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GAO

Report to the Administrator
Environmental Protection Agency

December 1986

WATER QUALITY

An Evaluation Method for the Construction Grants Program—Case Studies

131803

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Volume 2

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United States
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Program Evaluation and
Methodology Division

B-221558

December 17, 1986

The Honorable Lee M. Thomas
Administrator, Environmental Protection
Agency

Dear Mr. Thomas:

Within the past 2 years, several important studies have been published that address present water quality in the United States, how water quality has changed, what pollution sources exist, and whether the Construction Grants Program has contributed to any water-quality improvement that may have occurred. In particular, GAO's recent report entitled The Nation's Water: Key Unanswered Questions About the Quality of Rivers and Streams (GAO/PEMD-86-6) reviewed these studies and reported on the gaps in what is known about the effect of the Construction Grants Program on the quality of the nation's water. The present report demonstrates a way of closing some of these gaps by using data and methods of analysis available to the Environmental Protection Agency. This is the second volume of the report. The report contains recommendations to you in chapter 3 of volume 1.

As you know, 31 U.S.C. 720 requires the head of a federal agency to submit a written statement on actions taken on our recommendations to the House Committee on Government Operations and the Senate Committee on Governmental Affairs not later than 60 days after the date of the report and to the Committee on Appropriations in the House and in the Senate with the agency's first request for appropriations made more than 60 days after the date of the report.

We are sending copies of this report to appropriate House and Senate committees, members of the Congress from the states mentioned in the report, and the director of the Office of Management and Budget. We will also make copies available to interested organizations, as appropriate, and to others upon request.

Sincerely yours,

Eleanor Chelimsky

Eleanor Chelimsky
Director

Executive Summary

Purpose

Since the Clean Water Act was passed in 1972, the federal government has spent more than $39 billion to assist in constructing and upgrading municipal sewage-treatment plants under the Construction Grants Program. The Environmental Protection Agency (EPA) has not yet performed an adequate evaluation of how effective the program has been in cleaning up the nation's waters, although extensive water-quality data have been collected. GAO undertook this report in order to develop guidelines for the use of available data and software in evaluating sewage-treatment plant upgrades. This volume of GAO's two-volume report presents the results of four case studies that demonstrate the utility of GAO's guidelines for estimating the effect of selected upgrades. The volume accompanying this one includes a detailed discussion of GAO's methodology.

Background

Most of the Construction Grants Program funds have been spent on increasing the capacity of existing municipal sewage-treatment plants and on improving their efficiency in removing specific pollutants from the wastewater they discharge into rivers and streams. Past evaluations of the program's activities have looked only at the change in plant efficiency resulting from the upgrades and have failed to demonstrate rigorously the connection between changes in a plant's discharge and changes in a stream's water quality. GAO used its methodology—which includes a systematic analysis of four questions to measure the effect of upgrades to wastewater-treatment plants—to perform case studies of upgrades serving the Pennsylvania communities of Allentown, Hamburg, Lansdale, and Tamaqua.

Results in Brief

GAO found that two upgrades in its four case studies were effective in improving water quality downstream from the upgraded plants. The effect of a third upgrade was detectable but marginal. Although the fourth upgrade resulted in substantial decreases in the plant's pollutant discharge, GAO found that water quality failed to improve downstream because of offsetting increases in discharges from other plants in the vicinity.

GAO's Analysis

GAO determined that its evaluation methodology is appropriate because it successfully addressed four questions.

Analysis of Plant Effluent

1. Did the upgrade of the sewage-treatment plant decrease the amount of pollutants discharged?

In all four case studies, the volume of pollutants such as suspended solids and fecal coliform bacteria discharged from the plants declined substantially after the upgrades from the pre-upgrade levels, although total wastewater discharge increased significantly at all the sites except Tamaqua. Improvements in individual pollution measures ranged from 28 to 87 percent. At Hamburg, however, pollutant discharge first returned to pre-upgrade levels, a few years after the upgrade, and then declined. (See pages 14-19, 30-31, 41-45, and 50.)

Stream Water-Quality Improvements

2. Did water quality improve downstream from the treatment plant?

At Allentown and Tamaqua, significant improvements occurred in several water-quality indicators, primarily in levels of dissolved oxygen and nitrogen compounds. At Lansdale, water-quality measures generally remained unchanged or deteriorated after the upgrade. Water quality improved downstream from the Hamburg plant only slightly; few significant improvements were noted. In relation to the volume of the receiving stream, discharge was smaller from the Hamburg plant than from the three other plants. (See pages 20, 34, 45-46, and 57.)

Relationship Between Plant Discharge and Stream Water-Quality Indicators

3. Were changes in the plant's effluent related to changes in stream water-quality indicators?

In three case studies, GAO found a statistically significant association between the discharge from a treatment plant and the water quality at the observation point. This relationship was generally stronger at Allentown and Tamaqua, under low-flow conditions and when statistical adjustments were made for variations in stream flow levels. At Lansdale, no relationship was found. (See pages 22, 36, 47, and 58.)

Cause-and-Effect Relationships

4. Can other reasonable explanations of water-quality conditions be excluded?

The streams to which the Allentown and Lansdale plants discharge also receive pollutants from other municipal and industrial sources. GAO compared the records of all the dischargers and determined that at two locations downstream, the effect of the Allentown sewage-treatment plant could be distinguished from the significant influence of other dischargers. The Lansdale upgrade failed to result in downstream water-quality improvements because of simultaneous increases in pollutant discharges from other treatment plants. The influence of other dischargers near Tamaqua and Hamburg was secondary to the effect of these treatment plants on water quality in their receiving streams. (See pages 27, 36-39, 47, and 58-59.)

Recommendation

In the report that this volume supplements, GAO recommends that EPA perform additional evaluations of upgrades to sewage-treatment plants, using available data and methods similar to GAO's. The purpose of these evaluations would be to assess, insofar as possible, the effects of the Construction Grants Program on stream water quality.

Agency Comments

In the separate volume to this report, GAO reprints and discusses comments it received from EPA and the U.S. Geological Survey. EPA generally agreed with GAO's methodology and its application to the four case studies but said that it is applicable to only a small fraction of all the plant upgrades. GAO believes that the methodology could be used for more upgrades than this but agrees that the particular data sources and statistical methods GAO used in its case studies are not universally applicable and would have to be supplemented for many cases. However, GAO also believes that this consideration does not obviate the need to examine the empirical evidence on stream water quality in assessing the effects of the Construction Grants Program, particularly where the relevant data are already available to EPA.

The U.S. Geological Survey generally agreed with GAO's concern that evaluations be based on empirical evidence and offered some specific technical comments on the methodology.

GAO based appropriate changes to the report on the comments the agencies provided.

The four municipalities in which the upgrades GAO analyzed were made declined to comment on the report.

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Abbreviations

EPA	U.S. Environmental Protection Agency
GAO	U.S. General Accounting Office
GICS	Grants information control system
NASQAN	National stream quality accounting network
NPDES	National pollutant discharge elimination system
STORET	STOrage and RETrieval

Chapter 1

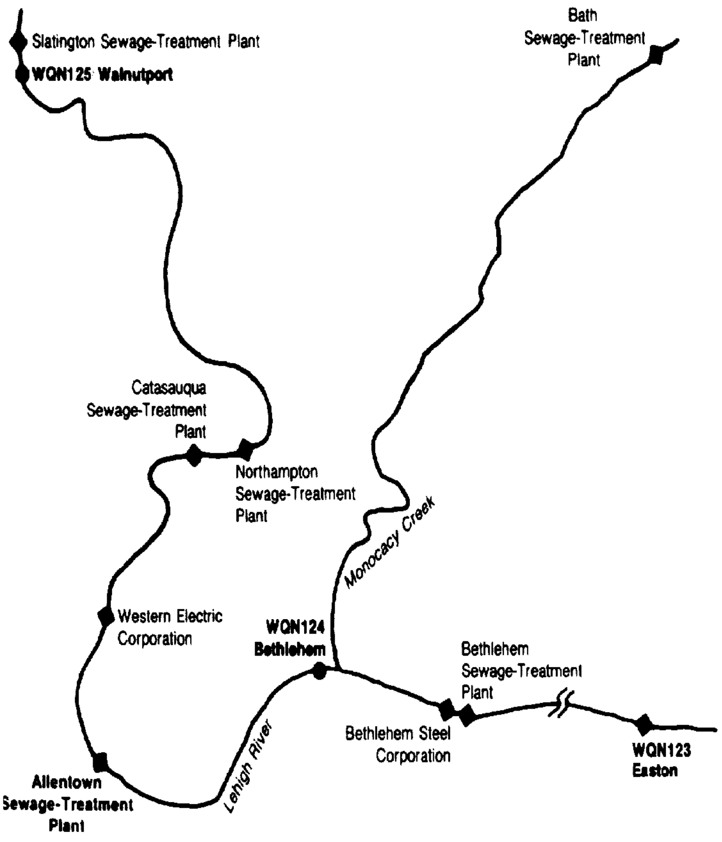
Introduction

This is the second and final volume of a report on our development of a methodology for evaluating the effect of the Construction Grants Program that uses changes in stream water quality as the criterion of effectiveness. The report was prompted by our concern that no adequate stream-based evaluation of the effects of the Construction Grants Program has yet been performed.

The present report is the first step toward such an evaluation. We developed a systematic set of procedures to assess the effect of a wastewater-treatment plant upgrade on downstream water quality and applied them to four cases of plant upgrades in eastern Pennsylvania. The methodology uses water-quality data and software that are already present in the computer system of the U.S. Environmental Protection Agency (EPA) and data on plant effluent that are available elsewhere in EPA's files.

The first volume of this report, entitled Water Quality: An Evaluation Method for the Construction Grants Program—Methodology (GAO/PEMD-87-4A), defines the requirements for an adequate evaluation, provides the details of the various adjustments and statistical techniques we applied to the data, and draws conclusions concerning the applicability of the method. For methodological considerations, the reader is therefore referred to that volume. That volume also contains our recommendations to EPA for further research, comments submitted by EPA and the Department of the Interior on our draft report, our response to these comments, and a bibliography of the relevant literature we consulted during our review.

The present volume presents the results of four case studies of wastewater-treatment plant upgrades, studies we performed to test our methodology. This volume includes four chapters, each one a synopsis of the substantive findings of one of the four upgrades, and four appendixes containing technical details related to the case studies. For the reader's convenience, foldout pages before the four case-study chapters provide profiles of essential information about the plants and maps showing the location of each plant, its stream quality observation points, and other important geographic features of the area.



Allentown Profile

Feature	Data
NPDES number	PA0026000
Type of change	Upgrade to advanced treatment; increase in capacity
Construction began	June 29, 1976
Works in operation	August 31, 1979
Project completed	August 31, 1979
Cost	$14.9 million
Average flow	30 million gallons per day
Discharge	Into the Lehigh River

Allentown Sewage-Treatment Plant Case Study

The wastewater-treatment plant in Allentown—a city of approximately 110,000 in eastern Pennsylvania some 50 miles north of Philadelphia—was constructed on the Lehigh River in the late 1920's and early 1930's. In 1968, the capacity of the original facility was expanded to 28.5 million gallons per day. In 1976, EPA issued a grant for a further expansion of the plant's capacity and an upgrade to advanced treatment. This upgrade included additional pumping stations, settling tanks, and digesters and new plastic media trickling filters to increase the capacity for nitrification and the removal of biochemical oxygen demand. Nitrification, the conversion of ammonia to nitrites and nitrates, is the advanced waste treatment component of the Allentown sewage-treatment plant. The plant's location and essential information about the plant are shown in the map and profile in foldout figure 2.1.

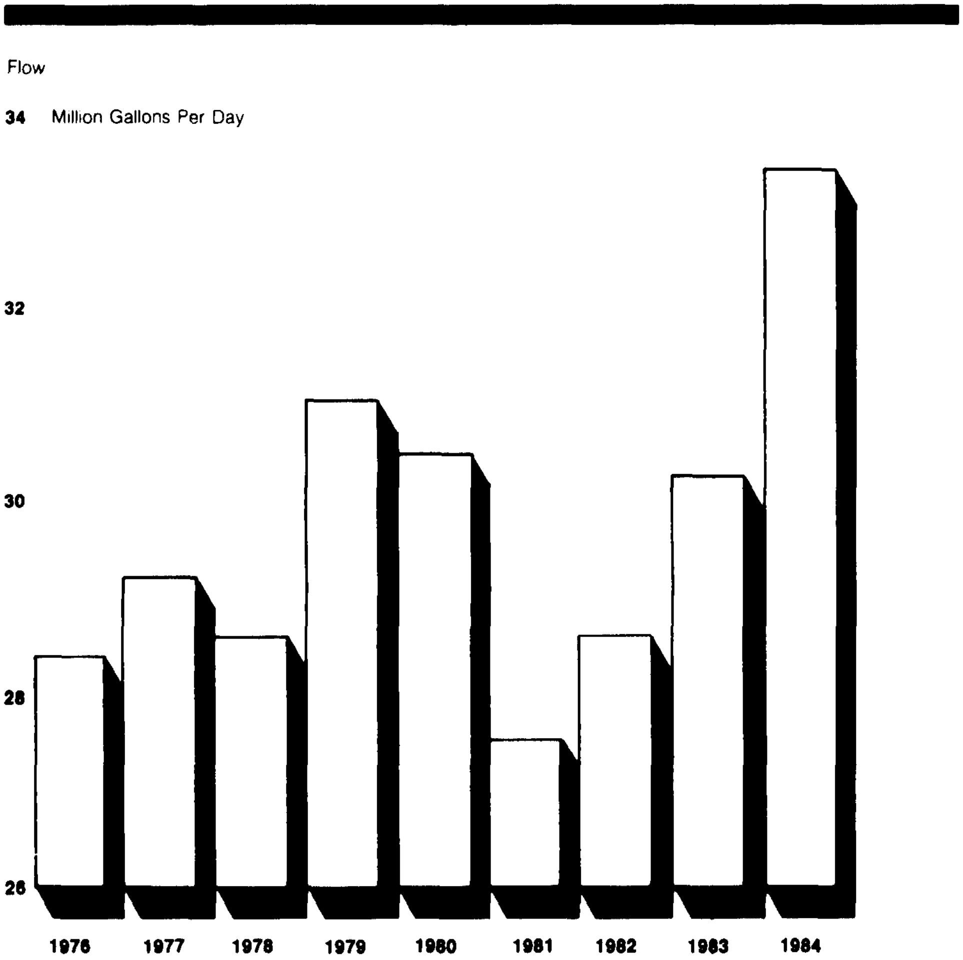
Did the Upgrade Decrease the Amount of Pollutants Discharged?

The discharge monitoring reports we reviewed from the Allentown plant covered the period January 1976 through August 1984. They reported monthly average levels of flow, BOD_5, total suspended solids, fecal coliform bacteria, and ammonia. Unfortunately, ammonia levels were reported only after May 1980 and, therefore, no direct comparison with pre-upgrade levels of ammonia can be made.

Our analysis of the Allentown data suggested a transition between the pre-upgrade and postupgrade periods starting approximately in January 1978. It appears that in 1978, a slight downtrend in pollutant discharge may have been partially related to upgrade activities. During 1979, the plant apparently failed to report effluent characteristics other than flow.

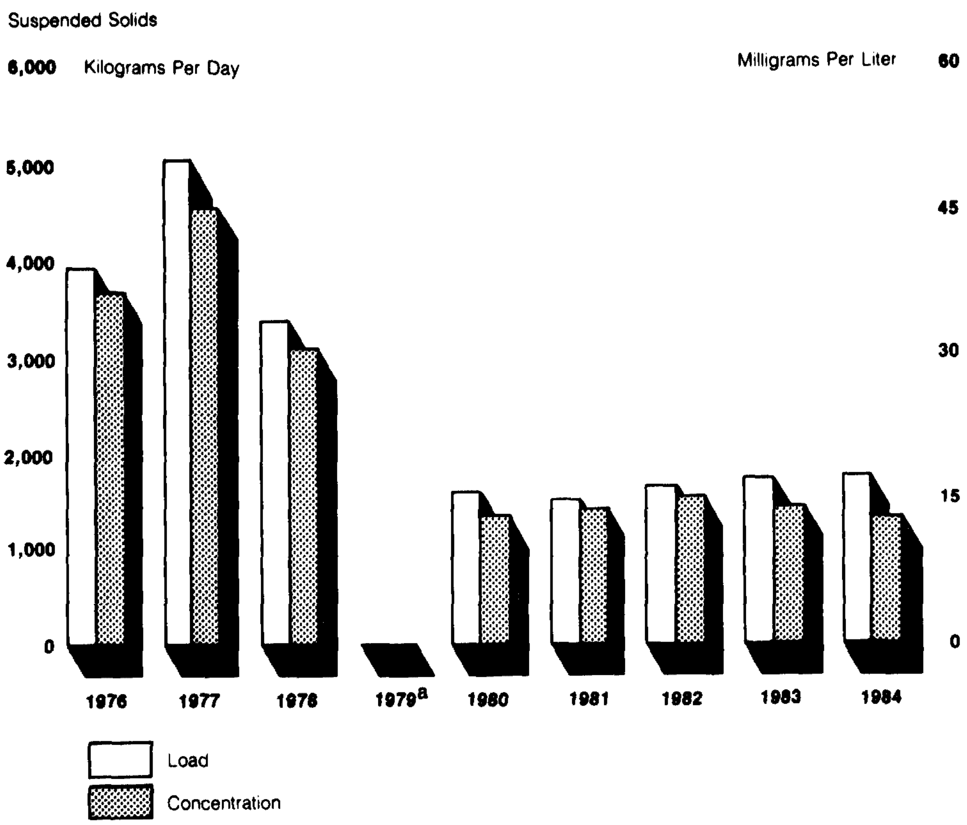
Because of this information gap and the possibility that the upgrade may have had some effects prior to the September 1979 completion date given in the grants information control system (GICS), we used two definitions of the pre-upgrade period in our analyses. We compared average effluent levels after September 1979 with the two earlier periods of January 1976 through December 1977 and January 1976 through August

Figure 2.2: Allentown Sewage-Treatment Plant Effluent Data 1976-84
(Annual Means)



The effect of upgrading the Allentown sewage-treatment plant is evident from figure 2.2, which presents annual mean loadings and concentrations of effluent from the plant. While effluent flow increased slightly in the postupgrade period, the level of monitored pollutants dropped sharply. Total suspended solids and BOD_5 dropped to less than half their previous levels, and fecal coliform bacteria averaged approximately 10 percent of earlier levels. The unfortunate lack of pre-upgrade readings for ammonia precludes a precise estimate of the change in this variable, but it seems safe to assume some sizable decrease in ammonia discharge, in view of the positive correlation of ammonia with other pollutants, since a primary purpose of the Allentown upgrade was to add nitrification processes in order to meet more stringent ammonia-reduction standards set by the Pennsylvania Department of Environmental Resources.

Figure 2.2 continued



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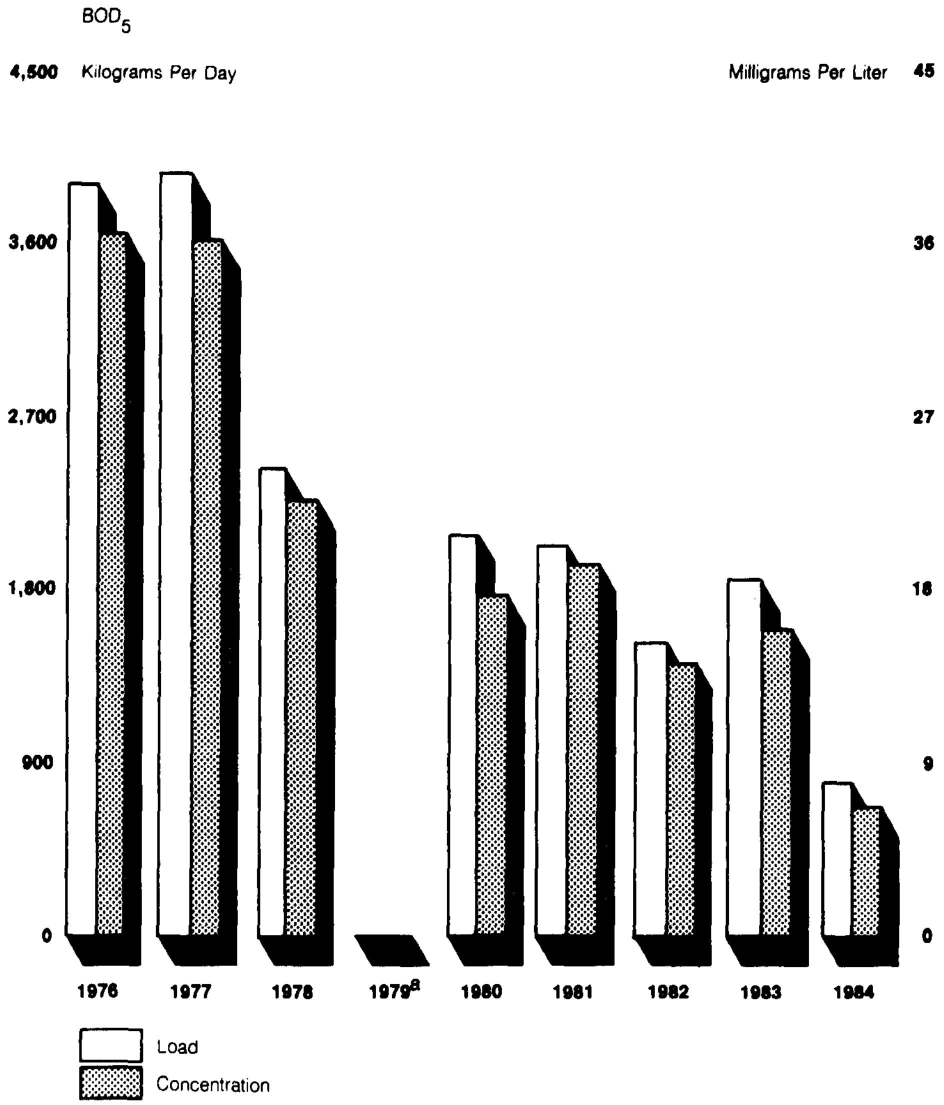

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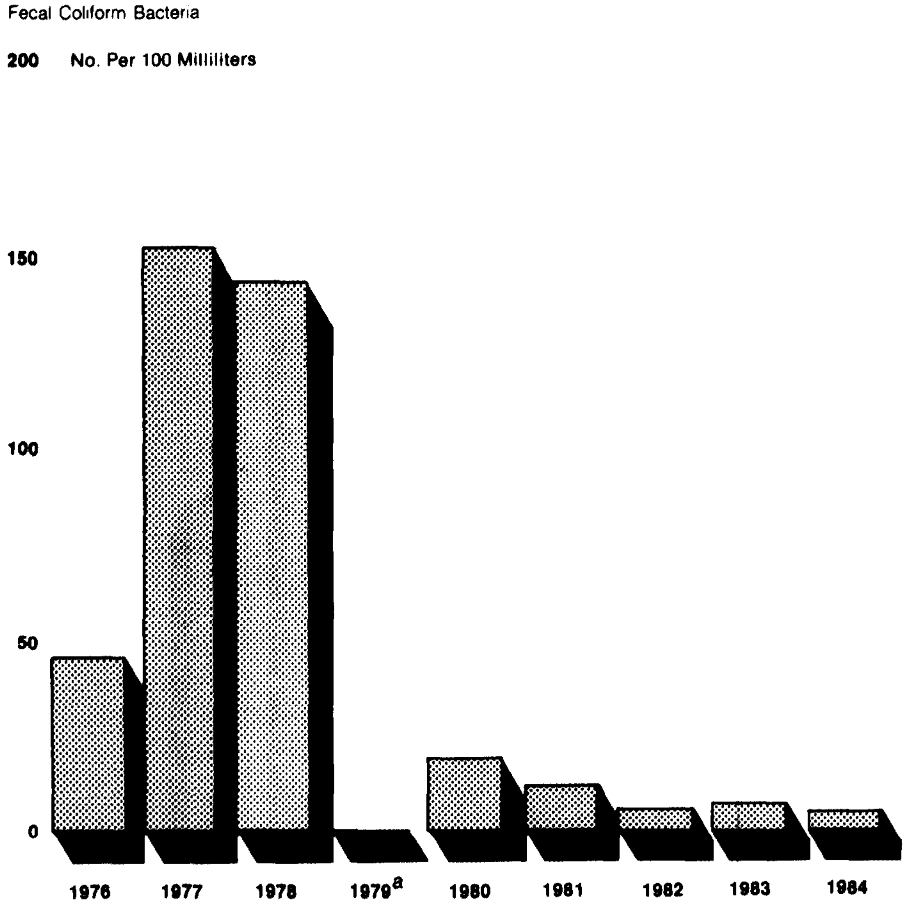

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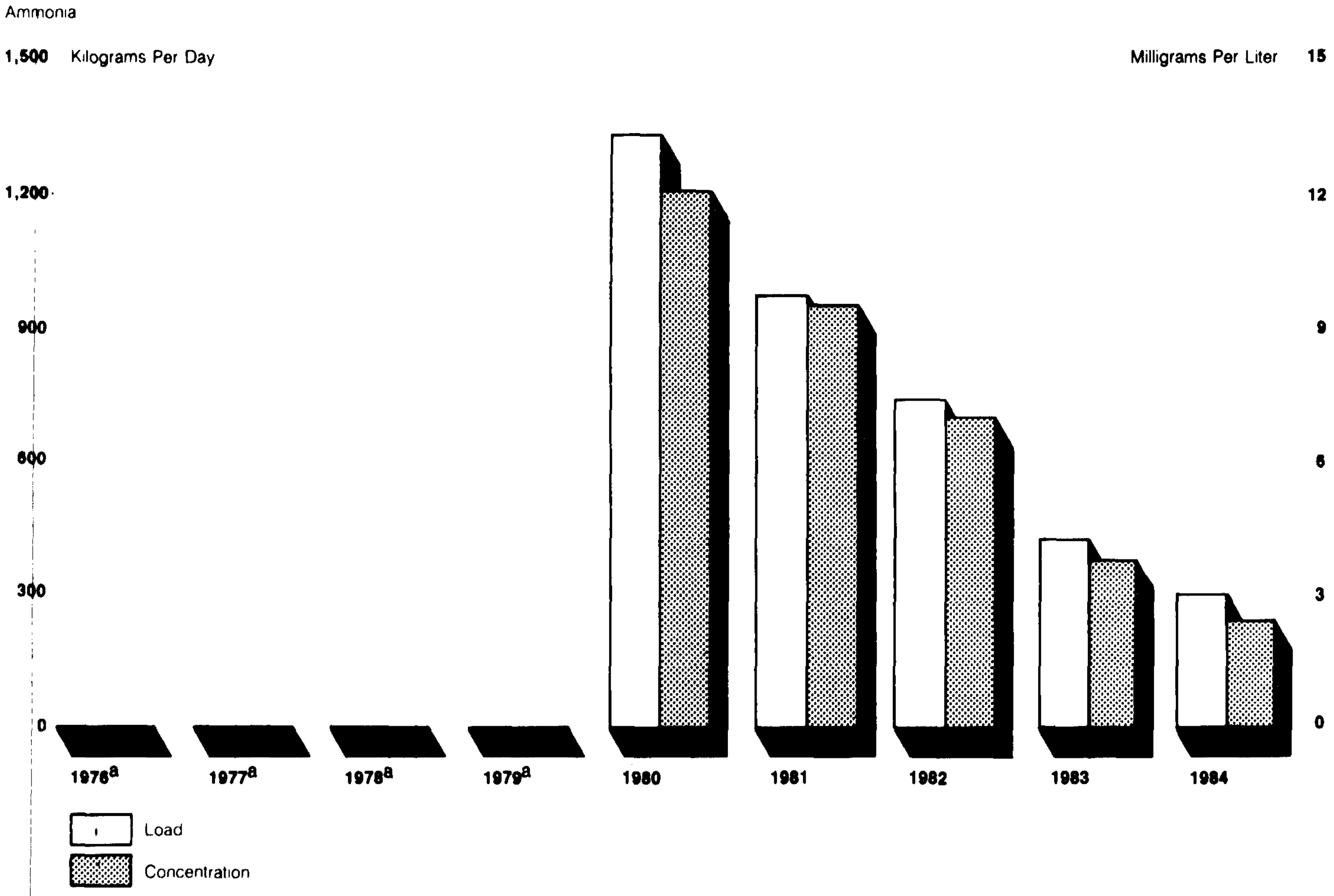


[a] Not available.

The alternative definitions of the pre-upgrade period offer somewhat different estimates of the effectiveness of the plant modifications. Excluding the transitional period would mean a greater drop in total suspended solids and BOD_5 but would diminish the estimated decrease in fecal coliform bacteria levels. Regardless of the exact assignment of a completion date, however, it is clear that the modifications to the Allentown plant significantly decreased the amount of pollutant it discharged into the Lehigh River.

Did Water Quality Improve Downstream From the Plant?

To find out whether downstream water quality improved, we compared postupgrade levels of stream dissolved oxygen deficit, BOD_5, ammonia, nitrite, and nitrate with levels from both pre-upgrade periods. We made these comparisons for the readings at the two monitoring stations downstream from the Allentown plant—WQN124, about 5-1/2 miles downstream, and WQN123, about 17 miles downstream—and at the upstream monitoring station—WQN125, about 16-1/2 miles upstream. Using both nonadjusted and flow-adjusted data, we compared mean pollutant levels at the stations. We also stratified the data into two additional low-flow subsets: observations taken when flow readings were in the lower half and in the lowest quartile of all flow readings at the monitoring stations. (The detailed results of these analyses are in tables I.3-I.8.)

In general, it appears that water quality downstream from the Allentown plant improved significantly in the 5 years after the completion of the upgrade. In the rest of this section, we discuss the changes in dissolved oxygen, BOD_5, ammonia, nitrite, and nitrate.

Dissolved Oxygen

Average dissolved oxygen deficit at WQN124 decreased from 7 percent before 1978 to approximately zero after the upgrade completion. Even after the upgrade, however, the dissolved oxygen readings at WQN123 average 5 percent below saturation. Flow adjustment tends to increase the estimate of effective change in dissolved oxygen.

Improvements in dissolved oxygen levels are more noticeable under low-flow conditions. At WQN124, there was an average 16-percent improvement in readings taken during the lowest flow conditions. At WQN123, dissolved oxygen readings improved 15 percent.

The differenced dissolved oxygen data express dissolved oxygen levels downstream in relation to upstream conditions. Before the upgrade, the levels at WQN124 were, on the average, 2 percent worse than upstream; after the upgrade, they were, on the average, 3 percent better. The improvement at WQN123 was similar. Although the readings at this station remained higher than upstream, they improved from 9 percent higher than upstream to only 3 percent higher. Since no statistically significant flow-adjustment model could be developed for dissolved oxygen at WQN125, flow-adjusted differenced data are not available.

BOD_5

Average BOD_5 levels recorded at WQN124 decreased some 35 percent in the postupgrade period. The flow-adjusted estimate of decrease is slightly larger. At WQN123, the BOD_5 decrease is even clearer, because of both a greater absolute decrease and a smaller variation in readings within the time periods. At both downstream stations, flow adjustment tends to give a greater estimated decrease in BOD_5 levels.

An examination of differenced BOD_5 data reveals that during the preupgrade period, BOD_5 levels at both WQN124 and WQN123 were substantially higher than upstream levels. After the Allentown upgrade, BOD_5 levels decreased to levels lower than those above the plant. The downstream improvement is compounded by a simultaneous deterioration in water quality upstream. As would be expected, the relative improvement in BOD_5 is most visible during low-flow conditions.

Ammonia

The change in the concentration of ammonia at WQN124 from the pretransition to the postupgrade period is less than statistically significant, although it is in the preferred direction. However, when flow-adjustment techniques are applied to the raw data, a significant change appears. Further downstream, at WQN123, the decrease in ammonia levels is clearly visible, even without flow adjustment, but is heightened when the flow-adjustment models are applied. After the upgrade, raw ammonia levels at lowest flow averaged less than one third of the levels prior to 1978.

Differencing the ammonia data has much the same effect as making flow adjustments. Because the upstream ammonia concentrations more than doubled from the pre-1978 period to the postupgrade period, the modest 0.05 mgl decrease in average ammonia levels at WQN124 results in readings that improve from substantially worse to slightly better than those further upstream. At WQN123, postupgrade ammonia readings remain higher than those upstream but drop when adjusted for flow.

Nitrite and Nitrate

The concentration levels of nitrite and nitrate at WQN124 did not change substantially, despite the tendency of nitrite to decrease and nitrate to increase. Adjusting these concentrations for flow results in an estimate of significant decrease in the levels of both nitrogen compounds. At WQN123, their levels are generally higher than at WQN124. The tendency of nitrite to decrease at WQN124 is also observable at WQN123 and is sharpened by flow-adjustment procedures. Making flow adjustments for the nitrate data also eliminates the apparent upward tendency.

When nitrite and nitrate data are compared with upstream levels through differencing, it becomes clear that these compounds had levels substantially higher downstream than up. The change over time in their relative values, however, appears to come mostly from upstream changes. Both nitrite and nitrate at WQN125 were significantly lower during the postupgrade period. For this reason, the tendency of nitrite to decrease downstream over time is largely invisible in differenced data, and the upward tendency of nitrate is accentuated by differencing.

Summary

A clear improvement occurred at both monitoring stations in the Lehigh River downstream from the Allentown sewage-treatment plant after the upgrade was completed. The levels of dissolved oxygen deficit, BOD_5, ammonia, nitrite, and nitrate were lower after the upgrade. Throughout the period of observation, water quality as defined by these constituents was better at WQN124, the closer downstream station, but the improvement at WQN123 was somewhat greater. In general, flow-adjustment procedures improved our ability to discern this change. Readings at WQN124 improved to the extent that postupgrade water quality, as measured by dissolved oxygen, BOD_5, or ammonia, was as good as or better than it was upstream. Differenced data on ammonia, nitrite, and nitrate, the three byproducts of nitrification, may be somewhat misleading in this case, since there were significant changes in the upstream concentration of these parameters. Upstream ammonia levels increased substantially during the postupgrade period, while nitrite and nitrate decreased.

Were Changes in the Effluent Related to Stream Water-Quality Indicators?

When the postupgrade improvement in water quality downstream from the Allentown sewage-treatment plant is combined with the demonstrated decrease in pollutant discharge from the plant, a causal link between the upgrade and the improvement is strongly suggested. However, the causal link cannot be confirmed without first demonstrating an unequivocal connection between the plant's effluent and water quality at the downstream monitoring stations and then demonstrating that other explanations of the stream changes are implausible. In the rest of this section, we discuss the statistical correlation between the plant's effluent and the levels of related water-quality parameters in the stream. We discuss alternative explanations in the section following this one. (The results of our computation of correlation coefficients for the association between each of the effluent parameters recorded on the Allentown discharge monitoring reports and the water-quality parameters downstream are given in tables I.9-I.16.)

Stream Correlates of Effluent BOD_5 and Suspended Solids

BOD_5 and suspended solids discharged from the plant are moderately associated (0.10-0.64) with levels of dissolved oxygen and ammonia in the Lehigh River. The relationship between effluent BOD_5 and suspended solids and all nonadjusted stream readings is generally stronger downstream at WQN123 than at WQN124. It is clearer after making flow adjustments and at low-flow levels. Even at its strongest, however, the relationship is only moderate. For example, the correlation between stream ammonia and effluent BOD_5 at low flow (in the lowest quartile) is 0.64. The common interpretation of this statistic would be that 41 percent (the square of 0.64) of the variation in downstream ammonia is explainable by variations in effluent BOD_5.

Stream Correlates of Effluent Ammonia

There is a strong association (0.77-0.94) between ammonia effluent from the Allentown plant and stream concentrations of ammonia 5-1/2 miles downstream at WQN124. Under low-flow conditions, nearly 90 percent of the stream ammonia variations can be explained by the variance in discharged ammonia. There are also moderate correlations (0.51-0.68) between effluent ammonia and the concentration of BOD_5 at WQN124. These relationships are most clearly reflected in low-flow readings. The relationship between ammonia effluent and stream ammonia at WQN123 is weaker (0.30-0.55) but statistically significant. Further downstream, the variance in ammonia effluent accounts for only 23 percent of the variance in the stream ammonia. There is a stronger relationship, however, between ammonia effluent, dissolved oxygen, and nitrate at WQN123 than at WQN124 further upstream.

Making flow adjustments for stream data tends to reduce the correlation between effluent ammonia and nearly all stream measures at both downstream stations. The correlation between effluent and stream ammonia at WQN124 is reduced to the 0.5-0.7 range by making flow adjustments (where flow-adjustment models were available). The effect of adjusting for flow is not as dramatic further downstream. The estimate of association between effluent and stream ammonia is decreased, while the weak positive correlation (0.15) of effluent ammonia and stream nitrite (at full flow) changes to a negative relationship.

Differencing the stream data also affects the estimate of association between effluent ammonia and stream water quality. The correlation with stream BOD_5 at WQN124 is strengthened to the extent that more than 90 percent of the variance in BOD_5 at low flow can be accounted for by variance in effluent ammonia. Differencing diminishes the correlation between effluent and stream ammonia to substantially lower levels than are found with absolute stream measures, and when stream ammonia levels are adjusted for flow and differenced, the correlation is not significantly different from zero.

These anomalous results are, at least in part, an artifact of the differencing process. Ammonia levels at WQN125, whose readings provide a baseline for differencing, increased significantly after 1979, while nitrite and nitrate nitrogen levels decreased. Because of these changes in the baseline conditions, variations in differenced downstream readings of ammonia, nitrite, and nitrate are reflective more of upstream than of downstream changes. It is not surprising that they correlate only weakly with the plant's effluent. Upstream levels of BOD_5 do not change significantly, which may explain why differencing the BOD_5 data tends to heighten rather than depress their correlation with the plant's effluent.

Flow-adjusted ammonia, nitrite, and nitrate readings may also distort the relationship between effluent and stream water quality. Our flow-adjustment models were developed to fit the stream data extending back to 1972. Unfortunately, ammonia effluent from the Allentown plant was recorded only for the postupgrade period and, consequently, a correlation between effluent and stream data is restricted to this period. (For BOD_5 effluent, however, we have records from 1976 to the present.) We have assumed that the levels of ammonia discharged during the postupgrade period represent a substantial decrease from previous levels. This change in what appears to be a major contributor to stream ammonia may have affected the relationship between stream flow and ammonia. A model fitted to data from both periods may be inadequate when its use is restricted to the later period.

Upstream Changes and Differencing

As we have reported above, ammonia levels at WQN125, the monitoring station 16-1/2 miles upstream from the Allentown plant, increased significantly during the period that we studied, and the nitrite and nitrate levels decreased. While it was not the primary target of this case study, we felt some attempt should be made to find an explanation for these changes. One hypothesis that we explored was that a treatment plant we identified fairly close to WQN125, at Slatington, had increased its effluent discharge and thus degraded upstream water quality. We collected the available discharge monitoring report data for the plant, all of which were from the post-upgrade period, and correlated the data with stream concentrations at WQN125. We found no significant positive correlations between the two sets of data and concluded that the changes at

WQN125 could not be ascribed to the Slatington plant's effluent on the basis of this evidence.

We asked Pennsylvania Department of Environmental Resources regional staff, whose area of responsibility includes Allentown, if they could suggest any explanation of water quality changes upstream from Allentown. They were unable to suggest any point source with increased ammonia discharges after 1979 to explain the phenomenon. One official recalled that some construction work on the bridge over the Lehigh River, from which the WQN125 water samples were taken, had been done about 1979. The construction included erecting a chain link fence along the sides of the bridge. Since this made sampling from the center of the span impractical, samples were now taken closer to the riverbank than they had been before. It is possible, therefore, that the changes noted in ammonia, nitrite, and nitrate in the WQN125 records are simply an artifact of a small but significant change in sampling location and do not reflect actual changes in stream conditions. If they are, differencing the downstream data would be inappropriate.

Even if changes recorded at WQN125 accurately represent stream conditions, upstream ammonia levels may not provide a valid baseline for downstream ammonia, since any decrease in ammonia downstream could be the result of the natural nitrification of ammonia as it moves between the monitoring stations as well as the result of decreases in effluent ammonia from intervening point sources. Upstream ammonia increases may be better reflected in downstream increases in nitrite or nitrate, the byproducts of the stream's assimilation of ammonia through biochemical processes.

Summary

We identified a significant correlation between effluent BOD_5 and ammonia loadings from the Allentown sewage-treatment plant to stream water quality at two downstream monitoring stations. Effluent ammonia appears to be more strongly related to nitrogen compounds at the closer station while effluent BOD_5 is more closely associated with water quality further downstream. Differencing and flow-adjustment procedures diminish the estimates of association between effluent ammonia and stream nitrogen. We suggested that this is a statistical artifact of the data limitations in this case or of changes in the upstream sampling location or both and the result of stream nitrification.

Can Other Reasonable Explanations of Water-Quality Conditions Be Excluded?

Before changes observed in water quality in the Lehigh River downstream from Allentown can be attributed to the upgrade of the Allentown plant, the likelihood that they are attributable to changes in discharge at other point sources must be excluded. For this reason, we examined all the available records of licensed dischargers into the Lehigh River between WQN125, the upstream monitoring station, and WQN124 downstream. We discovered that the Allentown plant contributed more than 85 percent of all the BOD_5 and ammonia discharged by licensed point sources into the river. Compared to Allentown, the influence of these pollutants from other dischargers at WQN124 must be considered negligible.

We did not collect discharge monitoring data for all the point sources EPA identified between WQN124 and WQN123. However, we were able to obtain these data for the Bethlehem sewage-treatment plant, the major, relevant, municipal discharger below WQN124, whose effluent enters the Lehigh River some 9-1/2 miles upstream from WQN123. Bethlehem received a $3.8 million grant under the 1956 Federal Water Pollution Control Act (Public Law 84-660) to expand and upgrade its secondary treatment plant. According to GICS, the project was completed in April 1980. Because of the plant's proximity to WQN123 and the consequent possibility of the Allentown upgrade's effects being confounded with those from Bethlehem, we examined changes in the Bethlehem effluent during the pre-upgrade and postupgrade periods that we defined for Allentown.

Pollutant discharged in the form of suspended solids, BOD_5, and ammonia from the Bethlehem plant declined approximately 50 percent between the pre-1978 period and the postupgrade period. Therefore, it appears that at least some of the improvement in water quality at WQN123 is attributable to the Bethlehem upgrade.

One of the few major sources of effluent ammonia other than sewage-treatment plants is in the coking process and blast furnace operations associated with steel production. Bethlehem Steel Corporation is the second largest discharger of ammonia, after the Allentown sewage-treatment plant, into a 40-mile stretch of the Lehigh River. Bethlehem Steel operates a coking plant located between WQN124 and WQN123 that discharged an average of 635 kilograms of ammonia per day from October 1980 through November 1984. We used multiple regression analysis to clarify the relative influence of sewage treatment at the Allentown plant and the Bethlehem plant and steel production at Bethlehem Steel. We regressed stream dissolved oxygen deficit, BOD_5, ammonia, nitrite, and nitrate readings on the BOD_5 and ammonia discharge monitoring data from each plant and the ammonia readings from Bethlehem Steel. (The detailed results are in tables I.17 - I.19.)

These analyses indicated that the effluent from all three sources affect water quality at WQN123. The extent and form of the influence vary across the dimensions of pollution analyzed. The Allentown plant, in particular its ammonia effluent, appears to be the most consistently associated with downstream pollution. The influence of ammonia discharged from Bethlehem Steel appears to be reflected in nitrite levels at WQN123. All three point sources appear to affect downstream BOD_5 levels.

The data we used for these regressions are all from the period following the Allentown and Bethlehem plant upgrades. In all likelihood, the relative influence of these dischargers was substantially different before the discharge reduction resulting from the upgrades. If we assume an ammonia reduction at the Allentown plant comparable to that at the Bethlehem plant, and a stable level of ammonia discharge at Bethlehem Steel, we may infer that before 1979 the ammonia from industrial waste was a less significant polluter of the river than ammonia from either of the wastewater-treatment plants. Under these assumptions, ammonia discharged from Bethlehem Steel prior to the two upgrades contributed 22 percent, on the average, to the total from all three sources. After the upgrade, the industrial discharge averaged 35 percent.

In summary, our comparison of the relative amount of pollutants discharged from point sources other than Allentown indicates that the changes in stream water quality downstream from the Allentown plant at WQN124 cannot logically be attributed to any other point source. The water-quality improvement further downstream at WQN123 appears to be a function of changes at both the Allentown and Bethlehem plants. The influence of effluent ammonia from Bethlehem Steel's coking plant is also discernible at WQN123. Additional influences at WQN123 cannot be ruled out.

Summary

As with all four case studies, our interest in the Allentown sewage-treatment plant was both substantive and methodological. We attempted to demonstrate, within the constraints of available data, the extent to which the investment of nearly $15 million of Construction Grants Program funds improved water quality in the Lehigh River. At the same time, we explored various methods of controlling potentially confounding hydrologic factors and competing explanations.

We demonstrated substantively that the upgrade at Allentown resulted in a substantial decrease in the amount of pollutant discharged into the Lehigh River, despite an increase in total effluent. Unfortunately, we have no direct evidence of a decrease in ammonia discharge and were forced to infer it. We demonstrated a decrease in dissolved oxygen deficit, BOD_5, and ammonia at two monitoring stations, one 5-1/2 and the other 17 miles downstream, after the upgrade was completed. We showed that changes in the Allentown plant were related to changes at these two stations and that the Allentown plant was overwhelmingly the largest point source of these contaminants at the nearer station. We also presented evidence that the improvement in water quality further downstream was in part a function of upgrades at the Allentown plant and at the Bethlehem plant downstream from Allentown and that industrial discharge contributed significantly to downstream pollution.

The results of this case study have implications for the analytic methodology we applied to the data. Most importantly, it appears that data from three independent EPA data bases (discharge monitoring reports, GICS, and STORET) can be merged to provide reliable data concerning the timing of plant modifications, and the consequent changes in plant effluent, and to test for the effect of these changes on downstream water quality.

Our analysis also suggests that this general conclusion requires qualification and that some refinements to our methodology may be necessary.

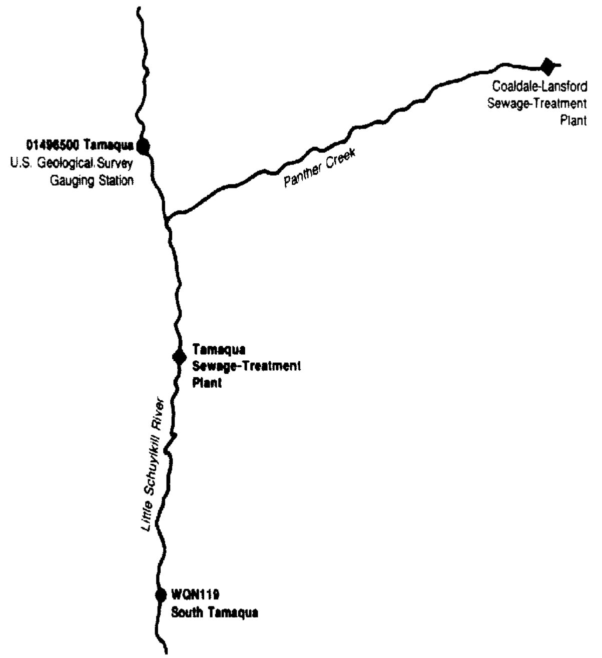
1. Appropriate discharge monitoring data are not always available. Because Allentown, unlike the Bethlehem plant, was not required to report ammonia levels in its effluent until after its upgrade was completed, it is not possible to estimate the effectiveness of the upgrade in reducing the discharge of this pollutant. This data gap probably also affected the sensitivity of our analysis in attempting to relate the plant's effluent with stream water quality.

2. The project completion date supplied by GICS may not be the best estimate of the time of the upgrade's effect. We provided an alternative computation of pre-upgrade levels by excluding an 18-month transition period prior to the GICS date. However, this alternative estimate did not substantially affect our conclusions.

3. Data differencing can be helpful in screening out background pollution. It may also distort the analysis, if significant changes occur in the upstream baseline during the period being studied. In the case of Allentown, differencing appeared to clarify the effects of the upgrade on dissolved oxygen and BOD_5, since there were no significant upstream changes in these parameters. However, the substantial upstream changes in ammonia, nitrite, and nitrate and the natural nitrification process in the stream between upstream and downstream monitoring stations probably resulted in an overestimate of ammonia changes and an underestimate of nitrite and nitrate changes downstream. Before relying exclusively on differenced data, an analyst must examine the baseline data and identify the source of changes resulting from differencing.

4. Flow-adjustment procedures appear to have successfully reduced the variation in stream readings attributable to variations in flow. Nevertheless, significant flow-adjustment models could not be found for some parameters. Furthermore, flow adjustment can have some negative effects if the relationship between effluent, stream flow, and stream concentration is fundamentally altered by a dramatic change in effluent, such as may result from an upgrade.

Figure 3.1: Tamaqua Map and Profile



Tamaqua Profile

Feature	Data
NPDES number	PA0027006
Type of change	Upgrade to secondary treatment
Construction began	June 9, 1975
Works in operation	December 31, 1976 (plant data) June 5, 1981 (GICS data)
Project completed	June 5, 1981
Cost	$2.2 million
Average flow	1.06 million gallons per day
Discharge	Into the Little Schuylkill River
Average stream flow	77 cubic feet per second
Setting	Rural
Monitoring stations	

Direction	Miles	Station	Location
Upstream	1.8	01496500[a]	Tamaqua
Downstream	2.5	WQN119[b]	South Tamaqua

[a] U.S. Geological Survey "gaging station."

[b] Pennsylvania Department of Environmental Resources monitoring station.

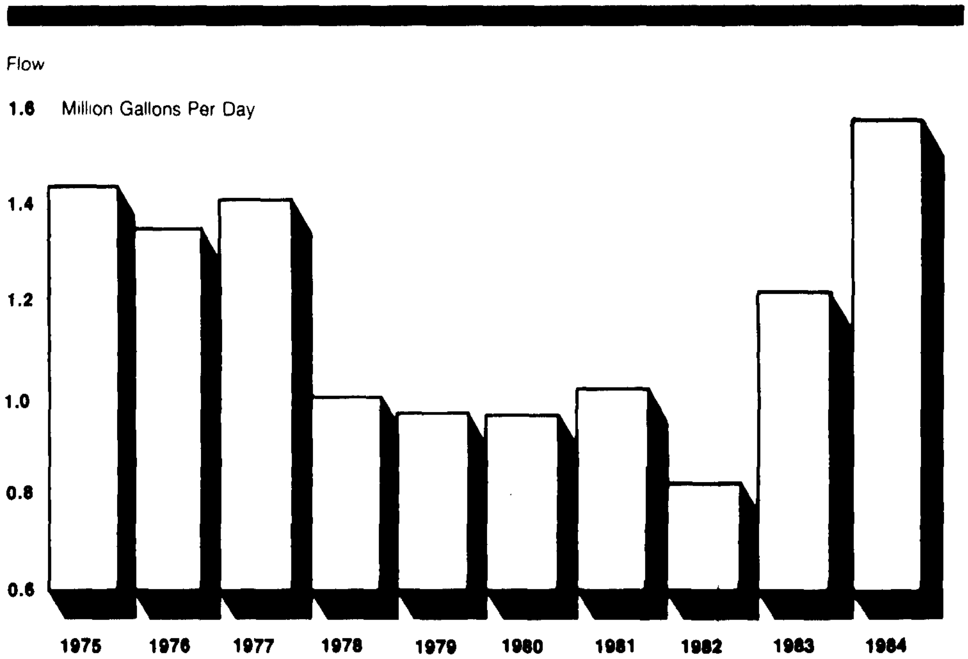
Tamaqua Sewage-Treatment Plant Case Study

Tamaqua is a borough of approximately 9,000 persons in a heavily strip-mined area some 40 miles northwest of Allentown. Our analysis of the effect of the upgrade at the Tamaqua sewage-treatment plant on the quality of water in the Little Schuylkill River downstream from the plant differed from our analysis in the Allentown case study in three respects. First, water-quality data were available from only one station, WQN119, about 2-1/2 miles downstream at South Tamaqua. We were not able to compute differenced data to control for other upstream sources. Second, rather than using the flow measures from the monitoring station as a source of stream flow data, we used flow data taken from a U.S. Geological Survey gauging station upstream from the plant and the monitoring station. We did this because flow data reported at the monitoring station were much less complete than—and highly correlated with—those from the gauging station. Third, because of our experience with analyzing the Allentown effluent data, we did not perform separate analyses for two different pre-upgrade periods. The nature of the Tamaqua upgrade suggested a much shorter transition period. The plant's location and essential information about the plant are shown in the map and profile in foldout figure 3.1.

Did the Upgrade Decrease the Amount of Pollutants Discharged?

The modifications to the Tamaqua plant consisted of a standard upgrade from primary to secondary treatment. When we dichotomized the discharge monitoring data from Tamaqua into two sets of data before and after the June 1981 upgrade date furnished by GICS, we were not able to detect substantial decreases in pollutant loading from the plant. In verifying the upgrade date with the plant's operator, we discovered that the plant had been upgraded from primary to secondary treatment more than 4 years before the GICS date, which apparently represents the date of final inspection by the U.S. Army Corps of Engineers. In fact, waste first entered the secondary treatment stage at Tamaqua in January 1977, and the upgrade was considered nearly complete by the contractor and the municipality in April 1977. These data are supported by a review of the discharge monitoring reports and suggest that June 1977 is an appropriate demarcation date for evaluating postupgrade effects.

Figure 3.2: Tamaqua Sewage-Treatment Plant Effluent Data 1975-84 (Annual Means)



As figure 3.2 indicates, the effect of increasing treatment levels at the plant was dramatic. After the upgrade to secondary treatment, the mean amount of suspended solids discharged was reduced to nearly one quarter of the pre-upgrade levels, BOD_5 levels fell to 20 percent of earlier levels, and fecal coliform bacteria counts were cut by more than half. Although wastewater flow also decreased after the upgrade, the decline is insufficient to account for the drop in pollutant loadings, which we ascribe to increased treatment efficiency after the upgrade.

Figure 3.2 continued

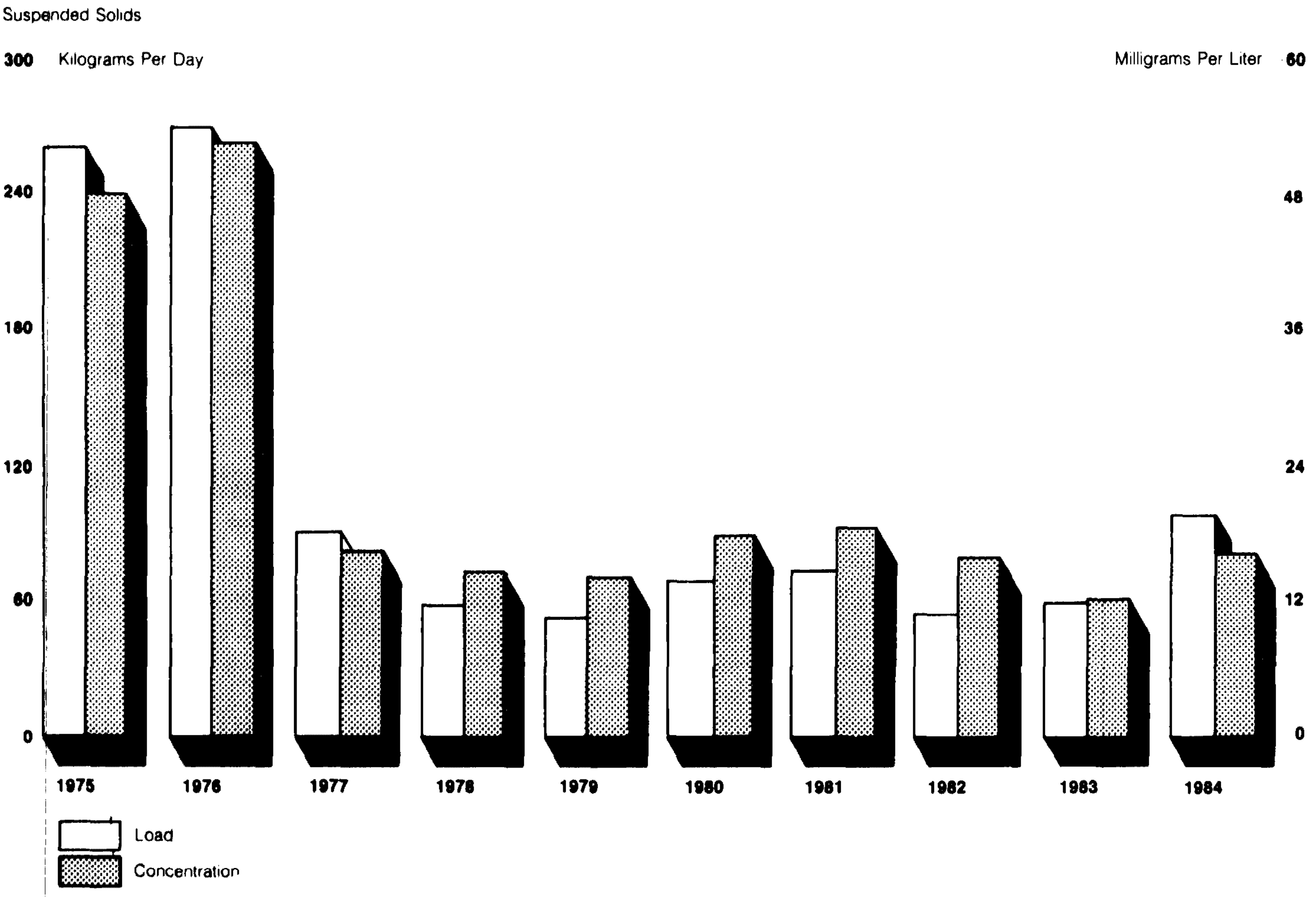


Figure 3.2 continued

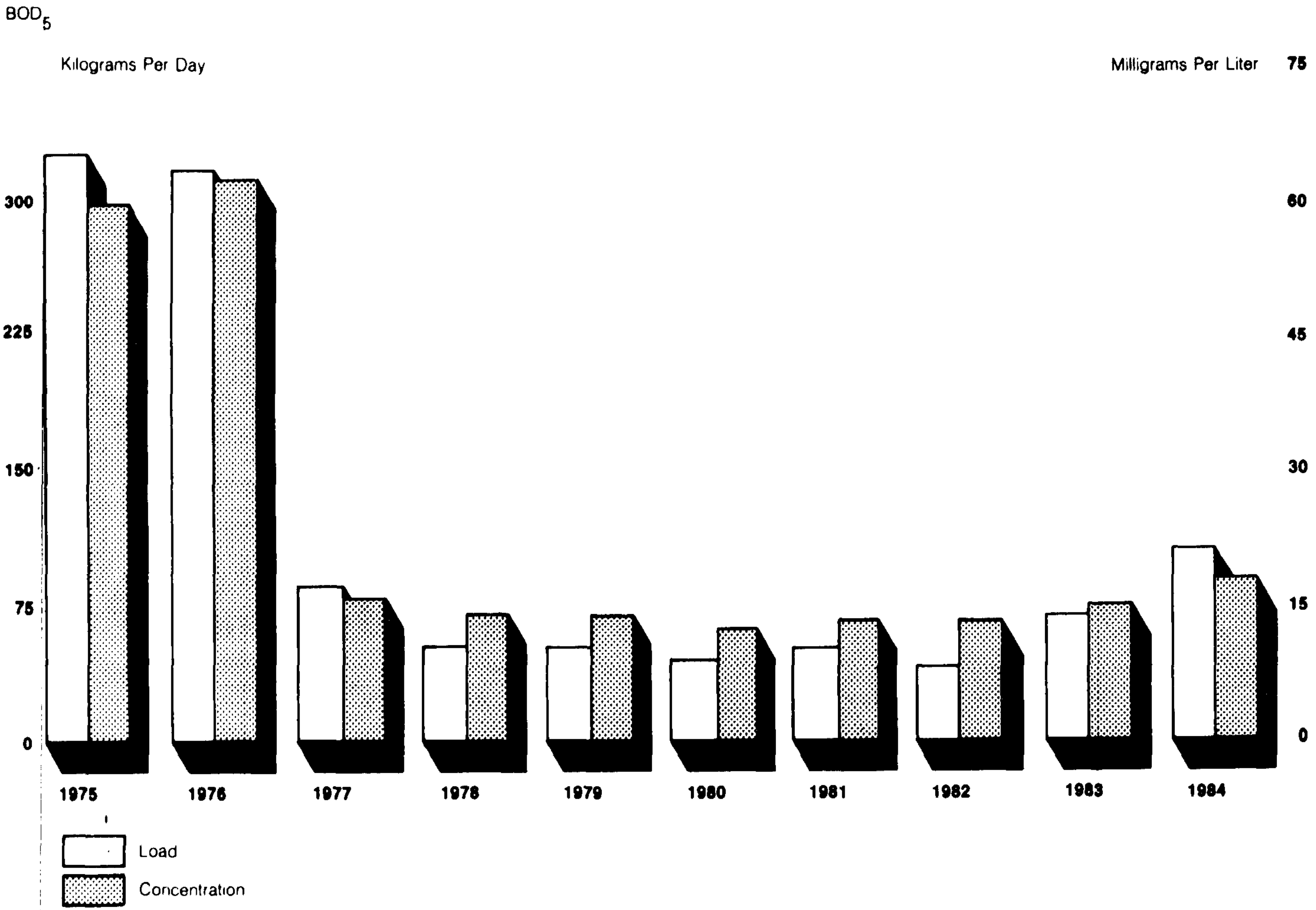
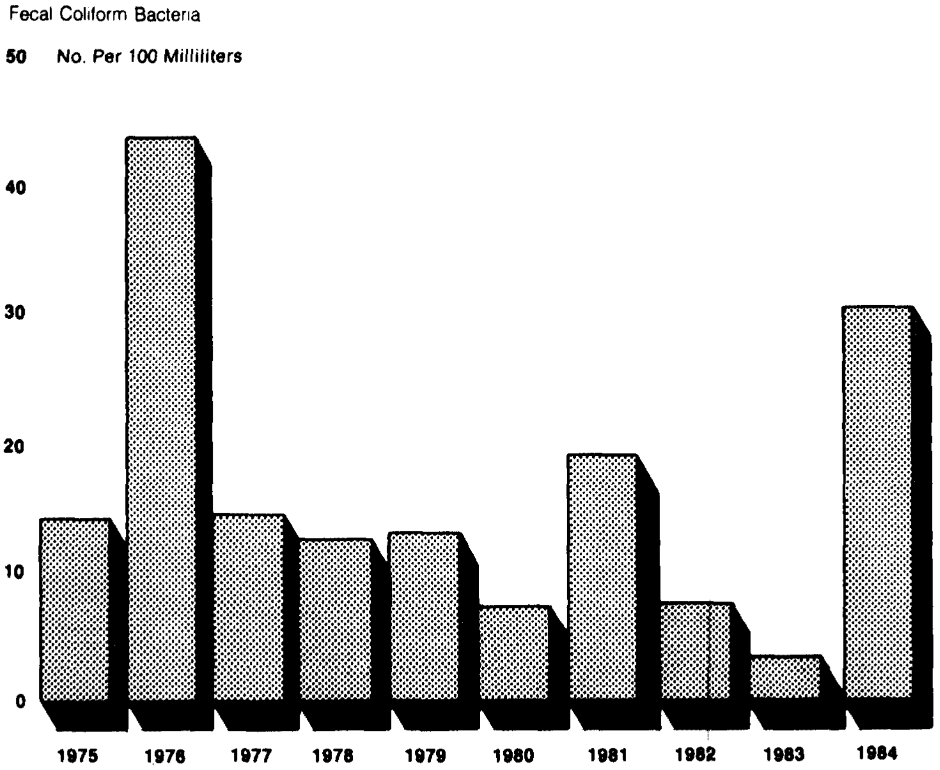


Figure 3.2 continued



Did Water Quality Improve Downstream From the Plant?

Stream water quality as measured by all the parameters we analyzed improved after the upgrade. Dissolved oxygen approximated saturation, while ammonia, nitrite, and nitrate decreased. The effect of making flow adjustments on the data accentuated these changes. (Mean water-quality values for the periods before and after the upgrade are in tables II.3 and II.4.)

As would be expected, the stream changes were greater under low-flow conditions. Unadjusted dissolved oxygen levels improved from 81 percent to 97 percent of saturation during low flow (stated conversely, dissolved oxygen deficit dropped from 19 percent to 3 percent), and ammonia concentrations decreased 42 percent. Once again, flow-adjustment procedures accentuated the water-quality improvements.

Were Changes in the Effluent Related to Stream Water-Quality Indicators?

The amount of pollutants discharged into the Little Schuylkill River from the Tamaqua sewage-treatment plant decreased dramatically after the plant was upgraded to secondary treatment. As measured by dissolved oxygen, ammonia, nitrite, and nitrate, water quality improved after 1977. Before attributing the improvement to the upgrade, we examined the extent to which water-quality changes as measured by monthly observations recorded in STORET could be associated with effluent records in the discharge-monitoring reports. (The associations between reported monthly average effluent from the plant and the stream readings taken at WQN119, expressed as correlation coefficients, are shown in tables II.5 and II.6.)

Several observations on the correlations are of interest. First, the relationship between the plant's effluent and unadjusted stream readings are moderate at best (the largest correlation coefficient is 0.64), particularly when readings taken during all flow conditions are pooled. The association represented by these coefficients can be expressed as the percentage of variance explained in the stream readings by the discharge monitoring data. This association is represented by the square of the correlation coefficient. Bivariate associations calculated in this manner range from a trivial (and statistically nonsignificant) 0.01 percent for effluent BOD_5 and stream ammonia under all flow conditions to a moderate 10.2 percent for effluent suspended solids and stream nitrate.

Second, the relationship between plant effluent and stream quality is more clearly visible under low-flow conditions. For example, the association between stream dissolved oxygen and effluent suspended solids is only 1 percent when all observations are used. It rises to 13.7 percent under low-flow conditions.

Third, flow-adjustment procedures appear to have been very effective in improving our ability to discern the relationship of effluent and stream quality. Nearly 45 percent of the variance in flow-adjusted dissolved oxygen readings taken at WQN119 under low-flow conditions can be explained by taking into account the amount of wastewater discharged from the Tamaqua plant. This represents an 11-percent increase over the unadjusted readings.

Finally, it may be possible to detect natural nitrification in process from the correlation matrixes. Under natural conditions, ammonia discharged into a stream uses stream dissolved oxygen for the conversion into nitrites and nitrates. Low-flow conditions and concomitant low levels of dissolved oxygen retard the oxidation. This may be reflected in the patterns of relationships between plant effluent and the ammonia, nitrite, and nitrate readings. Under all flow conditions, no significant relationship exists between effluent (total flow, BOD_5, or suspended solids) and stream ammonia levels. Effluent is, however, moderately correlated with nitrite and nitrate. Flow adjustment generally strengthens these relationships by removing the flow-related variations.

When we examine the data obtained during low-flow conditions, the pattern is reversed. At low flow, there is little relationship between effluent and stream nitrite and nitrate, but the association of stream ammonia with plant discharge increases to between 18 and 22 percent. This may be explained by the decreased ability of the stream, under conditions of low flow and depressed dissolved oxygen, either to dilute the ammonia contained in the effluent or to convert it to nitrite and nitrate.

In summary, by correlating the plant effluent data and water-quality measurements, we have been able to establish a moderate association between the two. The amount and quality of waste discharged from the Tamaqua sewage-treatment plant appears to have a discernible relationship with water quality some 2-1/2 miles downstream, particularly under low-flow conditions. However, without the use of flow-adjustment procedures, this relationship would be substantially understated.

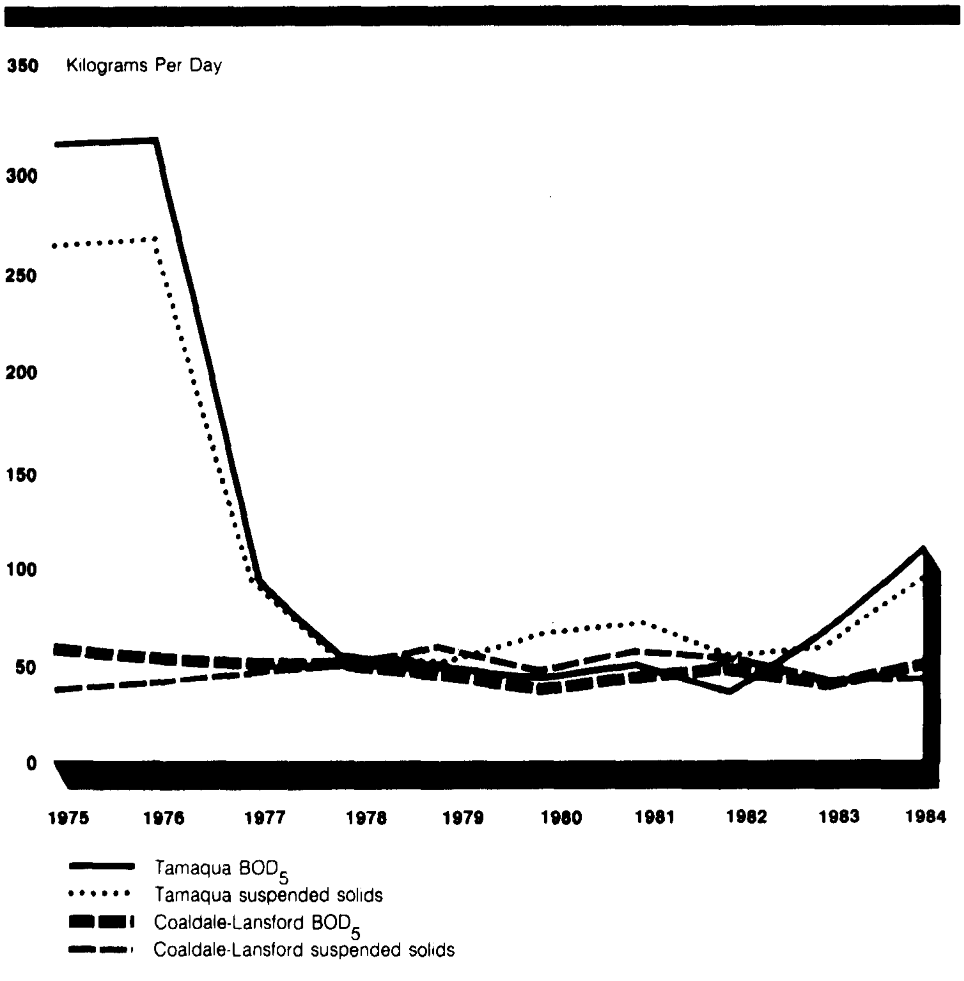
Can Other Reasonable Explanations of Water-Quality Conditions Be Excluded?

The data demonstrate a significant drop in pollutant levels from the Tamaqua plant after the upgrade and a significant improvement in water quality in the Little Schuylkill River. We have demonstrated a statistically significant association between effluent and stream water quality. However, this association does not explain all the variation in water quality downstream from the plant. One reason is that the two sets of data are not parallel: the discharge monitoring data provide the averages of readings taken on multiple occasions during a month, but the stream readings are taken only once a month and, hence, reflect some indeterminate influence from conditions that are representative not of that month's water quality but of conditions unique to the time when the readings were taken. Given these circumstances, it is not surprising that we have been able to explain only a moderate amount of the water-quality variation through these correlations.

In examining whether the changes in water quality could also—or better—be explained from the influence of other point sources, we identified only one as a potential influence on water quality at WQN119: the

Coaldale-Lansford sewage-treatment plant, approximately 6 stream miles from the Tamaqua plant, up Panther Creek, a tributary of the Little Schuylkill River, and some 8 miles from WQN119. We examined the discharge monitoring reports from Coaldale-Lansford for 1975-84. (Table II.7 presents the effluent history of the plant for this period.) The BOD_5 and suspended solids discharged from Coaldale-Lansford and Tamaqua are compared in figure 3.3.

Figure 3.3: Annual Mean BOD_5 and Suspended Solids Load at the Tamaqua and Coaldale-Lansford Sewage-Treatment Plants in 1975-84



Coaldale-Lansford averaged slightly smaller flows than Tamaqua during this period. To some extent, the changes at Coaldale-Lansford mirrored those at Tamaqua, but they lacked the precipitous drop from the primary treatment levels at Tamaqua. Nevertheless, Coaldale-Lansford experienced a statistically significant decrease in BOD_5 and fecal coliform bacteria in the postupgrade period. The relative stability of

Coaldale-Lansford's effluent history, compared with that of Tamaqua, indicates that the improvement in the Little Schuylkill River stems more from the changes at Tamaqua.

We attempted to confirm this hypothesis by regressing dissolved oxygen and ammonia levels at WQN119 on the effluent records from both plants. We constructed a number of regression models, using various combinations of the four time series (flow, BOD_5, suspended solids, and fecal coliform bacteria) from each of the two plants. (The results from our final models are presented in table II.8.) Models other than the three-predictor model we used (BOD_5 effluent from Tamaqua and suspended solids and BOD_5 from Coaldale-Lansford) have greater predictive power (explaining as much as 80 percent of the variance in stream readings), but we believe that more complex models can be misleading because of multicollinearity or for other technical reasons, such as a decrease in sample size caused by compounding data gaps.[1]

The association between effluent and stream data is difficult to discern when all flow conditions are considered and when the stream data are not adjusted for flow. Our full-flow models had little or no predictive power. However, when we examined flow-adjusted readings taken under low-flow conditions, the combined predictive effect of BOD_5 from Tamaqua and suspended solids BOD_5 from Coaldale-Lansford accounted for nearly half the variance in dissolved oxygen readings at WQN119 and nearly 40 percent of its ammonia readings.

Some estimate of the relative influence of the different effluent parameters can be formed by comparing the size of the beta weights within each regression model. It appears that Tamaqua's effluent had more influence than Coaldale-Lansford's on the dissolved oxygen level at WQN119 but that ammonia levels, particularly under low-flow conditions, are better explained by Coaldale-Lansford.

This modeling exercise reinforces the importance of using flow-adjustment techniques. For some parameters, the use of unadjusted data implies an inverse relationship between suspended solids from Coaldale-Lansford and ammonia in the river. In other words, the higher the level of suspended solids, the lower the stream ammonia. Clearly, this does not imply a causal connection. Rather, the relationship is explained by a third variable: flow. In months with high average flow, the ability of the

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[1] Entering highly intercorrelated predictor variables into a regression model can lead to uninterpretable results. The intercorrelation is termed "multicollinearity."

receiving stream to dilute a constituent is greater and the stream concentration of that constituent is diminished. Making flow adjustments for the data effectively eliminates the misleading negative correlation between effluent and stream concentration, caused by the dependence of concentration on flow, and succeeds in highlighting the explanatory contribution of Coaldale-Lansford's effluent to stream ammonia levels at WQN119.

Summary

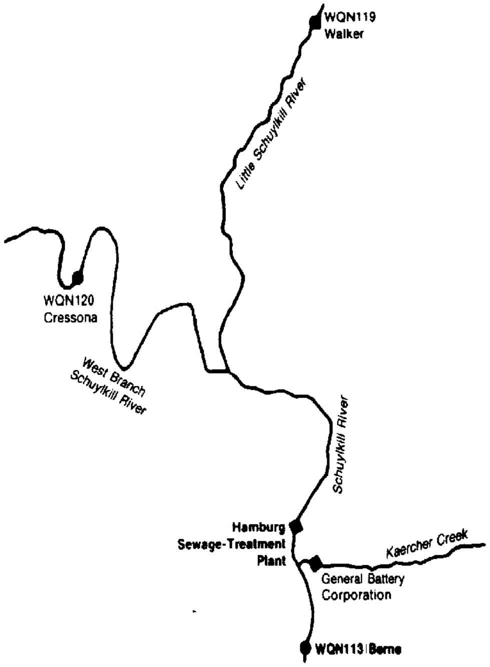
From mid-1977, the upgrade of the Tamaqua sewage-treatment plant to secondary treatment resulted in a dramatic decline in the level of pollutants discharged into the Little Schuylkill River. The upgrade was followed by a significant improvement in downstream water quality that appears to be related to effluent from Tamaqua. We inferred from our examination of effluent records from the nearby Coaldale-Lansford sewage-treatment plant that the improvements in dissolved oxygen noted at our measuring location were more likely to be the effect of changes at Tamaqua than at Coaldale-Lansford but that ammonia levels were more strongly affected by the latter treatment plant.

The influence of both point sources is clearly visible only under low-flow conditions. We were able to establish this relationship without upstream data to use as the basis for data differencing. However, flow-adjustment procedures were essential to our ability to demonstrate the connection between the Tamaqua upgrade and stream water quality.

In conclusion, it should be noted that effluent from wastewater treatment has not been the major source of water-quality problems in the Little Schuylkill River—not, at least, after the upgrade at Tamaqua was completed. The river has suffered from low pH levels and high sulfate concentrations, which are almost certainly associated with acid mine drainage from the strip mines in the area. During the past 20 years, pH levels have increased gradually, so that the river is now suitable for trout stocking. This improvement is presumably from a decrease in mining activity.

The methodology we applied to this case cannot address the stream improvement from lowered levels of acid mine drainage, except insofar as this nonpoint source is a function of stream flow and can be controlled by means of making flow adjustments. It is likely that the particular effectiveness of making flow adjustments in clarifying the relationship between effluent and water quality is a function of the importance of nonpoint-source pollution in the Little Schuylkill River.

Figure 4.1: Hamburg Map and Profile



Hamburg Profile

Feature	Data
NPDES number	PA0021601
Type of change	Upgrade to secondary treatment
Construction began	June 10, 1975
Works in operation	July 1976
Project completed	May 11, 1977
Cost	$952,720
Average flow	0.44 million gallons per day
Discharge	Into the Schuylkill River
Average stream flow	709 cubic feet per second
Setting	Rural
Monitoring station	

Direction	Miles	Station[a]	Location
Upstream	20.0	WQN120	Cressona
Upstream	20.0	WQN119	Walker
Downstream	1.8	WQN113	Berne

[a] Pennsylvania Department of Environmental Resources monitoring stations.

Hamburg Sewage-Treatment Plant Case Study

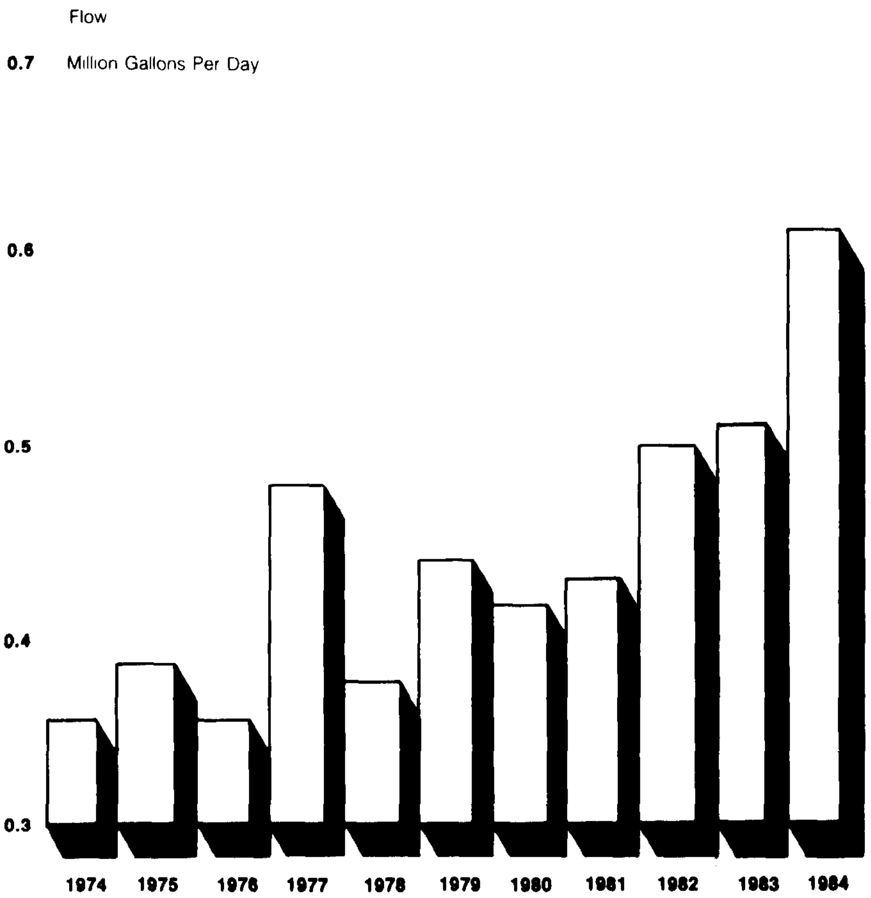
The Hamburg sewage-treatment plant discharges into the Schuylkill River approximately 5 miles downstream from the confluence of the West Branch Schuylkill River and the Little Schuylkill River. The facility receives 50 percent of its influent from industrial customers. A high percentage of this is from Mid-Atlantic Canners Association, a beverage canner whose discharge of sugar-laden wastewater to the plant varies seasonally. Several foundries and a dye manufacturer also discharge to the Hamburg plant. The plant's location and essential information about the plant are shown in the map and profile in foldout figure 4.1.

Beginning in 1975, construction upgraded the Hamburg plant from primary to secondary treatment. The upgrade consisted of using the existing primary tanks as secondary settling tanks and adding new primary tanks, aeration tanks, mechanical aerators, and a laboratory. Unlike the Allentown and Tamaqua upgrades, the Hamburg upgrade was not intended to, nor did it, increase plant capacity, which remained at 1.0 million gallons per day. The modifications were designed to enable the sewage-treatment plant to remove 90 percent of the BOD_5 and suspended solids from the flow of 1.0 million gallons per day.

The wastewater treatment at Hamburg consists of primary clarification, biological treatment using activated sludge, secondary clarification, and chlorination before discharge to the Schuylkill River. Waste-activated sludge and primary sludge are blended and thickened in the primary clarifiers. The thickened sludge is anaerobically digested and disposed on the farmland in the area.

A water-quality monitoring station, WQN113, operated by the Pennsylvania Department of Environmental Resources, is located 1.8 miles below the plant. Two more monitoring stations are situated upstream from the Hamburg plant; WQN119 is some 20 miles upstream on the Little Schuylkill River, and WQN120 is approximately the same distance upstream on the West Branch Schuylkill River. We thought the distance between these stations and the Hamburg plant was too great for their data to be useful in forming a baseline for downstream changes and did not include them in the analysis.

Figure 4.2: Hamburg Sewage-Treatment Plant Effluent Data 1974-84
(Annual Means)

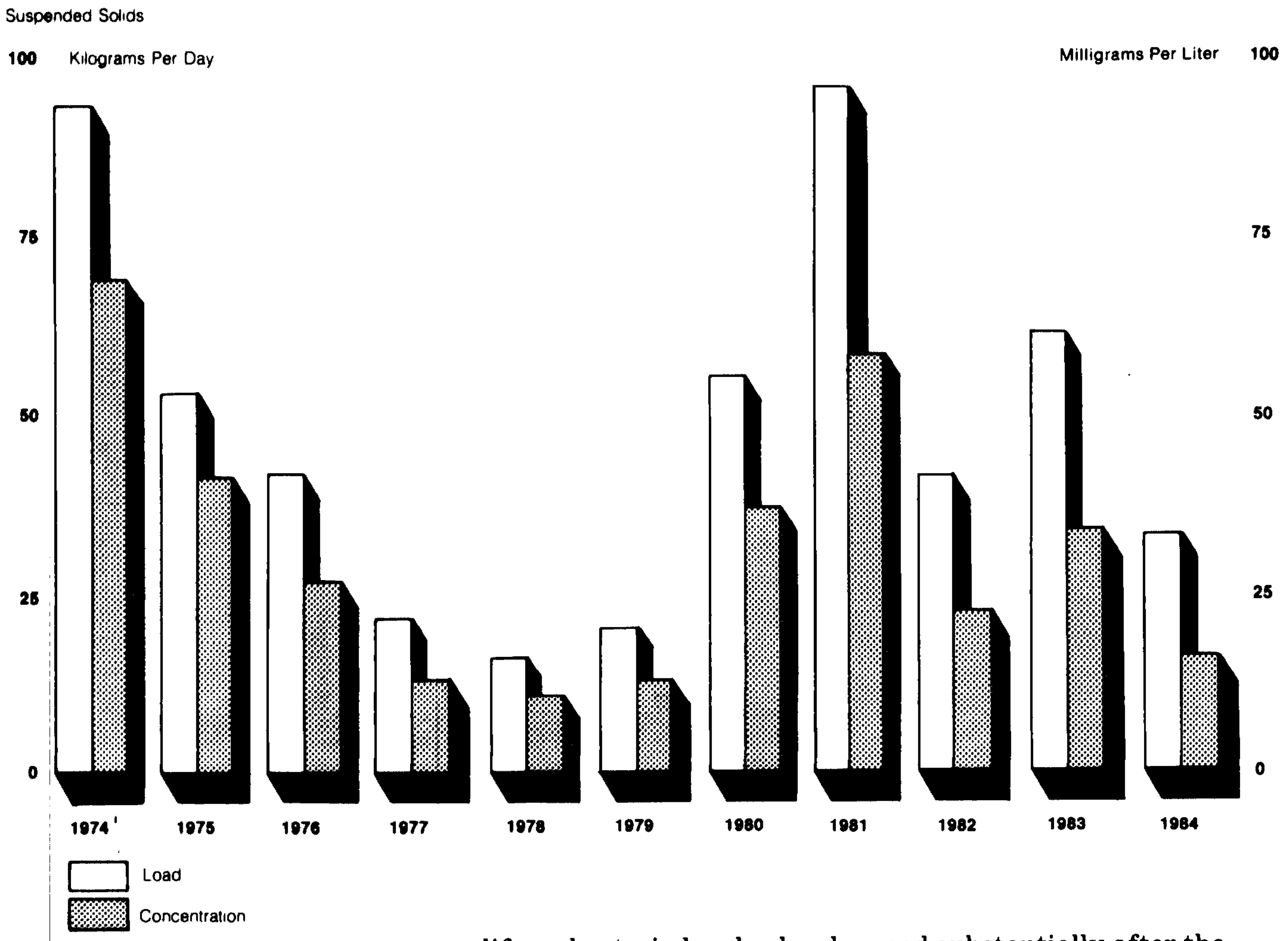


Did the Upgrade Decrease the Amount of Pollutants Discharged?

The Hamburg plant operator informed us that secondary treatment became operational in mid-1976; GICS did not provide a "works in operation" date for the plant. We were able to obtain discharge monitoring reports for Hamburg from April 1974 through October 1984 with only minor data gaps. Our review of these data revealed a sharp drop in effluent suspended solids and BOD_5 from June to July 1976. Accordingly, we set the effective date of the upgrade at July 1, 1976.

Annual means for the Hamburg plant are shown in figure 4.2. Since 1974, the amount of discharged wastewater has increased fairly steadily. The average postupgrade flow was 32 percent higher than before the upgrade. Despite this increase in flow, the average level of suspended solids was significantly lower in the postupgrade period, and BOD_5 levels dropped to 13 percent of their former average. Fecal

Figure 4.2 continued



coliform bacteria levels also dropped substantially after the upgrade, but this decrease is not statistically significant, because of the high variability of the readings.

Figure 4.2 continued

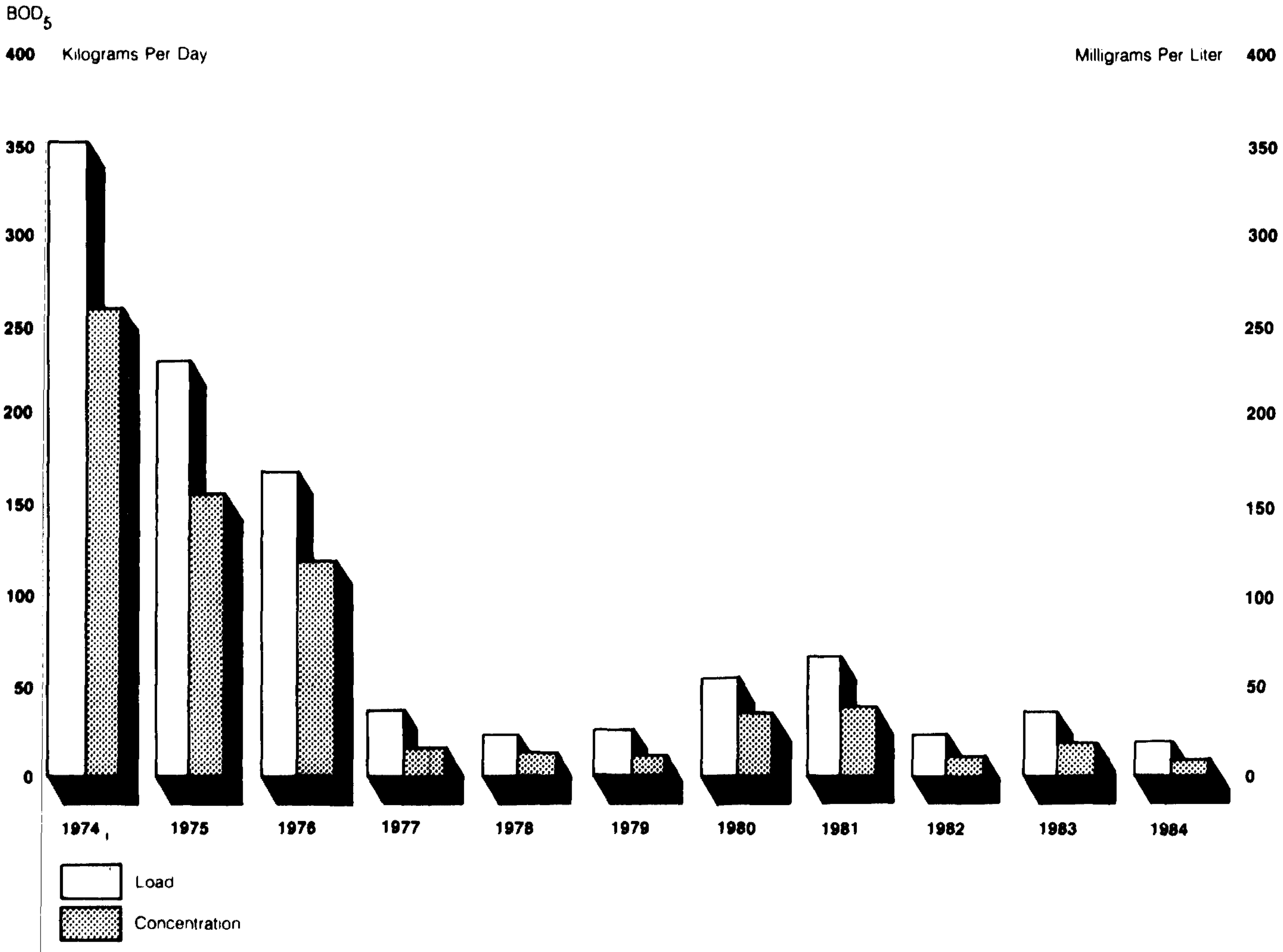
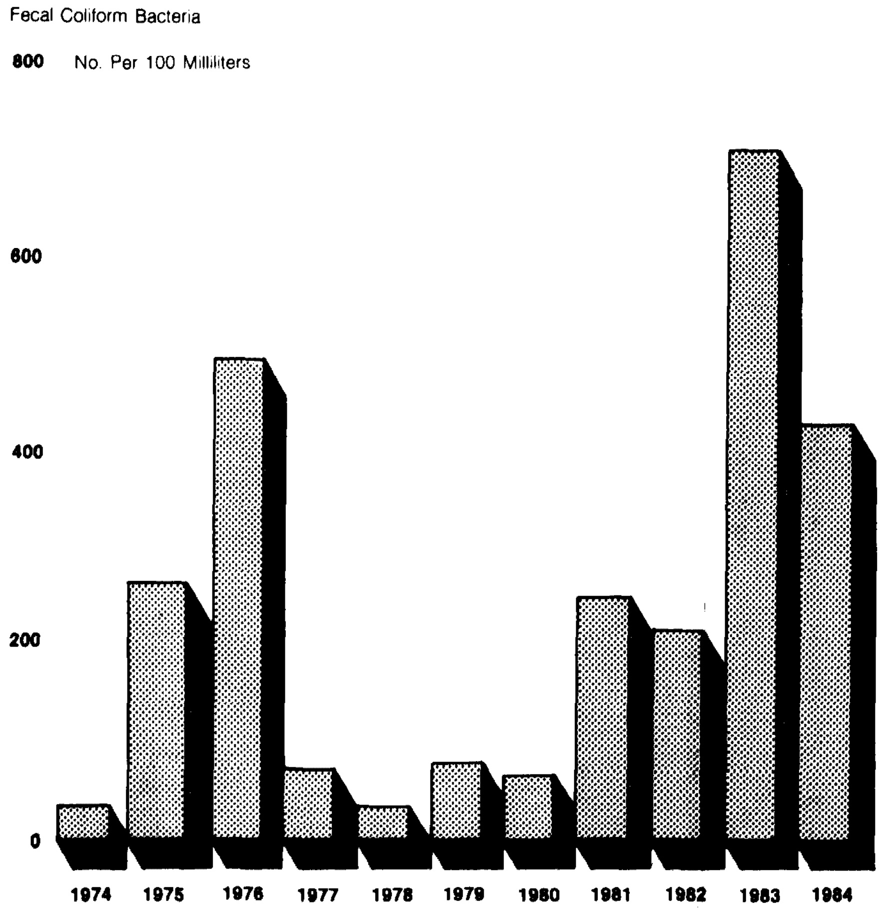


Figure 4.2 continued



The effect of the upgrade on the plant effluent was the most apparent in 1977-79, when the concentration of suspended solids was reduced to less than a third of its previous level, and the amount of BOD_5 discharged into the river fell to 10 percent of the pre-upgrade discharge. In the early 1980's, however, much of the reduction in pollutant discharge that followed the upgrade was lost. BOD_5 levels remained below the pre-upgrade levels but rose in 1980 and 1981, before falling off again to the level achieved in the late 1970's. The annual mean concentration of BOD_5 for 1980 and 1981 violates the standard of 30 mgl that EPA sets as a limit for a monthly average of effluent from secondary treatment plants. The level of suspended solids in the Hamburg effluent followed a similar pattern, rising above even the average pre-upgrade levels, and has violated the 30 mgl standard for 3 of the past 5 years.

We did not attempt to explain the cause of the upgrade's diminishing effectiveness, although some possible explanations have been suggested. The correspondence accompanying Hamburg's discharge monitoring reports and EPA's project history files on the plant consistently identify an industrial discharger, Mid-Atlantic Canners Association, a producer of soft drinks, as the cause of the permit violations by the sewage-treatment plant. The waste from Mid-Atlantic is discharged directly into the borough's sewer system and contains a much higher concentration of BOD_5 than the domestic sewage that the plant was designed to treat.

The Borough of Hamburg has been discussing the necessity of pretreating Mid-Atlantic's waste since 1975, and at the time of our last interview with the plant superintendent in March 1986, the issue was in litigation. In May 1984, EPA inspected the sewage-treatment plant and declared it organically overloaded but well below its hydraulic capacity; that is, although the amount of wasteflow the plant had been designed to handle had not been reached, the amount of organic content in its influent was beyond its capacity to treat adequately. The inspector believed that the Mid-Atlantic waste was a probable cause of permit violations by the plant. However, the inspector also noted that some deficiencies in the plant's operation resulted in an incomplete treatment of wastes.

Without additional data, we cannot assess whether the pattern of discharge of untreated waste from Mid-Atlantic can be associated with the apparent effectiveness of the plant in 1976-79 or with the increased levels of pollutant from the plant after 1979. Discharge monitoring reports are not available from Mid-Atlantic, since it does not discharge its waste directly into the river and, hence, is not regulated under NPDES, the national pollutant discharge elimination system. Other information necessary for an assessment would have to identify the various factors associated with the plant's performance history and would have to take into consideration the 1979 management changes at the plant.

Did Water Quality Improve Downstream From the Plant?

We compared the average stream readings, both flow-adjusted and unadjusted, of dissolved oxygen, BOD_5, ammonia, nitrite, and nitrate at WQN113 for the pre-upgrade and postupgrade periods.[1] (The results of these comparisons are presented in tables III.3 and III.4.) We found that changes downstream at WQN113 were mostly in the preferred direction

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[1] Significant ($p < .10$) flow-adjustment models could be developed only for dissolved oxygen, ammonia, and nitrite at full flow and ammonia at low flow.

but generally minor and less than statistically significant. The level of dissolved oxygen, which was quite high before the upgrade, increased only marginally by 1 to 2 percent. The decrease in BOD_5 was statistically significant when adjusted for flow, but the decrease in ammonia levels, both flow-adjusted and unadjusted, was less than statistically significant. Nitrite concentrations decreased significantly, and nitrate concentrations increased, which suggests some slight increase in the natural nitrification rate. As in the Allentown and Tamaqua cases, the changes noticed under all flow conditions were somewhat more pronounced under low-flow conditions.

Were Changes in Effluent Related to Changes in Stream Water-Quality Indicators?

In this section, we attempt to define the relationship between the Hamburg plant and downstream readings in terms of the correlation between discharge monitoring data records and water-quality data. As we have seen, the level of discharged pollutants decreased substantially following the upgrade to secondary treatment but, after 3 years, the discharge returned to higher levels, particularly for suspended solids. We were able to develop significant flow-adjustment models for only a fraction of the constituents we analyzed. Only 4 of the 10 possible sets of models for constituents at WQN113 produced significant results. Correlations were calculated first for all readings and then for only readings taken at low streamflow. (Tables III.5 and III.6 present a matrix of correlation coefficients for the relationship between Hamburg effluent and stream pollutants, both unadjusted and flow-adjusted, as measured at WQN113.)

These correlations follow a pattern similar to what we have seen in the other cases: associations between effluent data and stream data are generally stronger at low flow and when stream data are adjusted for flow. Stream dissolved oxygen levels are significantly correlated with effluent BOD_5, moderately (0.22) when all observations are used and strongly (0.70) under low-flow conditions. Other associations are less clear. There appears to be a strong link (0.87-0.99) between stream BOD_5 and plant effluent at low flow, but the correlation is less than statistically significant because of the paucity of stream BOD_5 data. Nitrite levels also appear to be related to effluent.

Flow adjustments were possible only for a fraction of the data sets. The available flow-adjustment models strengthened the association between effluent and stream BOD_5 and nitrite but had no effect on the relationship between stream ammonia and effluent. Unfortunately, flow adjustments were not possible for stream dissolved oxygen and nitrate at either full or low flow or for low-flow observations of BOD_5 and nitrite.

These analyses suggest a causal link between variations in the plant's effluent and changes in stream water quality, particularly as measured by dissolved oxygen, BOD_5, and nitrite. However, we must consider the possibility of other explanations for the stream variations.

Can Other Reasonable Explanations of Water-Quality Conditions Be Excluded?

With the help of EPA software and the Pennsylvania Department of Environmental Resources, we were able to establish that only one other point source of pollution within a reasonable distance of WQN113 offered any competing explanation of changes at our monitoring station.[2] The General Battery Corporation discharges into Kaercher Creek, which joins the Schuylkill River about a fifth of a mile above the plant. We were able to obtain most of the effluent records of this company from December 1979 through June 1984.

General Battery's discharge permit limits the amount of metals that it may discharge as well as its suspended solids effluent. From December 1979 through June 1984, the firm discharged an average of 15,300 gallons of wastewater per day, containing an average of 7.4 kilograms of suspended solids per day. By comparison, the Hamburg sewage-treatment plant discharged an average 442,000 gallons of wastewater per day, containing 45.9 kilograms of suspended solids.

We applied regression procedures to determine whether the amount of suspended solids discharged from General Battery helped explain water quality downstream from Hamburg. The firm's effluent was not found to be a significant predictor of any of the downstream constituents we analyzed when all stream observations were used. (The regression results are presented in table III.7.) Under low-flow conditions, it was significantly related to stream nitrite, but this apparent relationship is suspect and is probably a statistical artifact of multicollinearity and a small sample size.

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[2] The nearest upstream point sources, apart from General Battery, are more than 12 miles upstream, and the nearest source of a wasteflow as large as Hamburg's is more than 17 miles upstream.

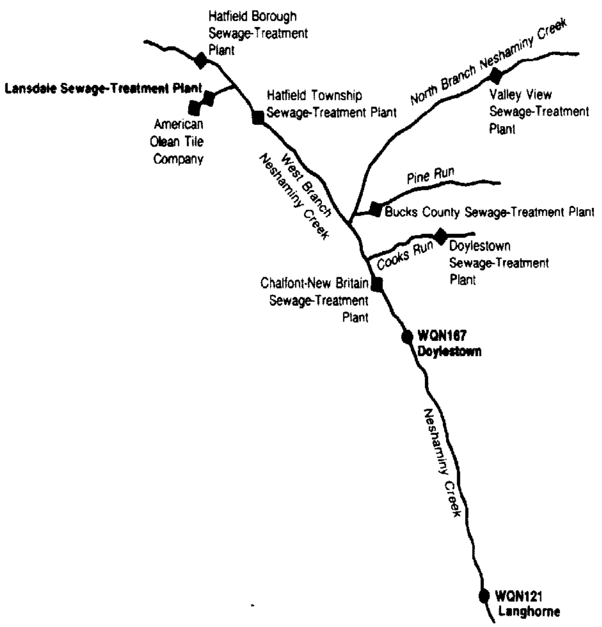
We would have preferred to examine data from General Battery extending back to the pre-upgrade period, but both the lack of correlation with downstream readings and the relatively small level of its effluent strongly suggested that the firm was not a major contributor to the variations in the levels of the constituents we analyzed from the WQN113 data. This does not imply, however, that there is no connection between effluent from this industrial firm and the levels of other pollutants, particularly metals, that may have been present in the river during this period.

Summary

The upgrade of the Hamburg sewage-treatment plant had a clear effect on the quality of the effluent being discharged from the plant, beginning in June 1976. During the 1980's, the degree of improvement was not maintained at the high level that had been attained in the first years after the upgrade. After the upgrade, water quality downstream from the plant tended to improve but the improvement was generally small. Only BOD_5 and nitrite levels decreased significantly. Correlation analysis indicated a connection between plant effluent and stream dissolved oxygen, BOD_5, and nitrite. The only other nearby discharger appears to have little influence on water-quality measurements at WQN113.

These findings suggest that the upgrade of the Hamburg sewage-treatment plant had a measurable effect on downstream water quality and that mean water quality throughout 1976-84 would have been substantially better if the upgrade's immediate effectiveness in improving the quality of plant's effluent had been maintained consistently during the entire postupgrade period.

Figure 5.1: Lansdale Map and Profile



Lansdale Profile

Feature	Data
NPDES number	PA0026182
Type of change	Upgrade to advanced treatment; increase in capacity
Construction began	August 2, 1978
Works in operation	December 1, 1980
Project completed	May 4, 1982
Cost	$16.1 million
Average flow	2.2 million gallons per day
Discharge	Into an unnamed tributary of West Branch Neshaminy Creek
Average stream flow	278 cubic feet per second
Setting	Suburban industrial
Monitoring stations	

Direction	Miles	Station[a]	Location
Downstream	9.9	WQN167	Doylestown
Downstream	21.9	WQN121	Langhorne

[a] Pennsylvania Department of Environmental Resources monitoring stations.

Lansdale Sewage-Treatment Plant Case Study

The upgrade of the sewage-treatment plant at Lansdale, a small suburb some 20 miles north of Philadelphia, was ordered by the Pennsylvania Department of Environmental Resources in 1967 to meet new and more stringent water-quality requirements for Neshaminy Creek, which receives the wastewater from the plant. In 1976, the Department approved a proposal to upgrade the plant by increasing both its capacity and level of treatment. The capacity was increased to 4.0 million gallons per day, and an advanced waste-treatment system was constructed that included nitrification-denitrification, phosphorus removal, and chlorination-dechlorination processes.

According to GICS, the upgrade became effective in December 1980. We collected discharge monitoring reports from 1978 and, after reviewing them, set the effective date of the upgrade as January 1, 1981. The Lansdale plant's location and essential information about the plant are shown in the map and profile in foldout figure 5.1.

Did the Upgrade Decrease the Amount of Pollutants Discharged?

The decrease in pollutant load after the upgrade is clear from figure 5.2. While wastewater flow increased an average of 15 percent after the upgrade, the pollution content of the wastewater decreased significantly in every parameter we examined. Suspended solids decreased 28 percent. BOD_5 dropped to less than a third of its former level, and fecal coliform bacteria counts were cut by half. Unfortunately, ammonia and phosphorus measurements were not recorded before the upgrade, so that no direct comparison with pre-upgrade levels can be made. The nitrification-denitrification process, at least insofar as it is reflected in effluent ammonia levels at the plant, does not seem to have been operating at full efficiency until a year after the upgrade's effects are clearly visible in suspended solids and BOD_5 effluent. The effluent ammonia levels for which we have records dropped sharply in 1982.

Figure 5.2: Lansdale Sewage-Treatment Plant Effluent Data 1978-84 (Annual Means)

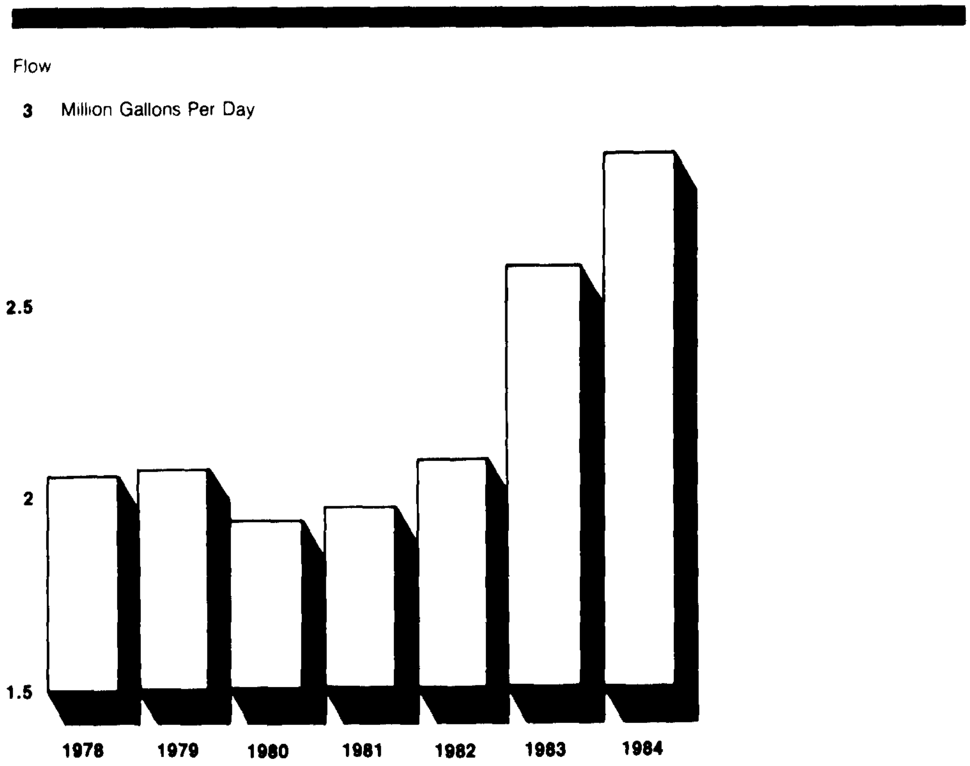


Figure 5.2 continued

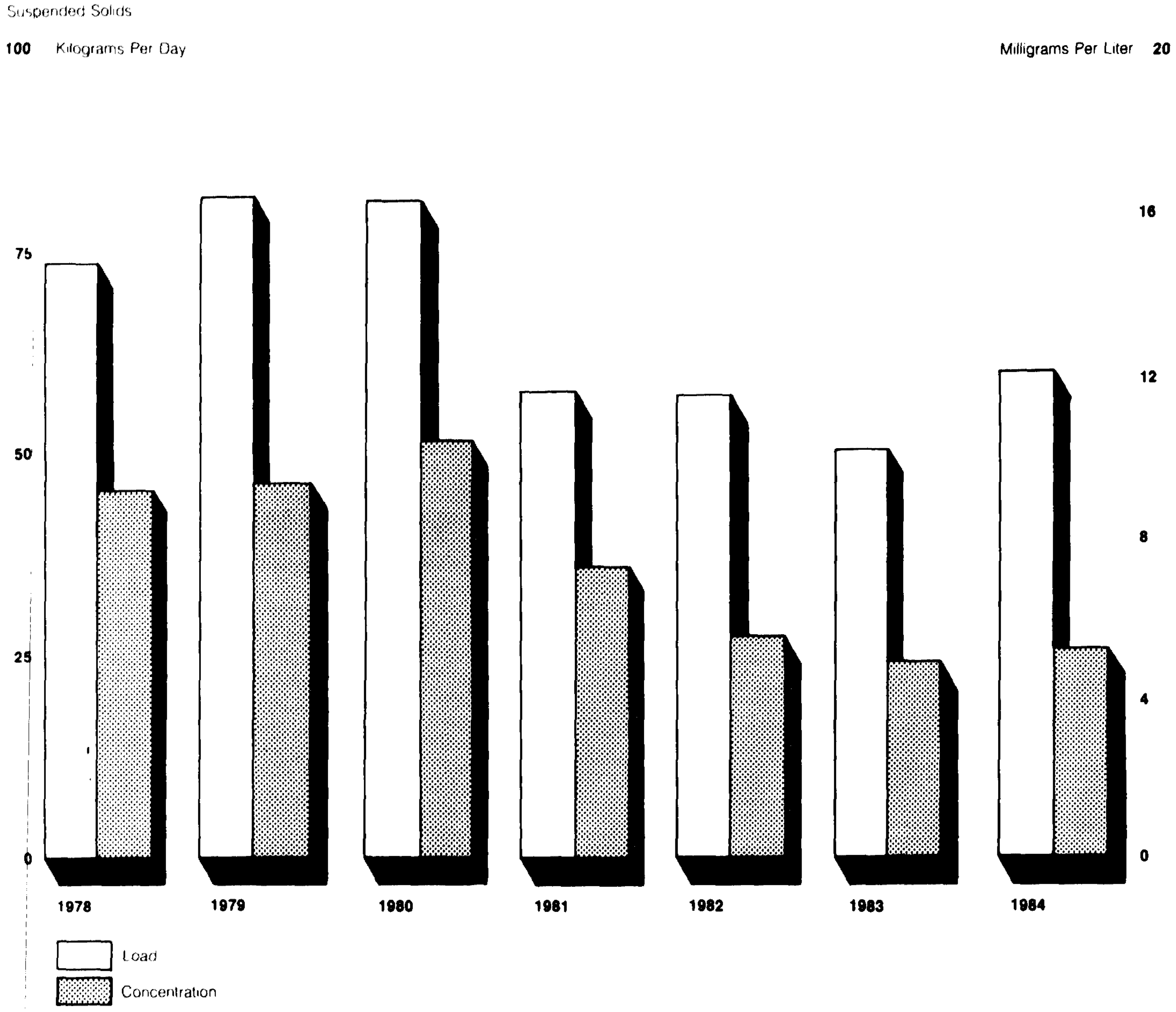


Figure 5.2 continued

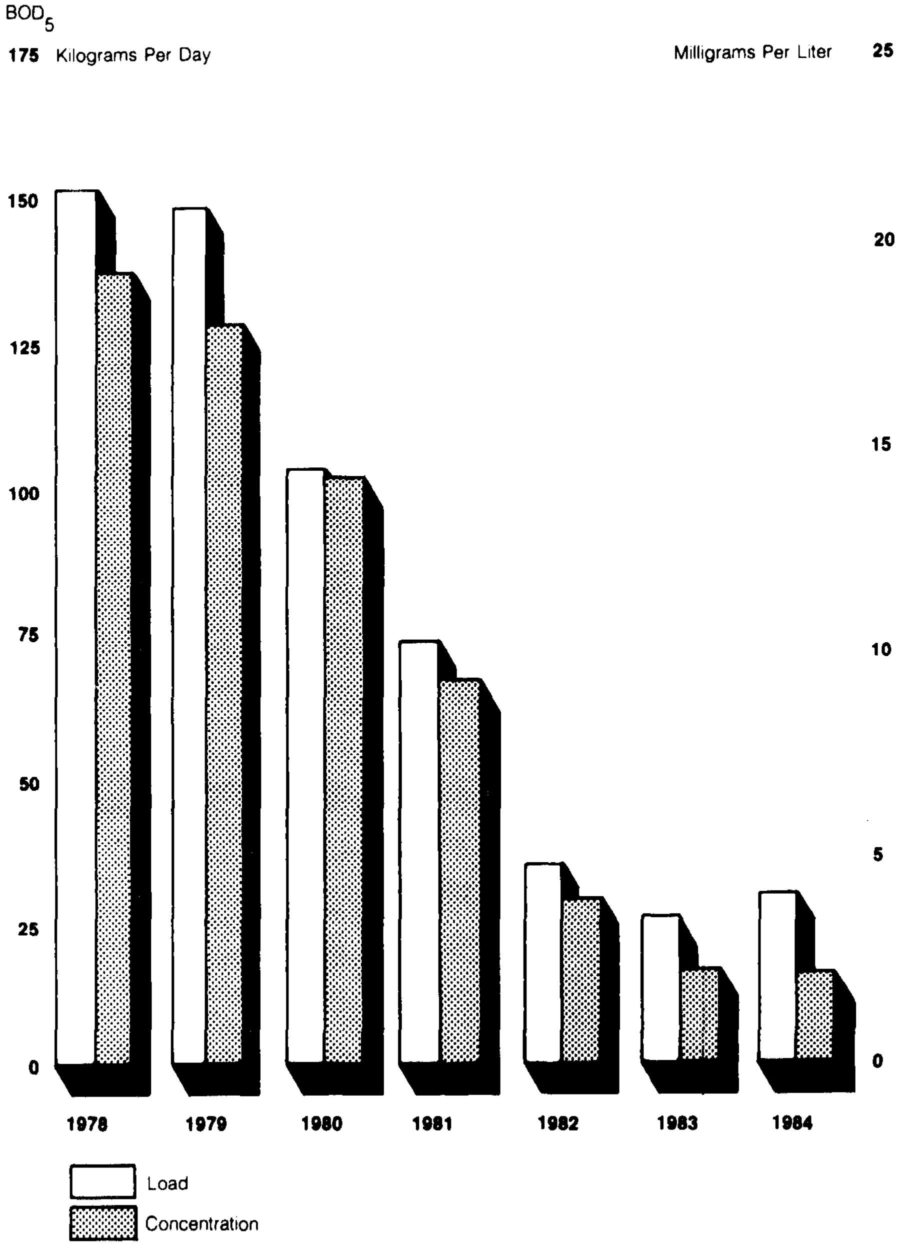
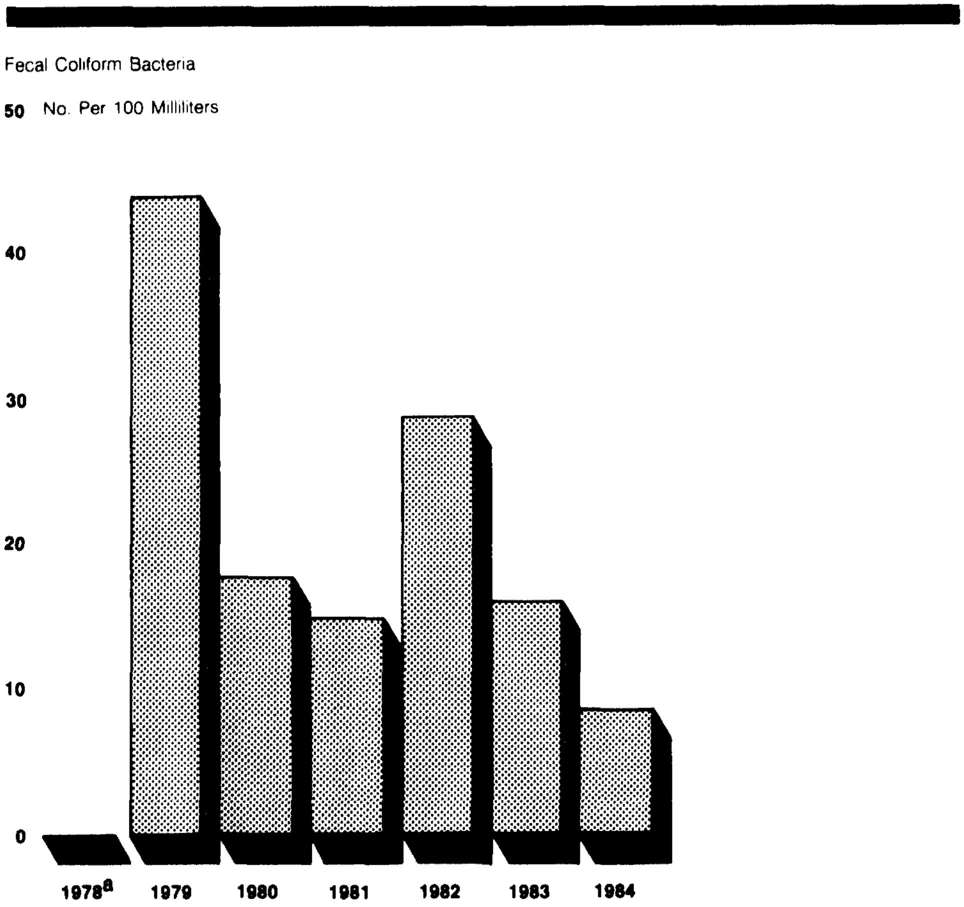
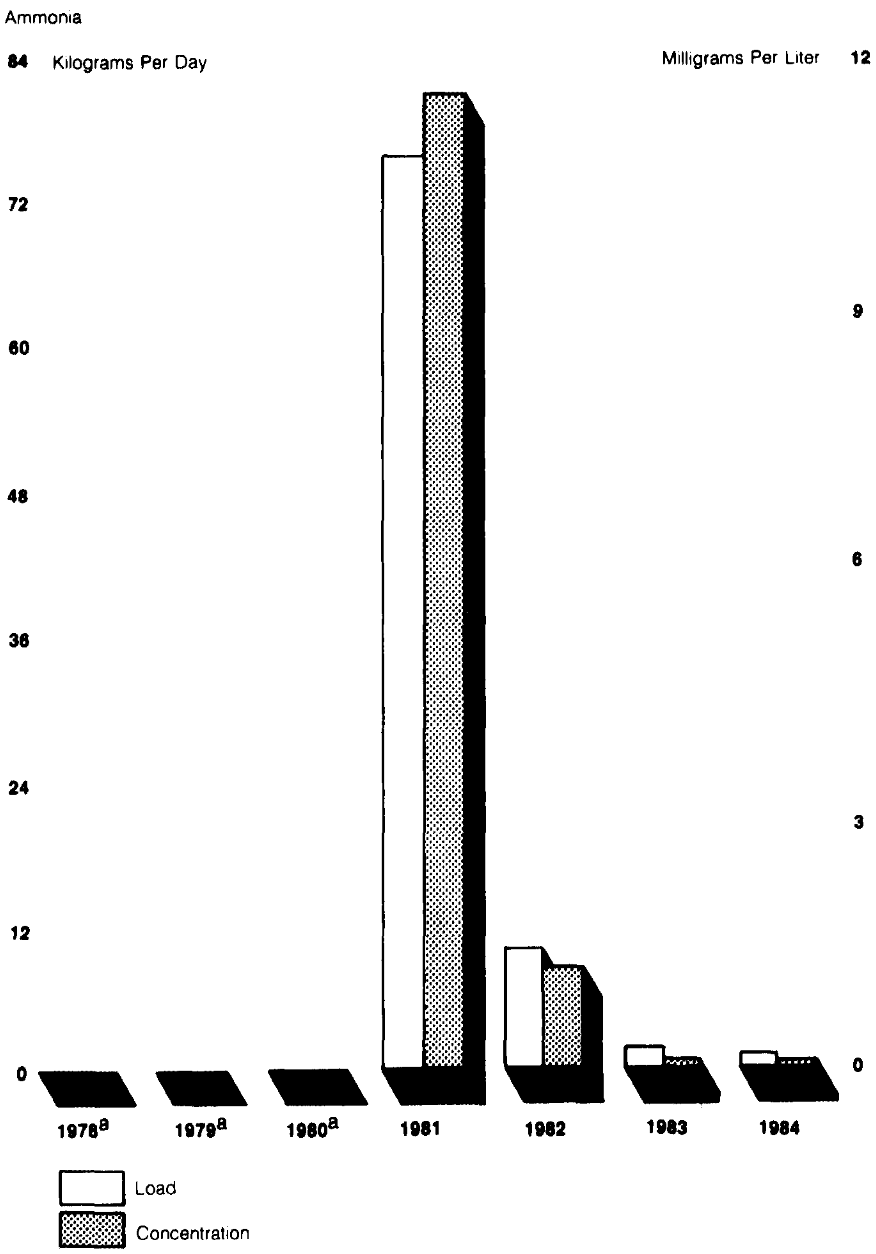


Figure 5.2 continued



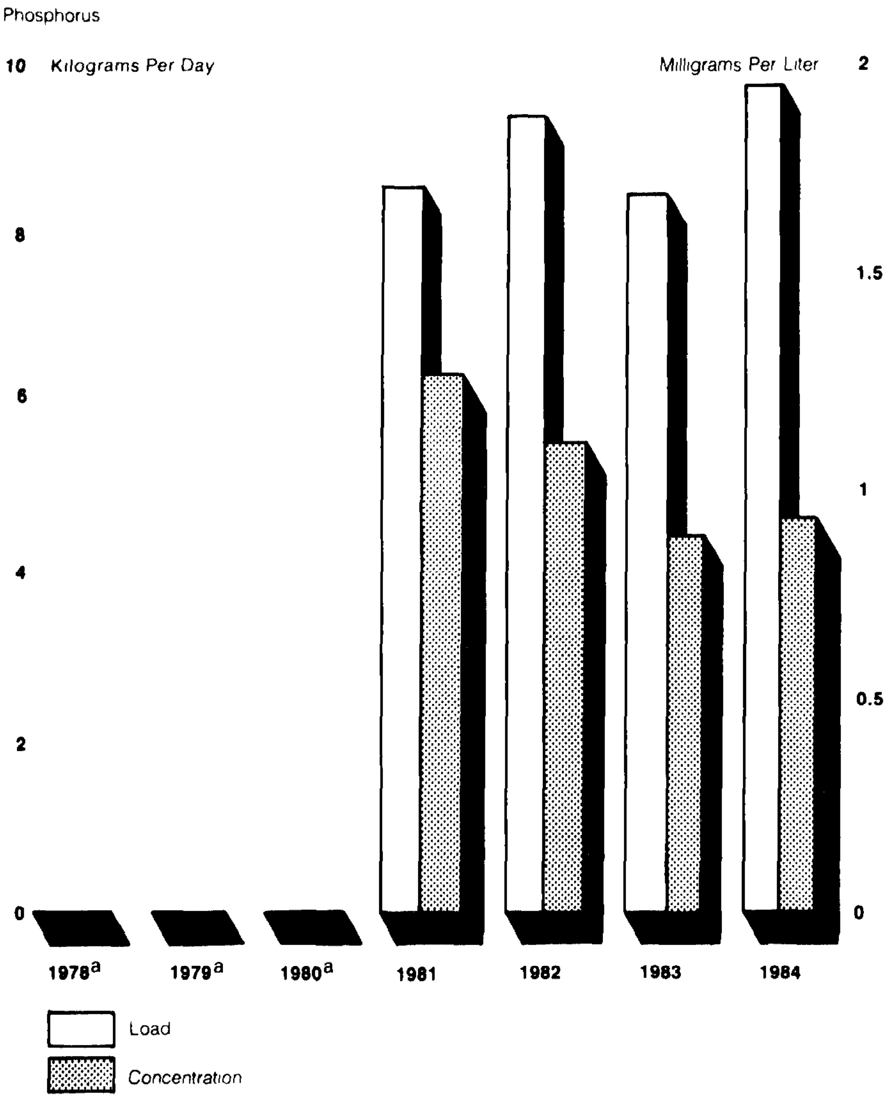
[a]Not available.

Figure 5.2 continued



[a]Not available.

Figure 5.2 continued



[a]Not available.

In contrast, the Tamaqua and Hamburg plants have very few competing point sources. While another plant does discharge indirectly to the same stream as the Tamaqua plant and appears to exert some influence on water quality at the monitoring station, its influence cannot account for the postupgrade improvement in the stream's water quality. The average postupgrade improvements at Hamburg were minimal, but the influence of the plant is still detectable downstream and cannot be ascribed to other point sources.

Summary

The Allentown and Tamaqua upgrades resulted in significant improvements in the quality of water downstream from the plants. The salutary effects of the upgrade at Hamburg on downstream water quality, while detectable, were less substantial. The sizable decrease in pollutant discharge that resulted from the upgrade at Lansdale failed to produce any lasting improvement in downstream water quality because of offsetting increases in discharges from other sewage-treatment plants in the vicinity.

increased significantly. Only nitrate and phosphorus levels declined, but not significantly, under low-flow conditions after the upgrade.

Were Changes in the Effluent Related to Stream Water-Quality Indicators?

The juxtaposition of the two sets of findings presented above makes a detailed analysis of the plant and stream water-quality correlations largely unnecessary. While the upgrade at the Lansdale plant produced some substantial decreases in the level of pollutants being discharged into Neshaminy Creek, little of this improvement seems to have been reflected in water-quality changes downstream. Since phosphorus and nitrate levels did decrease in the stream after the upgrade, however, we examined these two constituents for a statistical association with effluent from the Lansdale plant.

We correlated levels of stream phosphorus and nitrate with plant effluent. (The correlation matrixes are presented in table IV.5.) There appears to be no positive relationship between Lansdale's effluent and these stream parameters. Lower levels of effluent do not imply lower concentrations of pollutants in the stream. Decreasing effluent discharge from Lansdale, at least in the magnitudes recorded at the plant, had no discernible effect at the monitoring station.

Can Other Reasonable Explanations of Water-Quality Conditions Be Excluded?

In an attempt to identify the major determinants of water quality at WQN167, we examined the discharge monitoring reports of all point sources that the Pennsylvania Department of Environmental Resources identified upstream of WQN167. The sources of pollution near the origins of Neshaminy Creek are numerous, and three other sewage-treatment plants rival the Lansdale plant in the amount of pollutants discharged: Hatfield Township, Doylestown, and Chalfont-New Britain. The combined level of pollutants from these three plants increased substantially during the period following the upgrade at Lansdale, as we show in table 5.1. The net effect of the changes at all four of these major point sources was an increase of 14 percent in the amount of suspended solids being discharged into the river and an increase of 10 percent in BOD_5.

Table 5.1: Mean Levels of Effluent From Major Point Sources in Upper Neshaminy Creek Before and After the Lansdale Upgrade

	Flow (mgd)		Suspended solids (kgd)		BOD_5 (kgd)	
Point source	**Before**	**After**	**Before**	**After**	**Before**	**After**
Lansdale	2.05	2.36	79	57	135	43
Chalfont-New Britain	1.87	2.18	192	264	216	238
Hatfield Township	2.56	3.30	27	69	38	143
Doylestown	0.54	0.54	91	53	45	54
Total	**7.02**	**8.38**	**389**	**443**	**434**	**478**

In a series of analyses, we correlated effluent levels from these plants with water-quality measurements at WQN167, calculating both simple and multiple correlation coefficients. On the whole, the results of these analyses were not conclusive. However, flow-adjusted BOD_5 and nitrite levels during low-flow conditions at WQN167 were positively associated with the combined total BOD_5 effluent from Chalfont-New Britain and Hatfield. Flow-adjusted BOD_5 and nitrite were also positively associated with the levels of BOD_5 from Hatfield and with fecal coliform bacteria concentrations at Chalfont-New Britain. We found no positive correlation with Doylestown effluent. Adding the effluent statistics from Lansdale to the total of Hatfield and Chalfont-New Britain failed to improve the relationship with stream data.

From these analyses, it would appear that the effluent from the Lansdale sewage-treatment plant during 1978-84 had less of an effect on water quality in Neshaminy Creek, at least at WQN167, than the discharges from the Hatfield and Chalfont-New Britain plants. Since the connection between effluents and water quality is more clearly visible at low flow, our inability to develop more flow-adjustment models for low-flow conditions may have diminished our ability to separate the individual effects of effluent parameters from different point sources. At a minimum, however, it is clear that any gain in downstream water quality achieved by removing effluent pollutants at Lansdale was offset by deteriorating conditions at Hatfield and Chalfont-New Britain.

It should be noted that no positive relationship between effluent and stream concentrations could be established without our adjusting the data for flow. While the use of flow data from much further downstream almost certainly resulted in the failure to identify some significant relationships between flow and concentration and understated others, the procedure does seem to have greatly reduced the number of spurious correlations between effluent and stream data.

Summary

The upgrade of the Lansdale sewage-treatment plant resulted in a substantial decrease in the amount of pollutants being discharged from the plant into the headwaters of Neshaminy Creek. However, the condition of Neshaminy Creek, as measured 10 miles downstream from the plant, has not visibly improved. Despite improvement in some water-quality parameters, the conditions downstream deteriorated, on balance, from the pre-upgrade period. There seems to be no relationship between effluent from the plant and any stream water-quality parameter, including the two parameters that improved after the upgrade.

We found a connection between the effluent from other sewage-treatment plants upstream and water quality at the monitoring station, at least at low flow. As the effluent increased, the water quality fell. We were not able to develop appropriate flow-adjustment models for several water-quality constituents under low-flow conditions for lack of flow measurements at the monitoring station, and this hindered our ability to establish detailed links between effluent and stream parameters. The amount of pollutants discharged from other sewage-treatment plants increased after the Lansdale upgrade to the extent that there was a net increase in pollutants entering the stream, despite the improvements at Lansdale.

Summary of Case Study Findings

The primary purpose of this study was to develop and test a methodology for evaluating the effects of sewage-treatment plant upgrades funded by the Construction Grants Program. The method can be tested realistically only by applying it to actual upgrades. We chose for our case studies several upgrades for which the stream and effluent data appeared adequate. In the course of these case studies, we were able to demonstrate our method and refine it, but we also came to some substantive conclusions about the success of these upgrades. While we cannot generalize from our findings beyond these four case studies, we use them as examples of the results that this method can provide.

The findings we present in this chapter are the result of comparing and juxtaposing our case study analyses, without seeking to aggregate the data. Our conclusions flow from the evidence we inspected. A more exhaustive examination of each plant's history and each receiving stream's hydrology might well improve our understanding of their interaction, but we believe that it would not alter these first-level findings.

Did the Upgrades Decrease the Amount of Pollutants Discharged?

In each of the four case studies, pollution entering the receiving stream from the plant, whether measured in terms of suspended solids, BOD_5, or fecal coliform bacteria, decreased substantially after the upgrade. The decreases occurred despite significant increases in total wasteflow at three of the four plants. Decreases in other pollutants could not be measured directly at any of the plants. However, the evidence from Allentown and Lansdale suggests that the level of effluent ammonia dropped at both plants and that phosphorus effluent from Lansdale also declined. No information on effluent ammonia was available for Tamaqua and Hamburg, and phosphorus data were available only for Lansdale.

The decreases in pollutant effluent from the plants appear to have been of a magnitude such that any appropriate statistical technique for estimating it would not fail to detect it. Small inaccuracies in establishing effective upgrade dates would not seriously affect the analysis.

With the exception of Hamburg, the initial postupgrade decrease in effluent was maintained. At Hamburg, a surge in BOD_5 and suspended solids occurred some 3 years after the upgrade, which raised the loading of these pollutants to nearly pre-upgrade levels, but the effluent quality later returned to its initial postupgrade levels.

Did Water Quality Improve Downstream From the Plants?

Water quality, as measured by various indicators at the monitoring stations downstream from the four upgraded plants, improved in some, but not all, cases. Table 6.1 presents a summary of the results of our tests for significant improvements in water quality.

Table 6.1: Summary of Statistically Significant Decreases in Pollutants in Receiving Streams After the Allentown, Hamburg, Lansdale, and Tamaqua Upgrades by Flow Condition[a]

	Allentown[b]		Hamburg[c]		Lansdale		Tamaqua	
	Full	Low[d]	Full	Low[d]	Full	Low[d]	Full	Low[d]
Dissolved oxygen deficit								
Unadjusted	Yes	Yes	No	No	No	No	Yes	Yes
Adjusted	Yes	Yes	[e]	[e]	[e]	No[f]	Yes	Yes
BOD$_5$ (mgl)								
Unadjusted	Yes	No	No	Yes	No	No	[e]	[e]
Adjusted	No	No	Yes	[e]	No	No	[e]	[e]
Ammonia (mgl)								
Unadjusted	Yes	Yes	No	No	No	No[f]	No	Yes
Adjusted	Yes	No	No	No	No[f]	[e]	Yes	Yes
Nitrite (mgl)								
Unadjusted	No	No	Yes	No	No	No	Yes	No
Adjusted	Yes	No	Yes	[e]	No	No	Yes	No
Nitrate (mgl)								
Unadjusted	No	No	No[f]	No[f]	Yes	No	Yes	No
Adjusted	Yes	No	[e]	[e]	No	[e]	Yes	[e]
Phosphorus (mgl)								
Unadjusted	[e]	[e]	[e]	[e]	Yes	No	[e]	[e]
Adjusted	[e]	[e]	[e]	[e]	Yes	[e]	[e]	[e]

[a] Statistical significance at $p < .10$.

[b] Nondifferenced data and WQN124 readings only; includes all pre-upgrade observations.

[c] Nondifferenced data.

[d] Lowest quartile of observations.

[e] Not available.

[f] Significant increase.

The water quality downstream from the Allentown and Tamaqua plants improved significantly in nearly all parameters. (At Allentown, it also improved significantly at a monitoring station further downstream.) The water-quality improvements downstream from Hamburg were generally less than statistically significant. This is most likely a function of the small volume of wasteflow from the plant relative to the size of the receiving stream and of the plant's failure to maintain consistently low levels of pollutants in the effluent after the upgrade. At Lansdale, water quality failed to improve in most respects and, in fact, suffered significant degradation in dissolved oxygen and ammonia.

Were Changes in Effluent Related to Stream Water-Quality Indicators?

The results of our statistical tests for the association between a plant's effluent, as measured by the plant's discharge monitoring reports, and stream water quality, as measured by monitoring stations downstream from the plant, generally paralleled our findings regarding water-quality changes. Plant effluent was found to be significantly associated with water quality at Allentown and Tamaqua. This relationship was generally stronger under low-flow conditions and when stream observations were adjusted for flow. The effluent from Hamburg was also found to be associated with the level of some stream pollutants, although not as strongly as at Allentown and Tamaqua. At Lansdale, however, no positive relationship between variations in effluent and changes in water quality downstream could be found.

Can Other Reasonable Explanations of Water-Quality Conditions Be Excluded?

The streams to which the Allentown and Lansdale plants discharge are quite different in size, but both are affected by several other point sources of pollution. Allentown is by far the most important discharger to the Lehigh River for the 25 miles above our monitoring station, but it is rivaled by another municipal discharger, the Bethlehem sewage-treatment plant, and a major industrial discharger a few miles below this station. Upgrades both at Allentown and Bethlehem had distinguishable effects on water quality at another monitoring station further downstream that is also sensitive to ammonia discharges from the industrial source. At Lansdale, however, the substantial decline in effluent pollutant loadings following the upgrade was more than offset by an increase in effluent discharged from several other municipal sewage-treatment plants into the same stream. This resulted in a deterioration of downstream water quality to levels lower than those prevalent before the upgrade.

In contrast, the Tamaqua and Hamburg plants have very few competing point sources. While another plant does discharge indirectly to the same stream as the Tamaqua plant and appears to exert some influence on water quality at the monitoring station, its influence cannot account for the postupgrade improvement in the stream's water quality. The average postupgrade improvements at Hamburg were minimal, but the influence of the plant is still detectable downstream and cannot be ascribed to other point sources.

Summary

The Allentown and Tamaqua upgrades resulted in significant improvements in the quality of water downstream from the plants. The salutary effects of the upgrade at Hamburg on downstream water quality, while detectable, were less substantial. The sizable decrease in pollutant discharge that resulted from the upgrade at Lansdale failed to produce any lasting improvement in downstream water quality because of offsetting increases in discharges from other sewage-treatment plants in the vicinity.

Statistical Tables for Allentown Sewage-Treatment Plant

Table I.1: Annual Mean Effluent Levels at Allentown in 1976-84

Year	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)	Ammonia (kgd)
1976	28.39	3988.45	3919.18	47.10	[a]
1977	29.19	5012.27	3958.58	153.50	[a]
1978	28.61	3357.25	2425.33	144.08	[a]
1979	30.95	[a]	[a]	[a]	[a]
1980	30.46	1599.75	2075.83	20.00	1347.33
1981	27.48	1537.15	2016.28	12.55	981.00
1982	28.63	1696.51	1504.20	6.22	747.58
1983	30.23	1703.09	1812.55	7.09	429.62
1984	33.46	1763.00	895.66	5.50	308.12

[a] Not available.

Table I.2: Summary of Mean Effluent Characteristics Before and After the Allentown Upgrade

Effluent	Jan. 1976 - Dec. 1977	Jan. 1976 - Aug. 1979	Sept. 1979 - Aug. 1984
Flow (mgd)	28.81[a]	28.89[a]	29.94
Suspended solids (kgd)	4500.36[b]	4096.91[b]	1655.30
BOD_5 (kgd)	3939.74[b]	3420.51[b]	1694.02
Fecal coliform (no./100 ml)	[c]	[c]	728.33
Ammonia (kgd)	94.39[d]	114.27[d]	10.33

[a] Significant difference ($p < .10$).

[b] Significant difference ($p < .0001$).

[c] Not available.

[d] Significant difference ($p < .001$).

Table I.3: Mean Pollutant Levels at Stations WQN125, WQN124, and WQN123 Before and After the Allentown Upgrade: All Flow Conditions

	Unadjusted			Flow-adjusted		
Pollutant and stations	**Pretransition**	**Before**	**After**	**Pretransition**	**Before**	**After**
Dissolved oxygen deficit						
125	0.05	0.04	0.02	[a]	[a]	[a]
124	0.07[b]	0.05[b]	−0.01	0.03[c]	0.03[b]	−0.05
123	0.14[d]	0.11[b]	0.05	0.03[c]	0.03[b]	−0.04
BOD$_5$ (mgl)						
125	1.56	1.52	1.74	1.75	1.73	1.76
124	2.47[c]	2.42[c]	1.59	1.76	1.71	0.96
123	2.66[d]	2.53[d]	1.40	0.33	0.26[a]	−0.38
Ammonia (mgl)						
125	0.11[d]	0.12[c]	0.24	−0.04[e]	−0.03[b]	0.05
124	0.28	0.32[c]	0.23	0.04[d]	0.08[d]	−0.07
123	0.70[e]	0.70[d]	0.40	0.17	0.20[d]	−0.20
Nitrite (mgl)						
125	0.03[d]	0.03	0.01	[a]	[a]	[a]
124	0.05	0.05	0.04	0.01[e]	0.01[d]	−0.01
123	0.09	0.09	0.07	0.29[d]	0.32[d]	−0.32
Nitrate (mgl)						
125	0.87[d]	0.84[d]	0.53	0.12[d]	0.12[d]	−0.19
124	1.51	1.46	1.53	0.06	0.08[c]	−0.07
123	1.87	1.83	1.76	0.06[c]	0.07	−0.07

[a] Not available.

[b] Significant difference ($p < .01$).

[c] Significant difference ($p < .10$).

[d] Significant difference ($p < .0001$).

[e] Significant difference ($p < .001$).

Table I.4: Mean Pollutant Levels at Stations WQN125, WQN124, and WQN123 Before and After the Allentown Upgrade: Low-Flow Conditions, Lowest Quartile

	Unadjusted			Flow-adjusted		
Pollutant and station	**Pretransition**	**Before**	**After**	**Pretransition**	**Before**	**After**
Dissolved oxygen deficit						
125	0.07	0.05	−0.02	[a]	[a]	[a]
124	0.13[b]	0.10[b]	−0.01	0.07[b]	0.05[b]	−0.06
123	0.21[b]	0.16	0.09	0.12[c]	0.07[b]	−0.05
BOD$_5$ (mgl)						
125	1.20[d]	1.16[d]	2.13	[a]	[a]	[a]
124	3.25	3.11	2.10	0.08	0.05	−0.11
123	2.23	2.15	1.59	[a]	[a]	[a]
Ammonia (mgl)						
125	0.12[d]	0.15[d]	0.35	−0.16[d]	−0.12[b]	0.05
124	[a]	0.93[b]	0.42	[a]	0.51	−0.10
123	1.81[d]	1.68[b]	0.58	[a]	[a]	[a]
Nitrite (mgl)						
125	0.03	0.03[b]	0.02	0.28	0.29	−0.13
124	[a]	0.08	0.08	[a]	0.01	0
123	0.37[c]	0.30[c]	0.14	[a]	[a]	[a]
Nitrate (mgl)						
125	0.82[c]	0.86[c]	0.51	[a]	[a]	[a]
124	[a]	1.93	1.95	[a]	0.14	−0.03
123	1.97	2.40	2.24	[a]	[a]	[a]

[a] Not available.

[b] Significant difference ($p < .10$).

[c] Significant difference ($p < .001$).

[d] Significant difference ($p < .01$).

Table I.5: Mean Pollutant Levels at Stations WQN125, WQN124, and WQN123 Before and After the Allentown Upgrade: Low-Flow Conditions, Lower Half

	Unadjusted			Flow-adjusted		
Pollutant and station	**Pretransition**	**Before**	**After**	**Pretransition**	**Before**	**After**
Dissolved oxygen deficit						
125	0.05	0.04	0.04	[a]	[a]	[a]
124	0.11[b]	0.10[c]	−0.02	[a]	[a]	[a]
123	0.17[b]	0.16[c]	0.05	0.18[d]	0.16[d]	0.08
BOD$_5$ (mgl)						
125	1.29[d]	1.27[d]	1.74	[a]	[a]	[a]
124	2.88	2.76	2.27	0.14	0.09	−0.19
123	2.26	2.22	1.73	[a]	[a]	[a]
Ammonia (mgl)						
125	0.14[e]	0.15[e]	0.34	−0.09[b]	−0.08[b]	0.07
124	0.36	0.45	0.34	0.04	0.12	−0.08
123	1.09[b]	1.13[e]	0.58	[a]	[a]	[a]
Nitrite (mgl)						
125	0.03[e]	0.03[e]	0.01	[a]	[a]	[a]
124	0.06	0.06	0.06	0.25[b]	0.21[b]	−0.14
123	0.14	0.16	0.12	0.22[d]	0.28[c]	−0.17
Nitrate (mgl)						
125	0.79[b]	0.81[e]	0.53	[a]	[a]	[a]
124	1.55	1.62	1.78	−1.73[d]	−1.63[d]	−1.26
123	1.86	1.97	2.08	0.01	0.03	−0.02

[a] Not available.

[b] Significant difference ($p < .001$).

[c] Significant difference ($p < .01$).

[d] Significant difference ($p < .10$).

[e] Significant difference ($p < .0001$).

Table I.6: Mean Differenced Pollutant Levels at Stations WQN124 and WQN123 Before and After the Allentown Upgrade: All Flow Conditions

	Unadjusted			Flow-adjusted		
Pollutant and station	**Pretransition**	**Before**	**After**	**Pretransition**	**Before**	**After**
Dissolved oxygen deficit						
124	0.02[a]	0.02[a]	−0.03	[b]	[b]	[b]
123	0.09[a]	0.07	0.03	[b]	[b]	[b]
BOD_5 (mgl)						
124	0.95[a]	0.93[a]	−0.14	0.06	0.01	−0.74
123	1.16[c]	1.07[c]	−0.27	−1.25[a]	−1.32[a]	−2.12
Ammonia (mgl)						
124	0.18[c]	0.20[c]	−0.01	0.09[c]	0.11[c]	−0.13
123	0.59[c]	0.57[c]	0.16	0.21[c]	0.22[c]	−0.26
Nitrite (mgl)						
124	0.02	0.02	0.03	[b]	[b]	[b]
123	0.06	0.06	0.06	[b]	[b]	[b]
Nitrate (mgl)						
124	0.63[d]	0.63[c]	1.00	−0.05	−0.04[a]	0.12
123	0.99	0.99[a]	1.23	−0.06	−0.04[a]	0.12

[a] Significant difference ($p < .10$).

[b] Not available.

[c] Significant difference ($p < .0001$).

[c] Significant difference ($p < .001$).

Table I.7: Mean Differenced Pollutant Levels at Stations WQN124 and WQN123 Before and After the Allentown Upgrade: Low-Flow Conditions, Lowest Quartile

	Unadjusted			Flow-adjusted		
Pollutant and station	**Pretransition**	**Before**	**After**	**Pretransition**	**Before**	**After**
Dissolved oxygen deficit						
124	0.07	0.06	0.03	[a]	[a]	[a]
123	0.21	0.17	0.10	[a]	[a]	[a]
BOD_5 (mgl)						
124	1.89[b]	1.81[b]	0.13	[a]	[a]	[a]
123	1.03[c]	1.05[c]	−0.54	[a]	[a]	[a]
Ammonia (mgl)						
124	[a]	0.75	0.06	[a]	0.57[b]	−0.21
123	1.66[d]	1.50[e]	0.24	[a]	[a]	[a]
Nitrite (mgl)						
124	[a]	0.05	0.06	[a]	−0.29	0.13
123	0.33[d]	0.27[d]	0.12	[a]	[a]	[a]
Nitrate (mgl)						
124	[a]	1.01[b]	1.44	[a]	[a]	[a]
123	1.18	1.55	1.72	[a]	[a]	[a]

[a] Not available.

[b] Significant difference ($p < .10$).

[c] Significant difference ($p < .01$).

[d] Significant difference ($p < .001$).

[e] Significant difference ($p < .0001$).

Table I.8: Mean Differenced Pollutant Levels at Stations WQN124 and WQN123 Before and After the Allentown Upgrade: Low-Flow Conditions, Lower Half

	Unadjusted			Flow-adjusted		
Pollutant and station	**Pretransition**	**Before**	**After**	**Pretransition**	**Before**	**After**
Dissolved oxygen deficit						
124	0.06[a]	0.06[a]	−0.06	[b]	[b]	[b]
123	0.16[a]	0.15[a]	0.04	[b]	[b]	[b]
BOD_5 (mgl)						
124	1.38	1.31	0.62	[b]	[b]	[b]
123	1.06[a]	1.07[a]	0.01	[b]	[b]	[b]
Ammonia (mgl)						
124	0.25[c]	0.32[c]	0.02	0.15[d]	0.21[d]	−0.16
123	0.98[d]	1.00[d]	0.27	[b]	[b]	[b]
Nitrite (mgl)						
124	0.03[a]	0.03[a]	0.05	[b]	[b]	[b]
123	0.10	0.12	0.11	[b]	[b]	[b]
Nitrate (mgl)						
124	0.67[c]	0.74[c]	1.24	[b]	[b]	[b]
123	0.84[a]	0.99[a]	1.54	[b]	[b]	[b]

[a] Significant difference ($p < .10$).

[b] Not available.

[c] Significant difference ($p < .001$).

[d] Significant difference ($p < .0001$).

Table I.9: Correlation of Allentown Monthly Average Effluent Loads With Unadjusted Stream Observations at Station WQN124

		Effluent				
Stream measure	**Flow stratum**	**Flow (mgd)**	**Suspended solids (kgd)**	**BOD_5 (kgd)**	**Fecal coliform (no./100 ml)**	**Ammonia (kgd)**
Dissolved oxygen deficit	100	0.05	0.27[a]	0.25[a]	0.20[a]	0.22
	50	0.13	0.41[a]	0.34[a]	0.23	0.36
	25	0.22	−0.19	0.23	−0.28	0.29
BOD_5 (mgl)	100	−0.34	0.03	−0.01	0.05	0.51[b]
	50	−0.14	0.04	−0.06	−0.08	0.68[a]
	25	0.47	0.37	0.40	0.51	0.66
Ammonia (mgl)	100	−0.28[b]	0.14	0.13	0.26[a]	0.77[c]
	50	−0.05	0.22	0.17	0.20	0.89[c]
	25	−0.27	0.44	0.09	0.16	0.94[c]
Nitrite (mgl)	100	−0.14	0.08	0.03	0.12	0.41[b]
	50	0.56[d]	0.15	−0.03	−0.05	0.27
	25	0.57[a]	−0.18	−0.26	−0.22	0.28
Nitrate (mgl)	100	−0.01	−0.09	−0.16	0.12	0.20
	50	0.46[b]	−0.03	−0.13	0	0.33
	25	0.34	0.08	0.02	−0.01	0.48

[a] $p < .10$.

[b] $p < .01$.

[c] $p < .0001$.

[d] $p < .001$.

Table I.10: Correlation of Allentown Monthly Average Effluent Loads With Unadjusted Stream Observations at Station WQN123

		Effluent				
Stream measure	**Flow stratum**	**Flow (mgd)**	**Suspended solids (kgd)**	**BOD_5 (kgd)**	**Fecal coliform (no./100 ml)**	**Ammonia (kgd)**
Dissolved oxygen deficit	100	−0.05	0.17	0.16	0.14	0.52[a]
	50	0.24	0.31[b]	0.24	0.29	0.62[c]
	25	0.09	0.10	0.32	0.07	0.62[b]
BOD_5 (mgl)	100	−0.33	0.24	0.30[b]	0.30[b]	0.50[c]
	50	0.18	0.44[b]	0.39	0.47[b]	0.37
	25	0	0.11	−0.15	0.14	0.64
Ammonia (mgl)	100	−0.43[d]	0.30[b]	0.33[b]	0.31[c]	0.48[c]
	50	−0.30	0.46[c]	0.53[a]	0.44[c]	−0.42[b]
	25	−0.52[b]	0.55[b]	0.64[c]	0.52[b]	0.45
Nitrite (mgl)	100	−0.25[b]	0.08	−0.09	0.09	0.15
	50	0.14	0.27	−0.16	0.20	−0.21
	25	−0.07	0.72[a]	0.22	0.78[a]	−0.35
Nitrate (mgl)	100	−0.16	−0.09	−0.10	0.02	0.34[b]
	50	0.10	−0.11	−0.16	−0.10	0.41[b]
	25	0.02	0.04	−0.11	−0.03	0.44

[a] p < .001.

[b] p < .10.

[c] p < .01.

[d] p < .0001.

Table I.11: Correlation of Allentown Monthly Average Effluent Loads With Flow-Adjusted Stream Observations at Station WQN124

		Effluent				
Stream measure	**Flow stratum**	**Flow (mgd)**	**Suspended solids (kgd)**	**BOD_5 (kgd)**	**Fecal coliform (no./100 ml)**	**Ammonia (kgd)**
Dissolved oxygen deficit	100	0.04	0.36[a]	0.33[a]	0.20	0.17
	50	[b]	[b]	[b]	[b]	[b]
	25	−0.06	−0.05	0.36	−0.15	0.17
BOD_5 (mgl)	100	−0.30[c]	−0.07	−0.22	−0.02	0.48[c]
	50	−0	0.28	0.18	0.05	0.65[c]
	25	0.30	0.40	0.42	0.59	0.70
Ammonia (mgl)	100	−0.17	0.34[a]	0.24[c]	0.34[a]	0.54[a]
	50	0.21	0.37[c]	0.29[c]	0.32[c]	0.61[a]
	25	−0.41	0.53[c]	0.11	0.26	0.70[c]
Nitrite (mgl)	100	0.02	0.32[a]	0.08	0.20	0.03
	50	0.39[c]	0.52[a]	0.32[c]	0.25	−0.03
	25	0.55[c]	0	−0.16	−0.04	0.04
Nitrate (mgl)	100	0.28[c]	0.16	−0.03	0.25[c]	0.04
	50	0.48[a]	−0.13	−0.20	−0.11	0.35
	25	0.22	0.43	0.28	0.31	0.37

[a] p < .01.

[b] Not available.

[c] p < .10.

Table I.12: Correlation of Allentown Monthly Average Effluent Loads With Flow-Adjusted Stream Observations at Station WQN123

		Effluent				
Stream measure	**Flow stratum**	**Flow (mgd)**	**Suspended solids (kgd)**	**BOD$_5$ (kgd)**	**Fecal coliform (no./100 ml)**	**Ammonia (kgd)**
Dissolved oxygen deficit	100	0.03	0.29[a]	0.24[a]	0.15	0.45[a]
	50	0.26	0.25	0.17	0.24	0.64[b]
	25	0.08	0.27	0.47[a]	0.25	0.57[a]
BOD$_5$ (mgl)	100	−0.21	0.27	0.29	0.27	0.40
	50	[c]	[c]	[c]	[c]	[c]
	25	[c]	[c]	[c]	[c]	[c]
Ammonia (mgl)	100	−0.26[a]	0.45[d]	0.45[d]	0.38[b]	0.33[a]
	50	[c]	[c]	[c]	[c]	[c]
	25	[c]	[c]	[c]	[c]	[c]
Nitrite (mgl)	100	−0.04	0.39[b]	0.12	0.26[a]	−0.24
	50	0.12	0.40[a]	0.08	0.28	−0.37[a]
	25	[c]	[c]	[c]	[c]	[c]
Nitrate (mgl)	100	0.09	0.14	0.07	0.12	0.27
	50	0.05	0.01	0	−0.06	0.26
	25	[c]	[c]	[c]	[c]	[c]

[a] $p < .10$.

[b] $p < .01$.

[c] Not available.

[d] $p < .0001$.

Table I.13: Correlation of Allentown Monthly Average Effluent Loads With Unadjusted Differenced Stream Observations at Station WQN124

		Effluent				
Stream measure	Flow stratum	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)	Ammonia (kgd)
Dissolved oxygen deficit	100	0.10	0.24[a]	0.28[a]	0.18	0.14
	50	0.21	0.33[a]	0.39[a]	0.21	0.15
	25	0.19	−0.13	0.43	−0.02	0.16
BOD_5 (mgl)	100	−0.18	0.16	0.12	0.12	0.70[b]
	50	−0.06	0.21	0.09	0	0.86[c]
	25	0.24	0.10	0.15	0.47	0.95[a]
Ammonia (mgl)	100	−0.14	0.40[b]	0.36[c]	0.35[c]	0.39[c]
	50	−0.07	0.44[c]	0.35[a]	0.32[a]	0.32
	25	−0.40	0.47[a]	0.11	0.31	0.51[a]
Nitrite (mgl)	100	−0.07	−0.22[a]	−0.24[a]	−0.06	0.43[c]
	50	0.48[c]	−0.15	−0.26	−0.22	0.32
	25	0.51	−0.32	−0.25	−0.39	0.37
Nitrate (mgl)	100	0.04	−0.39[b]	−0.41[d]	−0.12	0.20
	50	0.42[c]	−0.35[a]	−0.38[a]	−0.20	0.34
	25	0.42	−0.22	−0.09	−0.28	0.49

[a] $p < .10$.

[b] $p < .001$.

[c] $p < .01$.

[d] $p < .0001$.

Table I.14: Correlation of Allentown Monthly Average Effluent Loads With Unadjusted Differenced Stream Observations at Station WQN123

		Effluent				
Stream measure	Flow stratum	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)	Ammonia (kgd)
Dissolved oxygen deficit	100	0.01	0.12	0.18	0.09	0.31
	50	0.23	0.21	0.31	0.23	0.39
	25	0.08	0.03	0.36	0.09	0.46
BOD_5 (mgl)	100	−0.05	0.33[a]	0.37[a]	0.32[a]	0.46[a]
	50	0.24	0.59[a]	0.50[a]	0.56[a]	0.23
	25	0.01	0.32	0.08	0.73	0.60
Ammonia (mgl)	100	−0.35[b]	0.43[c]	0.45[c]	0.36[d]	0.31[a]
	50	−0.30[a]	0.55[c]	0.59[c]	0.52[d]	0.16
	25	−0.55[a]	0.60[b]	0.63[d]	0.58[a]	0.23
Nitrite (mgl)	100	−0.23[a]	−0.03	−0.19[a]	0.02	0.15
	50	0.11	0.14	−0.29	0.10	−0.20
	25	−0.09	0.69[d]	0.19	0.75[b]	−0.31
Nitrate (mgl)	100	−0.11	−0.31[d]	−0.29[d]	−0.15	0.32[a]
	50	0.11	−0.33[a]	−0.36[a]	−0.26	0.41[a]
	25	0.07	−0.07	−0.18	−0.13	0.44

[a] $p < .10$.

[b] $p < .001$.

[c] $p < .0001$.

[d] $p < .01$.

Table I.15: Correlation of Allentown Monthly Average Effluent Loads With Flow-Adjusted Differenced Stream Observations at Station WQN124

		Effluent				
Stream measure	Flow stratum	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)	Ammonia (kgd)
BOD_5 (mgl)	100	−0.18	−0.03	−0.18	0.01	0.49[a]
Ammonia (mgl)	100	−0.10	0.45[b]	0.31[c]	0.33[c]	−0.07
	50	−0.14	0.50[c]	0.35[a]	0.35[a]	−0.10
	25	−0.47[a]	0.55[a]	0.07	0.35	0.16
Nitrite (mgl)	25	−0.02	−0.41	0.24	−0.31	0.16
Nitrate (mgl)	100	0.36[c]	−0.20	−0.30	−0.07	−0.04

[a] $p < .10$.

[b] $p < .0001$.

[c] $p < .01$.

Table I.16: Correlation of Allentown Monthly Average Effluent Loads With Flow-Adjusted Differenced Stream Observations at Station WQN123

		Effluent				
Stream measure	Flow stratum	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)	Ammonia (kgd)
BOD_5 (mgl)	100	−0.08	0.26	0.25	0.25	0.28
Ammonia (mgl)	100	−0.23[a]	0.52[a]	0.49[b]	0.39[c]	0.11
Nitrate (mgl)	100	0.18	−0.27[a]	−0.25[a]	−0.27[a]	0.15

[a] $p < .10$.

[b] $p < .0001$.

[c] $p < .01$.

Table I.17: Mean Effluent Levels at Allentown From Major Dischargers Between Stations WQN125 and WQN124 Before January 1978 and After September 1979

Discharger	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Ammonia (kgd)
Sewage treatment plant				
Allentown				
Before 1/78	28.81[a]	4500.36[b]	3939.74[b]	[c]
Before 9/79	28.89[a]	4096.91[b]	3420.51[b]	[c]
After 9/79	29.94	1655.30	1694.02	728.33
Bath				
Before 1/78	[c]	[c]	[c]	[c]
Before 9/79	0.21	9.03	9.49	10.22[b]
After 9/79	0.20	9.17	9.49	7.45
Catasauqua				
Before 1/78	1.34	405.00[d]	273.00[d]	[c]
Before 9/79	1.34	405.00[d]	273.00[d]	[c]
After 9/79	1.44	168.14	168.76	47.46
Northhampton				
Before 1/78	[c]	[c]	[c]	[c]
Before 9/79	[c]	[c]	[c]	[c]
After 9/79	0.66	72.72	68.79	45.09
Other				
Western Electric Corp.				
Before 1/78	[c]	[c]	[c]	[c]
Before 9/79	1.47[d]	11.35[a]	[c]	11.10[b]
After 9/79	1.92	15.33	[c]	15.94

[a] Significant difference ($p < .10$).

[b] Significant difference ($p < .01$).

[c] Not available.

[d] Significant difference ($p < .0001$).

Table I.18: Summary of Mean Effluent Characteristics Before and After the Bethlehem Upgrade

Effluent	Jan. 1976 - Dec. 1977	Jan. 1976 - Aug. 1979	Sept. 1979 - Aug. 1984
Flow (mgd)	11.76	12.18	12.02
Suspended solids (kgd)	2069.25[a]	2022.61[a]	1294.00
BOD_5 (kgd)	2098.58[a]	1735.14[a]	1010.34
Fecal coliform (no./100 ml)	559.13	317.30	12.18
Ammonia (kgd)	1072.18[a]	882.40[a]	464.41

[a] Significant difference (p < .0001).

Table I.19: Beta Weights and R^2 Estimates From Regression of Pollutants at Station WQN123 on Effluent BOD_5 and Ammonia From the Allentown and Bethlehem Sewage-Treatment Plants and Bethlehem Steel Corporation

	Beta weight					
	Sewage-treatment plant				Bethlehem Steel Corp.	
	Allentown		Bethlehem			
Stream measure	BOD_5 (kgd)	Ammonia (kgd)	BOD_5 (kgd)	Ammonia (kgd)	Ammonia (kgd)	R^2
Dissolved oxygen deficit						
Unadjusted	0.08	0.37[a]	−0.02	0.11	−0.51[b]	0.49[c]
Flow-adjusted	0.24	0.26	0.09	0.11	−0.47[a]	0.41[a]
BOD_5 (mgl)						
Unadjusted	−0.08	0.62[b]	0.52[b]	−0.19	0.33	0.60[b]
Flow-adjusted	0.18	0.62[a]	0.65[b]	0	0.31	0.64[a]
Ammonia (mgl)						
Unadjusted	−0.01	0.55[b]	−0.11	−0.17	0.15	0.27[a]
Flow-adjusted	0.33	0.36	−0.05	−0.07	0.14	0.23
Nitrite (mgl)						
Unadjusted	−0.55[b]	0.51[b]	0	−0.12	0.53[b]	0.36[a]
Flow-adjusted	−0.31	0.08	0.18	−0.31	0.40	0.34[a]
Nitrate (mgl)						
Unadjusted	−0.49[a]	0.47[b]	−0.29[a]	0.04	0.01	0.40[b]
Flow-adjusted	−0.44[a]	0.19	−0.51[a]	0.12	−0.08	0.41[a]

[a] $p < .10$.

[b] $p < .01$.

[c] $p < .001$.

Statistical Tables for Tamaqua Sewage-Treatment Plant

Table II.1: Annual Mean Effluent Levels at Tamaqua in 1975-84

Year	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)
1975	1.44	261.92	325.92	14.00
1976	1.35	270.08	321.75	44.00
1977	1.41	89.42	89.25	14.42
1978	1.00	57.50	52.50	12.92
1979	0.97	51.75	52.08	13.00
1980	0.96	66.36	46.08	7.25
1981	1.01	72.11	52.22	19.11
1982	0.82	53.27	40.10	7.82
1983	1.22	59.00	70.17	3.63
1984	1.58	96.45	109.09	30.50

Table II.2: Summary of Mean Effluent Characteristics Before and After the Tamaqua Upgrade

Effluent	Dec. 1974 - May 1977	June 1977 - Jan. 1985
Flow (mgd)	1.41	1.09[a]
Suspended solids (kgd)	238.00	66.18[a]
BOD_5 (kgd)	292.50	58.85[a]
Fecal coliform (no./100 ml)	29.21	12.80[b]

[a] Significant difference ($p < .0001$).

[b] Significant difference ($p < .01$).

Table II.3: Mean Pollutant Levels at Station WQN119 Before and After the Upgrade: All Flow Conditions

	Unadjusted		Flow-adjusted	
Pollutant	Before	After	Before	After
Dissolved oxygen deficit	0.08	0.02[a]	0.03	−0.04[a]
Ammonia (mgl)	0.46	0.39	0.07	−0.04[a]
Nitrite (mgl)	0.04	0.02[b]	0.01	−0.01[c]
Nitrate (mgl)	0.88	0.74[d]	0.06	−0.05[a]

[a] Significant difference ($p < .10$).

[b] Significant difference ($p < .001$).

[c] Significant difference ($p < .0001$).

[d] Significant difference ($p < .01$).

Table II.4: Mean Pollutant Levels at Station WQN119 Before and After the Tamaqua Upgrade: Low-Flow Conditions

	Unadjusted		Flow-adjusted	
Pollutant	**Before**	**After**	**Before**	**After**
Dissolved oxygen deficit	0.19	0.03[a]	0.10	−0.09[a]
Ammonia (mgl)	0.86[b]	0.50	0.25	−0.04[b]
Nitrite (mgl)	0.05	0.04	0.32	−0.06
Nitrate (mgl)	0.73	0.72	[c]	[c]

[a] Significant difference ($p < .01$).

[b] Significant difference ($p < .10$).

[c] Not available.

Table II.5: Correlation of Tamaqua Monthly Average Effluent Loads With Unadjusted Stream Observations at Station WQN119

		Effluent			
Stream measure	**Flow condition**	**Flow (mgd)**	**Suspended solids (kgd)**	**BOD_5 (kgd)**	**Fecal coliform (no./100 ml)**
Dissolved oxygen deficit	Full	0.20[a]	0.11	0.04	−0.02
	Low	0.58[b]	0.37	0.30	0.23
Ammonia (mgl)	Full	−0.12	0.06	0.04	−0.05
	Low	0.27	0.45[a]	0.48[a]	0.54[a]
Nitrite (mgl)	Full	0.01	0.27[b]	0.26[b]	0.03
	Low	−0.07	−0.11	−0.11	0.42[a]
Nitrate (mgl)	Full	0.27[b]	0.32[c]	0.30[b]	0.05
	Low	0.64[b]	0.22	0.25	−0.28

[a] $p < .10$.

[b] $p < .01$.

[c] $p < .001$.

Table II.6: Correlation of Tamaqua Monthly Average Effluent Loads With Flow-Adjusted Stream Observations at Station WQN119

		Effluent			
Stream measure	Flow condition	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)
Dissolved oxygen deficit	Full	0.32[a]	0.16	0.13	0.04
	Low	0.69[a]	0.56[b]	0.53[b]	0.24
Ammonia (mgl)	Full	0.20	0.19[b]	0.18	0.15
	Low	0.27[b]	0.43[b]	0.43[b]	0.26
Nitrite (mgl)	Full	0.30[a]	0.41[c]	0.42[c]	0.20[b]
	Low	0.13	0.15	0.18	0.23
Nitrate (mgl)	Full	0.37[d]	0.29[b]	0.26[b]	0.11
	Low	[e]	[e]	[e]	[e]

[a] $p < .01$

[b] $p < .10$.

[c] $p < .0001$.

[d] $p < .001$.

[e] Not available.

Table II.7: Annual Mean Effluent Levels at Coaldale-Lansford in 1975-84

Year	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)
1975	1.02	40.92	61.19	14.56
1976	1.02	43.75	55.17	12.58
1977	1.05	45.50	51.83	9.50
1978	1.04	52.50	52.67	5.83
1979	1.12	59.83	48.50	3.08
1980	0.89	47.42	37.92	6.17
1981	1.15	56.92	49.58	10.83
1982	1.14	53.18	48.92	9.00
1983	1.02	41.58	39.33	4.55
1984	1.25	43.50	52.17	4.33

Table II.8: Beta Weights and R^2 Estimates From Regression of Pollutants at Station WQN119 on Effluent BOD_5 From Tamaqua and Suspended Solids and BOD_5 From Coaldale-Lansford Sewage-Treatment Plants[a]

		Beta weight			
		Tamaqua	Coaldale-Lansford		
Stream measure	**Flow condition**	**BOD_5 (kgd)**	**Suspended solids (kgd)**	**BOD_5 (kgd)**	**R^2**
Dissolved oxygen deficit					
Unadjusted	All	0.03	−0.08	0	0.01
Flow-adjusted		0.09	0.09	0.13	0.05
Unadjusted	Low	−0.04	−0.05	0.50	0.21
Flow-adjusted		0.66[b]	0.06	0.03	0.49[b]
Ammonia (mgl)					
Unadjusted	All	−0.01	−0.32[b]	0.04	0.09
Flow-adjusted		0.12	−0.08	0.12	0.05
Unadjusted	Low	0.51[b]	−0.42[b]	0.01	0.42[b]
Flow-adjusted		0.06	−0.02	0.58	0.39

[a] Suspended solids omitted as a predictor from Tamaqua because of collinearity; its correlation with BOD_5 is 0.95.

[b] $p < .10$.

Statistical Tables for Hamburg Sewage-Treatment Plant

Table III.1: Annual Mean Effluent Levels at Hamburg in 1974-84

Year	Flow (mgd)	Suspended solids (kgd)	BOD_5(kgd)	Fecal coliform (no./100 ml)
1974	0.36	92.85	353.90	36.50
1975	0.39	53.11	234.82	259.67
1976	0.36	36.93	169.78	550.45
1977	0.48	21.65	35.15	76.55
1978	0.38	16.87	23.23	34.92
1979	0.44	21.00	25.11	77.92
1980	0.42	55.48	51.21	71.58
1981	0.43	95.98	65.59	248.73
1982	0.50	40.90	24.11	208.11
1983	0.51	61.72	38.38	735.36
1984	0.61	40.54	23.94	433.25

Table III.2: Summary of Mean Effluent Characteristics Before and After the Hamburg Upgrade

Effluent	Apr. 1974 - June 1976	July 1976 - Aug. 1984
Flow (mgd)	0.38	0.46[a]
Suspended solids (kgd)	58.95	42.40[b]
BOD_5 (kgd)	278.13	35.11[a]
Fecal coliform (no./100 ml)	456.75	210.37

[a] Significant difference ($p < .0001$).

[b] Significant difference ($p < .10$).

Table III.3: Mean Pollutant Levels at Station WQN113 Before and After the Hamburg Upgrade: All Flow Conditions

	Unadjusted		Flow-adjusted	
Pollutant	Before	After	Before	After
Dissolved oxygen deficit	−0.02	−0.03	[a]	[a]
BOD_5 (mgl)	1.88	1.44	0.07	−0.45 [b]
Ammonia (mgl)	0.36	0.28	0.02	−0.01
Nitrite (mgl)	0.03	0.02[c]	0.005	−0.002[c]
Nitrate (mgl)	1.10	1.54[c]	[a]	[a]

[a] Not available.

[b] Significant difference ($p < .10$).

[c] Significant difference ($p < .01$).

Table III.4: Mean Pollutant Levels at Station WQN113 Before and After the Hamburg Upgrade: Low-Flow Conditions

Pollutant	Unadjusted		Flow-adjusted	
	Before	After	Before	After
Dissolved oxygen deficit	−0.02	−0.04	[a]	[a]
BOD_5 (mgl)	1.83	0.93[b]	[a]	[a]
Ammonia (mgl)	0.37	0.25	0.17	−0.02
Nitrite (mgl)	0.04	0.03	[a]	[a]
Nitrate (mgl)	0.95	1.94[b]	[a]	[a]

[a] Not available.

[b] Significant difference ($p < .01$).

[c] Significant difference ($p < .0001$).

Table III.5: Correlation of Hamburg Monthly Average Effluent Loads With Unadjusted Stream Observations at Station WQN113

Stream measure	Flow condition	Effluent			
		Flow	Suspended solids	BOD_5	Fecal coliform
Dissolved oxygen deficit	Full	−0.12	−0.07	0.22[a]	−0.14
	Low	−0.06	0.34	0.70[b]	0.23
BOD_5 (mgl)	Full	−0.14	0.27	−0.02	0.11
	Low	−0.47	0.99[c]	0.86[c]	0.87[c]
Ammonia (mgl)	Full	−0.23[a]	−0.05	0.04	−0.14
	Low	0.09	0.13	0.20	−0.13
Nitrite (mgl)	Full	−0.31[b]	−0.16[a]	0.39[d]	−0.07
	Low	−0.15	−0.26	0.29	−0.18
Nitrate (mgl)	Full	−0.16[a]	−0.08	0	−0.06
	Low	−0.26	−0.12	0.09	0.29

[a] $p < .10$.

[b] $p < .001$.

[c] $p > .10$; $N = 3$.

[d] $p < .0001$.

Table III.6: Correlation of Hamburg Monthly Average Effluent Loads With Flow-Adjusted Stream Observations at Station WQN113

Stream measure	Flow condition	Effluent			
		Flow	Suspended solids	BOD_5	Fecal coliform
BOD_5 (mgl)	Full	−0.11	0.63[a]	0.43	0.53
	Low	[b]	[b]	[b]	[b]
Ammonia (mgl)	Full	0.19[a]	−0.04	−0.04	−0.14
	Low	0.39[a]	0.08	0.19	−0.04
Nitrite (mgl)	Full	−0.21[a]	−0.23[a]	0.35[c]	−0.06
	Low	[b]	[b]	[b]	[b]

[a] $p < .10$.

[b] Not available.

[c] $p < .001$.

Table III.7: Beta Weights and R^2 Estimates From Regression of Pollutants at Station WQN113 on Effluent BOD_5 and Suspended Solids From the Hamburg Sewage-Treatment Plant and Suspended Solids From General Battery Corporation

		Beta weight			
		Sewage-treatment plant		General Battery Corp.	
Stream measure	Flow condition	Suspended solids (kgd)	BOD_5 (kgd)	Suspended solids (kgd)	R^2
Dissolved oxygen deficit	All	−0.14	0.15	−0.16	0.04
	Low	0.11	0.58	−0.21	0.38
BOD_5					
Unadjusted	All	0.82	−0.53	0.17	0.27
Flow-adjusted		0.96[a]	−0.08	0.22	0.95[a]
Ammonia					
Unadjusted	All	−0.25	0.48[b]	0.09	0.18
Flow-adjusted		−0.15	0.60[a]	−0.21	0.26[a]
Unadjusted	Low	−0.49	0.94[a]	−0.49	0.37
Flow-adjusted		−0.23	0.58	−0.53	0.22
Nitrite	All	−0.16	0.40	0.03	0.13
	Low	0.42[a]	0.05	0.84[a]	0.82[b]
Nitrate	All	−0.19	0.06	−0.16	0.05
	Low	−0.30	0.58	0.17	0.35

[a] $p < .10$

[b] $p < .01$

Statistical Tables for Lansdale Sewage-Treatment Plant

Table IV.1: Annual Mean Effluent Levels at Lansdale in 1978-84

Year	Flow (mgd)	Suspended solids (kgd)	BOD_5 (kgd)	Fecal coliform (no./100 ml)	Ammonia (kgd)	Phosphorus (kgd)
1978	2.11	74.47	151.80	[a]	[a]	[a]
1979	2.17	81.78	148.94	44.08	[a]	[a]
1980	1.87	81.09	104.25	17.50	[a]	[a]
1981	1.95	58.09	74.13	15.33	75.92	8.62
1982	2.19	57.94	35.59	29.20	10.50	9.50
1983	2.59	50.48	26.67	16.27	1.68	8.41
1984	2.89	63.54	31.21	8.75	1.55	9.90

[a] Not available.

Table IV.2: Summary of Mean Effluent Characteristics Before and After the Lansdale Upgrade

Effluent	Jan. 1978 - Dec. 1980	Jan. 1981 - Aug. 1984
Flow (mgd)	2.05	2.36[a]
Suspended solids (kgd)	79.11	56.97[b]
BOD_5 (kgd)	135.00	42.87[c]
Fecal coliform (no./100 ml)	32.00	16.08[d]
Ammonia (kgd)	[e]	14.55
Phosphorus (kgd)	[e]	9.12

[a] Significant difference ($p < .01$).

[b] Significant difference ($p < .001$).

[c] Significant difference ($p < .0001$).

[d] Significant difference ($p < .10$).

[e] Not available.

Table IV.3: Mean Pollutant Levels at Station WQN167 Before and After the Lansdale Upgrade: Flow Conditions

	Unadjusted		Flow-adjusted	
Pollutant	Before	After	Before	After
Dissolved oxygen deficit	0.16	0.14	[a]	[a]
BOD_5 (mgl)	4.15	4.15	−0.02	0.01
Ammonia (mgl)	2.55	3.18	−0.12	0.19[b]
Nitrite (mgl)	0.40	0.37	0.05	−0.07
Nitrate (mgl)	3.98	3.21[b]	0.42	−0.67
Phosphorus (mgl)	1.54	1.0[c]	0.10	−0.16[b]

[a] Not available.

[b] Significant difference ($p < .10$).

[c] Significant difference ($p < .01$).

Table IV.4: Mean Pollutant Levels at Station WQN167 Before and After the Lansdale Upgrade: Low-Flow Conditions

	Unadjusted		Flow-adjusted	
Pollutant	**Before**	**After**	**Before**	**After**
Dissolved oxygen deficit	0.07	0.21	−0.10	0.07[a]
BOD$_5$ (mgl)	4.20	5.76	−0.26	0.06
Ammonia (mgl)	2.48	6.67[a]	[b]	[b]
Nitrite (mgl)	0.64	0.71	−0.06	0.08
Nitrate (mgl)	5.24	4.41	[b]	[b]
Phosphorus (mgl)	2.57	1.94	[b]	[b]

[a] Significant difference ($p < .10$).

[b] Not available.

Table IV.5: Correlation of Lansdale Monthly Average Effluent Loads With Stream Observations at Station WQN167

		Effluent			
Stream measure	**Flow condition**	**Suspended solids**	**BOD$_5$**	**Ammonia**	**Phosphorus**
Nitrate (mgl)					
Unadjusted	Full	−0.23[a]	−0.04	−0.19	−0.18
	Low	−0.51	−0.39	−0.58	−0.02
Flow-adjusted	Full	−0.07	0.19	−0.38[a]	−0.19
	Low	[b]	[b]	[b]	[b]
Phosphorus (mgl)					
Unadjusted	Full	−0.26[a]	−0.02	0.28[a]	−0.41[a]
	Low	−0.28	−0.03	−0.38	−0.58
Flow-adjusted	Full	−0.23[a]	0.14	0.08	−0.40[a]
	Low	[b]	[b]	[b]	[b]

[a] $p < .10$.

[b] Not available.

Table IV.6: Mean Effluent Loadings From Point-Source Dischargers to Neshaminy Creek Above Station WQN167 in 1981-84

Discharger	Flow (mgd)	Suspended solids (kgd)	BOD$_5$ (kgd)	Ammonia (kgd)
Sewage treatment plant				
Lansdale	2.36	56.97	42.87	14.55
Hatfield	0.32	11.58	20.13	[a]
Doylestown	0.54	53.50	54.41	[a]
Chalfont-New Britain	2.18	264.02	237.95	[a]
Hatfield Township	3.30	69.06	143.18	281.19
Valley View	0.03	1.73	1.23	1.16
Bucks County	0.05	2.97	1.84	0.44
Other				
American Olean Tile Co.	0.06	4.90	[a]	[a]

[a] Not available.

Flow-Adjustment Models

The U.S. Geological Survey has developed a series of models to adjust stream concentration data for variations in stream flow. To determine the best-fitting model, the Geological Survey regresses the time series of concentration readings on 14 different functions of stream flow, or Q. The Geological Survey then applies the best-fitting model (generally, the one with the highest R^2 value) to the concentration data and uses the residuals from the regression (the actual values minus the predicted values) as the "flow-adjusted concentrations " in further analyses. The types of models are shown in table V.1. The models as we used them in the case studies are shown in tables V.2 through V.5

Table V.I: Flow-Adjustment Models by Type

Model	Type
$C = a + bQ$	Linear
$C = a + b \ln Q$	Log-linear
$C = a + b [1/(1 + BQ)]$	Hyperbolic; B is a constant typically in the range $10^{-3}Q^{-1} \leq B \leq 10^{2} Q^{-1}$, where Q is mean discharge
$C = a + b (1/Q)$	Inverse
$C = a + b_1Q + b_2Q^2$	Quadratic
$\ln C = a + b \ln Q$	Log-log
$\ln C = a + (b_1 \ln Q) + (b_2 \ln Q)^2$	Log-quadratic log

Table V.2: Allentown Flow-Adjustment Models

Station and stratum	Model	R^2
Full flow		
WQN125		
Dissolved oxygen[a]	Not available	
BOD_5	$0.0004176227 - 3.98418E - 08*Q^2$	0.07[b]
Ammonia	$0.09333 + 79.500326*1/Q$	0.26[c]
Nitrite	Not available	
Nitrate	$0.618654 + 0.00005398157*Q$	0.12[d]
WQN124		
Dissolved oxygen[a]	$0.995619 - 33.413958*1/Q$	0.04[b]
BOD_5	$1.478741 - 854.620638*1/Q$	0.10[e]
Ammonia	$0.145162 + 177.737127*1/Q$	0.37[c]
Nitrite	$0.025992 + 25.574387*1/Q$	0.41[c]
Nitrate	$1.285904 + 319.143790*1/Q$	0.27[c]
WQN123		
Dissolved oxygen[a]	$0.961445 - 67.341799*1/Q$	0.08[e]
BOD_5	$2.501141 - 0.000386483*Q + 3.77520E - 08*Q^2$	0.19[e]
Ammonia	$2.463474 - 0.562192*\log_{10}Q$	0.21[c]
Nitrite[f]	$3.014719 - 1.720554*\log_{10}Q$	0.48[c]
Nitrate[f]	$1.786735 - 0.367901*\log_{10}Q$	0.17[c]
Half flow		
WQN125		
Dissolved oxygen[a]	Not available	
BOD_5	Not available	
Ammonia	$0.147534 + 62.044046*1/Q$	0.11[b]
Nitrite	Not available	
Nitrate	Not available	
WQN124		
Dissolved oxygen[a]	Not available	
BOD_5[f]	$3.353001 - 0.883245*\log_{10}Q$	0.08[b]
Ammonia	$0.181790 + 165.668404*1/Q$	0.28[e]
Nitrite[f]	$-19.65529 + 13.720571*\log Q - 2.706043*(\log_{10}Q)^2$	0.54[c]
Nitrate	$2.422957 - 0.00068352*Q$	0.35[c]
WQN123		
Dissolved oxygen[a]	$0.952564 - 61.354237*1/Q$	0.06[b]
BOD_5	Not available	
Ammonia	Not available	
Nitrite[f]	$-39.32869 + 26.183771*\log_{10}Q - 4.573292*(\log Q)^2$	0.22[e]
Nitrate[f]	$2.465740 - 0.586678*\log_{10}Q$	0.15[e]

Station and stratum	**Model**	**R^2**
Quarter flow		
WQN125		
Dissolved oxygen[a]	Not available	
BOD$_5$	Not available	
Ammonia	$0.072211 + 87.480808*1/Q$	0.14[b]
Nitrite[f]	$-9.693839 + 2.100999*\log_{10}Q$	0.14[b]
Nitrate	Not available	
WQN124		
Dissolved oxygen[a]	$0.760123 + 0.0002904618*Q$	0.16[b]
BOD$_5$[f]	$5.763546 - 1.748156*\log_{10}Q$	0.20[b]
Ammonia	$0.230843 + 146.634643*1/Q$	0.20[b]
Nitrite	$0.130973 - 0.0000773*Q$	0.31[b]
Nitrate	$2.837713 - 0.00133637*Q$	0.39[e]
WQN123		
Dissolved oxygen[g]	$-1.234036 + 0.375766*\log_{10}Q$	0.11[b]
BOD$_5$	Not available	
Ammonia	Not available	
Nitrite	Not available	
Nitrate	Not available	

[a] Percent saturation.

[b] $p < .10$.

[c] $p < .0001$.

[d] $p < .001$.

[e] $p < .01$.

[f] Log natural.

[g] Percent saturation; log natural.

Table V.3: Tamaqua Flow-Adjustment Models

Stratum	Model	R^2
Full flow		
Dissolved oxygen[a]	$0.990032 - 1.071463*1/Q$	0.05[b]
BOD$_5$	$1.258238 + 80.181036*1/(1 + (10^{(-2.5\text{-INT}(\log_{10}(Q)))})*10^{3.5}*Q)$	0.07[b]
Ammonia	$1.005984 - 0.326186*\log_{10}Q$	0.26[c]
Nitrite	$0.017230 + 0.388378*1/Q$	0.18[c]
Nitrate	$0.854200 - 1.727603*1/Q$	0.04[b]
Quarter flow		
Dissolved oxygen[d]	$-0.510125 + 0.326250*\log_{10}(Q)$	0.11[b]
BOD$_5$	Not available	
Ammonia	$16.894738 - 16.499747*1/ (1 + (10^{(-2.5\text{-INT}(\log_{10}(Q)))}))$	0.18[b]
Nitrite[e]	$-1.067353 - 2.032068*\log_{10}(Q)$	0.15[c]
Nitrate	Not available	

[a] Percent saturation.

[b] $p < .10$.

[c] $p < .0001$.

[d] Percent saturation; log natural.

[e] Log natural.

Table V.4: Hamburg Flow-Adjustment Models

Stratum	Model	R^2
Full flow		
Dissolved oxygen[a]	Not available	
BOD$_5$	$2.169704 - 0.000912991*Q + 1.97181E - 07*Q^2$	0.18[b]
Ammonia	$0.445953 - 1.24575*1/(1 + (10^{(-2.5\text{-INT}(\log_{10}(Q)))})*10^{3}*Q)$	0.07[b]
Nitrite	$0.035225 - 0.177887*1/(1 + (10^{(-2.5\text{-INT}(\log_{10}(Q)))})* 10^{3.5}*Q)$	0.04[c]
Nitrate	Not available	
Quarter flow		
Dissolved oxygen[a]	Not available	
BOD$_5$	Not available	
Ammonia	$-0.147356 - 69.468662*1/Q$	0.26[c]
Nitrite	Not available	
Nitrate	Not available	

[a] Percent saturation.

[b] $p < .01$.

[c] $p < .10$.

Table V.5: Lansdale Flow-Adjustment Models

Stratum	Model	R^2
Full flow		
Dissolved oxygen[a]	Not available	
BOD_5[b]	$2.054469 - 0.334468 * \log_{10} Q$	0.11[c]
Ammonia[b]	$3.012246 - 1.097905 * \log_{10} Q$	0.27[d]
Nitrite[b]	$1.398003 - 1.291886 * \log_{10} Q$	0.36[d]
Nitrate	$7.378976 - 1.713033 * \log_{10} Q$	0.13[e]
Phosphorus[b]	$2.57695 - 1.263128 * \log_{10} Q + 0.040838 * (\log_{10} Q)^2$	0.38[d]
Quarter flow		
Dissolved oxygen[f]	$-13.347665 + 17.688369 * \log_{10} Q - 5.898669 * (\log_{10} Q)^2$	0.55[c]
BOD_5[b]	$-84.771962 + 109.241264 * \log_{10} Q - 34.379749 * (\log_{10} Q)^2$	0.60[c]
Ammonia	Not available	
Nitrite	$-0.029825 + 23.107325 * 1/Q$	0.36[g]
Nitrate	Not available	
Phosphorus	Not available	

[a] Percent saturation.

[b] Log natural.

[c] $p < .10$.

[d] $p < .0001$.

[e] $p < .001$.

[f] Percent saturation; log natural.

[g] $p < .01$.

Glossary

Advanced Treatment	Wastewater treatment beyond the secondary, or biological, stage that includes removal of nutrients such as phosphorus and nitrogen and a high percentage of suspended solids.
Biochemical Oxygen Demand, or BOD	A measure of the oxygen consumed in the biological processes that break down organic matter in water. Therefore, it indicates the quantity of organic waste; large quantities of organic waste "demand" large amounts of dissolved oxygen for decomposition, posing a strain on the ecosystem. BOD_5 is a 5-day measure of biochemical oxygen demand.
Combined Sewers	A system that carries both sewage and storm-water runoff. In dry weather, all flow goes to the wastewater-treatment plant. During a storm, only part of the flow is intercepted, because of overloading; the remaining mixture of sewage and storm water overflows, untreated, into the receiving stream.
Dissolved Oxygen	A measure of the concentration of oxygen dissolved within a body of water, often used as a measure of the water's health.
Dissolved Oxygen Deficit	The difference between 1 and the percentage of dissolved oxygen saturation.
Dissolved Oxygen Sag Point	The location downstream from a point source of pollution where the pollutant discharge has its maximum effect on the stream's dissolved oxygen.
Dissolved Oxygen Saturation	The ratio, expressed as a percentage, of observed dissolved oxygen to the maximum amount of oxygen soluble under observed conditions, especially temperature.
Effluent	The discharge from an industrial or municipal wastewater-treatment plant into water such as a river or stream.
Effluent Load	A measure of the quantity of pollution being discharged from a point source into a body of water.

Fecal Coliform Bacteria	A group of organisms common to the intestinal tracts of humans and animals; their presence in water indicates pollution and potentially dangerous contamination.
Flow	The passage of a volume of liquid in a unit of time. As wasteflow, it is commonly measured in millions of gallons per day (mgd); as stream flow, in cubic feet per second (cfs).
Flow-Adjusted Concentration	The concentration of a stream water-quality indicator after mathematical adjustment to compensate for variations in stream flow.
Influent	Flow inward to an industrial or municipal wastewater-treatment plant.
NASQAN	National stream quality accounting network, more than 300 monitoring stations around the nation at which many water-quality characteristics are measured at regular intervals.
Nitrification	The biochemical process in which ammonia is oxidized to nitrate compounds. Some treatment plant upgrades are classified as advanced nitrification treatment, with the goal of reducing high ammonia levels in the water.
Nonpoint-Source Pollution	Diffused pollution resulting from water runoff from urban areas, construction sites, agricultural and silvicultural operations, and the like.
NPDES	National pollutant discharge elimination system, a permit program that imposes discharge limitations on point sources, basing them on national performance standards for new sources or on water-quality standards.
pH	A chemical measure of acidity and alkalinity; in water, the lower the pH is, the more acid is the water. A pH measure of 7 is neutral.

Point-Source Pollution	Pollution discharged through a pipe or other discrete source from municipal wastewater-treatment plants, factories, confined animal feedlots, or combined sewers.
Primary Treatment	The first stage in the treatment of sewage that uses screens and settling tanks to remove material that settles or floats.
River Reach	A segment of a river or stream of specific length. Most reaches extend between the points of confluence with other streams.
Secondary Treatment	The second stage in wastewater-treatment systems in which bacteria consume the organic content of wastes in trickling filters or activated sludge.
Sewage-Treatment Plant	A series of tanks, screens, and other processes by which pollutants are removed from domestic sewage.
STORET	A computerized data base utility that EPA maintains for the STOrage and RETrieval of parametric data on the quality of the waterways within and contiguous to the United States.
Stream Flow	See Flow.
Tertiary Treatment	See Advanced treatment.
Wasteflow	See Flow.
Water-Quality Criterion	A scientific requirement on which may be based a decision or judgment concerning the ability of water quality to support a designated use.
Water-Quality Standard	A government regulation mandating enforceable limits on water quality.

WQN	A prefix identifying water-quality monitoring stations maintained by the Pennsylvania Department of Natural Resources.

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