JOURNAL OF THE
BOSTON SOCIETY OF CIVIL ENGINEERS SECTION
AMERICAN SOCIETY OF CIVIL ENGINEERS

**Volume 63** | **July 1976** | **Number 2**

# EVALUATING WATER QUALITY IMPACTS OF SMALL STREAMS ON MAJOR URBAN RIVERS

By Mitchell J. Small,[1] A.M. ASCE,
and
William P. Darby,[2] A.M. ASCE

## Abstract

Application of the 1972 Federal Water Pollution Control Act Amendments to small urban streams presents complex managerial problems because of the dual role which these streams play in an urban water resources system. Each stream could provide a limited, yet valuable, set of intrinsic beneficial uses. Both collectively and individually, small streams influence the water quality of larger urban rivers. Before the intrinsic water quality demands of a small stream are evaluated, water quality goals to protect major river quality must be established.

Within any reach of a major river, differences in upstream and downstream water quality can be attributed to both:

(i) the tributary streams which enter the major river within the reach.

(ii) effluents (from both point and non-point sources) which enter the river directly.

This analysis determines what portion of major river degradation is due to the water quality conditions of the small streams. The methodology is illustrated with a case study of the region of Allegheny County, Pennsylvania (Pittsburgh SMSA), and concludes that for this region, little improvement in major river quality can be expected from upgrading the water quality of small streams.

## Introduction

Recent water pollution control legislation at state and federal levels has provided strict controls to protect the integrity and quality of the nation's watercourses. The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) establish the national goal of zero discharge of pollutants

---

(1) Engineer, Hydroscience, Inc., Westwood, New Jersey
(2) Assistant Professor, Department of Technology and Human Affairs, Washington University, St. Louis, Missouri

by 1985. The act further establishes an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water, to be achieved by July 1, 1983 [9]. To implement this act, the governor of each state was to designate areas within the state which had substantial water quality problems as a result of urban-industrial concentrations or other factors. Planning was then begun in an attempt to meet the national goals within the problem areas.

Both designation of and planning for problem areas have correctly been focused on major rivers within the urban areas. An urban area, however, consists typically of numerous small watersheds and storm drainage systems, draining into a small stream which eventually joins a large urban river. Nearly all the beneficial uses listed in the interim goal of PL 92-500 could be provided by a large urban river. Achieving these beneficial uses is often solely dependent on the water quality of the major river, which is partially determined by the water quality of small streams.

The small streams themselves, however, provide a valuable, yet often neglected resource. Although the potential for providing beneficial uses is severely limited irrespective of water quality, many are achievable. In particular, small streams can provide opportunities for local recreation and aesthetic enjoyment, uses particularly valued in a densely populated urban area. The role of small urban watersheds in water quality management is the particular focus of this study.

*Dual Impact of Small Urban Streams*

Although the economic and technological feasibility of compliance with the 1972 amendments will be debated at length, the amendments nevertheless provide the framework for efforts in water pollution control at present. When applying this legislation to small urban streams, complex management problems are encountered. The water quality conditions in small streams have a dual impact: not only do they affect the achievable beneficial uses of the individual watersheds, they also exert an influence on the water quality of major rivers.

Due to the dual impact of the small urban watersheds, water quality goals could be set either because of the water quality demands of the receiving rivers, or because of intrinsic demands on the small streams. At present, state and federal agencies are primarily interested in small watersheds as they affect implementation strategies for major rivers. Application of the legislation to protect small urban streams for their own sake usually rests with local regulatory authorities, often charged with responsibility for not one, but many such streams.

Because of budgetary limitations, the local authority usually cannot pursue a course of enforcement and implementation with equal vigor on all the streams under its charge. To do this would spread limited resources so thin that a wholly ineffective job would result. The local regulatory authority's first duty in the management of small urban watersheds is therefore to establish priorities. The method used to establish priorities must integrate the dual impacts to be expected through upgrading of the water quality of small urban streams. If the water quality in a small stream is such that it degrades the quality of the major river, thus limiting the achievable beneficial uses of the river, the small stream would be accorded management priority on that basis. Once that determination is reached, attention can be directed to protection of the intrinsic beneficial uses of the small stream. Several results are possible, for example:

(i) if the watershed has been assigned priority status based upon its impact of the major river, a still higher priority may be assigned to protect or preserve local beneficial uses of the watershed itself.

(ii) if the watershed has been found to exert a negligible effect on the major river, it may be accorded priority solely to protect or preserve local beneficial uses.

Thus, the first step in the management of urban watersheds is a determination of the impact which the water quality of the small streams exerts on the major rivers. Although information on the major rivers is usually readily available, data concerning small streams are typically very sparse, and thus the required analysis cannot normally be carried out using conventional methods. The objective of this study is to develop a methodology for performing the analysis under the data limitations often encountered by regulatory authorities. A case study of the region of Allegheny County, Pennsylvania (Pittsburgh SMSA) will be used to illustrate the methodology.

*Description of the Study Area*

Allegheny County, 730 square miles of densely populated and heavily industrialized area in southwestern Pennsylvania, includes 82 separate drainage areas. The 82 areas are listed in Table 1 under three categories:

(i) Watersheds of streams which are tributary to a major river (Allegheny, Ohio, Monongahela, or Youghiogheny) within the boundaries of Allegheny County.

(ii) Headwater areas of streams not tributary to a major river within Allegheny County.

(iii) Intervening areas directly abutting a major river, and not included in one of the well-defined watersheds.

The region (shown in Figure 1) is typical of urbanized areas throughout the United States with commercial and industrial activity concentrated along the banks of the major rivers. The analysis presented excludes the headwater areas since these have no influence on major river quality within the borders of Allegheny County. The headwater areas represent only about three percent of the total area of the study region.

## TABLE 1
## DRAINAGE AREAS IN THE STUDY REGION

| Area | 1970 Census Population | Total Area (square miles) | Area, Allegheny County (square miles) |
|---|---|---|---|
| **Category I: Watershed Areas** | | | |
| 1. Beckets Run | 611 | 3.53 | 3.10 |
| 2. Becks Run | 21,965 | 2.87 | 2.87 |
| 3. Big Sewickley Creek | 12,280 | 30.38 | 16.81 |
| 4. Bull Creek | 18,651 | 49.75 | 23.66 |
| 5. Bunola Run | 251 | 2.27 | 2.27 |
| 6. Campbells Run (tributary to Chartiers Creek) | 4,046 | 5.81 | 5.81 |
| 7. Chartiers Creek (except Campbells Run, Millers Run, & Robinson Run | 225,399 | 205.50 | 46.67 |
| 8. Crawford Run | 1,043 | 1.97 | 1.97 |
| 9. Crooked Run | 23,485 | 4.48 | 4.48 |
| 10. Days Run | 3,749 | 4.65 | 4.65 |
| 11. Deer Creek | 19,819 | 51.50 | 50.29 |
| 12. Douglass Run | 3,929 | 10.20 | 9.23 |
| 13. Fallen Timber Run | 5,700 | 9.75 | 9.75 |
| 14. Flaugherty Run | 5,203 | 8.95 | 7.73 |
| 15. Girtys Run | 44,543 | 14.22 | 14.22 |
| 16. Guyasuta Run | 12,821 | 3.46 | 3.46 |
| 17. Homestead - West Run | 38,351 | 5.69 | 5.69 |
| 18. Indian Creek | 3,268 | 0.66 | 0.66 |
| 19. Jacks Run | 19,559 | 3.04 | 3.04 |
| 20. Kelly Run | 830 | 2.41 | 2.41 |
| 21. Kilbuck Run | 755 | 5.17 | 5.17 |
| 22. Little Sewickley Creek | 3,899 | 9.62 | 9.62 |
| 23. Lobbs Run | 3,284 | 5.61 | 2.78 |
| 24. Long Run | 32,474 | 17.36 | 10.22 |
| 25. Lowries Run | 21,667 | 15.15 | 15.15 |
| 26. McCabe Run | 9,432 | 1.66 | 1.66 |
| 27. Millers Run (tributary to Chartiers Creek) | 8,783 | 24.48 | 11.35 |
| 28. Montour Run | 9,399 | 36.67 | 36.67 |
| 29. Moon Run | 3,758 | 5.28 | 5.28 |
| 30. Narrows Run | 3,190 | 1.68 | 1.68 |
| 31. Nine Mile Run | 57,011 | 6.68 | 6.68 |
| 32. Peters Creek | 69,854 | 51.39 | 35.25 |
| 33. Pine Creek | 67,050 | 66.88 | 66.88 |
| 34. Pine Run | 9,904 | 5.90 | 5.90 |
| 35. Plum Creek | 24,246 | 20.65 | 20.54 |
| 36. Pollock Run | 4,152 | 8.10 | 0.63 |
| 37. Pucketa Creek | 31,544 | 36.50 | 4.41 |
| 38. Quigley Creek | 3,997 | 1.14 | 1.14 |
| 39. Riddle Run | 1,241 | 1.88 | 1.88 |
| 40. Robinson Run (tributary to Chartiers Creek) | 18,914 | 41.21 | 30.96 |
| 41. Sandy Creek | 14,549 | 3.45 | 3.45 |
| 42. Saw Mill Run | 160,161 | 19.34 | 19.34 |
| 43. Shades Run | 4,809 | 1.44 | 1.44 |
| 44. Shouse Run | 4,586 | 2.36 | 1.31 |

TABLE 1 (Continued)
DRAINAGE AREAS IN THE STUDY REGION

| Area | 1970 Census Population | Total Area (square miles) | Area, Allegheny County (square miles) |
|---|---|---|---|
| 45. Spruce Run | 12,662 | 2.38 | 2.38 |
| 46. Squaw Run | 7,955 | 10.34 | 10.34 |
| 47. Streets Run | 31,383 | 10.43 | 10.43 |
| 48. Sunfish Run | 811 | 2.46 | 2.46 |
| 49. Tawney Run | 11,208 | 4.83 | 4.83 |
| 50. Thompson Run | 28,153 | 8.30 | 8.30 |
| 51. Thorn Run | 2,930 | 2.03 | 2.03 |
| 52. Toms Run | 1,966 | 2.24 | 2.24 |
| 53. Turtle Creek | 187,907 | 148.00 | 48.95 |
| 54. Wildcat Run | 3,630 | 3.99 | 3.99 |
| 55. Wylie Run | 3,815 | 4.67 | 4.67 |
| Sub-Total | 1,326,582 | 1,012.36 | 620.78 |
| **Category II: Headwater Areas*** | | | |
| 56. Breakneck Creek (42.60) | 424 | 4.12 | 4.12 |
| 57. Brush Creek (56.20) | 2,901 | 8.77 | 8.77 |
| 58. Glade Run (40.80) | 184 | 1.21 | 1.21 |
| 59. Potato Garden Run (10:31) | 1.757 | 10.31 | 10.31 |
| 60. Raccoon Creek (164.17) | 330 | 2.63 | 2.63 |
| 61. Raredon Run (9.52) | 318 | 5.46 | 5.46 |
| Sub-Total | 5,914 | 32.50 | 32.50 |
| **Category III: Intervening Areas** | | | |
| 62. A - Oakmont | 7,052 | 3.63 | 3.63 |
| 63. B - O'Hara | 2,816 | 1.50 | 1.50 |
| 64. C - North Side | 81,365 | 8.90 | 8.90 |
| 65. D - Emsworth | 758 | 0.60 | 0.60 |
| 66. E - Glenfield | 19 | 0.13 | 0.13 |
| 67. F - Leetsdale | 1,799 | 1.17 | 1.17 |
| 68. G - Smithdale | 39 | 0.51 | 0.51 |
| 69. H - McKeesport | 16,909 | 1.53 | 1.53 |
| 70. I - Forward | 130 | 0.49 | 0.49 |
| 71. J - Mt. Oliver | 27,660 | 2.70 | 2.70 |
| 72. K - South Side | 8,010 | 1.19 | 1.19 |
| 73. L - Stowe | 14,496 | 3.86 | 3.86 |
| 74. M - Moon | 1,171 | 0.57 | 0.57 |
| 75. N - Crescent | 151 | 0.26 | 0.26 |
| 76. O - Braddock | 27,522 | 3.22 | 3.22 |
| 77. P - Neville Island | 1,985 | 1.62 | 1.62 |
| 78. Q - Ohio River Basin | 7,675 | 5.09 | 5.09 |
| 79. R - Pittsburgh | 246,672 | 20.33 | 20.33 |
| 80. S - Upper Allegheny River Basin | 17,355 | 4.43 | 4.43 |
| 81. T - Upper Monongahela River Basin | 24,217 | 6.59 | 6.59 |
| 82. U - Youghiogheny River Basin | 12,347 | 8.40 | 8.40 |
| Sub-Total | 500,148 | 76.72 | 76.72 |
| Grand Total | 1,832,644 | 1,121.58 | 730.00 |

**Note:* Only the headwater area within Allegheny County was included in this study. The total area of the watershed (in square miles) is shown in parentheses.

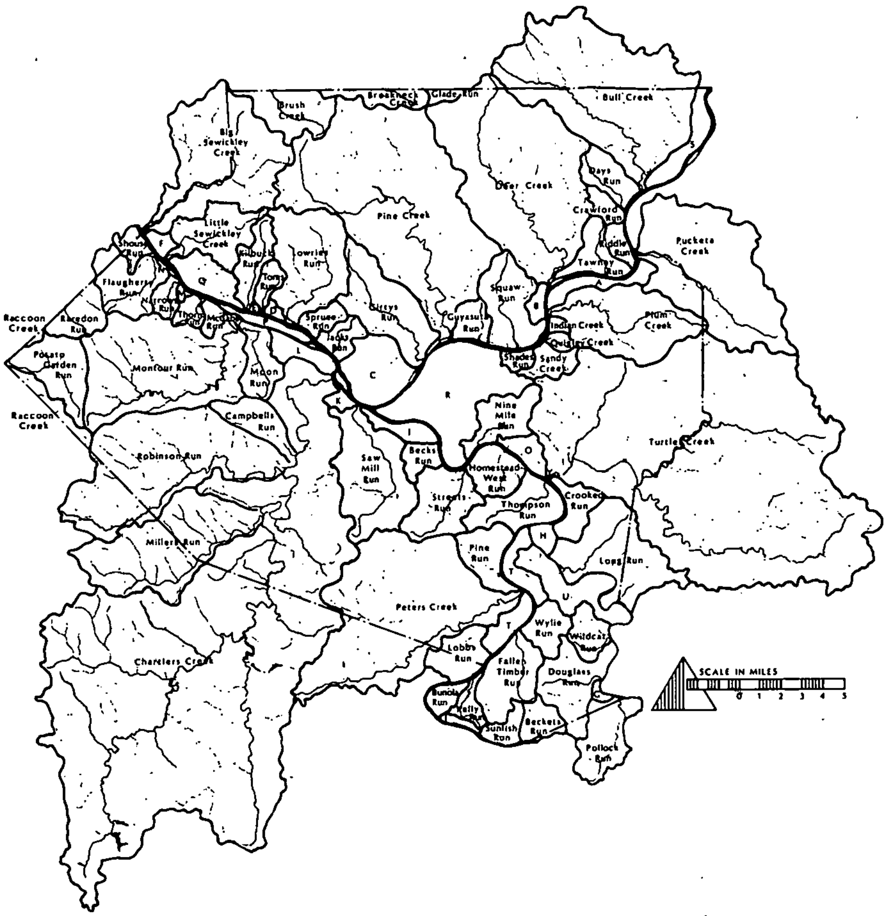



FIGURE 1: Allegheny County and Surrounding Watersheds

*Methods of Analysis*

The analysis of the impact on major river quality was approached through the following three tasks:

(i) comparison of the biodegradable organic loadings in small streams with those contributed by direct discharges to the major rivers.

(ii) analysis of the improvement in steady-state dissolved oxygen concentrations in the major rivers to be expected from reducing the biodegradable organic loading in the small streams.

(iii) analysis of the contribution of the small streams to the total dissolved solids load in the major rivers.

The first two tasks thus evaluate both the overall and localized impact on the major rivers due to the biodegradable organic load in the small streams. The impact which the streams exert on the inorganic (total dissolved solids) load in the major rivers is evaluated by the final task.

*Comparison of Biodegradable Organic Loadings*

An inventory of the major pollutant sources along the major rivers in Allegheny County has been compiled by the Environmental Protection Agency (EPA). This inventory includes industrial point sources and municipal sewage treatment plants.[6,11] In making the inventory, EPA has assumed best practicable treatment (BPT) for industrial discharges, and secondary treatment for all municipal sewage treatment plants with loads projected to 1980.

To evaluate the biochemical oxygen demand (BOD) load in the small streams, a knowledge of both streamflow and water quality characteristics is necessary.

*Streamflow Predictions*

Little streamflow data exist for the watersheds of the Allegheny County region. To estimate the total flow from the streams, records of eleven years (October, 1961 to September, 1972) of daily river flow were analyzed.[10] Major inflows are through the Allegheny, Monongahela, and Youghiogheny Rivers. Within the county (Figure 2) these three rivers join to form the Ohio River. Neglecting evaporative losses and infiltration, the streamflow in the Ohio leaving the Allegheny County region is the sum of the streamflows in the Allegheny, Monongahela and Youghiogheny Rivers, plus the runoff from the intervening drainage area (Figure 2).

Average monthly streamflow values were calculated for the following four gaging stations, shown in Figure 2:

(i) Allegheny River at Natrona

(ii) Monongahela River at Charleroi

(iii) Youghiogheny River at Sutersville

(iv) Ohio River at Sewickley

The monthly average runoff from the intervening drainage area was estimated as the monthly average streamflow at Sewickley, minus the sum of the monthly averate streamflows at Natrona, Charleroi, and Sutersville. The distribution of monthly average total runoff is shown in Table 2.

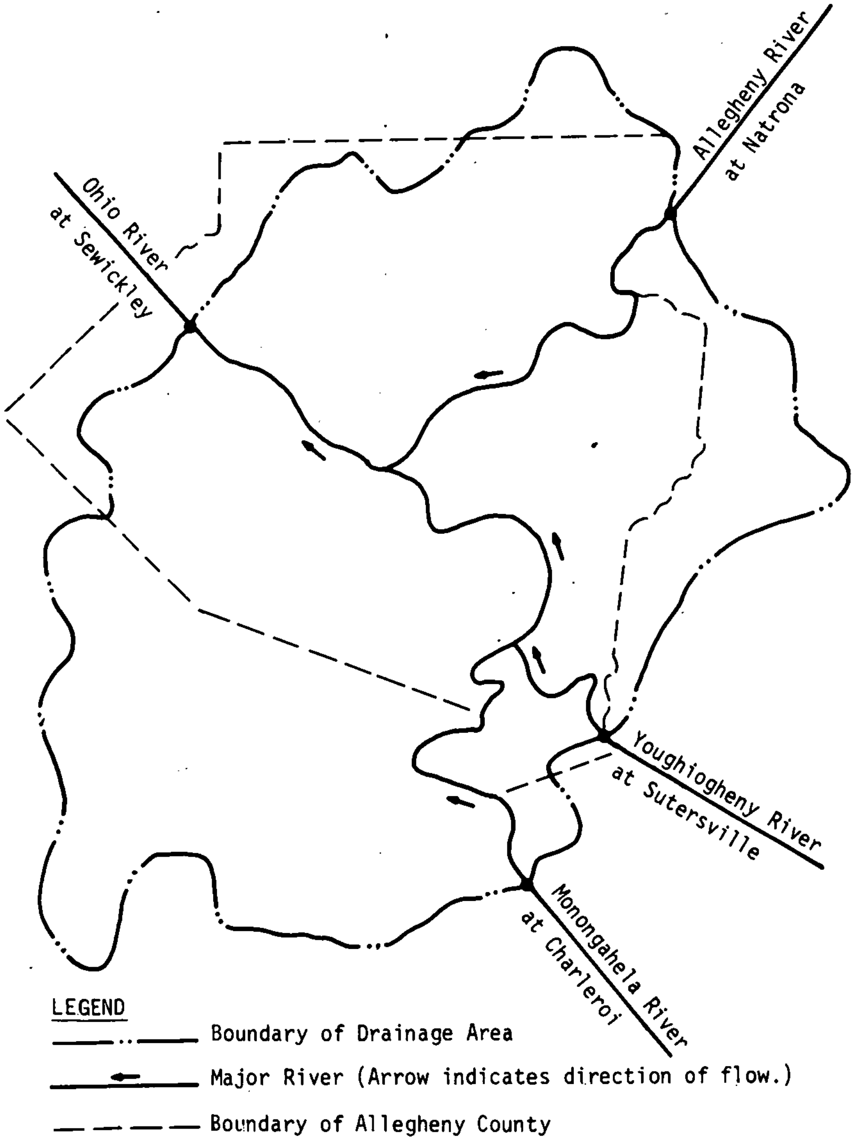



FIGURE 2: Allegheny County Flow System

*Partitioning the Total Runoff Among Watersheds*

Watershed area, precipitation, channel slope, soil type, land cover, and numerous other factors determine the volume of runoff contributed by a

TABLE 2
FREQUENCY DISTRIBUTION OF MONTHLY AVERAGE TOTAL RUNOFF FROM THE ALLEGHENY COUNTY REGION (CALCULATED BY OBSERVED DIFFERENCES)[14]

| Percent of Time Given Total Runoff Was Exceeded | Total Runoff (cfs), 1961-1972 Monthly Average |
|---|---|
| 10 | 2,400 |
| 20 | 1,600 |
| 30 | 1,200 |
| 40 | 940 |
| 50 | 740 |
| 60 | 580 |
| 70 | 450 |
| 80 | 340 |
| 90 | 235 |

Arithmetic Average = 960 cfs.
95% Confidence Limits = 160 - 3,400 cfs.

watershed. Thomas and Benson[7] conducted a study to relate streamflow to watershed characteristics statistically. The equations derived for watersheds in the eastern United States were applied to the drainage areas of Allegheny County to predict annual average streamflow values. The predictions for those individual areas which form the total intervening drainage area shown in Figure 2 were summed, and the resulting estimated total streamflow compared to the value obtained using observed differences. The observed annual average streamflow from the intervening drainage area is 960 cfs (Table 2), while the predicted value was 780 cfs.[6] The difference between these two values (18.8 percent) indicates that the equations predict average streamflow for the Allegheny County region quite well. The relative fraction of the predicted total streamflow contributed by each individual drainage area was used to partition a given value of total runoff among the separate drainage areas.

To determine the BOD loading contributed by the individual drainage areas, a total runoff value of 1,200 cfs was chosen. Since the worst water quality conditions usually occur during periods of summer low flow, analyses are typically performed assuming the occurrence of the seven-consecutive-day, ten-year low streamflow values. These values were used for streamflow in the four major rivers. However, to exaggerate the influence of the small streams, the 70 percentile value for total runoff was used. This choice has the effect of analyzing high streamflow volumes from the individual watersheds joining a low volumetric flow in the major rivers. Thus the analysis assumes:

(i) the worst water quality conditions in the major rivers; and,

(ii) very high influence from the small drainage areas throughout the region.

Both the overall load contributed by the individual drainage areas and the response to that load (change in dissolved oxygen concentrations in the major rivers) were analyzed under these conditions.

*Concentrations of Dissolved Oxygen and Biochemical Oxygen Demand in Small Streams*

Data for the small streams were compiled from records of the Allegheny County Health Department (ACHD), the Allegheny County Bureau of Tests (ACBT), and the Pennsylvania Department of Environmental Resources (Penn DER). Summer average concentrations of dissolved oxygen (DO) and five-day BOD ($BOD_5$) were computed. Unsampled streams were assigned stratified averages of the available data based on predicted overall water quality groupings from a previous study of watershed management.[3] Values for direct drainage areas and those streams not included in the previous study were assigned the overall averages for DO and $BOD_5$.[6] These values are shown in Table 3.

To apply the BOD data to the water quality model used, it was necessary to convert five-day BOD to ultimate BOD ($BOD_{ult}$). The ratio of $BOD_{ult}$ to $BOD_5$ varies with the level of pollution. More polluted waters tend to have a lower $BOD_{ult}/BOD_5$ ratio. The ratio used by the Penn DER for municipal sewage treatment plant (STP) effluent is 1.45.[4] To determine an appropriate ratio for the county streams, BOD tests were performed on four streams of varying overall water quality (as shown in Table 3). The Thomas method[8] was used to calculate the reaction-rate constant, k, for each stream. From these analyses, the average reaction rate was calculated to be 0.14 (base e). The ratio $BOD_{ult}/BOD_5$ is thus 2.0, and this value was used to convert the $BOD_5$ concentrations to $BOD_{ult}$.

*Overall Organic Loads*

The total amount of BOD entering each of the four rivers within Allegheny County was computed. The overall totals for the county are shown in Figure 3 while those for each river are shown in Figure 4. Clearly demonstrated is the dominance of the Allegheny County Sanitary Authority (ALCOSAN) regional wastewater treatment facility. The 103,000 lb/day ($BOD_{ult}$) load represents about 42 percent of the total BOD load entering the rivers within the county. It is approximately equivalent to the total organic

## TABLE 3
## SUMMER AVERAGES OF DISSOLVED OXYGEN AND $BOD_5$ CONCENTRATIONS[3]

GROUP 1 (Worst Overall Water Quality)

| | Dissolved Oxygen (mg/l) | $BOD_5$ (mg/l)[tc |
|---|---|---|
| Becks Run | (7.6) | (4.1) |
| Bunola Run | 6.0 | (4.1) |
| Crawford Run | (7.6) | 4. |
| Days Run | (7.6) | (4.1) |
| Fallen Timber Run | 7.5 | (4.1) |
| Girtys Run | (7.6) | (4.1) |
| Kellys Run | (7.6) | (4.1) |
| Millers Run | 5.4 | 2. |
| Plum Creek | 8.6 | 3.8, k*=0.14 |
| Potato Garden Run | 8.2 | 6. |
| Riddle Run | (7.6) | (4.1) |
| Saw Mill Run | 8.5 | 8. |
| Spruce Run | (7.6) | 1., k*=0.15 |
| Streets Run | 8.7 | (4.1) |
| Thorn Run | (7.6) | (4.1) |
| Wildcat Run | (7.6) | (4.1) |
| Nine Mile Run | (7.6) | 4. |

GROUP 2

| | | |
|---|---|---|
| Campbells Run | (9.0) | (3.5) |
| Crooked Run | (9.0) | 2., k*=0.12 |
| Homestead-West Run | (9.0) | (3.5) |
| McCabe Run | (9.0) | (3.5) |
| Montour Run | 8.5 | 2.2 |
| Moon Run | 7.5 | (3.5) |
| Narrows Run | (9.0) | (3.5) |
| Peters Creek | 8.5 | 4.8 |
| Pine Creek | 10.7 | 1.8 |
| Quigley Creek | (9.0) | 1. |
| Robinson Run | 8.9 | (3.5) |
| Thompson Run | (9.0) | 11. |
| Turtle Creek | 9.0 | 3.5 |

GROUP 3

| | Dissolved Oxygen (mg/l) | $BOD_5$ (mg/l) |
|---|---|---|
| Beckets Run | (9.2) | 1. |
| Big Sewickley Creek | 9.0 | 3.1 |
| Bull Creek | 11.4 | 1. |
| Chartiers Creek | 8.3 | 3.0 |
| Deek Creek | 9.7 | 2.9 |
| Douglass Run | (9.2) | 1., k*=0.16 |
| Flaugherty Run | 10.5 | (2.0) |
| Indian Creek | (9.2) | (2.0) |
| Jacks Run | (9.2) | (2.0) |
| Kilbuck Run | 8.6 | 1. |
| Lobbs Run | (9.2) | (2.0) |
| Long Run | 8.0 | (2.0) |
| Lowries Run | 8.2 | 4. |
| Pucketa Creek | (9.2) | 1.4 |
| Sandy Creek | (9.2) | (2.0) |
| Sunfish Run | (9.2) | (2.0) |
| Toms Run | (9.2) | 2. |
| Wylie Run | (9.2) | (2.0) |

GROUP 4 (Best Overall Water Quality)

| | | |
|---|---|---|
| Guyasuta Run | (9.9) | 1. |
| Little Sewickley Creek | 9.8 | 1. |
| Pine Run | (9.9) | (2.0) |
| Squaw Run | 10.0 | 4. |
| Tawney Run | (9.9) | (2.0) |

Overall Arithmetic Averages:
Dissolved Oxygen=8.7 mg/l
$BOD_5$=3.0 mg/l

Values in parentheses are the averages, in mg/l, of known data within the group.

*k=BOD reaction-rate constant (base e)

load from all other municipal wastewater treatment plants and industrial sources which enter the rivers directly. The total load contributed by the individual drainage areas in the region, about 43,000 lb/day ($BOD_{ult}$), represents only seventeen percent of the total. About seven percent of the total is attributable to Chartiers Creek and Turtle Creek, the largest two watersheds in the region. Deer Creek, Pine Creek, Peters Creek, and Saw Mill Run collectively account for about three percent of the total BOD load. Combined, all the remaining drainage areas contribute only about seven percent of the BOD load. Note that this analysis assumes high values of flow from

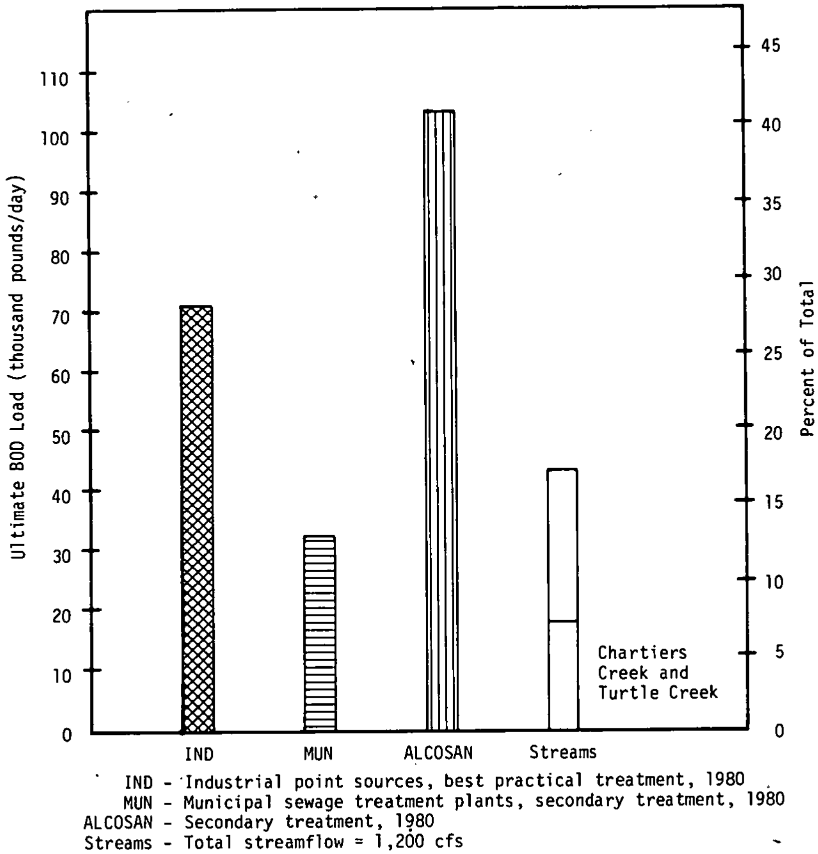
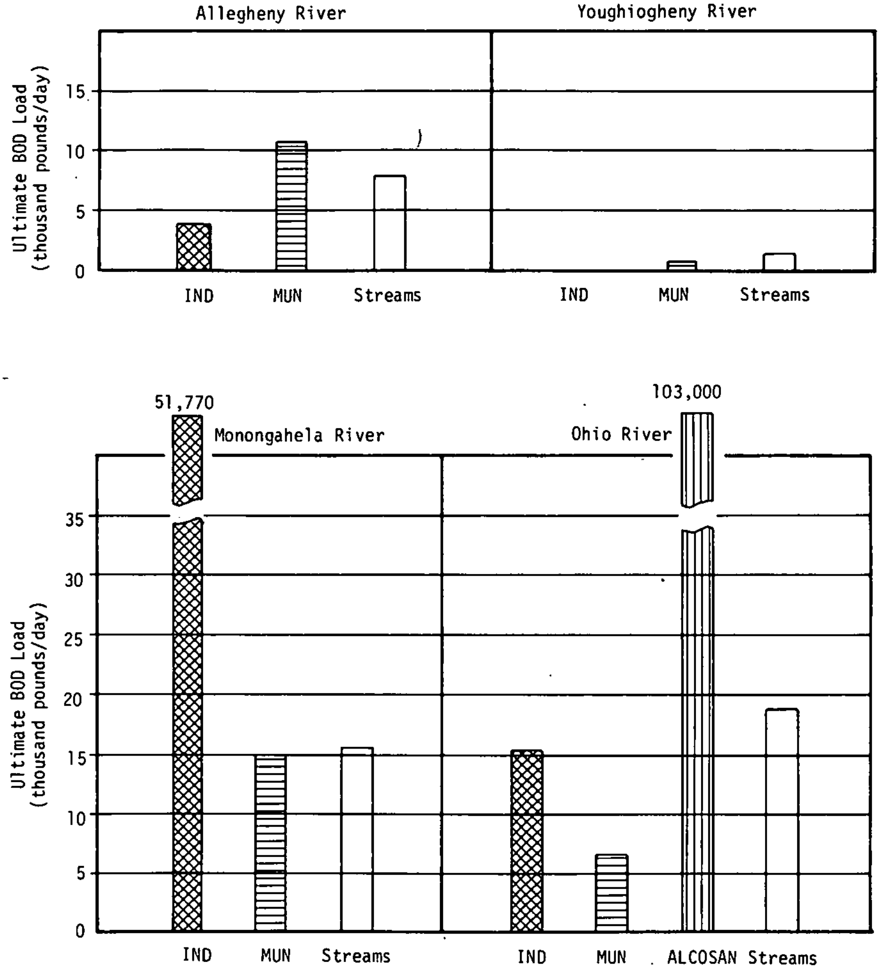



FIGURE 3: Total Organic Pollutant Load Entering Major Rivers in the Allegheny County Region

the streams and high levels of treatment at the industrial and municipal sources which enter the rivers directly; treatment levels not yet attained.

The distribution of BOD loads on each of the rivers is shown in Figure 4. On the Allegheny and Youghiogheny Rivers, the loads are fairly small, with municipal sewage treatment plants causing the biggest problem on the Allegheny. The small drainage areas collectively contribute a high proportion of the BOD load entering the Youghiogheny River within Allegheny County. On the Monongahela, industrial sources dominate, while on the Ohio, ALCOSAN contributes by far the greatest portion of the total load. The individual drainage areas contributing the greatest organic load drain into the Monongahela and Ohio Rivers.




IND - Industrial point sources, best practical treatment, 1980
MUN - Municipal sewage treatment plants, secondary treatment, 1980
ALCOSAN - Secondary treatment, 1980
Streams - Total streamflow = 1,200 cfs

FIGURE 4: Organic Pollutant Load Entering Major Rivers: Allegheny, Youghiogheny, Monongahela, Ohio

The overall portion of organic loads due to the individual drainage areas is small. However, an additional analysis was performed to determine the expected improvement in dissolved oxygen concentrations in the major rivers resulting from reducing the organic load contributed by the individual drainage areas.

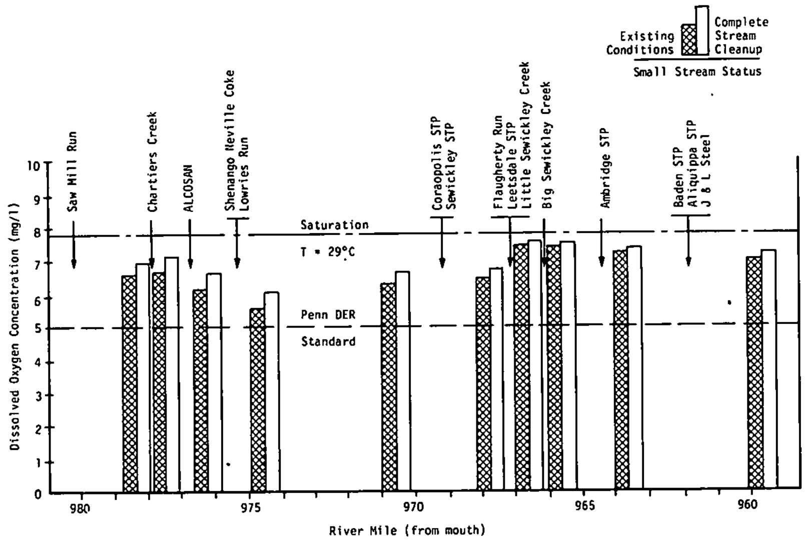



FIGURE 5: 1980 Projected Dissolved Oxygen Concentrations: Ohio River

*Major River Response to Small Stream Improvement*

The Environmental Protection Agency has developed a steady-state oxygen sag model for the Pittsburgh area.[11] The model requires BOD and DO loadings from point sources and applies first order reaction difference equations to predict BOD and DO concentrations along the river. The model accounts for varying velocities, deoxygenation rates, and reaeration rates along the rivers and over the locks and dams. All rate constants have been estimated by EPA, and the model has been verified by EPA with four separate surveys on the Ohio River and three on the Monongahela.[6]

To assess the maximum impact which the streams could have on the rivers under steady-state conditions, the model was used under two conditions of loading:

(i) normal pollution load contributed by individual drainage areas.

(ii) assuming BOD=0 mg/l and DO=10 mg/l (or higher, in the few cases that the normal summer average exceeds 10 mg/l) for all drainage areas.

In both cases, seven-consecutive-day, ten-year low streamflow was assumed in the Allegheny, Monongahela, and Youghiogheny Rivers. This low streamflow received a high value of runoff (1,200 cfs, the streamflow exceeded only 30 percent of the time), partitioned among the individual drainage areas.

The difference in the resulting DO concentrations along the major rivers

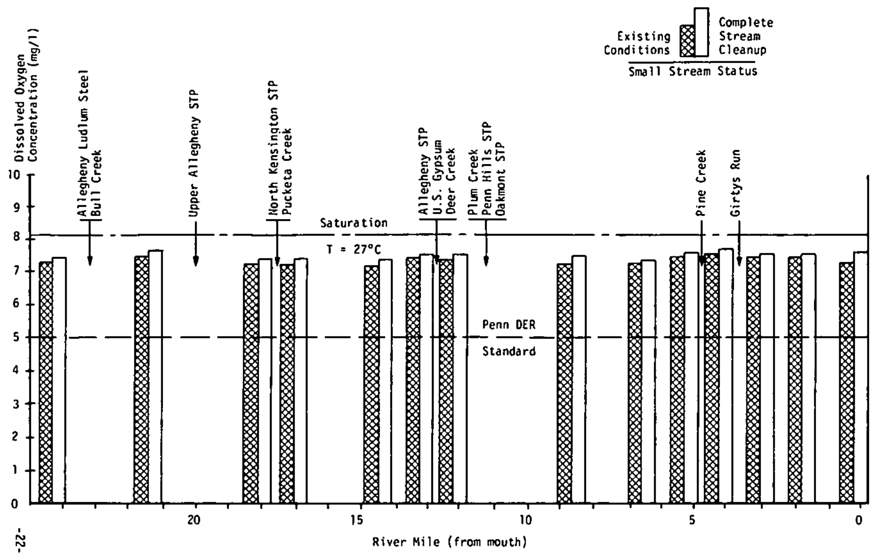



FIGURE 6: 1980 Projected Dissolved Oxygen Concentrations: Allegheny River

between the above two conditions of loading gives a good indication of the maximum impact of the tributaries, and thus the maximum major river response to an absolute cleanup of the small streams. (Note that realistically, some background BOD in the range of 2 mg/l $BOD_{ult}$ would be inevitable). The DO profiles which result are plotted in Figures 5 through 9, comparing the response to the normal BOD load with the zero BOD load case. The locations of the major point sources and tributaries are shown on the graphs, as are the dissolved oxygen saturation level for the given temperature and the Penn DER water quality standard for the rivers, (DO=5 mg/l, minimum daily average).

The results demonstrate that only small, and in general, negligible, differences in predicted DO concentrations exist. At no point do DO concentrations fall below the 5 mg/l Penn DER standard in the unimproved case. The greatest single difference in DO concentrations between the improved and unimproved cases is 0.5 mg/l, occurring along the Monongahela downstream of Turtle Creek (Figure 8, River Mile 8.5).

Examination of the DO profile for the Ohio River (Figure 5) demonstrates the impact of ALCOSAN. There is a noticeable oxygen sag from the effluent of the ALCOSAN facility, between River Miles 967 - 977 (Figure 5). Downstream, water quality is further deteriorated by the Shenango Coke Plant on Neville Island (River Mile 975.5, Figure 5). (Note that only the main channel around Neville Island is shown, since it has a lower DO concentration than the back channel). The major stream impact occurs at the source of the

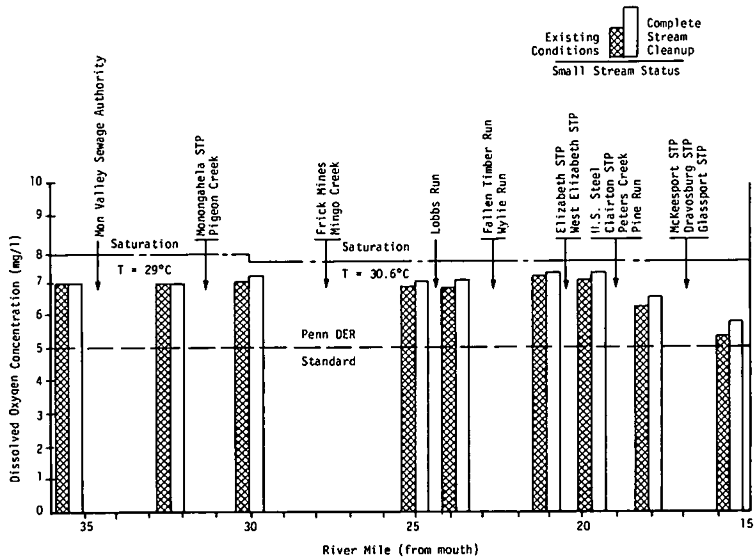



FIGURE 7: 1980 Projected Dissolved Oxygen Concentrations: Monongahela River (Mile Points 36 - 15)

Ohio River, near the confluences with Saw Mill Run and Chartiers Creek (River Miles 978 - 980, Figure 5). These two streams, along with Lowries Run may require more care, since they enter near the "hot spot" of the river, ALCOSAN. Figure 5 does show, however, that under both conditions of loading, significant water quality impact on the Ohio River within Allegheny County is projected to occur in the vicinity of the ALCOSAN sewage treatment facility.

The results of the analysis of the Allegheny River are shown in Figure 6. DO levels remain fairly constant with insignificant differences between the two cases of organic loadings.

The problems found along the Monongahela are probably the most severe. The DO profile is plotted in Figures 7 and 8. The first major problem occurs at River Mile 18 (Figure 7) where the Clairton Coke Works of U.S. Steel, the Clairton municipal sewage treatment plant, Pine Run, and Peters Creek all enter the river. There is a drop in the total DO concentration, and an increase in the difference between the river responses to the two conditions of loading. Three municipal sewage treatment plants in the next reach further affect the water quality and the DO level drops near 5 mg/l standard, at River Mile 15. The Monongahela recovers when it is met by the cleaner Youghiogheny. The next problem occurs as Turtle Creek and Thompson Run enter the river in the same areas as the Edgar Thompson Works of U.S. Steel and the Duquesne municipal sewage treatment plant (River Miles 11 - 13, Figure 8). The river begins to recover, but is further

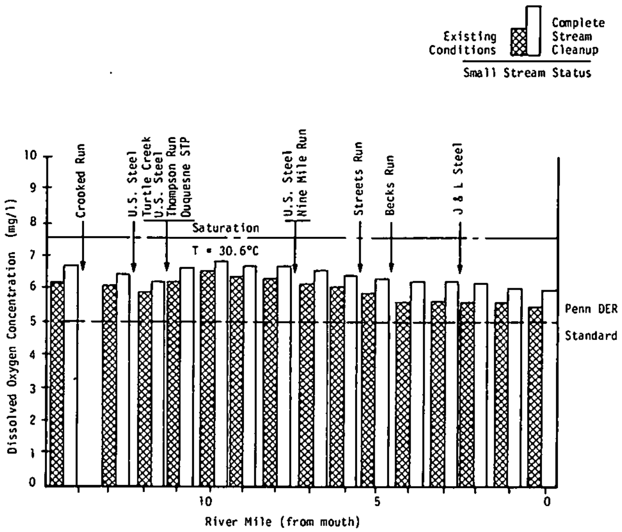



FIGURE 8: 1980 Projected Dissolved Oxygen Concentrations: Monongahela River (Mile Points 15 - 0)

degraded by U.S. Steel at Homestead and J & L Steel, and an extended sag is noticeable from River Mile 10 to the mouth. Here again, the differences due to stream improvement are predicted to be small, even in this extreme case. There may be some concern for the areas around Peters Creek and Pine Run (River Mile 19, Figure 7) and Turtle Creek (River Mile 11, Figure 8), because of their coincidence with other large point sources. The analysis does show, however, that the tributaries have a small impact on water quality in the Monongahela River.

The Youghiogheny River analysis, shown in Figure 9, indicates there is no DO problem from organic pollutant loadings along that portion of the river in Allegheny County, either from industrial sources, municipal sources, or the tributaries. Figure 4 indicates that the greatest proportion of the organic load entering the Youghiogheny River is from the combined effects of the small streams. This analysis has shown that eliminating that load completely produces a negligible improvement in the dissolved oxygen content of the Youghiogheny River.

*Inorganic Pollutant Load*

Thus far, the analysis has shown that the overall organic load contributed to the rivers by the small drainage areas is negligible. In addition, the improvement in the rivers' dissolved oxygen concentrations resulting from an absolute cleanup of the small streams is barely noticeable. Analysis was next directed toward evaluating the impact on major river quality resulting from the inorganic load contributed by the small drainage areas.

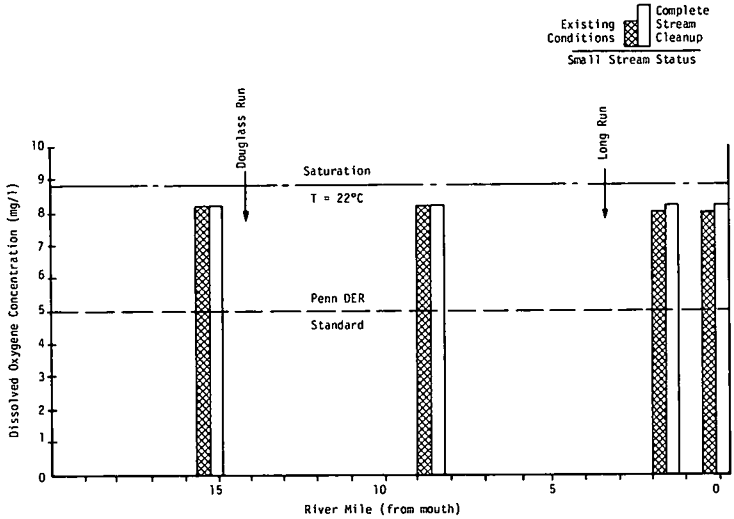



FIGURE 9: 1980 Projected Dissolved Oxygen Concentrations: Youghiogheny River

Once streamflows have been calculated, they may be studied in combination with pollutant concentration data to determine pollutant load. This was done for total dissolved solids (TDS), which is a good measure of the inorganic pollution problems of a body of water. This approach is conservative; concentrations vary only with the mass of dissolved solids and the volume of streamflow. Findings on the impact of the streams on the TDS problem in the rivers may be applied to other non-reactive pollutants.

To measure the potential overall TDS impact of the small streams, various runoff totals were assumed to enter the county rivers at various average TDS concentrations. The resulting portion of the TDS concentration in the Ohio River due to the TDS load contributed by the small streams was then calculated. Two cases were considered:

(i) median flow in the Ohio River (flow at Sewickley=20,000 cfs),

(ii) low flow in the Ohio River (flow at Sewickley=6,400 cfs, exceeded about 85% of the time[1]).

The resulting effects are plotted in Figures 10 and 11. Noted on the graphs are the Penn DER TDS standard of 500 mg/l (monthly average) and the calculated weighted average of the county streams: 770 mg/l. The average was calculated by weighting available TDS data[2] with predicted flows for those watersheds draining into the rivers upstream from Sewickley. The graphs show that the impact of the streams is minimal.

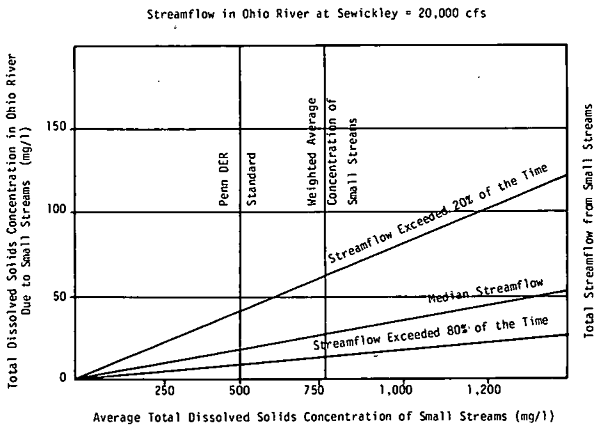



FIGURE 10: Total Dissolved Solids Concentration in Ohio River (Median Flow) Due to Total Dissolved Solids from Allegheny County Streamflow

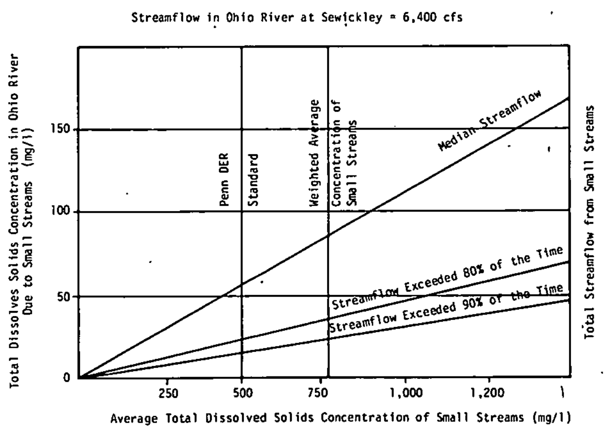



FIGURE 11: Total Dissolved Solids Concentration in Ohio River (Low Flow) Due to Total Dissolved Solids from Allegheny County Streamflow

Figure 10 assumes the following:

(i) median streamflow in the Ohio River at Sewickley (20,000 cfs),

(ii) weighted average TDS concentration (770 mg/l) in the county streams.

Under these assumptions, varying the value of total runoff from the individual drainage areas from the 20 percentile to the 80 percentile (340 - 1,600 cfs, monthly average) in no case contributes more than 60 mg/l to the total concentrations of TDS in the Ohio River at Sewickley. Assuming median streamflow conditions in both the individual drainage areas (740 cfs, monthly average) and the Ohio River at Sewickley, the small streams contribute about 25 mg/l to the TDS concentration measured at Sewickley.

Even assuming the worst conditions:

(i) low streamflow in the Ohio River at Sewickley (6,400 cfs),

(ii) weighted average TDS concentration (770 mg/l) in the county streams,

Figure 11 indicates that the effect is small. Assuming the median streamflow value (740 cfs, monthly average) for the small streams, the contribution to the total concentration of TDS in the Ohio River at Sewickley is about 80 mg/l. Under the above assumptions, note that reducing the weighted average TDS concentration (770 mg/l) in the small streams to the Penn DER standard (500 mg/l) reduces the average TDS concentration in the Ohio River at Sewickley by about 30 mg/l. These values can be compared to the average TDS concentration in the Ohio River at Sewickley, 254 mg/l.[5] This value (254 mg/l) is about one-half the Penn DER standard (500 mg/l). The above analysis has shown that even under assumptions which tend to exaggerate the impact of the individual drainage areas, a TDS problem in the major river is unlikely to be caused by the TDS concentrations in the small streams. Further, reducing TDS concentrations in the small streams will likely have a minor impact on concentrations in the major rivers, which are already well below the Penn DER standard.

## Summary and Conclusions

An in-depth study of the effect of low water quality in the small streams on the quality of water in major rivers in Allegheny County (1974) has demonstrated that the small stream impact is minimal. The flow from the streams is small compared to the flow of the rivers, and the pollution load delivered is small compared to the load from industrial and municipal point sources along the rivers. This conclusion assumes the following:

(i) present pollution levels in the small streams.

(ii) best practicable treatment applied to industrial sources.

(iii) secondary treatment at all municipal wastewater treatment facilities, with loads projected to 1980.

The study included both inorganic and organic pollutant problems. Total flow frequencies from the tributaries were estimated by analyzing river data, and a prodecure determined for partitioning this flow among the small streams and drainage areas. Total dissolved solids, BOD, and DO data were gathered and compiled for the streams. An analysis showed that the overall stream impact on TDS concentrations in the Ohio River is minimal. The

BOD and DO data were used to include the streams in an EPA inventory of point sources along the major rivers, and a water quality model was utilized to predict the response of the rivers to these point sources. It was demonstrated that the overall loads from the streams are small relative to other sources of organic pollution, and that even with extreme assumptions, little response in the quality of the major rivers can be expected from improvements in the water quality of small streams.

Note that while the major constituents of the inorganic and organic pollution problem, TDS, BOD, and DO concentrations, have been studied, there are other sources of river deterioration which have not been investigated. Of particular importance are problems with coliform bacteria and mine acid. The data and techniques necessary to analyze the county stream impact on these problems are not presently available, and this may be an important area for future research.

The methodology for assessing the impact of small streams on major rivers has been illustrated using the case study of Allegheny County, Pennsylvania. This analysis has shown that for this particular area, local priorities can be set for individual drainage areas, independent of their negligible effect on water quality in the major rivers. The intrinsic demands on each stream can determine local management priorities throughout the Allegheny County region, and the benefits of cleaning up the small streams must be measured within the individual watersheds.

## Acknowledgements

The work reported in this paper was performed while both authors were students at Carnegie-Mellon University, Pittsburgh, PA. Mitchell Small was employed by the Allegheny County Health Department, Division of Water Quality and Solid Waste Control, under the internship program of the Program in Engineering and Public Affairs at Carnegie-Mellon University. The contributions and cooperation of E. Dale Wismer of the Basin Planning Section, Water Programs Branch, U.S. Environmental Protection Agency, Region III, are gratefully acknowledged, as are those of Wilder D. Bancroft of the Allegheny County Health Department and Francis Clay McMichael and Robert W. Dunlap of Carnegie-Mellon University.

## References


1. Busch, W.F., and L.C. Shaw, "Pennsylvania Streamflow Characteristics, Low-Flood Frequency and Flow Duration," *Water Resources Bulletin No. 1*, United States Geological Survey, Harrisburg, PA, 1966, 289 pp.
2. Darby, William P., and Eugene G. Duvernoy, *Management of Urban Watersheds: An Assessment for Regulatory Action,* Allegheny County Health Department, Pittsburgh, PA, 1973, 129 pp.
3. Darby, William P., and Francis Clay McMichael, and Robert W. Dunlap, "Urban Watershed Management Using Activity Indicators to Predict Water Quality," *Water Resources Research* 12:245-252 (4/76).
4. Pennsylvania Department of Environmental Resources, "Dissolved Oxygen Calculations," internal memorandum, January 10, 1969.
5. Pennsylvania Department of Environmental Resources, unpublished data, 1974.
6. Small, Mitchell J., and William P. Darby, *Urban Watershed Management: The Potential Impact of Regulatory Action,* Allegheny County Health Department, Pittsburgh, PA, October, 1974, 184 pp.
7. Thomas, D.M., and M.A. Benson, "Generalization of Streamflow Characteristics from Drainage Basin Characteristics," *Water Supply Paper 1975*, U.S. Geological Survey, 1970.
8. Thomas, H.A., "Graphical Determination of BOD Curve Constants," *Water and Sewage Works* 97:123 (1950).
9. U.S. Congress, "An Act to Amend the Federal Water Pollution Control Act, Public Law 92-500, 92nd Congress," October 18, 1972.
10. *Water Resources Data for Pennsylvania. Part 1. Surface Water Records, 1961 - 1972*, U.S. Department of the Interior, Geological Survey.
11. Wismer, E. Dale, Basin Planning Section, Water Programs Branch, United States Environmental Protection Agency, Region III, Philadelphia, PA, personal correspondence, 1974.