

The researchers have their own river with its own ecological loads to study to determine the effects of pollution.

The computer, scientists say, mathematically recreates a river with varying characteristics of depth, widths, currents and falls. The programming also inputs the results of some natural processes like re-aeration.

The simulation is based upon the material balance formula which calculates the amount of oxygen in the river. Two common types of pollution are being researched - organic materials that can be water assimulated and suspended solids.

The project, according to the Institute scientists, allows the study to estimate the effectiveness of pollution abatement programs, procedures and devices.

Thermal Pollution

In another project, the University of South Florida is studying the effects of thermal pollution in the Gulf of Mexico. Special buoys, each one a virtual laboratory, are anchored near known heated water discharge outlets. The buoys measure temperature and salinity at various depths. The data obtained from the buoys is then analyzed on the University's computers.

Article from COMPUTERWORLD, Vol. V, No. 20, May 19, 1971.

MONITORING NETWORK CHECKS ON OHIO RIVER POLLUTION

CINCINNATI, Ohio - A computer here keeps the Ohio River Valley Water Sanitation Commission (Orsanco) informed on the filth, or cleanliness, of the 981-mile-long Ohio River.

Electronic samplers at 27 stations along the river and its tributaries constantly analyze water for dissolved oxygen, temperature, pH, conductivity, oxygen reduction potential, chloride and solar radiation intensity, and a computer analyzes the findings hourly.

Data monitored at each sampling station is sent on-line to Orsanco headquarters and fed to an IBM 1130. The CPU combines the input with riverflow forecasts from the U.S. Weather Bureau and analytical data forecasts from the U.S. Geological Survey to produce appraisals of the river's water quality conditions.

Using the hourly reports, Orsanco technicians are able to pinpoint a polluting source by identifying the condition of the water and where in the river the pollution was first detected.

Orsanco is an interstate compact agency created by joint consent of the states involved, providing support services for Ohio, Illinois, Indiana, Kentucky, New York, Pennsylvania, Virginia and West Virginia. Each of the states either borders on the Ohio or has tributaries feeding into the Ohio.

Robert K. Horton, executive director of the commission, said Orsanco's use of the computer makes it possible to analyze a massive amount of data and react to water problems as they are occurring.

"Our goal," Horton added, "is to bring about full compliance with water quality standards established by the commission."

He noted that in 1948, when the commission was founded, only a fraction of 1% of the 3.6 million population on the Ohio River was served by sewerage treatment facilities. At present, 99.5% of the population is served.

"The job is far from complete," Horton added, "because many of these facilities must be expanded to provide a greater degree of treatment.

"We also want to refine the computer monitoring network so that it is even more responsive to situations that result from industrial or municipal accidents or negligence," he concluded.

BAY GETS HELP FROM SIMULATION

MONTEREY, Calif. - A college professor here has called in airplanes, ships, radar and computers to help map pollution in Monterey Bay.

Oceanographer Edward Thornton of the U.S. Naval Post-graduate School uses the computer to simulate mathematically the bay's natural current. He expects his study eventually to assist public health authorities in improving the quality of California coastal waters.

The ships and planes, operated by the school, are used by researchers gathering visual data. The currents are measured directly using current meters placed in the deep ocean and also by floats tracked by radar from shore. These floats follow the currents, indicating basic floor patterns in the crescent-shaped bay down the Pacific coast from San Francisco.

Thornton has built a mathematical replica of Monterey Bay inside the 360/67. The bay's coastline coordinants and depth are recorded, along with tide factors and wind speed and direction.

"Ocean currents outside the bay can drive the water of the interior of the bay to create large eddies," Thornton said. "These eddies can either enhance the dispersion of pollutants or, under different conditions, act to concentrate them close to shore.

"This model should help us understand how the water circulates in the bay and tell us where the pollutants go under various conditions."

After collecting the water flow information through air and sea observation and radar tracking of the floats, Thornton adds weather data, tide information and other variables to his model.

The model represents the bay in the form of a grid pattern. When all details are provided for a specific date and time, the system can deliver current velocity at each intersection on the grid - hundreds of points in all.

Article from COMPUTERWORLD, Vol. V, No. 20, May 19, 1971.

STATISTICS SHOW ATLANTIC FISH POPULATION DWINDLING

WOODS HOLE, Mass. - The famed fishing grounds of the Grand Banks, Georges Bank, and other Northeast Atlantic areas, face depletion of fish which have populated them for ages.

The numbers of haddock, herring, cod and some other species of fish are dwindling in the waters off Labrador, Greenland, and Newfoundland, according to the National Marine Fisheries Service's Biological Laboratory in Woods Hole.

As part of its studies, the lab compiles complete statistics on fishing in the Northeast Atlantic area from Nova Scotia to Cape Hatteras, using a computer. Its reports cover about 100 species of fish, showing where they are caught, what type of equipment was used, and other information.

In 1969, about 1.58 million metric tons of fish were caught in the area, according to the computer's statistics. This included 25,000 tons of haddock, 45,000 tons of cod, and 58,000 tons of yellowtail flounder, species which are of particular importance to New England fishermen. Final totals for 1970 are expected to be over 1 million tons.

The haddock situation looks particularly serious, according to Richard Hennemuth, chief of the population dynamics program at the laboratory.

Herring, scallops and cod are also dwindling fast, Hennemuth adds, and the yellowtail flounder is in immediate danger of possible depletion.

Overfishing accounts for much of the increasing scaracity, Hennemuth asserts, pointing out that as many as 150 vessels may fish at Georges Bank, between Cape Cod and Nova Scotia, at one time.

The "fishing computer," a Univac 9200, at Woods Hole receives its data chiefly from forms filled out by dealers, interviews taken by port agents after a fishing vessel comes home, and from survey cruises by the two research vessels operated in the area by the Fisheries Service.

The computer prepares reports on landings by gear, species and area, or on the special scientific surveys. This information is published in the U.S. Fisheries Statistics Bulletin at the end of the year, as well as in the bulletins of the International Commission for the Northwest Atlantic Fisheries.

The statistics deal mainly with high seas species - fish caught ten miles or more off the U.S. coast. At present, the Woods Hole office has no evidence that pollution is affecting these species, although pesticide residues tend to cut down the productive processes of plankton closer to shore. These residues may also affect the survival of some fish, such as summer flounder, whose larval stages are spent inshore.

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Federal Environmental Agencies

Council on Environmental Quality
722 Jackson Place, N.W.
Washington D.C. 20006

Environmental Protection Agency
1626 K Street, N.W.
Washington, D.C. 20460

State Environmental Agencies

Usually a division of the
Department of Conservation and Natural Resources
Your State Capital, Your State and Zip Code

Private Agencies

League of Women Voters of the U.S.
1730 M Street, N.W.
Washington, D.C. 20036

III. SAMPLE RUNS

Note: The plotting is accurate to within .25 ppm on the oxygen scale and to within .5 ppm on the waste scale.

RUNS 1 & 2 - Even with dumping rates of 10 ppm/day for either industrial waste (RUN 1) or sewage (Run 2) and no treatment of waste, the dissolved oxygen level in a fast-moving river where the water temperature is 60° F remains above 5 ppm.

RUN 3 - The conditions present in RUN 1 cause the dissolved oxygen level in a slow-moving river to fall below 5 ppm rapidly.

RUN 4 - In this case, primary treatment of the industrial waste dumped into a slow-moving river maintains the oxygen level above 5 ppm.

RUN 5 - The increased dumping rate (now 14 ppm/day) for the river in RUN 4 renders primary treatment of industrial waste inadequate.

RUN 6 - This run demonstrates the dependence of the dissolved oxygen level on the water temperature. At 35° F and a dumping rate of 10 ppm/day (industrial waste), the dissolved oxygen level remains above 5 ppm even with no waste treatment.

RUN 7 - For a large lake, the same conditions as were present in RUN 4 (case of a slow-moving river) cause the oxygen level to fall below 5 ppm by the 5th day.

RUN 8 - RUN 8 demonstrates the effectiveness of secondary treatment for industrial waste in the case of a large lake being polluted at a rate of 10 ppm/day (water temperature 60° F).

RUN 9 - A comparison of RUN 9 with RUN 7 illustrates the fact that, in general, industrial waste does not decompose as readily as sewage; for this reason, the dissolved oxygen level falls below 5 ppm more rapidly in RUN 9. The waste build-up is much higher, of course, in the case of industrial waste (RUN 7).

RUN 10 - When the water temperature of the lake rises to 85° F, even secondary treatment cannot keep the oxygen level above 5 ppm.

WATER POLLUTION STUDY

INSTRUCTIONS (1=YES, 0=NO)? 1

IN THIS STUDY YOU CAN SPECIFY THE FOLLOWING CHARACTERISTICS:

A. THE KIND OF BODY OF WATER:
   1. LARGE POND
   2. LARGE LAKE
   3. SLOW-MOVING RIVER
   4. FAST-MOVING RIVER

B. THE WATER TEMPERATURE IN DEGREES FAHRENHEIT:

C. THE KIND OF WASTE DUMPED INTO THE WATER:
   1. INDUSTRIAL
   2. SEWAGE

D. THE RATE OF DUMPING OF WASTE, IN PARTS PER MILLION (PPM)/DAY.

E. THE TYPE OF TREATMENT OF THE WASTE:
   0. NONE
   1. PRIMARY (SEDIMENTATION OR PASSAGE THROUGH FINE
             SCREENS TO REMOVE GROSS SOLIDS)
   2. SECONDARY (SAND FILTERS OR THE ACTIVATED SLUDGE
               METHOD TO REMOVE DISSOLVED AND COLLOIDAL
               ORGANIC MATTER)

****

BODY OF WATER? 4
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 0

DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1

```
         0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
         0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY      I---------I---------I---------I---------I---------I---------I
 0      I   W                                 O
 1      I            W                      O
 2      I                   W            O
 3      I                        W     O
 4      I                            WO
 5      I                            O  W
 6      I                           O      W
 7      I                          O         W
 8      I                         O           W
 9      I                         O             W
10      I                         O             W
11      I                        O               W
12      I                        O                W
13      I                        O                W
14      I                        O                 W
15      I                        O                 W
16      I                        O                 W
17      I                        O                 W
18      I                        O                 W
```

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.

```
***********

BODY OF WATER? 4
WATER TEMPERATURE? 60
KIND OF WASTE? 2
DUMPING RATE? 10
TYPE OF TREATMENT? 0
```

RUN 2

```
DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1


        0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
        0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
 DAY    I---------I---------I---------I---------I---------I---------I
  0    I   W                                  O
  1    I          W                     O
  2    I             W             O
  3    I               W         O
  4    I               W        O
  5    I                W       O
  6    I                W       O
  7    I                W       O
  8    I                W       O
  9    I                W       O

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.


***********

BODY OF WATER? 3
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 0
```

RUN 3

```
DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1


AFTER DAY 3 THE GAME FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.

        0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
        0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
 DAY    I---------I---------I---------I---------I---------I---------I
  0    I   W                               O
  1    I            W                   O
  2    I                    W       O
  3    I                      O  W
  4    I                   O        W
  5    I                 O              W
  6    I               O                   W
  7    I             O                       W
  8    I            O                         W
  9    I           O                            W
 10    I          O                             W
 11    I          O                              W
 12    I         O                                W
 13    I         O                                W
 14    I        O                                  W
 15    I        O                                  W
 16    I        O                                  W
 17    I        O                                  W
 18    I        O                                  W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

****

```
BODY OF WATER? 3
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 1
```

RUN 4

```
DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1



       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0     I  W                              O
 1     I      W                         O
 2     I          W                  O
 3     I            W              O
 4     I              W           O
 5     I                W       O
 6     I                 W     O
 7     I                  W    O
 8     I                   W  O
 9     I                    W O
10     I                    WO
11     I                    WO
12     I                     @
13     I                    OW
14     I                    OW
15     I                    OW
16     I                    OW
17     I                    OW

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

****

```
BODY OF WATER? 3
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 14
TYPE OF TREATMENT? 1
```

RUN 5

```
DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1

AFTER DAY 6 THE GAME FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.

       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0     I  W                              O
 1     I        W                      O
 2     I             W              O
 3     I                 W       O
 4     I                   W   O
 5     I                     OW
 6     I                   O    W
 7     I                  O      W
 8     I                  O       W
 9     I                 O         W
10     I                O          W
11     I                O           W
12     I                O           W
13     I               O             W
14     I               O             W
15     I               O             W
16     I               O             W
17     I               O             W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```


****

```
BODY OF WATER? 3
WATER TEMPERATURE? 35
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 0
```

RUN 6

```
DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1

        0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
        0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY     I---------I---------I---------I---------I---------I---------I
 0      I   W                                                O
 1      I            W                                    O
 2      I                   W                        O
 3      I                        W               O
 4      I                            W        O
 5      I                               W  O
 6      I                                O W
 7      I                               O    W
 8      I                              O      W
 9      I                             O         W
 10     I                            O          W
 11     I                           O            W
 12     I                           O             W
 13     I                           O             W
 14     I                          O               W
 15     I                          O               W
 16     I                          O               W
 17     I                          O               W
 18     I                          O               W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.

***********

BODY OF WATER? 2
WATER TEMPERATURE? 60
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 1
```

RUN 7

```
DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1

AFTER DAY 4 THE GAME FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.

        0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
        0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY     I---------I---------I---------I---------I---------I---------I
 0      I   W                            O
 1      I       W                      O
 2      I           W               O
 3      I             W          O
 4      I               W     O
 5      I                 W O
 6      I                 OW
 7      I                O  W
 8      I               O    W
 9      I              O      W
 10     I              O      W
 11     I             O       W
 12     I             O        W
 13     I             O        W
 14     I            O         W
 15     I            O         W
 16     I            O         W
 17     I            O         W
 18     I            O         W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

```
***********

BODY OF WATER? 2
WATER TEMPERATURE? 60                                     RUN 8
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 2

DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1


       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0    I   W                            O
 1    I    W                          O
 2    I    W                          O
 3    I     W                        O
 4    I     W                       O
 5    I      W                      O
 6    I      W                      O
 7    I      W                     O
 8    I      W                     O
 9    I      W                     O
 10   I      W                     O
 11   I      W                     O

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.


***********
                                                          RUN 9
BODY OF WATER? 2
WATER TEMPERATURE? 60
KIND OF WASTE? 2
DUMPING RATE? 10
TYPE OF TREATMENT? 1

DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1


AFTER DAY 2 THE GAME FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.


       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY    I---------I---------I---------I---------I---------I---------I
 0    I   W                            O
 1    I      W                    O
 2    I        W            O
 3    I         W       O
 4    I         W    O
 5    I         W   O
 6    I         W  O
 7    I         W  O
 8    I         W  O
 9    I         W  O
 10   I         W  O

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```



```
***********
```

```
BODY OF WATER? 2
WATER TEMPERATURE? 85
KIND OF WASTE? 1
DUMPING RATE? 10
TYPE OF TREATMENT? 2
```

RUN 10

```
DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)? 1


AFTER DAY 1 THE GAME FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.


         0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
         0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY      I---------I---------I---------I---------I---------I---------I
 0       I   W                O
 1       I    W               O
 2       I    W              O
 3       I     W             O
 4       I     W            O
 5       I      W           O
 6       I      W           O
 7       I      W          O
 8       I      W          O
 9       I      W          O
 10      I      W          O
 11      I      W          O

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.
```

```
 50 REM W1:  WASTE DUE TO NATURAL POLLUTANTS; INITIALIZATION
100 REM POLUT -- WATER POLLUTION SIMULATION FROM ECCP
105 REM COPYRIGHT 1971  - POLYTECHNIC INSTITUTE OF BROOKLYN
110 REM MAJOR VARIABLES: X(OXY. CONTENT);  W1,W2,W(POLLUTION CONTENT)
115 REM OTHERS ARE DEFINED AS THEY APPEAR; EITHER IN PRINTS OR REMS
120 REM DEVELOPED BY L. BRAUN, T. LIAO, AND D. PESSEL
125 REM PROGRAMMED BY L. BRAUN, C. LOSIK, AND D. PESSEL
130 REM LATEST REVISION: 8-18-71
135 DIM X(51),W(51)
140 PRINT " ","WATER POLLUTION STUDY"
145 PRINT
150 PRINT "INSTRUCTIONS (1=YES, 0=NO)";
155 INPUT Q
160 IF Q=0 THEN 310
165 IF Q <> 1 THEN 150
170 REM INTRODUCTION
175 PRINT
180 PRINT
185 PRINT "IN THIS STUDY YOU CAN SPECIFY ";
190 PRINT "THE FOLLOWING CHARACTERISTICS:"
195 PRINT
200 PRINT "A. THE KIND OF BODY OF WATER:"
205 PRINT "   1. LARGE POND"
210 PRINT "   2. LARGE LAKE"
215 PRINT "   3. SLOW-MOVING RIVER"
220 PRINT "   4. FAST-MOVING RIVER"
225 PRINT
230 PRINT "B. THE WATER TEMPERATURE IN DEGREES FAHRENHEIT:"
235 PRINT
240 PRINT "C. THE KIND OF WASTE DUMPED INTO THE WATER:"
245 PRINT "   1. INDUSTRIAL"
250 PRINT "   2. SEWAGE"
255 PRINT
260 PRINT "D. THE RATE OF DUMPING OF WASTE,";
265 PRINT " IN PARTS PER MILLION (PPM)/DAY."
270 PRINT
275 PRINT "E. THE TYPE OF TREATMENT OF THE WASTE:"
280 PRINT "   0. NONE "
285 PRINT "   1. PRIMARY (SEDIMENTATION OR PASSAGE THROUGH FINE"
290 PRINT "                  SCREENS TO REMOVE GROSS SOLIDS)"
295 PRINT "   2. SECONDARY (SAND FILTERS OR THE ACTIVATED SLUDGE"
300 PRINT "                     METHOD TO REMOVE DISSOLVED AND COLLOIDAL"
305 PRINT "                     ORGANIC MATTER)"
310 PRINT
315 PRINT
320 PRINT "***********"
325 PRINT
330 REM INPUT PARAMETERS
335 PRINT "BODY OF WATER";
340 INPUT Q
345 REM D1:  RATE OF INJECTION OF NATURAL POLLUTANTS
350 LET D1=2
355 REM N:  NATURAL WASTE DECOMPOSITION COEFF.
360 LET N=.75
365 REM C:  RATE OF WATER ABSORPTION OF OXYGEN (BASED ON Q)
```

```
370  IF Q=4 THEN 420
375  IF Q=3 THEN 410
380  IF Q=2 THEN 400
385  IF Q <> 1 THEN 335
390  LET C=.4
395  GOTO 425
400  LET C=1
405  GOTO 425
410  LET C=1.5
415  GOTO 425
420  LET C=3
425  PRINT "WATER TEMPERATURE";
430  INPUT T
435  IF T>90 THEN 1055
440  IF T <= 32 THEN 1070
445  IF T>50 THEN 465
450  REM X9=MAX. OXYGEN CONTENT OF WATER
455  LET X9=15-2*(T-32)/9
460  GOTO 470
465  LET X9=11-(T-50)/9
470  PRINT "KIND OF WASTE";
475  INPUT Q
480  REM H:  HUMAN WASTE DECOMPOSITION COEFF.
485  IF Q=2 THEN 505
490  IF Q <> 1 THEN 470
495  LET H=.25
500  GOTO 510
505  LET H=.75
510  PRINT "DUMPING RATE";
515  INPUT D2
520  REM KEEPS D2 IN RANGE 0 TO 14
525  IF ABS(D2-7)>7 THEN 1040
535  REM W2:  WASTE DUE TO HUMANS; INITIALIZATION
540  REM X:   OXYGEN CONTENT; INITIALIZATION
545  LET W1=D1/N
550  LET W2=0
555  LET X=X9-D1/C
560  REM W(1),X(1):  INITIALIZE STORAGE ARRAYS (TOTAL WASTE,OXYGEN)
565  REM T2,K:  STORE DAY FISH BEGIN TO DIE, IF THEY DO
570  REM T9:  NEEDED FOR DAY COUNT;  M:  TOTAL DAYS FOR RUN
575  REM T1:  INTEGRATION INTERVAL
580  LET T2=0
585  LET T9=0
590  LET K=0
595  LET T1=.1
600  LET W(1)=W1+W2
605  LET X(1)=X
610  LET M=31
615  REM D2:  RATE OF INJECTION OF HUMAN POLLUTANTS
620  PRINT "TYPE OF TREATMENT";
625  INPUT Q
630  IF Q=0 THEN 660
635  IF Q=1 THEN 655
640  IF Q <> 2 THEN 620
645  LET D2=.1*D2
650  GOTO 660
655  LET D2=.5*D2
660  PRINT
665  PRINT
670  FOR J=2 TO M
```

```
675 FOR I=1 TO 10
680 LET T9=T9+T1
685 REM PAIR OF DIFF. EQNS. , EULER INTEGRATION
690 LET X=X+T1*(C*(X9-X)-N*W1-H*W2)
695 REM PREVENTS NEGATIVE OXYGEN LEVEL
700 IF X>0 THEN 710
705 LET X=0
710 LET W1=W1+T1*(D1-N*W1)
715 LET W2=W2+T1*(D2-H*W2)
720 IF X>5 THEN 740
725 LET K=K+1
730 IF K>1 THEN 740
735 LET T2=INT(T9)
740 NEXT I
745 REM W(J),X(J): STORAGE OF RESULTS IN ARRAYS
750 LET X(J)=X
755 LET W(J)=W1+W2
760 NEXT J
765 PRINT "DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3)";
770 INPUT Q
775 IF (Q-1)*(Q-2)*(Q-3) <> 0 THEN 765
780 PRINT
785 PRINT
790 REM TABLE OUTPUT ROUTINE
795 IF K<1 THEN 820
800 PRINT
805 PRINT
810 PRINT "AFTER DAY";T2;"THE GAME FISH BEGIN TO DIE, BECAUSE"
815 PRINT "THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM."
820 PRINT
825 IF Q<2 THEN 880
830 PRINT
835 PRINT
840 PRINT "TIME","OXY. CONTENT","WASTE CONTENT"
845 PRINT "DAYS","     PPM     ","     PPM      "
850 PRINT "----","------------","-------------"
855 FOR J=1 TO M
860 PRINT J-1,INT(100*X(J)+.5)/100,INT(100*W(J)+.5)/100
865 NEXT J
870 IF Q=2 THEN 1005
875 REM GRAPHING ROUTINE
880 PRINT
885 PRINT
890 PRINT "       0...OXYGEN-SCALE....5...OXYGEN-SCALE...10";
895 PRINT "...OXYGEN-SCALE...15"
900 PRINT "       0..WASTE.10..SCALE.20..WASTE.30..SCALE.40";
905 PRINT "..WASTE.50..SCALE.60"
910 PRINT "DAY    I---------I---------I---------I---------I";
915 PRINT "---------I---------I"
920 FOR J=1 TO M
925 PRINT J-1;TAB(6);"I";
930 IF 4*X(J)>W(J) THEN 945
935 PRINT TAB(7+INT(4*X(J)+.5));"O";TAB(7+INT(W(J)+.5));"W"
940 GOTO 950
945 PRINT TAB(7+INT(W(J)+.5));"W";TAB(7+INT(4*X(J)+.5));"O"
950 IF J<5 THEN 985
955 FOR K=1 TO 4
960 REM DETERMINES WHEN SYSTEM HAS REACHED EQUILIBRIUM
965 IF INT(W(J)+.5) <> INT(W(J-K)+.5) THEN 985
970 IF INT(4*X(J)+.5) <> INT(4*X(J-K)+.5) THEN 985
```

```
975  NEXT K
980  GOTO 990
985  NEXT J
990  PRINT
995  PRINT "THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT"
1000 PRINT "THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES."
1005 PRINT
1010 PRINT
1015 PRINT "ANOTHER RUN (1=YES, 0=NO)";
1020 INPUT Q
1025 IF Q=1 THEN 310
1030 IF Q <> 0 THEN 1015
1035 STOP
1040 PRINT "NEW YORK CITY ONLY POLLUTES ITS WATER AT THE RATE OF"
1045 PRINT "12 PPM/DAY.  MAKE YOUR RATE BETWEEN 0 AND 14."
1050 GOTO 510
1055 PRINT "THE WATER TEMPERATURE IS HIGH ENOUGH TO DESTROY MOST LIFE."
1060 PRINT "TRY A NEW TEMPERATURE."
1065 GOTO 425
1070 PRINT "YOUR BODY OF WATER IS A BLOCK OF ICE, AND CAN'T"
1075 PRINT "ACCEPT ANY WASTE.  TRY A NEW TEMPERATURE."
1080 GOTO 425
1085 END
```

V. THE POLUT MODEL

The defining equations and the constants used in the model are as follows:

$$\frac{dW1}{dt} = D1 - NW1 \qquad (1)$$

$$W1(0) = D1/N \qquad (2)$$

$$\frac{dW2}{dt} = D2 - HW2 \qquad (3)$$

$$\frac{dX}{dt} = C(X9 - X) - NW1 - HW2 \qquad (4)$$

$$W = W1 + W2 \qquad (5)$$

$$X(0) = X9 - D1/C \qquad (6)$$

$$N = 0.75 \qquad (7)$$

$$H = 0.25, \text{ for industrial waste, or } 0.75 \text{ for sewage} \qquad (8)$$

$$W2(0) = 0 \qquad (9)$$

$$D1 = 2 \qquad (10)$$

$$C = \begin{cases} 0.4, & \text{Pond} \\ 1.0, & \text{lake} \\ 1.5, & \text{slow river} \\ 3.0, & \text{fast river} \end{cases} \qquad (11)$$

in which

W1 = waste due to natural pollutants (dead fish, leaves, etc.) in parts per million (ppm).

W2 = waste due to humans (in ppm).

D1 = rate of injection of natural pollutants (in ppm per day).

D2 = rate of injection of human pollutants (in ppm per day).

N = waste decomposition coefficient for natural wastes.

H = waste decomposition coefficient for human wastes (sewage or industrial).

X = dissolved oxygen level (in ppm).

X9 = saturation oxygen level (function of temperature) (in ppm).

W = total waste in water (in ppm).

C = rate of absorption of oxygen in water (in ppm per day).

Equation 1 states that the change in the amount of natural pollutants in the water from day to day equals the rate at which natural pollutants are injected minus the rate at which these pollutants are decomposed. Notice that the waste due to natural pollutants at any time is constant, unless the rate of injection of natural pollutants changes with time i.e., $W1 = W1(0)$ for all $t > 0$. For this program, the assumption has been made that the rate of generation of natural wastes is constant throughout the year, but Equation 1 is retained in the event that a more elaborate model is desired at some future time.

Equation 2 ensures that the water system is in equilibrium at day 0 (i.e., before human wastes begin polluting the water).

According to Equation 3, the change in the amount of human pollutants in the water from day to day equals the rate at which human pollutants are injected minus the rate at which these pollutants are decomposed. HW2 represents the rate of decomposition of human waste. Note that when the human waste is sewage, the decomposition coefficient, H, takes on the same value as the decomposition coefficient for natural wastes. The value of H is considerably higher for sewage than for industrial waste.

Equation 4 states that the dissolved oxygen level of a body of water changes from day to day, depending on the difference between the saturation level and the actual oxygen level and the rates at which natural and human pollutants are decomposed. It is significant to note here that the saturation level of dissolved oxygen in water decreases as the water temperature increases, according to the formula:

$$X9 = \begin{array}{ll} 15 - 2\left[(T-32)/9\right] & \text{for } 32 < T \leq 50 \\ 11 - \left[(T-50)/9\right] & \text{for } 50 < T < 90 \end{array}$$

The graph in Fig. 1 depicts this relationship.

Equation 5 states that the total waste in the water is the sum of the natural and human wastes in the water.

Equation 6 states that at day 0 (i.e., before human wastes begin polluting the water) the level of dissolved oxygen in the

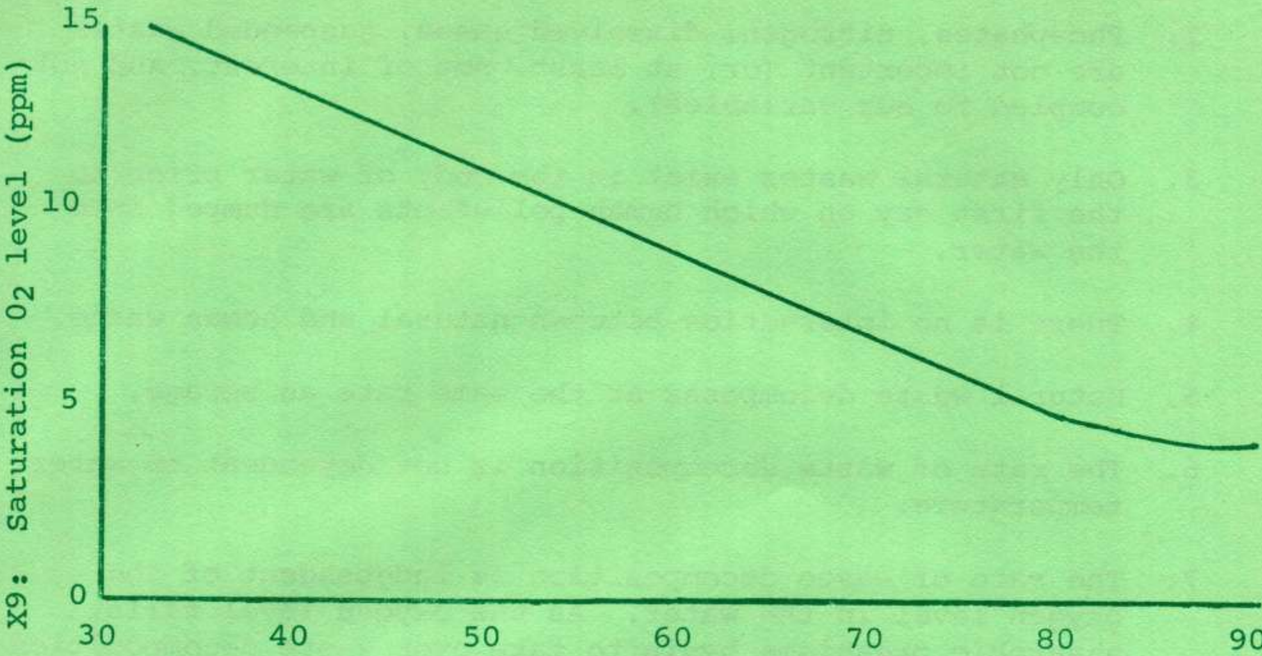

Fig. 1. Water temperature vs. saturation level of dissolved oxygen in water

water is less than the saturation level of dissolved oxygen in water by the amount required to decompose the natural waste.

Equations 7-10 state the constant values for waste decomposition coefficients, initial human pollutants, and rate of injection of natural pollutants.

Equation 11 states the rates of absorption of oxygen in water for each type of body of water. In effect, the varying constants reflect the effect of surface area or speed of the body of water on oxygen absorption.

ASSUMPTIONS

The assumptions under which the model operates are the following:

1. The rate of generation of natural wastes and human wastes is constant throughout the year.

2. Phosphates, nitrogen, dissolved gases, suspended wastes are not important (or, at least, not of interest, and not coupled to our variables).

3. Only natural wastes exist in the body of water prior to the first day on which human pollutants are dumped into the water.

4. There is no interaction between natural and human waste.

5. Natural waste decomposes at the same rate as sewage.

6. The rate of waste decomposition is not dependent on water temperature.

7. The rate of waste decomposition is independent of the oxygen level in the water. As the oxygen level falls, anaerobic organisms begin to take over waste decomposition and maintain the same rate of breakdown.

8. There are no differences in industrial pollutants (e.g., no difference is acknowledged between the wastes from a vegetable cannery and those from a chemical plant).

9. There are no seasonal variations in the water body.

10. Game fish (perch, trout, etc.) die or leave the area when the oxygen level drops below 5 ppm.