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Costs and Water Quality Effects of Controlling Point and Nonpoint Pollution Sources

C. M. Macal and B. J. Broomfield

ENVIRONMENTAL POLLUTANTS and the URBAN ECONOMY

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COSTS AND WATER QUALITY EFFECTS OF CONTROLLING POINT AND NONPOINT POLLUTION SOURCES

by

Charles M. Macal and Barbara J. Broomfield
Energy and Environmental Systems Division

January 1980

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FOREWORD

This document is one of a series of policy statements prepared by the Environmental Pollutants and the Urban Economy Program. The program is conducted jointly by Argonne National Laboratory and The University of Chicago and sponsored by the National Science Foundation. Previous policy statements have examined impacts of air pollution control regulations. This is one of two case studies concerned with water quality management issues. In a companion policy analysis, wastewater treatment plant centralization is analyzed from a cost-effectiveness perspective.

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COSTS AND WATER QUALITY EFFECTS OF CONTROLLING POINT AND NONPOINT POLLUTION SOURCES

by

Charles M. Macal and Barbara J. Broomfield

ABSTRACT

Costs and water quality effects of controlling point and nonpoint pollution sources are compared for the DuPage River basin in northern Illinois. Costs are estimated for improving water quality through stricter water pollution effluent standards for municipal wastewater treatment plants and for the alternative, controlling runoff from nonpoint sources such as streets, agricultural lands, and forests. A dynamic water-quality/hydrology simulation model is used to determine water quality effects of various treatment plant standards and nonpoint-source controls. Costs and water quality data are combined, and the point-source and non-point-source plans are compared on a cost-effectiveness basis. Nonpoint-source controls are found to be more cost-effective than stricter control of pollutants from point sources.

1 THE ISSUE

The relative costs and water quality effects of controlling point and nonpoint sources of water pollutants are important issues in river basin planning. In the past, point sources -- particularly municipal wastewater treatment plants -- have been prime targets of control for environmental authorities. Since point sources of water pollutants are limited in number, regularly monitored, and already controlled, and treatment methods are well developed, point-source control is relatively easy to implement. In contrast, nonpoint sources fall under numerous jurisdictions. Because of the intermittent nature of pollution due to nonpoint sources and the large land area that may be involved, it is often difficult to determine the quantity of pollutants from a particular source. Control techniques such as vacuum sweeping of streets and improved agricultural management practices may be difficult to implement.

A concern has developed over whether effluent standards for municipal treatment plants are excessively strict, resulting in a situation in which only small improvements in water quality would result from large financial investments in more-advanced treatment processes. The argument is that treatment plant effluent is treated to such a high degree that nonpoint sources have become the controlling factor in water quality degradation. If this is the case, a wiser investment strategy could be to prevent or treat nonpoint-source pollution.

This study compares the costs of improving water quality through control of point and nonpoint sources of water pollutants. A case study of the point/nonpoint control tradeoff issue in DuPage County, Illinois, is presented here. While study results are not directly transferable, they are suggestive of the situation in other areas with similar conditions.

2 THE STUDY AREA

The study area consists of the East and West Branches of the DuPage River and their drainage basins. This area, shown in Fig. 1, is part of a rapidly developing region of suburban Chicago.

2.1 THE DUPAGE RIVER

The headwaters of the East Branch lie in northern DuPage County. The stream, fed by four major tributaries, flows south for 24 miles to the confluence with the West Branch. As indicated in Table 1, the East Branch is a small stream with low velocity and flows that result in a relatively small waste assimilative capacity. These conditions inhibit the rate of reaeration, resulting in suppressed levels of dissolved oxygen. The East Branch drainage area is heavily populated, and both point and nonpoint sources contribute significant pollution loads to the stream. Major nonpoint-source pollution loads are due to overland runoff. Pollution loads and population are forecast to increase steadily until the year 2000. A concomitant shift in land use is anticipated, as indicated by Table 2.

The source of the West Branch is in northern Cook County. Fed by five primary tributaries, the stream flows south for 31 miles to the confluence. The West Branch is a somewhat larger stream than the East Branch, and slightly higher velocity and flows result in a waste assimilative capacity that, while still small, is better than that of the East Branch. The West Branch drainage area is larger and less populated than that of the East Branch. Pollution loads and population are anticipated to increase substantially by the year 2000. A dramatic shift in land use is also expected to occur, as shown in Table 2.

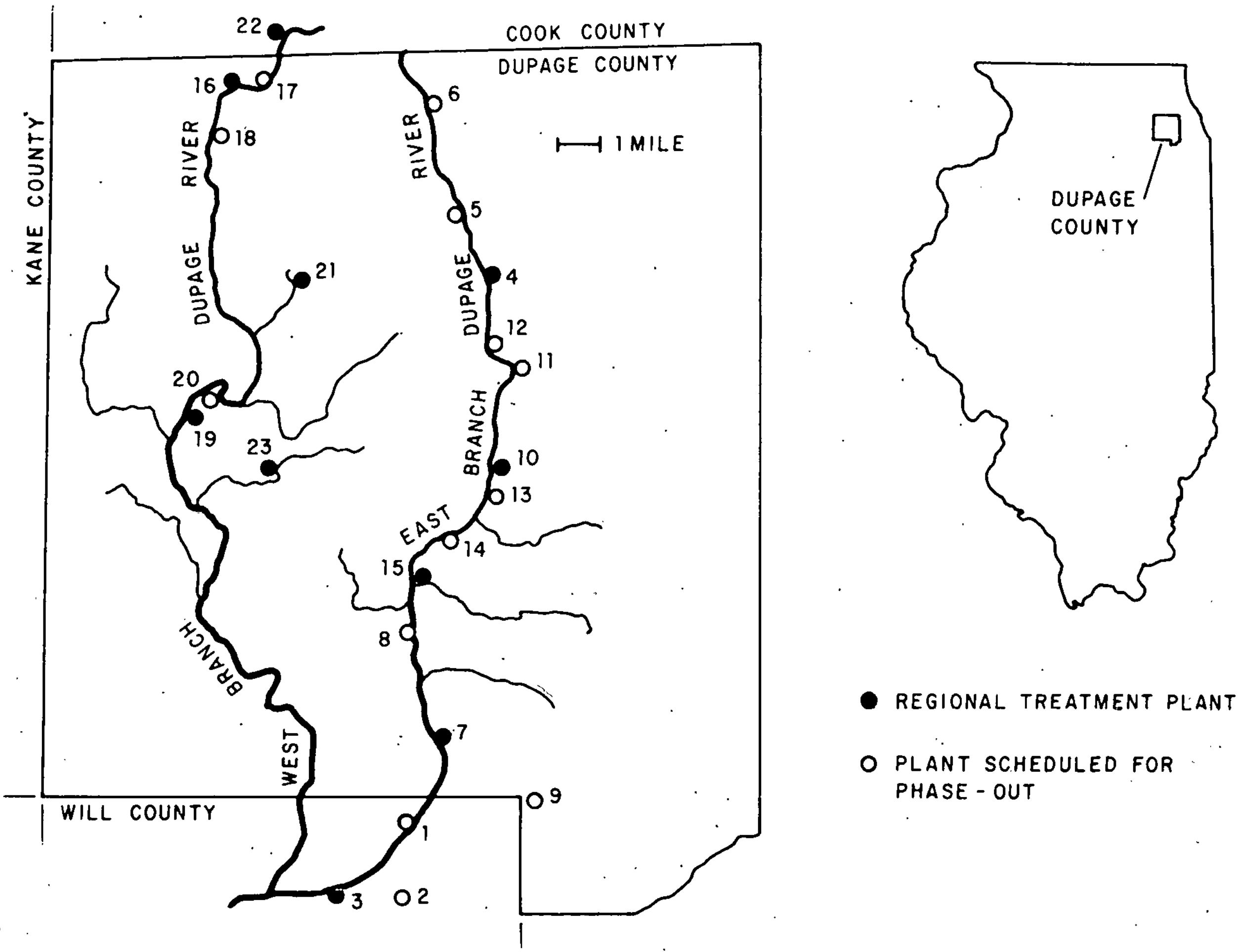
State water quality standards for the DuPage River directly affecting municipal wastewater treatment plants require that (1) the dissolved oxygen level not be less than 6 mg/L for more than 16

Table 1. Characteristics of DuPage River Branches and Basins

Characteristics	East Branch	West Branch
Stream		
Width (ft)[a]	47	66
Depth (ft)[a]	5.8	4.7
Grade (%)	0.071	0.095
Flow Rates (cfs)[a]		
Source	15	21
Confluence	118	134
Drainage Basin		
Area (sq miles)	84	124
Population		
1977	243,000	130,000
2000[b]	412,000	262,000

[a]Mean values.

[b]Estimated by Northeastern Illinois Planning Commission.



EAST BRANCH FACILITY PLANNING AREA	TREATMENT PLANT	WEST BRANCH FACILITY PLANNING AREA	TREATMENT PLANT
Bolingbrook	1 Bolingbrook	Bartlett	16 Bartlett
	2 Citizens Utility #1		17 Hanover #1
	3 Citizens Utility #2		18 Hanover #2
Glendale Heights	4 Glendale Heights	West Chicago	19 West Chicago
	5 Bloomingdale South		20 Winfield
	6 Roselle Waterbury	Carol Stream	21 Carol Stream
Woodridge	7 Woodridge	Metropolitan Sanitary District	22 Hanover Park
	8 Lisle		
	9 Farmingdale	Wheaton	23 Wheaton
Glenbard	10 Glenbard		
	11 Lombard		
	12 Glen Ellyn Heights		
	13 Citizens Utility-Butterfield		
	14 Citizens Utility-Valley View		
Downers Grove	15 Downers Grove		

Fig. 1. DuPage River Basin

hours in any 24-hour period and never be less than 5 mg/L, and (2) ammonia nitrogen levels never exceed 1.5 mg/L.

The State of Illinois has designated the East and West Branches as "water quality limited," implying that water quality standards will not be met even when wastewater effluent standards are achieved. Sampling studies have revealed that state standards for dissolved oxygen and ammonia are violated regularly with violations more frequent and severe in the East Branch.[1]

Table 2. Land Use Breakdown and Forecast

Category	Land Use (%) 1977	2000
East Branch		
Impervious surface[a]	10	18
Cropland[b]	9	6
Grassland[c]	61	68
Lowland[d]	20	8
West Branch		
Impervious surface[a]	6	11
Cropland[b]	40	15
Grassland[c]	45	66
Lowland[d]	9	7

[a]Consisting of streets, parking lots, and building roofs.

[b]Regularly tilled for agricultural purposes.

[c]Pastures, parks, golf courses, and upland forest.

[d]Marshes, swamps, and forests near rivers.

2.2 WASTEWATER TREATMENT PLANTS

Five facility-planning areas containing 15 municipal treatment plants serve the population of the East Branch basin. Four of the areas plan to consolidate 14 plants into four; the fifth planning area consists of a single regional plant. Total treatment design capacity of the five regional plants in the year 2000 is expected to be 63 million gallons per day (MGD). The West Branch also is served by five facility-planning areas, three of which consist of single treatment plants. Plans call for consolidating five facilities in the two other areas into two regional plants. The total capacity of the plants is expected to be 42 MGD in the year 2000.

The treatment plant configuration used in this study (see Fig. 1) represents current plans for expanding and phasing out treatment plants between now and the year 2000, as outlined in regional water quality management documents. No new plants are planned, only modifications to existing facilities.

2.3 NONPOINT-SOURCE CONTROL OPTIONS

Nonpoint-source pollution loads can have a significant impact on stream water quality. Diffuse loadings to the stream result from the accumulation and attenuation of pollutants on land surfaces and their subsequent transport to the water system. Pollutants that acccumulate on land surfaces wash into streams during periods of rainfall and snow melting. Adverse water quality impacts are most apparent immediately after storms; the effects can be especially severe when heavy rainfall follows a drought. The problem is created by a large surge of highly polluted runoff water entering the stream in a short time period -- this is commonly referred to as a shock load.

Effective management of nonpoint-source pollution includes control of runoff along with reduction of pollutant concentrations. This requires systems for water storage and treatment and land management practices appropriate for the community.

Investigations into the characteristics of the DuPage River basin reveal two major sources of diffuse pollution loads: runoff from impervious surfaces, discharged through storm sewers, and overland runoff, particularly from grassland areas. Both the volume and high pollutant loads associated with runoff could be reduced to lessen the impact on the DuPage River.

Many strategies for management of runoff have been suggested and discussed at public water quality management planning meetings held by the Northeastern Illinois Planning Commission (NIPC). Those plans recognized as having the greatest practical potential for implementation in the DuPage River basin are analyzed in this study.

The first strategy for nonpoint-source control studied was presented by NIPC in the areawide water quality management plan (AWQMP).[2*] The NIPC plan assumes a 25% reduction of biochemical oxygen demand (BOD) in runoff for existing urban areas and a 50% BOD reduction for newly urbanized areas as a result of vacuum sweeping of streets and parking lots. In addition, NIPC assumes that "best management practices" gradually will be implemented for agricultural land with a goal of 100% of agricultural land under such practices by the year 2000. The stream loadings estimated by NIPC to result from the above assumptions are used in this analysis. Cost data are taken from the AWQMP and modified to a form consistent with the framework followed throughout the cost analysis.

The second nonpoint-source strategy consists of control options for overland runoff. Since the sudden, large volume of runoff entering the river during a storm has a major impact on water quality, methods to restrict the flow would mitigate some of the detrimental effects. The option analyzed is the construction of numerous retention basins along the streams to catch surface runoff and distribute the flow over a period of time, thereby reducing the shock-loading impact on the two branches of the river. The conservative assumption is made that pollution levels are not significantly reduced but that total suspended solids, sediment, and BOD are decreased due to settling.

The third control method analyzed, for impervious surfaces, is use of porous pavements. While still in the experimental stages, porous pavements show promise as an effective means of regulating runoff from streets and parking lots. The lifetime of roadways is limited in the study area due to severe winters that cause rapid deterioration; many roads will have to be replaced before the year 2000. Use of porous materials for road repair and new construction could transform much of the existing impervious surface into permeable surface.

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*NIPC is responsible for developing the areawide water quality management plan for the six-county Chicago Standard Metropolitan Statistical Area in accordance with Section 208 of the Federal Water Pollution Control Act Amendments of 1972.

3 COST ANALYSIS

This analysis estimates the costs of improving water quality through control of point and nonpoint sources of water pollutants. For point sources, the incremental costs of treatment are estimated for effluent requirements more stringent than present standards. For nonpoint sources, the costs of the AWQMP and overland runoff control strategies are estimated using a framework consistent with the point-source cost analysis. Costs are calculated for a planning period of 1980 to 2000. The year 2000 time horizon is selected to be consistent with the planning objectives issued by NIPC and other onging water quality planning studies in the basin. Costs are not analyzed for the porous pavement option because of a lack of data on the cost of converting impervious pavement to porous pavement.

The cost analysis follows procedures set forth by the U.S. Environmental Protection Agency (EPA).[3] Some important parts of the method are: (1) all costs are calculated in constant 1977 dollars, (2) all costs are discounted to a present worth in 1977 to consider the time value of money, (3) capital costs represent depreciation of capital during the planning period, rather than total capital expenditures, by considering the salvage value of equipment and structures at the end of the planning period, and (4) sunk costs, that is, those incurred before the planning period, are not considered. The discount rate used is 6.375%, the rate designated by the Council on Environmental Quality for water quality management cost analyses for the second quarter of 1977.

3.1 POINT SOURCES

The operation of each treatment plant is simulated for each year in the planning period, 1980 to 2000, and the following costs are estimated:

- Capital costs, representing depreciation of existing wastewater and sludge treatment processes, laboratory and administrative facilities, and equipment added between 1980 and 2000 in response to scheduled expansions of treatment plant capacity. Capital costs also are estimated for modifying treatment plants to meet various effluent standards, given the particular types of treatment processes already in place.

- Costs of engineering, contingencies, and interest during project construction. These costs are estimated as a fraction of construction costs.

- Land costs. The salvage value of land at the end of the planning period is assumed to be equal to the land's market value at the beginning of the planning period. The land cost represents the opportunity cost of investing in the land between 1980 and 2000.

- Operation and maintenance costs of wastewater and sludge treatment processes and laboratory and administrative facilities.

- Disposal costs for residual sludge.

Operation, maintenance, and sludge disposal costs are based on plant capacity and flow. Costs of phasing out treatment plants are assumed to be negligible. Treatment processes already in place are assumed to have negligible net salvage value if discarded when a plant is expanded or upgraded.

Information on the types of treatment processes existing at the plants was obtained from local treatment facility plans, interviews with treatment plant operators, and areawide water quality management documents. Representative costs of treatment processes in general, land, operation, and maintenance were obtained from a U.S. EPA report;[4] data on pollutant removal efficiencies for each treatment process were taken from the same document. Administrative and laboratory facility costs were obtained from another U.S. EPA report.[5] All cost data were updated to reflect second-quarter 1977 Chicago-area price levels using U.S. EPA procedures and regional data and general economic statistics published for the area.

The level of detail used to represent the treatment plants is based on a tradeoff between accuracy of the predictions and costs of obtaining and analyzing data. Since representative treatment process data are used, cost estimates for any particular treatment plant may not be highly accurate; however, for several treatment plants taken together the accuracy of the total cost estimate may improve as underestimates and overestimates cancel out.

At the beginning of the planning period, treatment plant performance and technology reflect current effluent standards, generally BOD_5* concentrations of 10 mg/L and ammonia removal to 1.5 mg/L, future plans for upgrading treatment systems, and basic types of equipment existing at the plants. Successive simulation runs are made over the planning period. The effluent standards for BOD_5 are changed uniformly for all plants in 1980 and costs are estimated based on the technology required to meet the standards. (In the past, treatment plant effluent standards have been fairly uniform from plant to plant because of flow conditions in various parts of the river.)

A key aspect of the cost analysis concerns how to predict modifications of treatment plant technology in response to changes in effluent standards or capacity expansions. The particular treatment processes that are selected for the plant determine subsequent costs of plant modification, land, operation, and maintenance. Treatment technology is selected by calculating the capital and land costs of converting the original treatment process sequence to all technically feasible new process sequences. These costs are amortized and added to the estimated annual operating, maintenance, and sludge disposal costs. The sequence having the smallest annual costs is selected to represent the treatment plant from the time the modification occurs until the next modification or the end of the planning period.

The present worths of costs from 1980 to 2000 for all plants in each basin are added to obtain the cost of attaining a specific effluent quality. Several simulations are made with different effluent quality specifications to construct a relationship between the total basin-wide treatment cost and effluent quality.

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*Biochemical oxygen demand, five-day.

3.2 NONPOINT SOURCES

Data developed by NIPC on controlling runoff from impervious surfaces and agricultural land are used in determining the cost of the first nonpoint-source control strategy. Capital, operation, and maintenance costs are estimated over the planning period for vacuum sweepers and improvements in agricultural land necessary to apply best management practices.

The following costs are estimated for controlling overland runoff, the second nonpoint-source control strategy:

- Capital costs arising from the construction of reservoirs and open channels. Reservoir costs include those for construction, embankment, and lining. The consumption of capital between 1980 and 2000 is estimated by subtracting the discounted salvage value in the year 2000 from the initial capital expenditure.
- Costs of engineering, contingencies, and interest during project construction, estimated as a fraction of construction costs.
- Land costs, representing the opportunity cost of land investment.
- Field preparation costs.
- Yearly operation and maintenance costs of reservoirs and open channels.

3.3 RESULTS

The results of the treatment plant cost and effluent quality analysis are presented in Fig. 2. The horizontal axis represents BOD_5 effluent concentrations for all treatment plants on a branch after the necessary modifications have been made. The total incremental present worth of plant operation and modification above the BOD_5 treatment level of 10 mg/L for all plants between 1980 and 2000 is represented along the vertical axis. In all cases, costs include ammonia treatment and removal of suspended solids to a concentration of the BOD_5 concentration plus 25%.

From the figure, for example, if all plants initially produce effluent with a BOD_5 concentration of 10 mg/L, the additional cost of converting and operating all plants at a BOD_5 concentration of 4 mg/L would increase the present worth over the period 1980 to 2000 by $37 million for the East Branch and $22 million for the West Branch. The significantly lower costs for the West Branch reflect the difference in total treatment capacity.

The results of the nonpoint-source-control cost analysis are presented in Table 3 for the period 1980 to 2000. The costs for the NIPC plan are similar for both branches because of the similarity in the amount of impervious surfaces in the two drainage basins by the year 2000. In addition, because of the insignificant amount of agricultural land in the East Branch basin, all agricultural control costs accrue to the West Branch, which serves to offset the fact that the East Branch has a greater amount of impervious surface throughout most of the period before the year 2000. The cost of overland runoff control is greater for the West Branch because of the larger land area.

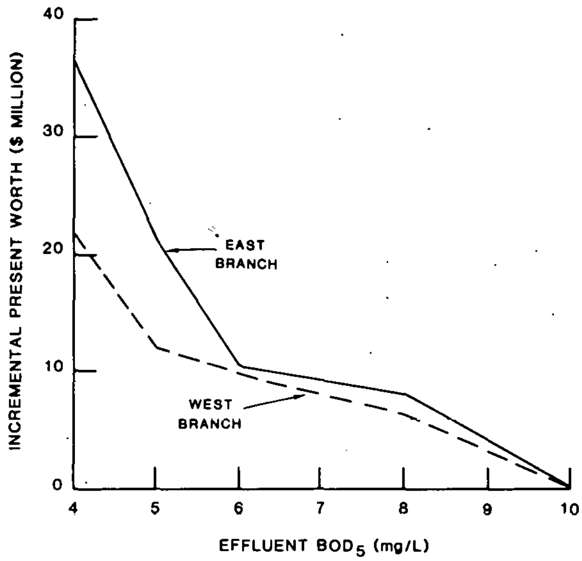

Fig. 2. Incremental Treatment Plant Cost as a Function of Degree of Treatment

4 WATER QUALITY ANALYSIS

The water quality analysis estimates the impact on the East and West Branches of various levels of municipal wastewater treatment and of nonpoint-source pollution loads. It also predicts the water quality effects of implementing different nonpoint-source control strategies. Water quality assessment studies are conducted to estimate stream conditions under possible pollution control options. The results provide the basis for comparing and evaluating the overall effectiveness of the proposed pollution control methods. In conforming to a regional planning study being conducted by NIPC, the year 2000 is used as the basis for the water quality analysis. Major consequences of the anticipated population increase are considered, including increases in wastewater flows, changes in land use and development, and improvements in water pollution control practices.

Table 3. Costs of Controlling Nonpoint-Source Runoff[a]

	Present Worth in 1977 ($$10^6$)[b]	
Plan	East Branch	West Branch
NIPC Plan	9.0	8.7
Overland Runoff Control	21.5	31.6

[a]Costs are calculated for the period 1980-2000.

[b]Costs are in 1977 dollars.

A mathematical model that quantitatively describes the behavior and interactions of water quality parameters is employed to simulate the effects of different wastewater effluent characteristics on the DuPage River. The model used was developed by Hydrocomp, Inc., of Palo Alto, California. Known as HSP (Hydrocomp Simulation Program), it is a continuous dynamic model that simulates hydrologic and water quality processes.

The data base used to calibrate, verify, and operate the water quality component of the HSP model is derived from data collected in 1976 by the Illinois EPA as part of a continuous water quality monitoring program, and from the results of a water quality sampling survey conducted by NIPC between April 1976 and April 1977. Based upon population statistics and growth trends in the study area, NIPC forecast conditions expected to exist in the DuPage River Basin by the year 2000 and calibrated the model accordingly.*

For purposes of simulation, the East and West Branches of the DuPage River are divided into reaches, which are defined as stream segments having uniform biological and physical characteristics. Water quality parameters simulated are:

- Stream flow,
- Water temperature,
- Dissolved oxygen (DO),
- Biochemical oxygen demand (BOD),
- Ammonia,
- Nitrates,
- Phosphates, and
- Algae, measured as chlorophyll A.

Evaluations of water quality are based primarily upon State of Illinois water quality standards. Overall stream quality is represented by the weighted means of the parameters taken over all the reaches. Although all the constituents are analyzed, in-stream levels of DO and ammonia are more significant because they are regulated by the state standards. Particular attention is given to the frequency and duration of violations of the water quality stancards. A statistical analysis is performed for each parameter modeled for all reaches.

As the primary purpose of this study is to compare the cost-effectiveness of nonpoint-source control options, some value or set of values to assess water quality conditions is needed. The overall stream quality can be reasonably represented by the weighted average of mean DO and ammonia concentrations, minimum DO values, and the percent of time the stream standard for DO (5 mg/L) is violated. The weighted average is calculated as follows:

$$\sum \text{(parameter value of reach} \times \text{reach length)} \div \sum \text{reach length}$$

Because the lengths of the reaches vary considerably -- from 0.4 mile to 6.6 miles -- a weighted average is a more realistic approximation of overall conditions in the stream than is a simple average.

The HSP model operates by time series analysis. The value of each parameter is calculated for every reach in one-hour intervals over the entire simulation period. Each value is thus considered to represent the average concentration of the constituent over the length of the reach for the time modeled. In this study, a three-year simulation period is used. Wastewater treatment plant operating conditions and nonpoint-source control practices are

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*Hydrocomp, Inc., has been contracted by NIPC to do water quality modeling for the 208 program. The water quality and treatment facility data collected by NIPC and the Hydrocomp models are used in this study to be consistent with the 208 planning program.

kept constant for each simulation; only the weather conditions (i.e., rainfall, snow melt, cloud cover, wind, temperature, dewpoint, etc.) vary. Meteorological conditions necessary for operation of the model are taken from data collected at local monitoring stations. Weather parameters from 1971 to 1973 are used in all simulations.

4.1 POINT SOURCES

Each municipal wastewater discharge into the DuPage River is represented in the model. The effluents are characterized by flow rate; temperature; and concentrations of DO, BOD, ammonia, nitrates, and phosphates. The parameter values are stored in daily time series to allow representation of the variability of effluent quality. In considering alternative treatment processes, it is assumed that the concentrations of BOD, ammonia, nitrates, and phosphates in the effluent change, but that the temperature and DO level remain constant. The degree of variability of constituent concentrations in the effluent also is assumed to remain constant; only the average yearly values for BOD, ammonia, nitrates, and phosphates are adjusted.

In each simulation, all wastewater plants are assumed to operate at the same treatment levels; the yearly average concentrations of the effluent parameters are identical for all the facilities. However, the degree of variability over time of the constituent levels in the effluents is uniquely defined for each facility, and these distribution functions are maintained for all simulations.

4.2 NONPOINT SOURCES

An important objective of this study is to determine the influence of alternative nonpoint-source controls on water quality in the DuPage River. Diffuse pollution characteristics as described for existing conditions and NIPC assumptions for future controls of nonpoint sources are both considered. Additionally, the HSP model is used to simulate conditions resulting from control of runoff from pervious and impervious surfaces. The following mechanisms were incorporated into the model for simulation:

- Overland flow rates from pervious areas are reduced, thereby decreasing peak storm and snow-melt runoff to the stream. The runoff volume is not changed; only the rate of entry to the stream is reduced. In considering the use of detention basins for flow control, it is assumed that all overland runoff from pervious surfaces is diverted to the stream without further treatment. A maximum detention allowance of three days is imposed upon the system, and the discharge rates are adjusted accordingly to reflect the runoff rate. Pollution concentrations associated with the runoff are calculated for each storm, and the results are used to determine the corresponding characteristics of the stormwaters in the basins. As a conservative estimate, it is assumed that a 20% reduction of BOD occurs as a result of settling.

- Runoff from impervious surfaces, dicharged through storm sewers, is controlled by reducing flow rates and pollution loads, thereby decreasing peak storm and snowmelt runoff and the associated pollutant discharges to the stream. Again, the runoff volume is not changed, but pollutant concentrations are reduced by approximately 90%, and the rate of entry to the stream is reduced about 50%. In considering the use of porous pavements to achieve this control, it is assumed that all paved areas can be represented as porous surfaces. Consequently, all direct runoff from those areas is elimianted. Because experimentally designed porous pavements can have infiltration rates in excess of 25 inches/hour,[6] which is greater than the maximum rainfall expected to occur in the study region, this assumption is believed to be reasonable. Water that seeps through porous pavements is presumed to become part of subsurface or groundwater flows without influencing the water quality of those flows. Appropriate modifications are made in the model to represent the expected increase in subsurface flows.

These nonpoint-source control options are very generally represented in the model; therefore, the water quality results can be applied to other methods that achieve a similar effect. For example, the simulated water quality anticipated to result from porous pavement installation could be almost equally the result of the development of an extensive retention system designed to collect and contain waters currently discharged through storm sewers for subsequent diversion and treatment in wastewater treatment facilities. For control of pervious surface runoff, any one of a number of feasible flood control methods could be developed to achieve water quality effects similar to those to the detention basin option studied.

In the analysis of the nonpoint-source control options, two levels of treatment by wastewater treatment plants are considered, with the following effluent characteristics:

- BOD5 = ammonia = nitrates = phosphates = 0 mg/L
- BOD5 = 10.0 mg/L, ammonia = 0.6 mg/L, nitrates = 2.0 mg/L, phosphates = 1.0 mg/L

Temperature, dissolved oxygen, and flow rates for each point source are maintained at the levels determined by NIPC in its survey work. All wastewater treatment facilities are presumed to operate at the same standards.

In the first case, only hydraulic loads from the municipal wastewater treatment facilities are included in the simulations. Essentially, this represents the maximum pollution removal theoretically possible. The results demonstrate the impact on water quality due only to nonpoint sources of pollution. The second case typifies treatment processes likely to be implemented by the year 2000 for a majority of the facilities where nitrification-denitrification and some removal of phosphorous would be included.

4.3 RESULTS

Special care is required to interpret the results of the model. There are several drawbacks to the model that limit its accuracy and usefulness.

- Spatial representation of water quality conditions is poor. Only one value is calculated for each reach, so unless the reaches are made very small (which would result in exorbitant computer costs), a dissolved oxygen sag curve is not generated and cannot be derived from the results. Thus, the true minimum DO levels due to point-source pollution loads cannot be determined. Also, the true maximum ammonia levels due to pollution stress cannot be calculated.
- The model cannot recognize distributional flows; all flows into the stream must be represented as point discharges. The model will assume that all inputs to the reaches occur at the head of the respective reach. This includes water and mass flows such as wastewater effluents, tributaries, and nonpoint-source discharges (both surface runoff and subsurface flows). Such considerations could skew the calculated values of parameters such as DO level.
- Many of the calibration parameters are based on very general assumptions and qualitative judgments. The model is sensitive to these parameters. Any deviation of the parameter value from the actual condition it represents will alter the model's prediction. Thus, at best, the model can only be assumed to approximate real world conditions.

An advantage of the HSP model is that it can estimate the amount of time that a given parameter will exceed or fall below a set value. Thus a frequency distribution can be made for any parameter. Since calculations are made on an hourly basis and a three-year period is assumed for this simulation, there is a large basis from which to generate a distribution function. The results can be particularly useful for evaluating water quality conditions.

Modeling techniques, as used in this study, are most useful for comparing the effects of different conditions. In this case, the water quality effects of various management schemes to control nonpoint-source pollution are compared. The results obtained from the model help evaluate the effectiveness of each scheme in achieving a set goal for water quality improvement in the DuPage River.

Table 4 summarizes the simulation results for the proposed nonpoint-source controls. It is apparent that the nonpoint-source pollution loads have severe detrimental effects on the DuPage River and that water quality can be improved significantly by implementing adequate control measures.

It had been determined previously that many violations of water quality standards occur as a consequence of storms. The extent and severity of water

Table 4. Water Quality Effects of Nonpoint-Source Control in the Year 2000

Nonpoint-Source Control Plan	Without Point-Source Pollutant Loadings[a]		With Point-Source Pollutant Loadings[b]	
	Avg. of Min. DO Values (mg/L)	Avg. of % Time DO < 5 mg/L	Avg. of Min. DO Values (mg/L)	Avg. of % Time DO < 5 mg/L
East Branch				
Present Controls	1.9	2.4	1.5	23.3
NIPC Controls	2.3	1.9	2.0	15.5
Overland Runoff + NIPC Controls	3.2	1.5	2.4	3.8
Porous Pavement + NIPC Controls	3.2	1.1	1.1	5.6
Porous Pavement + NIPC and Overland Runoff Controls	-	-	-	1.4
West Branch				
Present Controls	2.5	1.3	2.2	4.0
NIPC Controls	3.2	0.95	3.0	2.2
Overland Runoff + NIPC Controls	3.6	0.73	3.3	1.1
Porous Pavement + NIPC Controls	2.5	0.85	2.4	1.7
Porous Pavement + NIPC and Overland Runoff Contols	-	-	-	0.1

[a]Point sources have no pollutant load on the stream but full hydraulic load.

[b]All point sources discharge effluent with the following pollutant characteristics: mean BOD_5 - 10 mg/L; mean ammonia < 1 mg/L; all other pollutants are at concentrations generally expected for these BOD and ammonia levels.

quality impacts are directly related to the accumulation of pollutants on the land and the intensity and duration of the storm. In several instances the effects are evident for days after a storm. The time delay involved for runoff to reach the river is a major cause of this effect; land surface features retain rainfall and restrict movement of overland flows so that runoff can persist for an extended period following a storm.

The control of overland runoff, as proposed and simulated in this study, results in significant water quality improvements for both the East and West Branches. While the total amount of pollutants is not reduced significantly, controlling the rate of discharge to alleviate the shock loadings is sufficient to mitigate detrimental water quality impacts. Treatment of runoff, through mechanical or natural means, would further improve water quality.

Control of impervious surface runoff through the use of porous pavements significantly improves water quality. While the total volume of runoff eliminated by this method is small in comparison with the overland flows of the grassland areas, the concentration of pollutants is significantly higher; basically this is due to greater pollutant accumulation on impervious surfaces. (It should be noted that a similar effect could be realized by collecting and storing the stormwater runoff from paved areas and treating it before discharge.)

Implicit in these results is the finding that nonpoint sources contribute significantly to in-stream pollution levels and are a major cause of stream degradation and violations of state standards. An important observation in support of this finding is that even without considering pollution loads from point sources (that is, when only the hydraulic load is simulated) -- which would significantly dilute the stream -- violations of standards still occur (see Table 4). This is a further indication of the poor assimilative capacity of both the East and West Branches. The overland runoff control is demonstrated to be more effective than the control of runoff from impervious surfaces.

5 COST-EFFECTIVENESS COMPARISON

In the previous sections the costs and water quality improvements of the NIPC plan and overland runoff control are estimated. Thus, two data points for nonpoint-source control in each river branch are derived. To derive a function of cost versus water quality improvement, a linear cost-effectiveness relationship is assumed for intermediate improvements in water quality. If, for example, half of the communities along a river implement street sweeping or develop overland runoff control programs, it is reasonable to assume that the cost incurred is half of what the cost would be if all communities implemented the programs. If these communities are located throughout the basin proportionately to the nonpoint-source pollution loads, results indicate that improvements in mean DO are also about half of what they would be if all communities adopted the plan. It is recognized that dissaggregate results, in which the incremental effects of nonpoint-source controls for individual reaches are considered, might be more instructive. However, the large computational requirements necessary to determine the true shapes of the curves at all points, based on varying the locations and sequencing of the nonpoint-source controls in the individual reaches, is beyond the scope of this study.

Cost-effectiveness results for the East Branch of the DuPage River are illustrated in Figs. 3 and 4. From Fig. 3, a significant cost differential in favor of nonpoint-source control is apparent for improvements in the average minimum DO level. Nonpoint-source control costs range between 25% and 50% of point-source control costs. The NIPC plan improves the average minimum DO level to more than 2.0 mg/L at a cost of $9 million. Similar improvements in water quality cannot be achieved by point-source control even if all plants produce effluent with a BOD_5 concentration of 4 mg/L. Overland runoff control in conjunction with the NIPC plan improves the average minimum DO level but at a considerably higher cost.

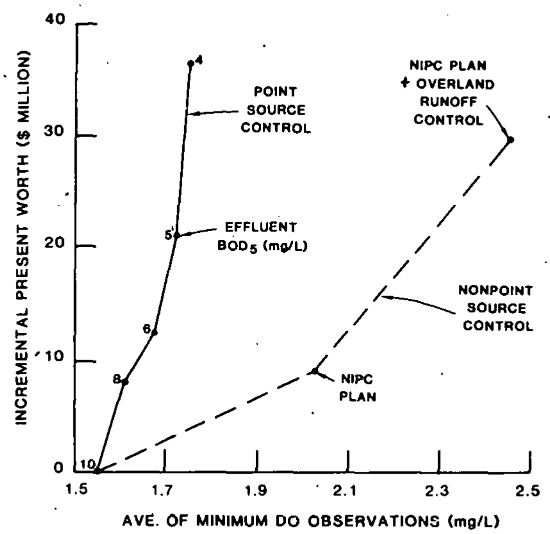

Fig. 3. Cost as a Function of Dissolved Oxygen Concentration - East Branch

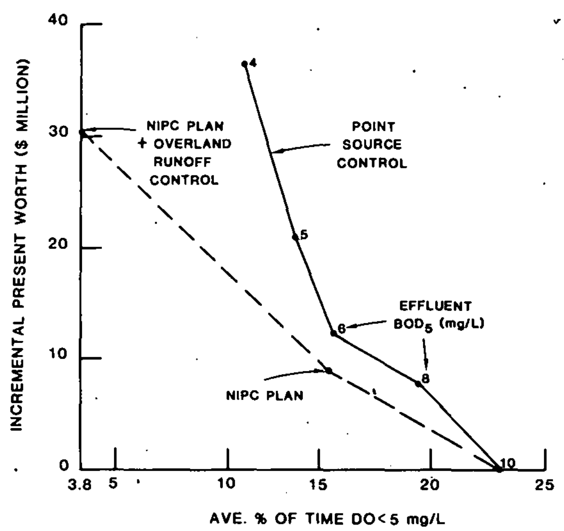

Fig. 4. Cost as a Function of Dissolved Oxygen Violations - East Branch

Figure 4 illustrates a significant cost differential in favor of nonpoint-source control for reductions in the percentage of time mean in-stream DO levels fall below 5 mg/L. Nonpoint-source control can achieve reductions similar to those of point-source control, but at only 40-75% the cost.

Cost-effectiveness results for the West Branch are illustrated in Figs. 5 and 6. Figure 5 shows a significant cost differential in favor of nonpoint-source control for improvements in the average minimum DO level between 2.2 mg/L and 2.4 mg/L. Nonpoint source control costs are less than 30% of point-source control costs in this range. The NIPC plan improves the average minimum DO level to more than 3.0 mg/L at a cost of $8.7 million. Similar improvements in water quality are not achieved by requiring point sources to discharge at 4 mg/L. Overland runoff control in conjunction with the NIPC plan improves the average minimum DO level but at a significantly greater cost.

Figure 6 reveals a significant cost differential in favor of nonpoint-source control for reductions in the percentage of time mean in-stream DO levels fall below a concentration of 5 mg/L. Nonpoint-source control can achieve the same reductions as point source control, but at only a fraction of the cost.

6 CONCLUSIONS

The foregoing results indicate that control of nonpoint sources is a more cost-effective means of improving water quality than further control of point sources for the East and West Branches of the DuPage River. Furthermore, nonpoint-source control offers the potential to improve water quality beyond that achievable through total elimination of pollutants in wastewater treatment plant effluent.

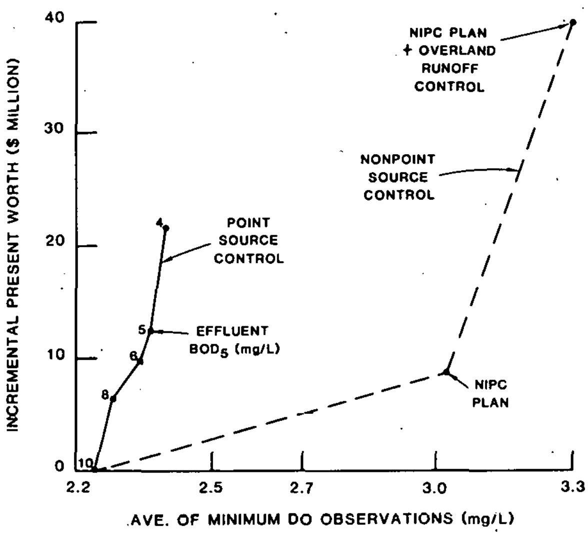

Fig. 5. Cost as a Function of Dissolved Oxygen Concentration - West Branch

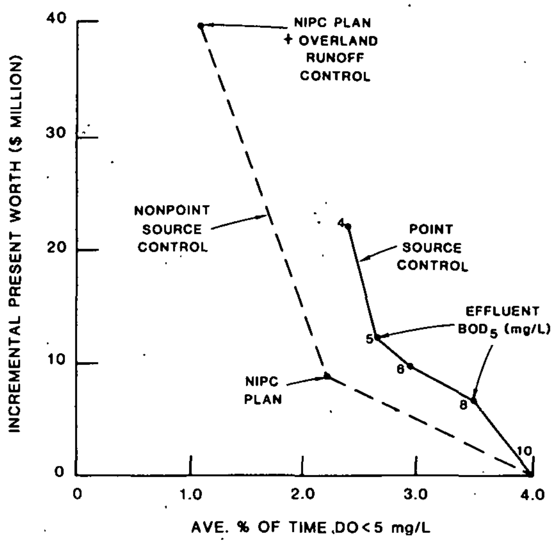

Fig. 6. Cost as a Function of Dissolved Oxygen Violations - West Branch

Care should be taken when interpreting these results because representative cost and performance data are used to characterize treatment processes and nonpoint-source control strategies. Detailed site-specific analyses are not conducted. In addition, social and institutional impediments to implementing nonpoint-source control methods are not addressed. These results suggest that further analysis of such strategies is warranted.

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