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PLANNING METHODOLOGIES FOR ANALYSIS OF LAND USE / WATER QUALITY RELATIONSHIPS

TECHNICAL APPENDIX

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PLANNING METHODOLOGIES FOR ANALYSIS OF

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TECHNICAL APPENDIX

Introduction

The Planning Methodologies report has dealt with analysis and control of unrecorded pollution from urban land, excluding combined sewer overflows. This technical appendix presents various supporting materials which have been assembled as part of the project. Three general aspects of unrecorded pollution are addressed: (1) magnitude and variation of loadings; (2) water quality impacts; (3) biological effects. These materials are not intended to represent a comprehensive overview of the subject; they have been developed primarily to address the specific issues discussed in the text. The overall impression which is conveyed is that the seriousness of unrecorded pollution is highly variable among urban areas, and that many aspects of this problem remain poorly understood, particularly the response of aquatic biota to transient pollutant inputs.

Empirical Analysis

A substantial body of literature describes unrecorded pollutant loadings and loading relationships for urban basins in the U.S. However, very few of these studies have attempted to provide a balanced characterization of the effects of urban land on in-stream conditions. Most studies of unrecorded pollutant loadings have not attempted to deal systematically with the land use determinants involved; many have focused upon very small catchments which may differ substantially from larger basins in pollutant generation. The present study has therefore included a modest study of loading relationships, based upon two existing data sources which are relatively comprehensive.

One data set analyzed here was obtained by AVCO Corporation (AVCO, 1970) in a study of stormwater pollution in Tulsa, Oklahoma. Storm runoff quality was sampled during a number of storm periods in each of 15 basins in Tulsa. The catchments ranged from 64 acres to 938 acres, averaging about 370 acres (0.6 square mile). These basins provided good examples of the residential, commercial and industrial land uses typically found in a medium-sized urban center. Population density ranged from zero to 14 persons per acre, with an average between 6 and 7 per acre. The proportion of impervious land ranged from 11 percent to 74 percent. All but one of the residential basins were served by separate sanitary sewers. Varying degrees of storm sewerage were represented, ranging up to complete replacement of natural channels by artificial conduits. Over 400 chemical samples were taken. The water quality parameters analyzed in the present study were: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), organic Kjeldahl nitrogen (OKN), soluble orthophosphate (OPO4) and suspended solids (SS). Both individual concentrations and annual loadings of these constituents were available from the AVCO report.

The second data set was obtained from an ongoing program conducted jointly by the U.S. Geological Survey and the City of Philadelphia, which has involved monthly sampling of numerous watersheds in and near Philadelphia since 1970 (Radziul, et al, 1973). Many of these watersheds were chosen explicitly on the basis of land use. The network thus provided an excellent representation of urban and suburban land in the Philadelphia area, with the exception of very high-density urban development. Ten of these basins, ranging from 1 to 21 square miles in area and containing no authorized point discharges, were selected for analysis here. Although the U.S.G.S./Philadelphia sampling program was not specifically oriented toward storm runoff, the available data were considered adequate to characterize wet-weather conditions and to compute annual pollutant loadings for the selected watersheds.* Similar use of the data has been reported by other investigators (Radziul, et al, 1973).

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* Annual loadings were prepared in the following fashion. Pollutant concentrations during wet weather and dry weather were segregated and related to stream discharge by logarithmic regression. Flow-duration curves, expressing percentages of the time that stream flow was within specified intervals, were then prepared for wet and dry conditions at each station, utilizing the continuous stream flow records available. (Wet and dry days were identified for this purpose by hydrograph behavior rather than precipitation records; the number of wet days in each case corresponded roughly to the number of days with rainfall exceeding 0.1 inch.) The estimated pollutant concentration corresponding to each level of discharge was then multiplied by discharge and by the percent of time that discharge was within the given interval; these products were summed over all discharge intervals and multiplied by appropriate constants to yield an annual loading during wet or dry conditions.

Relationships Between Pollutant Concentrations and Precipitation Variables

It was considered of interest to examine the relationships between pollutant concentrations and various precipitation variables, such as the time since start of rainfall, average intensity of precipitation, and time since the previous storm. These relationships bear upon several important issues involving the origin of pollutants, as discussed in the text of the Planning Methodologies report. If pollutants are derived from diffuse materials which build up gradually on watershed surfaces, the loadings and concentrations observed in a given storm should be positively related to time since the previous storm. Individual concentrations should also be negatively related to time since the start of rainfall and the average intensity of rainfall (due to reduction during a storm in the amount of material available for transport). On the other hand, if pollutants are derived from land erosion, or processes resembling land erosion, the only expected relationship with precipitation variables might be a positive association between pollutant concentrations and the average intensity of precipitation.

In order to examine these relationships for a representative sample of urban basins, the Tulsa data were subjected to a series of regression analysis. Each observed concentration of a chemical constituent was related to the following precipitation variables:

- X1 Time since start of precipitation, in hours
- X2 Amount of precipitation since start of event, in inches
- X3 Average intensity of precipitation, in inches per hour (from start of rainfall to time of sample)
- X4 Time since antecedent rainfall event, in hours
- X5 Amount of antecedent rainfall event, in inches
- X6 Duration of antecedent rainfall event, in hours
- X7 Average intensity of antecedent event, in inches per hour
- X8 Antecedent precipitation index (an index of soil wetness)

Due to the limited number of observations available for each basin, and the known tendency of pollutant concentrations in storm water to behave erratically, the chosen procedure was to develop pooled estimates of relationships by considering the data for all basins simultaneously. It was thus necessary to control for variation in pollutant concentrations due to land use and other characteristics of individual basins. This was done by including dummy variables, in a manner which is explained in Addendum 1. Prior to the regression analysis, all variables except the dummy variables were converted to logarithmic form. (Unity was first added to each of the chemical concentrations to prevent domination of the regression results by low observations.) A large number of regression analyses were conducted, each of which involved one of the chemical concentrations as dependent variable and one or more of the explanatory factors listed above as independent variables (in addition to the dummy variables). A major objective was to examine relationships between chemical concentrations and X4, time since antecedent rainfall event.

Somewhat surprisingly, none of the regression analyses based on the full sample of observations revealed strong relationships with time since antecedent rainfall. This was true regardless of the other independent variables entered along with X4. A very mild positive relationship with X4, significant at the 5% level but not the 1% level, was observed for suspended solids. No other significant relationships with time since antecedent rainfall were obtained, despite considerable experimentation.*

An additional group of regression analyses were therefore conducted utilizing only those observations occurring in the first four hours since the start of rainfall. Deletion of

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* A similar lack of positive association with X4 was observed in regression analyses conducted as part of the AVCO study (which did not control for variation in basin characteristics). All regression coefficients applying to X4 were negative, although only two were statistically significant (AVCO, Table K-2).

observations with X1 greater than 4.0 hours reduced the size of the sample by approximately half. It was reasoned that observations occurring near the beginning of a storm should be most influenced by time since the previous storm event. The results of this series of regressions are summarized in Table A-1. Statistically significant, but very mild, positive relationships with time since antecedent rainfall were obtained for BOD, total organic carbon, and soluble orthophosphate. These findings are presented graphically in Figure A-1, which shows the ratio of pollutant concentration to the value which would occur if time since previous rainfall were equal to 100 hours (holding constant all variables besides X4). For purposes of comparison, the diagonal line shows the relationship which would be expected if the sole pollutant source consisted of easily-transportable materials which accumulated on watershed impervious surfaces at a constant daily rate.

A lack of strong association between pollutant concentrations and time since antecedent rainfall has also been observed by other investigators. The North Carolina study cited in the text (Colston, 1974), which involved more than 500 samples of storm runoff from a 1.67-square-mile basin in Durham, North Carolina, included regression analyses in which pollutant loading rates were related to the following variables: rate of stream discharge, time from storm start, time from last storm, and time from last hydrograph peak.* The latter two variables did not contribute significantly to the explanation of loading rates, and thus they were deleted from the analysis. A similar situation was observed in a study by Weibel, Anderson and Woodward (1964) of runoff from an urban area in Cincinnati, Ohio. The authors reported

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* In logarithmic regressions where stream discharge is included as an independent variable, use of the pollutant loading rate (or rate of flux) rather than pollutant concentration as dependent variable does not affect the regression coefficients and standard errors obtained for the other independent variables. In effect, both sides of the equation are multiplied by discharge (before taking logs), which simply serves to elevate R-square and the significance of discharge as an explanatory variable.

TABLE A-1

SUMMARY OF REGRESSION RESULTS FOR OKLAHOMA WATER QUALITY DATA

Dependent Variable (ln(Y+1))	Regression Coefficients for Independent Variables (log form), Excluding Dummy Variables				Multiple R-Square
	X_1	X_3	X_4	X_8	
BOD	-0.297**	-0.512**	0.085*	--	0.4524
COD	-0.317**	--	--	-0.123*	0.4532
TOC	-0.283**	-0.211**	0.171**	--	0.4452
OKN	-0.231**	-0.176**	--	-0.097**	0.3787
OPO4	--	--	0.098**	0.158**	0.4632
SS	--	0.460**	--	0.205*	0.4672

Definitions: X_1 = time since start of rainfall

X_3 = average intensity of rainfall

X_4 = time since antecedent rainfall

X_8 = antecedent precipitation index

Note: Single asterisk denotes statistical significance at the 5% level; double asterisk denotes significance at 1% level. The number of observations ranges from 147 to 207.

Source: Analysis by Betz Environmental Engineers, Inc., based upon data from AVCO (1970).

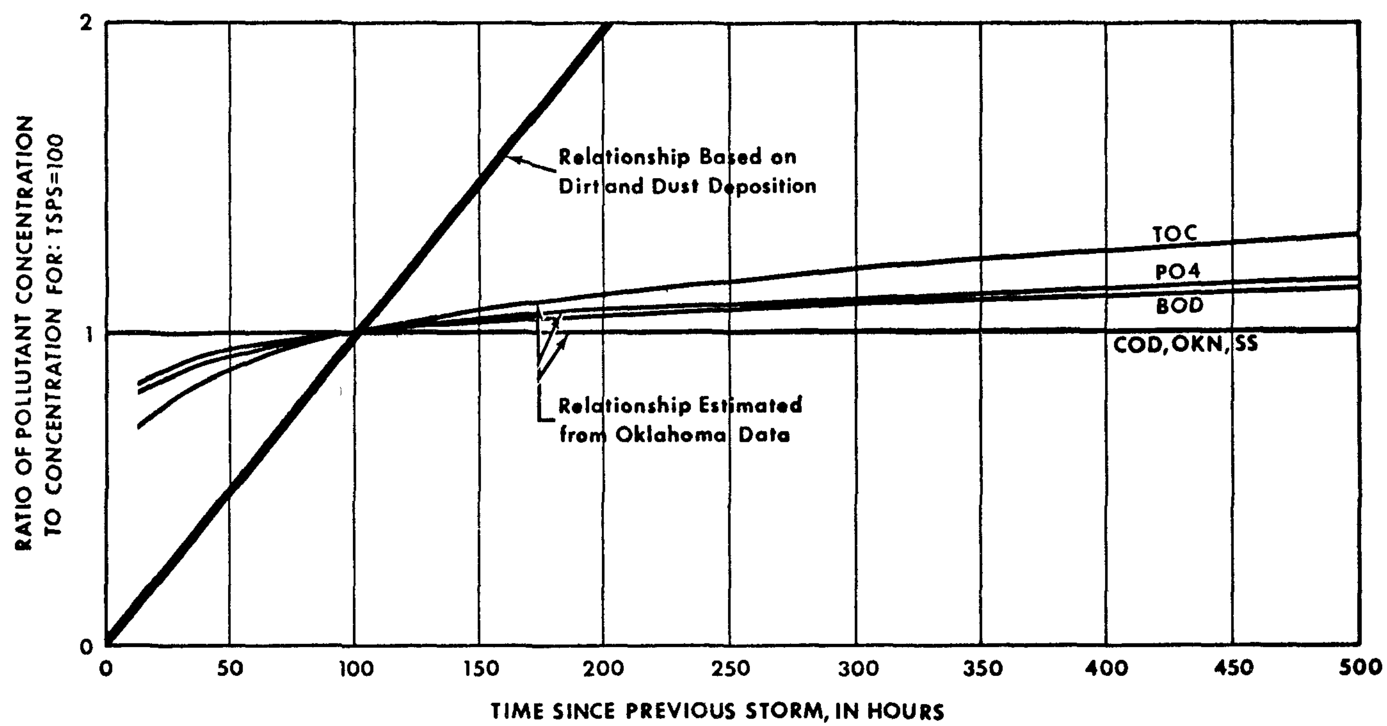

Figure A-1 RELATIONSHIPS BETWEEN POLLUTANT CONCENTRATION AND TIME SINCE PREVIOUS STORM

SOURCE: Betz Environmental Engineers Inc.

that "The relationship, if there is one, between the length of antecedent (dry) interval and runoff loads has not been evidenced in the data examined thus far." (p. 923). The data included more than 25 rainfall events exceeding 0.1 inch.

Failure to observe strong relationships between pollutant concentrations and time since previous rainfall is inconsistent with the assumptions contained in STORM, and similar predictive methodologies, which attribute pollutant loadings to progressive dirt and dust accumulation. The findings presented here are also inconsistent with a number of other empirical studies that have found antecedent rainfall to be important to pollutant concentrations or loadings (e.g., Lager and Smith, 1974, p. 81). Several possible explanations for this situation are the following:

Random variation. Pollutant concentrations during storm conditions are heavily influenced by transient and random factors (as evidenced by the fact that less than half of total variance was explained in each of the Oklahoma regressions). However, given the large numbers of chemical samples analyzed in the Tulsa, Durham and Cincinnati studies, it is highly unlikely that random variation would obscure relationships with previous rainfall if such relationships were strong. Municipal street sweeping operations also do not appear to be a major explanatory factor. Most of the Oklahoma basins were swept less often than once every six weeks. Furthermore, Sartor and Boyd (1972) have estimated that conventional sweeping practices are only 50% effective in removing dirt and dust from street surfaces. If particle size is taken into account, Sartor and Boyd indicate that sweeping is only 43% and 34% effective for BOD and COD, respectively.

Behavior of loadings versus concentrations. Pollutant loadings, as opposed to concentrations, have not been related here to precipitation variables, because loading estimates for individual storms were not available from the AVCO study. It is conceivable that loadings may be more strongly related to time since antecedent rainfall than concentrations. However, since the total loading for a storm is simply equal to a constant times concentration times discharge, integrated over the duration of the storm, loading rates and concentrations cannot differ systematically in their relationships to time since antecedent rainfall unless the runoff rate is somehow related to antecedent rainfall. Storms which follow long dry periods might tend to be relatively heavy (which would result in high runoff volumes and total loadings) or relatively short in duration (which would result in above-average concentrations; see below). However, neither of these possibilities would appear important. Also, variation in discharge should be largely controlled in the present equations by the inclusion of X3 (average intensity of rainfall) as an independent variable along with X4.

Nonlinear surface pollutant accumulation rates. As described in the Planning Methodologies report (pp. 42-44), there is a strong possibility that dirt and dust accumulation rates--as opposed to deposition rates--may be nonlinear, so that the total amount of accumulated material approaches an upper bound rather than increasing indefinitely. This finding, by Shaheen (1975), applies specifically to roadway surfaces. Its significance for overall pollutant yields is somewhat unclear, however, because pollutants removed from roadways by wind and other mechanisms may remain available for transport by stormwater (a point which is emphasized by Shaheen). In any case, it appears likely that nonlinearity of pollutant accumulation rates bears some responsibility for the failure of pollutant concentrations to be strongly related to time since antecedent rainfall in some instances. This is an important point to note because the available predictive methodologies--e.g., STORM--presently do not incorporate nonlinear accumulation rates (as of early 1976).

Pollutant sources besides washoff. The present findings are probably due to some extent to the role of pollutant sources which do not involve washoff of diffuse materials from impervious surfaces. The two source classes for which the pollutant yields would not be positively related to time since antecedent rainfall are: (1) erosion and erosion-type processes, in which the pollutant yields are not limited by the amount of material present; and (2) erratic and continuous discharges which are not rainfall-activated. The present findings thus provide some indication that diffuse materials on impervious surfaces are not overwhelmingly responsible for pollutant yields from medium-density areas.

The use of unsubstantiated assumptions about pollutant buildup on watershed surfaces would lead to significant forecasting errors in some instances. For example, suppose that a stormwater model such as STORM is calibrated for streams in the Philadelphia area. In this region, the annual probability (P) of observing a period "T" days or longer without rainfall exceeding 0.1 inch is roughly predictable by the following expression:

$$P = 1 - \exp(-40\exp(-.17T).$$

Based on this formula, there is an even chance that a dry interval of 33 days or greater will occur in any five-year period, or that an interval of 24 days will occur in any given year. Thus, the critical condition for stormwater pollution might be defined as a dry interval of perhaps 30 days, followed by a brief storm. However, the only water quality data available for calibration of the model might apply to conditions very different from this. For example, a typical three-month sampling period would contain a maximum dry interval of only 15 days; and this interval might be followed by a storm that failed to resemble critical conditions in other respects. Thus, application of the model to predict the critical pollutant loading or concentration would require substantial extrapolation beyond the observed data. If based upon an assumption of progressive pollutant accumulation, this extrapolation could involve very serious error.

Returning to the analysis of the Oklahoma data, the regression coefficients obtained for variables other than time since previous storm are also of interest. Significant negative relationships with time since start of rainfall (X1) were observed for BOD, COD, TOC and organic Kjeldahl nitrogen.* All of these constituents except COD were also related negatively to average intensity of precipitation (X3). Both types of relationships were consistent with the pattern normally expected if pollutants are washed from impervious surfaces. Negative relationships with antecedent

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* Strong negative relationships with time since start of storm were also obrained in the North Carolina regression analyses (Colston, 1974, p. 57).

soil moisture (X8) were observed for COD and OKN. No obvious explanation is available other than the possibility that high soil moisture was associated with low availability of organic material, due to removal during previous wet periods.

Suspended solids concentrations reflected the influence of erosion, being positively related to average intensity of precipitation and unrelated to time since the start of rainfall. Soluble orthophosphate was an intermediate case, because no significant relationships with either of these precipitation variables were observed. Suspended solids and soluble orthophosphate were both positively related to antecedent soil moisture (X8). This is expected for pollutants yielded by erosion, because soil moisture influences the quantity of runoff from pervious land.

An important aspect of these relationships is the implied magnitude of the "first-flush" effect. Very high pollutant concentrations often occur in the initial stages of storm events, due to washoff from watershed surfaces and also the scouring of accumulated material from catch basins and storm sewers. The shock effect of these contaminants upon receiving stream biota is often cited as one of the most serious consequences of urban runoff, and has led to the view that urban stormwater can have disproportionately large environmental impacts relative to the annual pollutant loadings involved.

The magnitude of the first-flush effect relative to pollutant concentrations occurring later is expressed in the relationship between pollutant concentration and time since start of storm. In the regression results presented above for Tulsa, and in the Durham and Cincinnati studies cited earlier, the relationship for COD has been typical of the strongest relationships observed. Table A-2 summarizes COD levels during three time periods, each taken as a ratio to the concentration which would be observed one hour after the start of the storm. The Tulsa and Durham figures have been derived by evaluating regression equations; the Cincinnati figures are from a direct tabulation of mean concentrations (Weibel, et al, 1964, p. 923).

The magnitude of the first-flush effect is perhaps less than might be expected. In all cases, average COD concentrations during the first 15 minutes of storm events are less than twice the concentrations observed at 1 hour after start of storm, and are less than 2.5 times as great as the average concentrations for all stormwater samples (not indicated in Table A-2). In the Cincinnati case, the average COD concentration during the first 15 minutes of storm events is only 72% greater than the overall average concentration. The persistence of pollutant loadings after two hours is also considered significant. Other investigators have noted that the magnitude of the first-flush effect tends to be variable among regions and individual basins (see the forthcoming Hydroscience report referenced in the text). The important point is that the existence of a highly pronounced first-flush effect should not be automatically assumed.

TABLE A-2

COD CONCENTRATION, RELATIVE TO CONCENTRATION ONE HOUR AFTER START OF STORM

	Time Since Start of Storm		
	0-15 minutes	15-30 minutes	120 minutes and over
Tulsa, Oklahoma	1.90	1.26	0.65
Cincinnati, Ohio	1.62	1.24	0.69
Durham, North Carolina	1.79	1.32	0.68

Source: Weibel, et al (1964); computations based on data from AVCO (1970) and Colston (1974).

Relationships Between Pollutant Loadings and Watershed Characteristics

The Tulsa data, the Philadelphia data, and information for three basins in New Jersey have been utilized to estimate urban pollutant-generation relationships for various water constituents.* The annual loadings of these constituents

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* The three New Jersey basins were sampled during 1969-1972 by the Water Resources Research Institute at Rutgers (Whipple et al, 1974). Annual BOD loadings based on these data have been prepared utilizing revised estimates of annual runoff quantity.

were related to several indices of human activity and land condition by multiple regression. The explanatory factors which could be considered were seriously constrained by data availability. (See the discussion in the text of variables needed for complete watershed description.) However, the simple equations obtained were felt to be instructive and potentially usable for limited forecasting activities.

A basic requirement for the analysis of pollutant-generation relationships was that the data should pertain to multiple watersheds in a given geographic area. This was considered necessary in order to control for the effects of regional factors such as climate. The Pennsylvania and New Jersey basins were considered to be in the same region, because they were separated by less than 100 miles and exhibited similar loading characteristics. The overall sample consisted of 13 basins in the Pennsylvania/New Jersey region, and 13 basins in the Tulsa region.

The quantities analyzed were the annual loadings in pounds per acre per year of the following water constituents: BOD, COD, OKN (organic Kjeldahl nitrogen), NH3 (ammonia), NO3 (nitrate), OPO4 (soluble orthophosphate), and PO4 (total phosphate). Unfortunately, comparable data for both sets of basins were available only for the organic constituents, BOD, COD and TOC. The watershed characteristics considered in the analysis were the following:

P1 - Population density in persons per acre

P2 - Density of population in dwellings constructed before 1940, in persons per acre

P3 - Density of population in dwellings constructed after 1940, in persons per acre

M - Median family income (as reported in 1970 Census for the year 1969)

E - Employment density in persons per acre

I - Impervious surface as percent of watershed area

All of the density measures were gross rather than net density, i.e., consisted of population or employment divided by the acreage of the entire watershed. In preparing population and income data, it was necessary to consult the

1970 U.S. Census, Census Tract Statistics, for all of the basins studied (although total population was available for the Tulsa basins from the AVCO study). Approximation was required because census tract boundaries generally did not correspond to drainage area boundaries. However, nearly all of the measurements were considered accurate to within 10%. Separate tabulations of population in dwelling units constructed before and after 1940 were prepared using the Census table which lists number of units by year structure built. This distinction is significant to pollutant generation.

Detailed land use data were assembled for the Pennsylvania watersheds using census tract information developed by the Delaware Valley Regional Planning Commission. Land use data were also available for the Oklahoma basins from the AVCO report. This information was not utilized directly in the analysis of pollutant loadings, however, due to definitional differences and other factors. Total employment in each basin (i.e., employment at place-of-work, not place-of-residence) was estimated on the basis of the land use data, using a methodology which is discussed later. Although all available information was utilized in preparing these estimates, the values for some of the individual basins could be in error by as much as 25%. However, test application of the methodology to large segments of the Philadelphia region indicates that the overall magnitude of estimates is probably correct. Finally, watershed imperviousness was obtained from the AVCO study, previous studies of the Philadelphia area, and direct measurement (Hammer, 1973a).

The analysis involved simple and multiple regressions in which dependent variables expressing pollutant loadings were related to the above factors as independent variables. Two of the fifteen Oklahoma basins studied by AVCO were not included in this investigation. One was a basin draining part of the Tulsa airport; the other was a basin for which runoff consisted of intermittent overflow from an abandoned strip-pit.

In cases where constituent loadings were available for both Oklahoma and Pennsylvania/New Jersey, the annual loads per acre were higher on the average for Oklahoma by amounts ranging from 15% in the case of BOD, to 100% for TOC. In view of the descriptions given in the AVCO report, and the author's knowledge of the other basins, it is believed that differences in general cleanliness were partly responsible for this occurrence. In any case, it was necessary to control for these systematic differences in some fashion, since the factors responsible would clearly not be expressed in the independent variables. The adopted procedure was based on the following assumptions: (1) for any given values of the independent variables, it was assumed that the loading of a chemical constituent in Oklahoma would be equal to the loading which would occur in Pennsylvania/New Jersey, times a constant factor "k"; and (2) it was assumed that the value of "k" for each constituent was equal to the ratio of observed mean values for the two regions. The procedure was to divide the constituent loading for each basin by the mean loading for that region. This dimensionless ratio was used as the dependent variable in all but one of the regression analyses involving data for both regions. Such a procedure is legitimate only when the means of the independent variables are similar for the regions involved, which was generally true in the present case.* Subsequent to the regression analysis, predictive equations were obtained for each region by multiplying each of the coefficients in the regression equation by the mean loading for that region.

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* Let Y1 and Y2 denote loadings of a given chemical constituent for the Pennsylvania/New Jersey and Oklahoma regions, respectively; and let X1 and X2 be corresponding vectors denoting independent variables. the first of the two assumptions made here is that: $Y1=f(X1)$ and $Y2=kf(X2)=f(kX2)$, where f is a linear function. Suppose that separate linear regressions of this form were conducted for the two regions, and that the mean values of independent variables in the two cases were substituted into the regression equations obtained. Because regression equations hold exactly at the means, the following relationships would be obtained: $Y'=F(X'1)$ and $Y'2=kG(X'2)$, where F and G are the estimated functions in each case, and primes denote mean values. If it is assumed that $k=Y'2/Y'1$, the second relationship becomes: $y''1=G(X'2)$. Clearly, the functions F and G cannot be approximately the same unless the vectors X'1 and X'2 are similar, or unless the differences in mean values of individual variables are internally compensating.

The findings of the analysis can be summarized as follows. Strong relationships with watershed characteristics were identified for a majority of the chemical loadings analyzed. However, due to the small sample sizes and the existence of substantial random error, it was considered appropriate to restrict regression equations to very simple forms. Population density was found to be generally a poor predictor of pollutant loadings. The best explanatory variable in almost all cases was employment density. Percent imperviousness, which covers the effects of both residential and non-residential development, was also found statistically significant in a majority of cases when entered as a single independent variable.

Experimentation with population-related variables indicated that two factors are potentially very important: age of housing, and income levels. The role of age of housing emerged when residential basins were segregated from other basins (see below). Median family income was attributed substantial importance in a number of regressions when entered in an interactive form with population density, (e.g., an independent variable might consist of population density divided by median family income. The findings involving income are not reproduced here because the equations are not considered reliable and have little practical usefulness. The important finding is that medium and high-income housing constructed since 1940 has minimal impact on pollutant loadings (see discussion below).

BOD was analyzed in somewhat greater detail than the other constituents because the most observations (26 basins) were available in this case. The findings, which are summarized in Table A-3 and Figure A-2, are considered to have general relevance for other pollutant loadings. The equations describing relationships with imperviousness and employment density are presented in the first line of Table A-3 and in the upper two graphs of Figure A-2. Employment density was a relatively stronger explanatory variable, and would have dominated the regression results if entered along with imperviousness in a multiple regression. As was typical for most constituents, the constant term in the predictive equations for BOD was lower when imperviousness was the independent variable than when employment density was used. This is logical because low imperviousness always implies low employment density, whereas the reverse is not necessarily true.

TABLE A-3

REGRESSION RESULTS FOR BOD LOADINGS

		Regression Coefficients for Independent Variables					
		Population Density			Percent Imperviousness		
	Constant Term	Pre-1940 Dwellings	Post-1940 Dwellings	Employment Density	All Basins	Industrial Basins Only	R-Square
BOD Loadings:							
1. All Basins	0.464				0.0168**		0.400
2. All Basins	0.758			0.0911**			0.592
3. All Basins	0.394				0.0172**	0.0127**	0.541
4. Labor-Exporting Basins	0.665	0.0906**	0.0158				0.496
5. Labor-Importing Basins	12.69			3.0947**			0.688

Note: Single asterisk denotes statistical significance at the 5% level; double asterisk denotes significance at the 1% level.

Source: Betz Environmental Engineers, Inc.

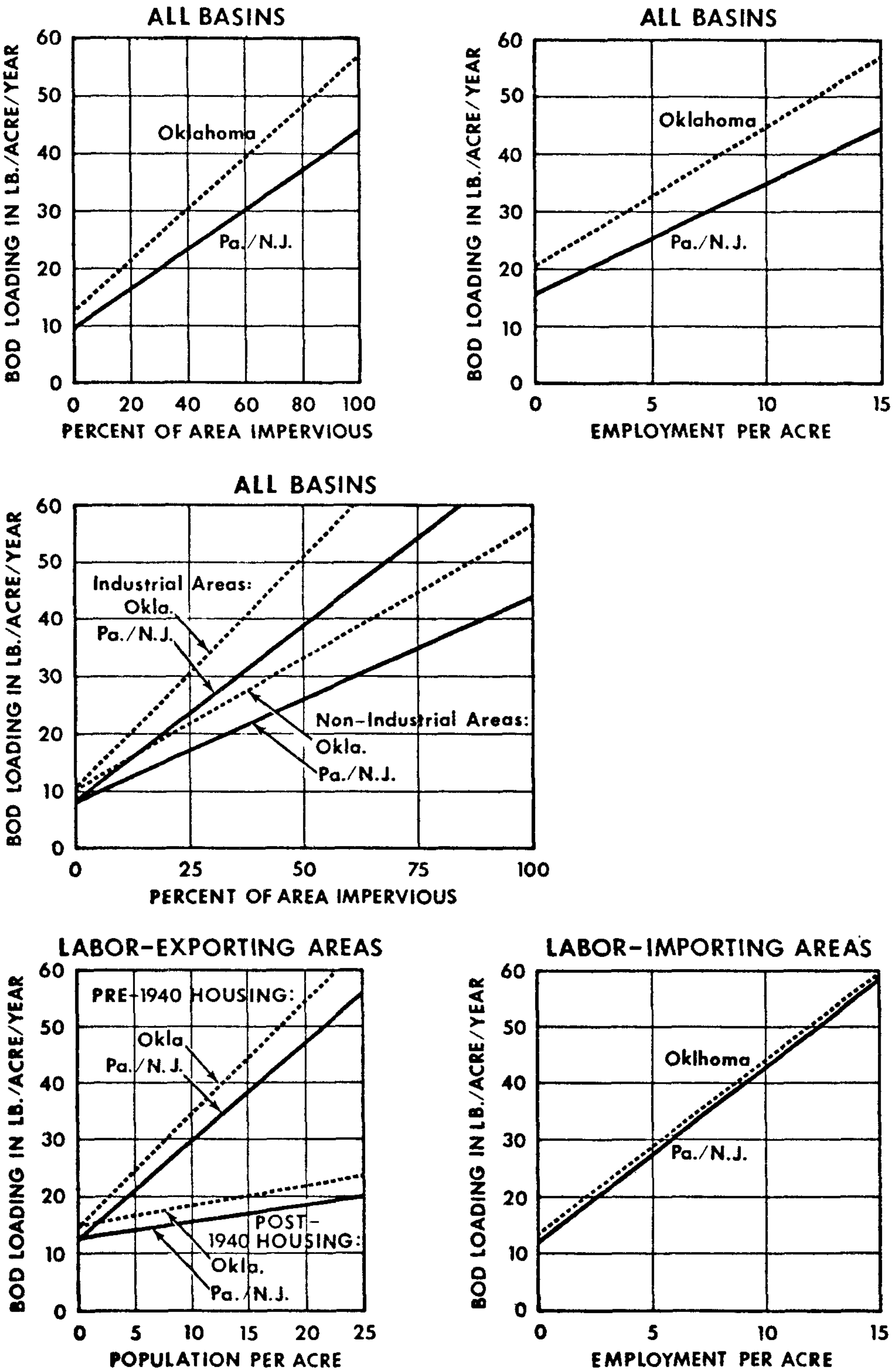

Figure A-2 ESTIMATED LOADING RELATIONSHIPS FOR BOD

SOURCE: Betz Environmental Engineers Inc.

The other BOD regressions involved partitioning the sample of observations according to the predominant type of urban development present. Basins which were primarily residential were defined as "labor-exporting" areas according to the following criteria: (1) employment in the basin was less than 0.4 times basin population (i.e., was less than the approximate number of workers residing in the basin); and (2) the total acreage of commercial and industrial land use was less than half the acreage of residential land. For all basins in the present sample, these two criteria were equivalent, although this might not always be true in general. Basins for which the above criteria did not hold were designated "labor-importing" areas. These were in turn classified either "industrial" or "commercial" according to which land use was predominant in terms of acreage.* In the third regression listed in Table A-3, an imperviousness variable was utilized which consisted of total imperviousness for basins designated industrial, and zero for all other basins. This variable was entered in a multiple regression along with the overall imperviousness variable, and was found significant at the 1% level with a positive coefficient. The implication is that a pollutant yield per acre of impervious surface is significantly higher for industrial areas than other areas. The estimated relationships for Oklahoma and Pennsylvania basins are graphed in the middle section of Figure A-2.**

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* For present purposes, industrial land use will include construction, manufacturing, utilities, bulk wholesaling and rail and truck transportation. Commercial land use will include retail trade, finance, and all personal and professional services except education, public administration and cemeteries.

** Note that these results apply to the <u>entire</u> impervious portion of industrial basins, not just the impervious area of industrial establishments (which was not measured separately). Since the latter was typically no more than half of total impervious surface, the impact of industrial land <u>per se</u> is probably greater than indicated in the graph.

A regression dealing only with labor-exporting basins yielded the results shown in the fourth line of Table A-3 and in the lower left section of Figure A-2. Population in dwellings constructed before 1940, and population in post-1940 dwellings, were entered as separate variables. The former was statistically significant (i.e., significantly different from zero) at the 1% level; but the coefficient for population in post-1940 dwellings was smaller than its standard error. A joint test indicated that the two coefficients were significantly different at the 2% level. If interpreted literally, the regression results would indicate that the marginal BOD of residential population is more than five times as great for pre-1940 housing as for post-1940 housing. A regression relating BOD loads to employment density for labor-importing areas is described in the last line of Table A-3 and in the lower right section of Figure A-2. In spite of the small sample size in this case, a strong positive relationship was obtained, with a substantially greater slope than was estimated on the basis of the full sample.

It was decided, on the basis of these BOD results and similar analyses for other constituents, that the best general procedure would be to relate each constituent to imperviousness and employment density in separate univariate regressions. Use of the resulting relationships for predictive purposes would then involve averaging the two loading estimates yielded by these relationships. For example, a 40% impervious basin in Oklahoma with 2.5 employees per acre would be expected to yield: (30 + 26)/2 = 28 pounds of BOD per acre per year (based on the upper two graphs in Figure A-2). This approach was favored for three reasons: (1) the use of additional predictive variables would complicate the relationships and would not be justified in terms of increased accuracy; (2) employment and impervious surface are relatively unambiguous variables, in comparison with land use measurements; and (3) in intensively developed areas, imperviousness is subject to an upper bound (i.e., 100%) whereas employment density is not. Due to this fact, and the above-mentioned characteristic of constant terms, the loading estimates obtained as averages in the above fashion are believed to reflect the actual loading characteristics of urban land over a wide range of development intensity.

In the case of BOD, which is somewhat more difficult to estimate accurately than other constituents (e.g., COD), the loadings predicted by this methodology for the sample basins are within 15% of their true values half the time, and within 30% of their true values 80% of the time. This is felt to be reasonable accuracy given that the other factors shown in the lower portion of Figure A-2 are not considered.

The estimated loading relationships for COD, organic carbon, and suspended solids are shown in the upper portion of Table A-4 and in Figure A-3. In each of these cases, employment density explains more than half the variation in observed loadings, and imperviousness explains slightly less than half. The suspended solids relationships are based on the Oklahoma data only. One of the Oklahoma basins contained a large amount of construction activity at the time of the AVCO study. The suspended solids loading from this basin was more than three times as great as the next highest loading, and seven times as great as the average. This basin was eliminated from the present sample when analyzing suspended solids because there was insufficient information to deal systematically with construction impact. The estimated relationships are thus intended to apply to suspended solids yields from developed urban land.

Loading relationships for organic Kjeldahl nitrogen, ammonia and nitrate are depicted in Figure A-4. OKN is the only constituent for which imperviousness was found to be a stronger explanatory variable than employment density. For ammonia, there was not a significant relationship between annual loading and percent impervious. However, such a relationship did appear to exist for industrial basins alone. This situation is depicted in Figure A-4 (although the number of industrial basins was not sufficient for regression analysis). For nitrate, the only relationship observed was a mild positive association with population density in sewered dwelling units. (The one Pennsylvania basin containing a significant number of dwellings with on-site disposal was deleted.) A relationship pertaining to nitrate yield from dwellings with on-site sewage disposal was available from previous research in Chester County, Pennsylvania, which is within the region covered by the present study (Howard and Hammer, 1973). This relationship, converted to population units, is presented in the lower portion of Figure A-4. Its difference from the estimated relationship for sewered population is striking, especially because soils in the area studied are generally considered suitable for on-site waste disposal. Finally, no significant relationships with watershed characteristics were observed for

TABLE A-4

REGRESSION RESULTS FOR OTHER CONSTITUENTS

	Constant Term	Regression Coefficients for Independent Variables: Employment Density	Percent Imperviousness	Population Density (Sew.)	R-Square
COD	0.605	0.1330**			0.665
	0.264		0.0219**		0.411
Total Organic Carbon (TOC)	0.716	0.0964**			0.611
	0.440		0.0167**		0.454
Suspended Solids (SS); Oklahoma only	444.2	66.85**			0.554
	151.3		13.42*		0.472
Organic Kjeldahl Nitrogen (OKN); Oklahoma only	1.472	0.1674**			0.451
	0.597		0.0395**		0.479
Ammonia (NH_3); Pennsylvania only	1.509	0.508*			0.445
Nitrate (NO_3); Pennsylvania only	29.32			1.928*	0.372

Note: Single asterisk denotes statistical significance at the 5% level; double asterisk denotes significance at the 1% level.

Source: Betz Environmental Engineers, Inc.

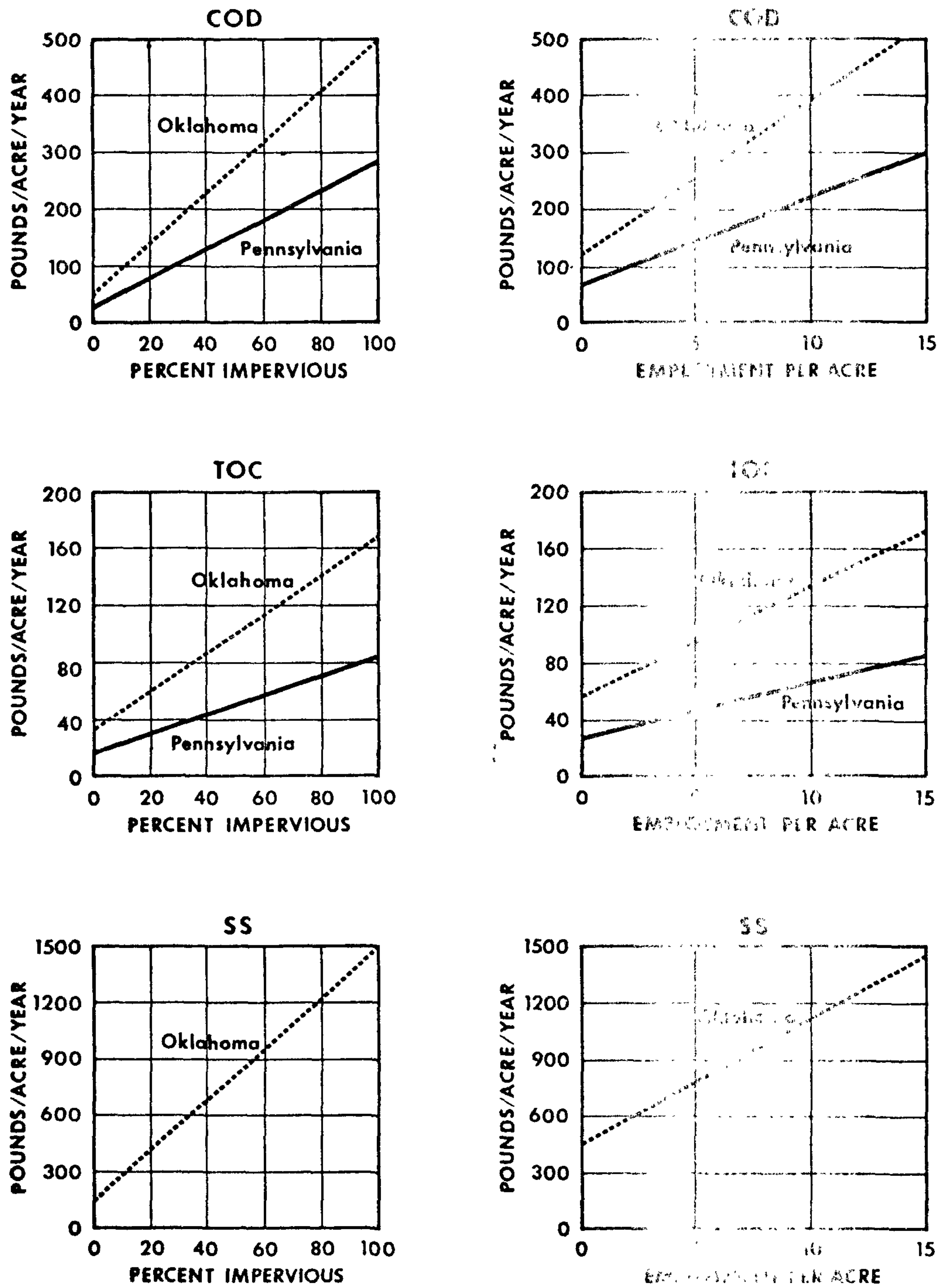

Figure A-3 ESTIMATED LOADING RELATIONSHIPS FOR COD, TOC, AND SS

SOURCE: Betz Environmental Engineers Inc.

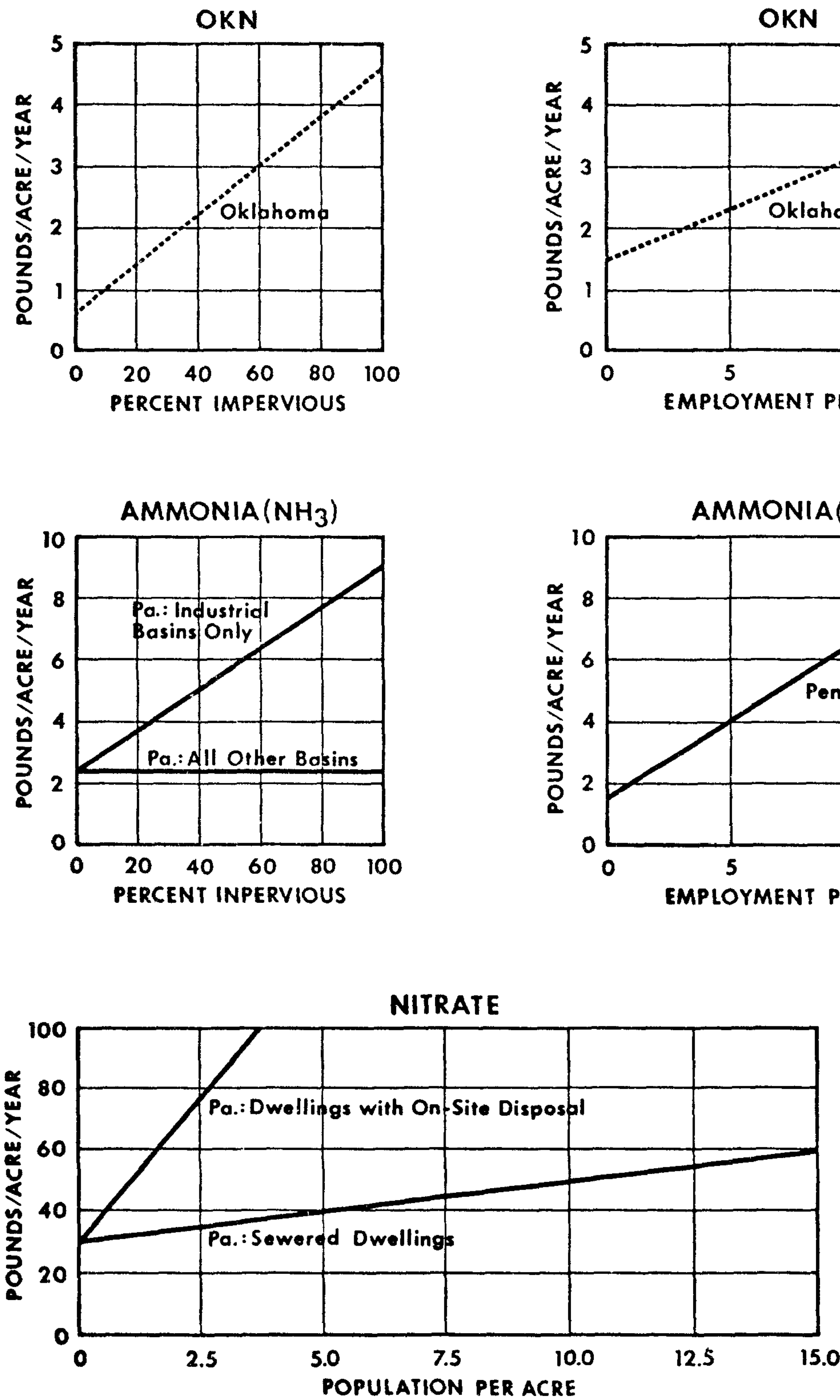

Figure A-4 ESTIMATED LOADING RELATIONSHIPS FOR ORGANIC KJELDAHL NITROGEN, AMMONIA, AND NITRATE

SOURCE: Betz Environmental Engineers Inc.

soluble orthophosphate or total phosphate. The mean annual loadings per acre for these constituents were 2.61 and 3.71, applying to Oklahoma and Pennsylvania, respectively.

Overall, the regression results are remarkably consistent. The major finding is the greater importance attributed to economic activity than to population, except in the case of nitrate. Employment density and imperviousness were both statistically significant in explaining the annual loadings of five constituents: BOD, COD, TOC, SS and OKN. In all of these cases, the regression coefficient for employment density was four to six times as large as the coefficient for imperviousness. A formula has been developed as part of this study which relates imperviousness to population and employment densities (see the discussion below of planning applications). If this formula is substituted into the regression equation containing imperviousness, and this equation is averaged with the employment density equation, the result is a linear equation for each constituent which relates loadings to employment density and population density. The ratio of coefficients for the latter two variables in this equation ranges from 4.6 for BOD, down to 3.7 for organic Kjeldahl nitrogen. Thus, the equations would indicate that each additional employee in a watershed increases pollutant yields by roughly four times as much as each additional resident. This finding has clearly been influenced, however, by the fact that approximately three-fourths of the total residential population in the basins studied lived in post-1940 dwelling units.

There are a number of possible explanations for the great importance attributed to age of housing in the regression results. This finding appears to be due in part to associations between age of housing and various socioeconomic characteristics, which are in turn correlated with cleanliness, age and condition of automobiles, and other factors that directly affect pollutant generation. Some other possibilities which have been mentioned are: physical deterioration of streets and buildings; existence of more dense vegetation in older areas; and negative associations between age of housing and air quality. A potentially very important factor is condition of the sanitary sewer system. Sewer leaks and bypasses can be highly significant pollutant sources in older neighborhoods. Deterioration of sewer pipes causes leakage of wastewater, and also results in infiltration/inflow problems which necessitate creation of bypasses. In any case, an important question is whether these differences between pollutant yields for new and old development are due strictly to former construction practices, or whether we can expect progressive increases in pollutant yields to occur for recently constructed development.

Application of Loading Relationships in Reconnaissance Studies

Given the variation which appears to exist among pollutant loadings from urban areas in the U.S., the relationships presented in the previous section are not considered to be directly applicable for prediction purposes outside the study areas for which they were estimated (i.e., Tulsa and eastern Pennsylvania/New Jersey). However, the relationships may be useful in reconnaissance studies to establish standards of comparison for field data. The objective of reconnaissance studies is to characterize subareas of a region by pollutant yields relative to expected loadings, and to identify and isolate high-yield source areas as efficiently as possible. The following is a hypothetical example which illustrates various aspects of such a procedure. The objective in this case is to extract as much information as possible from field data, given limited resources for data collection. This emphasis is not intended to imply that minimal data collection programs are appropriate in cases where greater resources exist.

The present example involves the hypothetical urban area shown in Figure A-5. A metropolitan area of somewhat less than a million people is situated at the head of an estuary. A large portion of the urbanized region is drained by Muddy Creek, which enters the estuary from the west. Organic loadings to the estuary during storm periods are known to be a major problem. For several days after a storm, particularly a [illegible] storm, dissolved oxygen in the estuary is depressed relative to normal dry-weather levels. Upgraded treatment at existing waste disposal plants--which will be necessary in any case to meet secondary standards--is not expected to eliminate this post-storm DO problem.

The [illegible] portion of the urban area is served by combined sewers. Due to the known importance of combined sewer overflows, the regional planning agency is devoting a large proportion of its study grant to SWMM modeling of these areas. Only moderate funding is available for study of other unrecorded sources, about which relatively little is known.

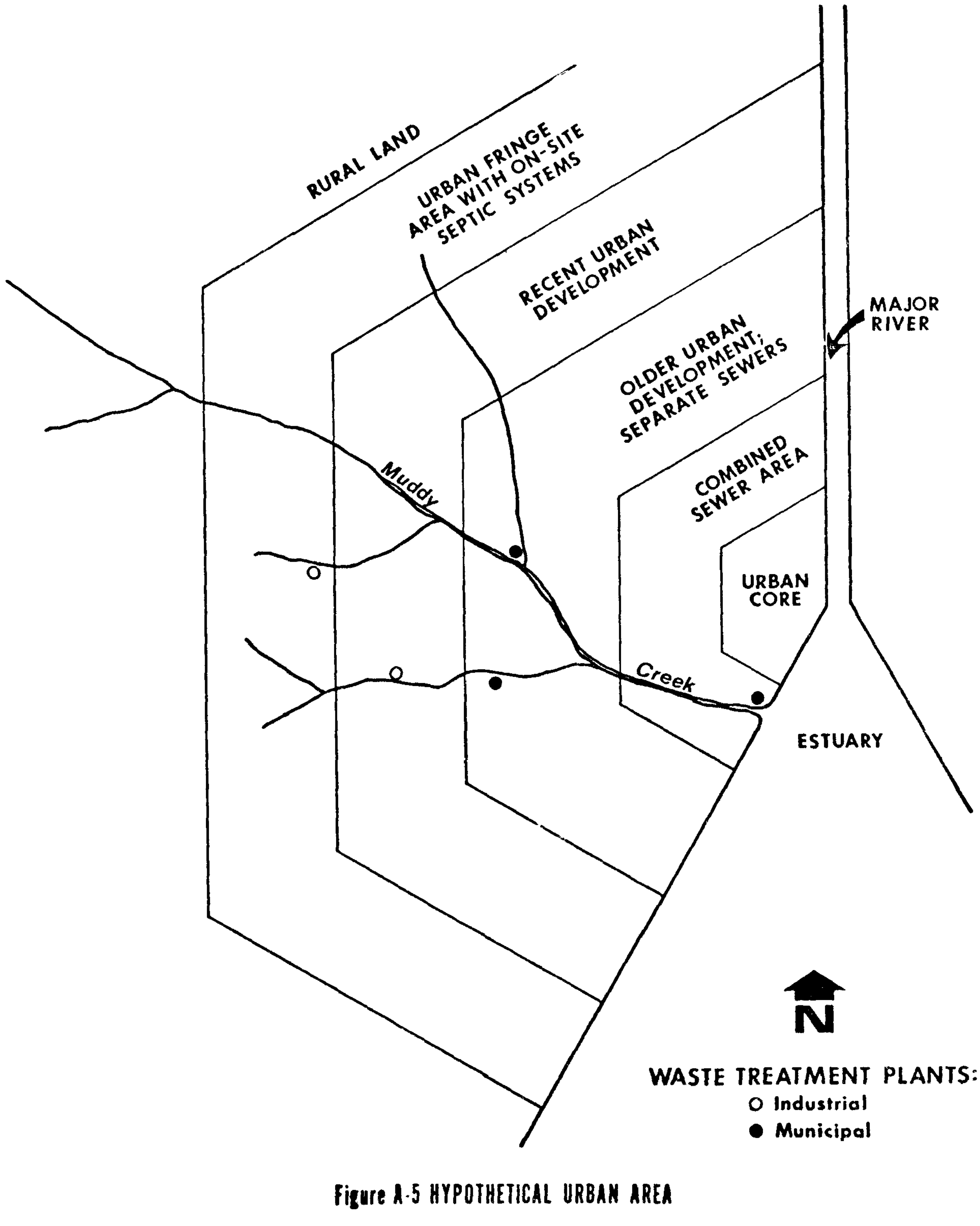

Figure A-5 HYPOTHETICAL URBAN AREA

SOURCE: Betz Environmental Engineers Inc.

A reconnaissance procedure has been chosen as the most efficient means of assessing unrecorded pollution outside the combined sewer area. The hydrologic subdivisions utilized in carrying out this procedure for the Muddy Creek watershed are shown in Figure A-6, which is an enlargement of Figure A-5. Eight areas are shown, ranging in size from 3,000 to 5,000 acres. (In an actual situation, more subdivisions might be desired.) Characteristics of these areas are summarized in Table A-5. The southern portion of the Muddy Creek watershed contains substantial industrial development. A new industrial park is located in areas 5 and 7, whereas area 8 contains older industrial development. Relatively new suburban housing is located in areas 2, 3 and 5. Areas 4, 6 and 8 contain older housing, plus substantial commercial development, particularly in area 6. Two municipal treatment plants are located in the watershed, a large regional facility in area 6, and a smaller plant in area 8. Industrial dischargers are located in areas 5 and 8.

TABLE A-5

DESCRIPTIVE DATA FOR HYDROLOGIC SUBDIVISIONS
IN HYPOTHETICAL STUDY AREA

Hydrologic Subdivisions	Area in Acres	Population	Employment	Densities (#/Acre) Population	Densities (#/Acre) Employment	Percent Imprevious (Estimated)
1	3,000	9,000	0	3.0	0.0	14
2	4,000	32,000	4,000	8.0	1.0	27
3	3,000	18,000	3,000	6.0	1.0	23
4	5,000	55,000	10,000	11.0	2.0	36
5	4,000	16,000	8,000	4.0	2.0	22
6	4,000	36,000	16,000	9.0	4.0	39
7	5,000	15,000	15,000	3.0	3.0	18
8	5,000	40,000	25,000	8.0	5.0	40
	33,000	221,000	81,000			

Source: Betz Environmental Engineers, Inc.

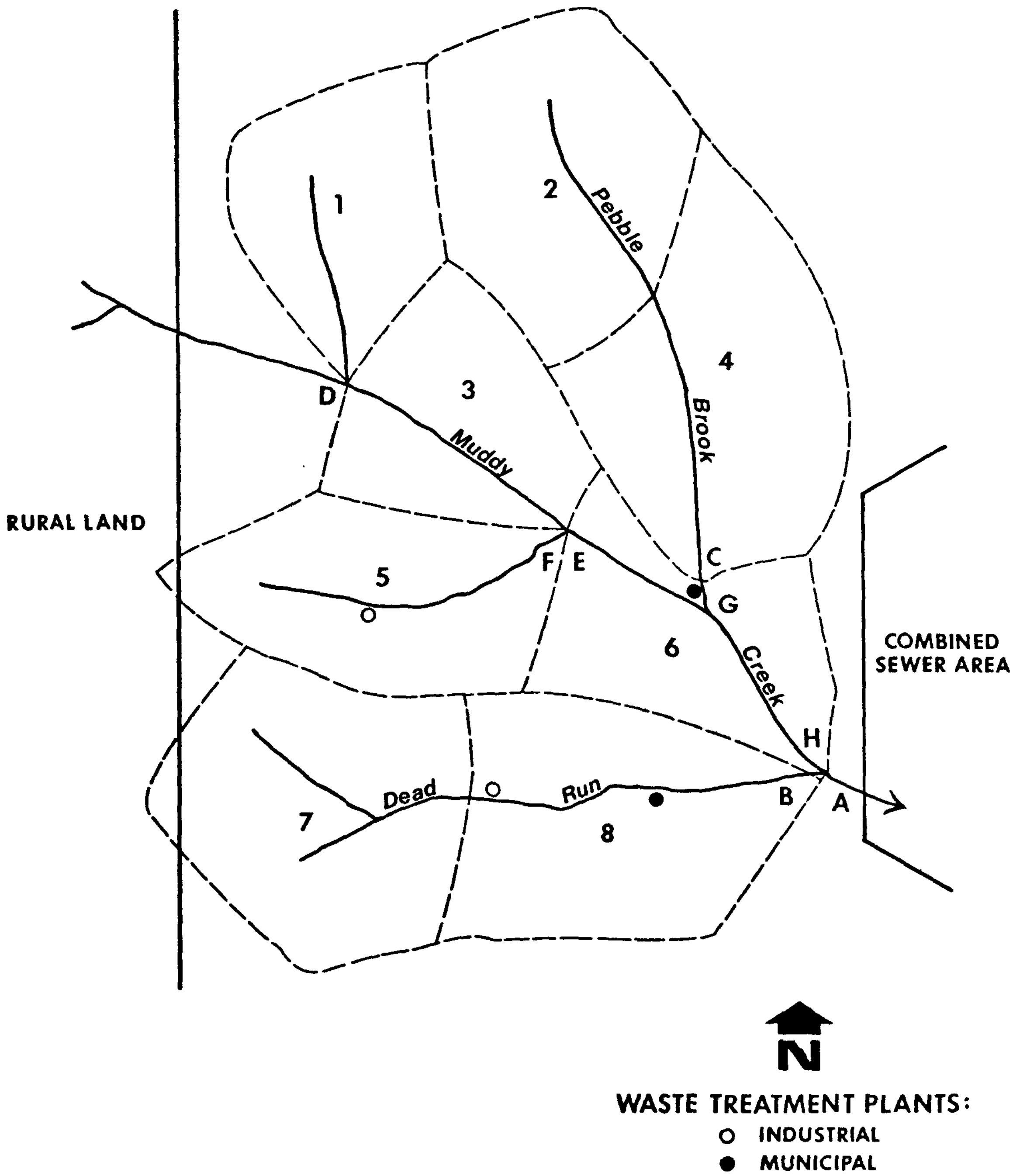

Figure A-6 MUDDY CREEK WATERSHED (HYPOTHETICAL)

SOURCE: Betz Environmental Engineers Inc.

The planning agency has chosen 5-day BOD as the index of organic loadings, due to the availability of BOD data for the estuary and for treatment plant effluents. No water quality or streamflow data initially exist for the Muddy Creek watershed. Three or four persons can be made available for field sampling during storms; but only one current meter is available for measurement of discharge.

A first step is to compute the expected BOD loadings from the eight hydrologic subdivisions, based on the information given in Table A-5 and the relationships presented in Figure A-2 of this report. The Oklahoma relationships are utilized in this case, although the choice is unimportant in practice since the Pennsylvania relationships are proportional. The resultant loading estimates are presented in Tables A-6 and A-7. Table A-6 is based on the standard relationships involving imperviousness and employment density, presented in the upper portion of Figure A-2. Table A-7 is based on the alternative relationships shown in the lower portion of Figure A-2, which consider age of housing and the existence of industrial areas. The total estimated BOD loading from the urbanized portion of the Muddy Creek watershed is almost exactly the same in the two cases, although some significant differences exist for individual hydrologic subdivisions. The discussion hereafter will refer just to Table A-7.

Top priority is assigned to measurement of pollutant loads at point A, which subtends the entire Muddy Creek watershed outside the combined sewer area (see Figure A-6). An initial sampling network is established at points A, B, C and D, to characterize pollutant loads from the Muddy Creek watershed as a whole, from the tributary basins of Pebble Brook and Dead Run, and from the 30 square miles of largely rural land subtended by point D. Arrangements are made at these and the other stations to record water stage as part of sampling procedures, using either a staff gage or an overhead reference point such as a bridge railing.

The first storm event sampled is a frontal storm involving somewhat less than one inch of rain in two hours. The storm is known not to resemble critical conditions for the estuary, but is favorable for research purposes because the rainfall is uniform throughout the region and because advance warning is adequate for deployment of the field crew. Sampling is conducted for eight hours at points B and C, and for four additional hours at A and D. Water samples are taken and stage is recorded several times each hour. The

TABLE A-6

ESTIMATED BOD LOADING FOR HYPOTHETICAL STUDY AREA, BASED ON STANDARD OKLAHOMA RELATIONSHIPS*

	BOD Loading in lb/Acre/Year			
Hydrologic Subdivision	Based on Impervi-ousness	Based on Employment Density	Average	Estimated Annual BOD Loading in Pounds
1	19	21	20	60,000
2	25	23	24	96,000
3	23	23	23	69,000
4	29	25	27	135,000
5	23	25	24	96,000
6	30	30	30	120,000
7	21	28	24	120,000
8	30	33	32	160,000
				856,000

Source: Betz Environmental Engineers, Inc.

TABLE A-7

BOD LOADINGS BASED ON ALTERNATIVE OKLAHOMA RELATIONSHIPS*

Hydrologic Subdivision		BOD Loading in lb/Acre/Year				
Number	Type**	Popu-lation	Impervi-ousness	Employ-ment	Average	Annual Loading in Pounds
1	R	17	17		17	51,000
2	R	20	23		22	88,000
3	R	22	21		21	63,000
4	R	33	27		30	150,000
5	I		28	19	24	96,000
6	N		29	25	27	108,000
7	I		25	22	24	120,000
8	I		43	28	35	175,000
						851,000

* The standard relationships are shown in the upper two graphs of Figure A-2; the alternative relationships are shown in the middle and lower graphs.

** Land Use Types: R, labor-exporting; I, labor-importing/industrial; N, labor-importing/non-industrial. For the labor-exporting areas, the following percentages of population are assumed to live in pre-1940 dwellings: 20% for Area 1, 20% for Area 2, 50% for Area 3, and 80% for Area 4.

Source: Betz Environmental Engineers, Inc.

current meter is used to measure discharge repeatedly at points A and B, which are adjacent. Based on water stage data, and the actual discharge measurements at points A and B, the shape of the flow hydrograph at each station is roughly determined. This is used to form discharge-weighted composites of the BOD samples (i.e., each composite sample is assumed to represent an equal volume of water). Roughly five composite samples are prepared for each station: one or two representing rising stage, one representing peak stage, and two representing falling stage. The roughly 20 composite samples obtained in this fashion are analyzed for BOD in the lab; and the concentrations are averaged for each station. The results are shown in the upper portion of Table A-8.

Determination of the total volume of storm runoff from various areas is problematic because discharge hydrographs are available only at points A and B. The eight-hour period of maximum flow at point B is defined as the storm period. The last two hours of this period are not included for point D, since travel time from D to A is approximately two hours. Base flow during the storm period is not distinguished from surface runoff. Total discharge during the storm period amounts to roughly 200 acre-feet at point B, and 860 acre-feet at point A. Runoff from hydrologic subdivisions 2 through 6 is estimated by assuming 0.02 acre-feet per acre, as observed at point B (areas 7 and 8). A lower value is assumed for area 1. Runoff from the rural area is then obtained as a residual. The resulting runoff volumes, shown in Table A-8, are known to be subject to error. This is usually not critical in reconnaissance studies, however, as long as total runoff from the study area is known, and the figures for subdivisions are reasonably consistent.

The remaining columns of Table A-8 show the estimated BOD loading at each station during the storm period, the estimated load from point sources during this period, and the net load due to land drainage. The net loads for the urban portion of the Muddy Creek watershed, and for basins 1, 3, 5 and 6 taken together, are estimated by subtraction. The loadings from various areas are then divided by the corresponding annual loadings estimated from the Oklahoma relationships (from Table A-7). This is done in order to control for general land characteristics when making internal comparisons among loadings.

As indicated by the last column of Table A-8, the lowest BOD load on a relative basis is yielded by areas 2 and 4, subtended by point C. The highest relative load is produced by the area consisting of subdivisions 1, 3, 5 and 6. With regard to subdivision 6, one possibility is that the loadings from the municipal and industrial dischargers are not represented correctly. The volumes of municipal effluent released during the storm period are known from treatment plant records; but effluent strength may be a variable factor. Arrangements are therefore made for systematic effluent sampling by treatment plant operators during future storm periods.

In the next storm sampled (storm 2 in Table A-8), station D is replaced by stations F and E. Stations A, B and C are retained, in order to corroborate the findings made in the first storm. Discharge measurements are again conducted at stations A and B. Discharge-weighted average BOD concentrations and runoff volumes are obtained in a fashion similar to that described earlier, except that somewhat different assumptions are employed due to different storm characteristics. The findings are reported in the central portion of Table A-8. As indicated in the right-hand column, subdivisions 5 and 6 appear to be the high-yield areas, relative to expectations. (However, the loading estimate for area 6 is not considered highly reliable because it was obtained as a difference between larger numbers.) The municipal treatment plant in area 6 is also found to contribute a larger BOD loading than previously thought, due to relatively high wastewater volume and inefficient treatment during the storm period.

The network of stations is changed again when sampling the third storm. Stations A and C are retained, due to the need to accumulate as much data as possible for the whole basin (point A), and the desire to use C as a "baseline" case. Adequate stream flow rating curves have been developed for points A and B using data from the first two storms, so that the current meter can now be used to measure discharge at point F. Points G and H have been added in order to investigate a suspected source of pollutant loadings in part of basin 6, namely, an antiquated separate sewer system which links to the combined sewer area.

The third storm is a convective shower in which rainfall is distributed unevenly over the region. The estimated runoff volumes at points C, G and H are therefore very approximate. The data for points G and H are nevertheless valuable in

TABLE A-8
SUMMARY OF FIELD DATA FOR HYPOTHETICAL WATERSHED

Sampling Station	Relevant Hydrologic Subdivisions	Average BOD Concentration in mg/l (Discharge-weighted)	Volume of Storm Runoff, in acre-feet	Estimated BOD Load, in Pounds	BOD Load From Point Sources	Net Load due to Land Drainage	Ratio to Expected Annual Load
STORM 1 - Observed Data							
A	1-8 plus rural land	7.0	860	16,400	2,840	13,560	
B	7,8	9.0	200	4,900	740	4,160	.0142
C	2,4	4.0	180*	1,950	0	1,950	.0082
D	Rural land	2.0	200*	1,100	0	1,100	
Derived Data							
-	1-8					12,460	.0146
	1,3,5,6					6,350	.0200
STORM 2 - Observed Data							
A	1-8 plus rural land	5.0	1920	26,100	4,300	21,800	
B	7,8	6.0	440	7,180	975	6,200	.0210
C	2,4	3.5	400*	3,800	0	3,800	.0160
E	1,3,5 & rural	3.0	900*	7,340	400	6,940	
F	5	9.0	180*	4,400	400	4,000	.0417
Derived Data							
-	6					4,870	.0450
STORM 3 - Observed Data							
A	1-8 plus rural land	9.0	500	12,240	2,450	9,790	
C	2,4	5.0	100*	1,360	0	1,360	.0057
F	5	12.0	50	1,630	300	1,330	.0139
G	1-5 plus 6 (part) and rural land	5.4	380*	5,580	1,800	3,780	
H	1-6 plus rural land	6.2	400*	6,750	1,800	4,950	

* Estimated
Source: Betz Environmental Engineers, Inc.

revealing a significant difference in average BOD concentrations, which would suggest that the sewer system problem is important.

The sampling program thus indicates that basin 5 and the southeast portion of basin 6 are relatively high-yield areas. These areas receive primary attention in later reconnaissance activities, which include direct inspection of streams and land areas. In addition, the industrial discharge in basin 5 (about which little has been known other than the information in discharge permits) is monitored directly in later storms and non-storm periods.

The data presented in Table A-8 can be used to estimate annual pollutant loadings for the various subdivisions, although it is understood that the resulting figures are approximate. Annual loadings are computed directly for stations A and C, which have been monitored in all three storms. The overall discharge-weighted average BOD concentrations in the two cases are 6.134 mg/l and 3.853 mg/l, respectively. Independent estimates are prepared of stream discharge during all storm periods in a typical year; these amount to 43,300 acre-feet for station A and 9,000 acre-feet for station C. The estimated annual BOD loadings produced during storm periods are thus 722,000 pounds and 94,000 pounds, respectively.

The loading estimates prepared for other subdivisions pertain only to land drainage, not point sources. In the estimation process, the loading from subdivisions 2 and 4 is used as a benchmark for extrapolating from observed data to annual loading values. For example, the ratio of the land drainage loading from subdivision 5 to the loading from subdivisions 2 and 4 was: 4,000/3,800 = 1.05 in storm 2, and 1,330/1,360 = 0.98 in storm 3. The average of these figures, 1.02, is multiplied by the annual load of 94,000 pounds for subdivisions 2 and 4 to yield a value of 96,000 pounds for subdivision 5. Similar computations are carried out for other areas. In the case of subdivisions 1 and 3 (which contain low-density residential development similar to area 2) no direct data are available from the monitoring program. Thus, the ratio used for extrapolation purposes is based on the loading figures presented in Table A-7. The results of these computations are given in the first column of Table A-9.

TABLE A-9

TABULATION OF ANNUAL BOD LOADINGS
DURING STORM PERIODS, IN POUNDS

Land Drainage Loadings	Estimated Annual Loading	"Baseline" Loading (Theoretical)	Loading Objective*
Subdivisions 1 & 3	45,000	45,000	36,000
Subdivisions 2 & 4	94,000	94,000	75,000
Subdivision 5	96,000	38,000	45,000
Subdivision 6	120,000	43,000	54,000
Subdivisions 7 & 8	177,000	117,000	109,000
Total, Land Drainage	532,000	337,000	319,000
Rural land and Point Sources	190,000		
Total	722,000		

* The loading objective for each area is equal to the actual loading, minus 75% of the difference between actual and baseline loadings, minus 20% of the baseline loadings (see text).

Some insight into the loading reductions achievable by various types of controls can be gained by computing "baseline" loading values, again utilizing the loading from subdivisions 2 and 4 as a reference point. As indicated earlier, subdivisions 2 and 4 are characterized by relatively clean surface conditions, no point sources, and no known discrete sources of stormwater pollution. The loading from this area thus provides a rough indication of the pollutant-generation levels which could possibly be achieved in other areas through general cleanup measures and site-specific controls. The estimated BOD yield from subdivisions 2 and

4 is first divided by the loading predicted in Table A-7 (238,000 pounds, based on the Oklahoma relationships). The resulting ratio is 0.395, indicating that annual loadings in the study area run about 40% of the levels predicted by the Oklahoma relationships. This ratio is then applied to the other annual loading figures in Table A-7 to yield the "baseline" estimates shown in the second column of Table A-9. These are the loadings which theoretically would be observed (without point sources) if all land conditions resembled subdivisions 2 and 4, given the existing differences in factors such as population, employment, and imperviousness.

The deviation between actual and baseline conditions tends to be a good indicator of the relative importance of site-specific pollutant sources in an area. Control of these sources can often be achieved at low public cost once their presence is established. In the present case it is assumed that the planning agency places a high priority upon detection and control of high-yield sources. A first-cut estimate of the effectiveness of controls is obtained by assuming that site-specific corrective measures can potentially reduce the loadings from subdivisions 5 through 8 by amounts equal to 75% of the difference between present and baseline loadings. In addition, it is anticipated that general improvement in land management practices such as rubbish removal and street sweeping will reduce loadings from all areas by amounts equal to 20% of baseline. Given these assumptions, the loading objectives shown in the right-hand column of Table A-9 are established.

If the loading objectives were met, the total BOD yield of Muddy Creek due to urban land drainage would decline from 532,000 pounds per year to 319,000 pounds per year, a reduction of 40%. The bulk of the reduction (about 150,000 pounds) would be due to the implementation of site-specific controls. These hypothetical figures would not be a sufficient basis for determining whether urban runoff control, along with point source abatement, would produce satisfactory conditions in the estuary. However, such computations provide helpful insights into the stormwater control problem.

Water Quality Aspects of Nonpoint Sources

The remaining portion of the appendix was assembled to help the reader understand some important aspects of water quality response to nonpoint source pollutants. It does not detail all, or even most, of the considerations which must go into analyzing and monitoring water quality. Several subjects are discussed; some rather well known but worthy of repeating, and others which can often be overlooked or underemphasized. The discussion assumes the reader will have a relatively sound understanding of steady-state water quality problems.

The methodologies for nonpoint analysis presented in the body of the report stressed quantitative analysis of existing water quality data, collection of additional water quality data through a well-structured sampling program, and analysis techniques such as mass balances, nomagraph methodologies, etc. Computer modeling approaches were deemphasized. It is felt that this overall approach is appropriate for 208 water quality management studies which have a limited time and budget for ranking nonpoint problems and recommending controls.

Most likely, the important outputs from the nonpoint element of 208 programs following the proposed approach will be:

1. Determine what kinds of nonpoint problems exist, their extent and severity

2. Rank nonpoint problems based upon water quality impairment and probability control

3. Recommend general "Best Management Practices" for selected sources

4. Present preliminary site-specific recommendations on significant nonpoint sources

5. Develop a long-term program for further study of unresolved nonpoint problems along with a specific monitoring program to aid future analysis and help gage pollution control progress

The recommended approach relies heavily on a thorough understanding of water quality, especially the impact of nonpoint sources on water quality. Unlike many approaches currently in use, the proposed methodology does not concentrate on loads delivered to receiving waters, but instead focuses on the reaction of the receiving water to nonpoint loads. If a structured water quality monitoring and analysis program indicates no significant water quality problems due to nonpoint sources, then it does not appear appropriate to commit resources to developing estimates of lbs per day of pollutant from various land uses and watersheds. Likewise, computer modeling of storm water would appear unwarranted.

Important Considerations in Water Quality Analysis

This section attempts to provide an overview of the water quality impact of nonpoint source pollutants and describe several selected phenomena which occur after nonpoint pollutants are discharged to the receiving water. The section is organized as follows:

- Time Frame for Analyzing Water Quality Impacts
- Decomposition and Reaeration at High Flow
- Influence of Benthic Deposits on Water Quality
- Types of Water Bodies and Significance to Nonpoint Sources
- Some Comments on Probable Control Recommendations

Time Frame for Analyzing Water Quality Impacts: The appropriate time frame for analyzing nonpoint water quality impacts is the "worst case condition." This condition will vary from watershed to watershed and also will depend on the pollutant under study. Substantial pollutant loads are washed into the receiving water during a storm and this may cause transient water quality problems. However, many pollutants cause long-term problems; in this case, worst case conditions would be defined as the sequence of activities (e.g., storms) which resulted in the long-term water quality problem.

It is suggested that investigation of the persistence and time frame associated with some storm-related pollutants may show that single storm analysis can be abandoned in favor of seasonal or annual runoff loads (generally a much simpler approach than storm-by-storm analysis). Rather than proceed directly to sophisticated modeling approaches, consideration of existing data and the persistence of pollutants may allow cost-effective short-cuts.

1. Pollutant Persistence and Impact Distance

Figure A-7 graphically presents the relative persistence of various stormwater constituents. Such constituents as floating solids, bacteria and viruses, have a relatively short persistence, ranging from hours to days. Those constituents which directly affect dissolved oxygen have a persistence span ranging from hours to months. Other constituents (e.g., suspended solids, nutrients, dissolved solids and metals) can remain in the aqueous system for relatively long periods of time (e.g., for years). Many of these constituents can settle out and accumulate in the benthic layers. These materials can be continually released or remain in the sediments until they become resuspended by turbulent conditions during high flow periods. Metals, pesticides and certain suspended solids can accumulate in the systems of aquatic plants and animals and have a cumulative, long-range toxic effect on aquatic biota.

The area affected by various stormwater-related constituents varies depending on such factors as the constituent's lifespan, stream's transport capability, and various other factors relating to stream hydraulics. Because of this, various areas of the stream network can be affected in different ways by a single storm. Figure A-8 schematically presents the relative distance affected by various stormwater constituents. Those constituents with relatively short persistence, such as floatables and bacteria, affect a relatively small area, ranging from extremely local to within a few miles downstream of the discharge point. The affected downstream area depends on stream transport factors. Impoundments and low stream velocities tend to impede

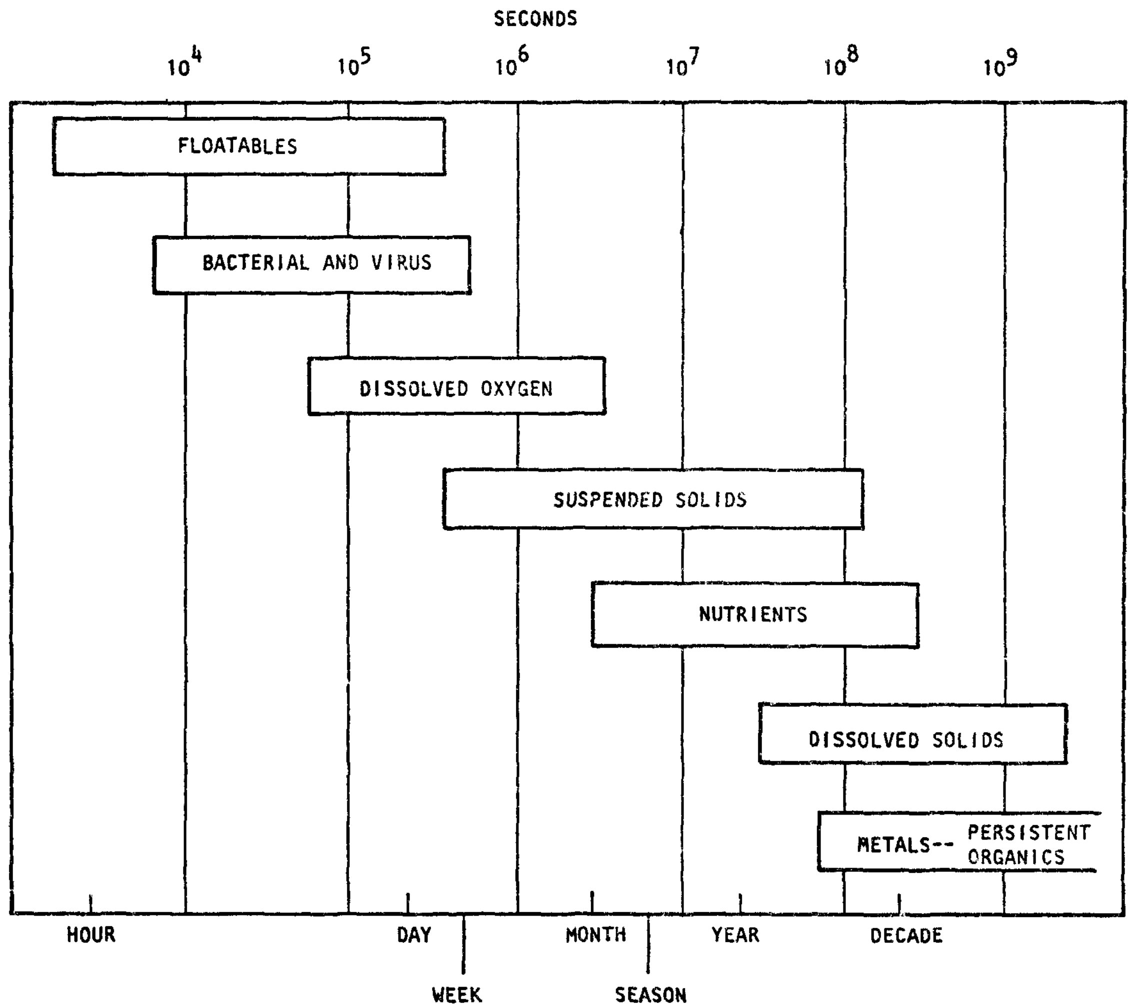

Figure A-7 STORMWATER CONSTITUENTS AND THEIR PERSISTENCE

SOURCE: Eugene Driscoll, "Instream Impacts of Urban Runoff," a paper delivered at the Urban Stormwater Management Seminar, Atlanta, Georgia, November 4-6, 1975

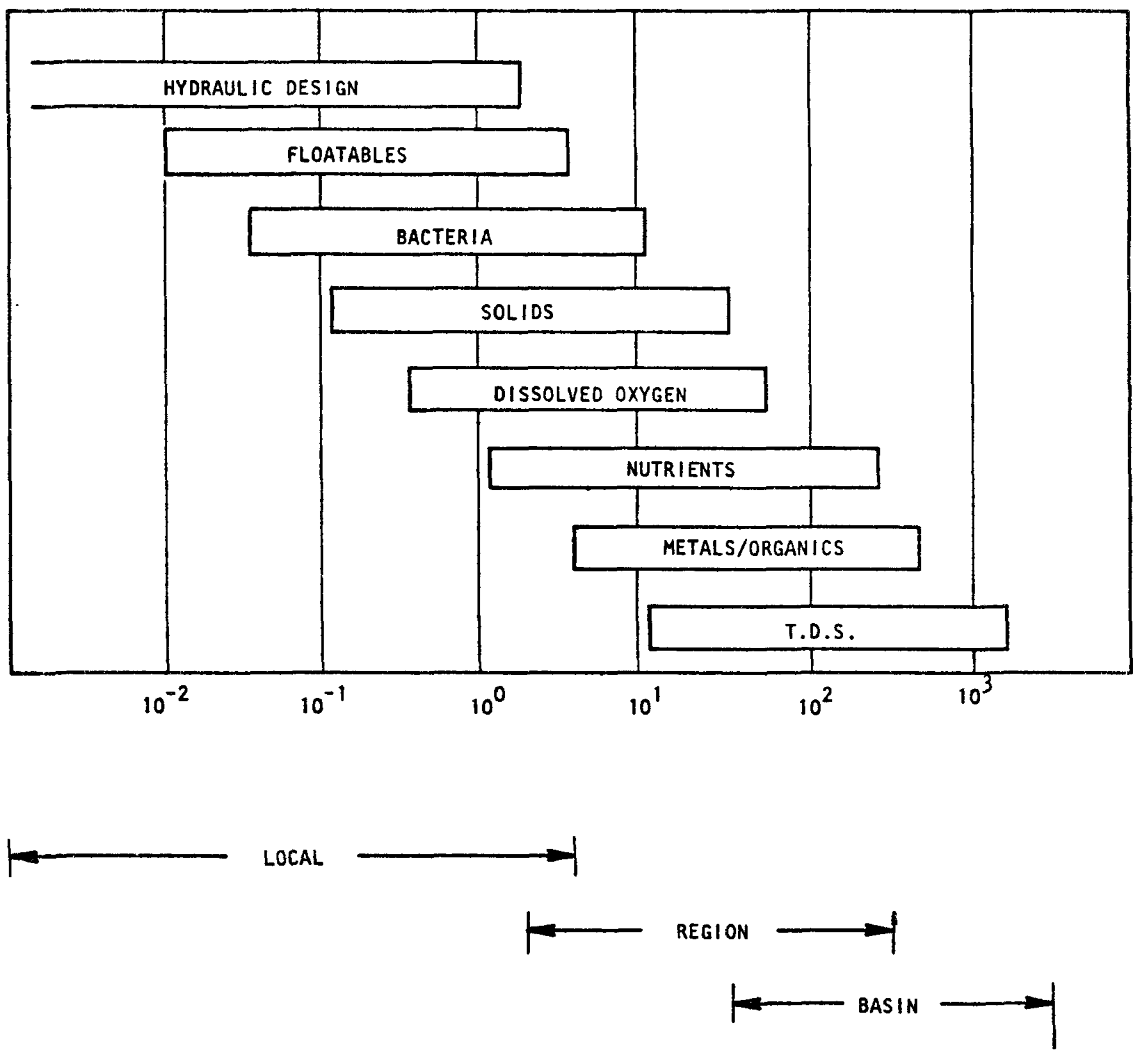

Figure A-8 STORMWATER CONSTITUENTS AND THEIR EFFECTIVE DISTANCE

SOURCE: Eugene Driscoll, "Instream Impacts of Urban Runoff," a paper delivered at the Urban Stormwater Management Seminar, Atlanta, Georgia, November 4-6, 1975 transport and thereby localize the effect of most constituents. Constituents with longer lifespans, such as nutrients, metals and organics, can eventually affect the entire downstream portion of the stream network.

2. Significance of Nonpoint Assessment and Water Quality Criteria

Table A-10 provides an assessment of stormwater-related constituents. Each constituent is described by its particular persistence, area affected, scope and significance. Examination of the table indicates that annual loading rates may be acceptable in dealing with several storm-related pollutants. Other constituents should be dealt with on a storm-by-storm basis _if_ a transient problem is caused by the pollutant of interest. Investigation of existing water quality data, if extensive enough, will often indicate that no transient problems exist. Analysis of biologic data is often helpful in this regard. BOD is a parameter that receives significant attention and, because it has a short persistence, an attempt is often made to model the transient BOD/DO event. Modeling may be appropriate in dense urban areas, combined sewered watersheds, etc.; it may not be cost-effective in suburban areas with fast moving streams. This consideration is discussed further in the next section. The persistence and impact distance of nonpoint pollutants also affect the selection of applicable water quality criteria. Generally, existing criteria are based primarily on long-term problems likely to occur during summer low flow periods (when point sources are the dominant load). These criteria may or may not be applicable to nonpoint sources.

Heavy runoff can produce two types of water quality conditions:

a. Pollutant concentration in the stream can be diluted due to large volumes of relatively clean runoff.

TABLE A-10

ASSESSMENT OF STORM RELATED CONSTITUENTS

	Storm Water Parameter	Persistence of Pollutant	Probable Area Effected: Slow Moving Stream	Probable Area Effected: Fast Moving Stream	Problem/Scope	Significance
1.	Floating Material	hours-weeks	local[1]	sub-basin[2]	individual storm event	impedance of flow and navigation, detrimental to aesthetics
2.	Bacteria & Viruses	days-months	local	sub-basin	individual storm event	potential health hazards
3.	BOD	days-months	local	sub-basin	individual storm event(4)	DO depletion
4.	Settleable Solids	days-years	local	sub-basin	annual loading	detrimental to biota and aesthetics
5.	Nutrients	months-years	basin-wide[3]	basin-wide	annual loading	eutrophication
6.	Metals/Organics	months-years	sub-basin	basin-wide	annual loading	toxic to biota, public water supply problem
7.	Total Dissolved Solids	months-years	sub-basin	basin-wide	annual loading	possible toxicity

[1] local - refers to immediate portion of stream and/or nearby impoundments.
[2] sub-basin - refers to the immediate stream and its impoundments.
[3] basin-wide - all downstream portions of the network to the mouth of the system.
[4] Individual event appropriate for BOD only if transient problems are identified; if problems are caused several days later in downstream water bodies, it may be more appropriate to deal with weekly or monthly BOD loads.

b. Pollutant concentration can be increased by highly contaminated runoff.

For the long-duration pollutants shown in Figure A-7 (heavy metals, nutrients, etc.) either condition may produce problems. The concern should not be so much with the peak loadings which occur with heavy runoff, but rather with the long-term, average loads. For these types of pollutants, steady-state water quality criteria may be appropriate (when applied to average conditions rather than peak storm conditions).

If the first condition is applied to the short-term pollutants listed in Figure A-7 (BOD and bacteria) then runoff is unlikely to cause a problem because these pollutants will decay and be assimilated in the stream. If the short-term pollutant concentration increases (Condition 2) a transient problem <u>may</u> occur.*

If, for example, a dissolved oxygen sag occurs due to BOD decomposition, a decision must be made on whether this sag is harmful and nonpoint controls are necessary. Comparison of the low DO with steady-state DO criteria is not appropriate because the criteria (say 4.0 mg/l) is generally based upon aquatic life reaction to several consecutive days of low DO levels. Post-storm DO levels may drop below 4.0 mg/l for several hours and then recover to 5-6 mg/l. The decision on whether a problem exists should be based on the impact of the short-term sag on aquatic life. Biological assessment can aid in this determination. Also, research, as depicted in Figure A-9, may lend itself to assisting in establishing water quality criteria applicable to short-term storms. The figure shows the mortality of trout as a function of short-duration DO levels. The figure is an example of how bioassay data based on laboratory tests may be presented; it does not

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* See following section for detailed discussion of BOD/DO relationship.

show antagonistic effects of other pollutants. Nevertheless, information similar to that shown in the figure could be applied to establish short-term DO conditions as follows:*

a. Establish percent mortality acceptable; this would have to be linked to storm frequencies.

b. Determine DO/time relationship of worst storm (i.e., runoff) condition occurring once a year. This can be approximated by examining existing data or receiving water modeling. For example, assume that this worst case condition results in a minimum DO of 1.0 mg/l for 50 minutes.

c. Referral to Figure A-9 indicates that a value of 1.0 mg/l for only 30 minutes causes 80% mortality.

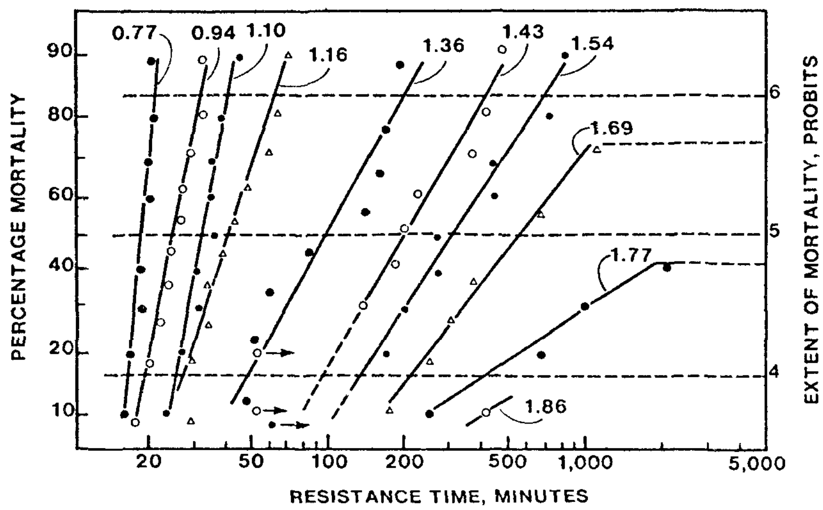

Figure A-9 TROUT MORTALITY TO LOW OXYGEN LEVELS

Note: Numbers applying to each line (0.77, 0.94, etc) denote dissolved oxygen in mg/l.

Source: Cairns and Dickson, 1973

* The example procedure is conceptual only; much more research is needed to develop "real-world" data similar to Figure A-9. Also, the effects besides mortality (reproduction, growth rates, etc.) are also ignored in the example.

Decomposition and Reaeration at High Flow: Depending on the physical characteristics of the receiving stream, climatic conditions, and the storm-related BOD load, the stream's dissolved oxygen levels may increase or decrease. The following paragraphs indicate that in relatively small, fast moving streams, BOD from storm runoff probably is not a problem. If the BOD is not decomposed by the time it reaches slower moving downstream water bodies (e.g., estuaries, impoundments), DO depletion problems may occur, depending on the assimilative capacity of the downstream body.

Both decomposition and reaeration rates are affected by a number of variables. The following paragraphs list a number of these factors and briefly describe the general impact of each factor on decomposition and reaeration rates. Special emphasis will be placed on those factors directly related to storm events.

The biological decomposition of organic matter is commonly conceptualized by the following equation:

$$L_t = L_o e^{-K_1 t}$$

where:

L_t = BOD at time t

L_o = initial (ultimate) BOD

K_1 = overall deoxygenation rate (day^{-1})

t = time since discharge (days)

The amount of decomposable matter in the stream is usually measured in terms of biochemical oxygen demand (BOD) which is defined as the amount of dissolved oxygen consumed in the bacterial oxidation of decomposable matter.

Reaeration can be defined as the replenishment of dissolved oxygen. This is basically a chemical and physical process, although some biological processes may come into play. Reaeration can be considered as a function of molecular diffusion and the following stream characteristics: depth, velocity, slope and channel irregularity. The reaeration rate is used to calculate the stream DO deficit which is commonly conceptualized by the following equation:

$$D_t = D_o e^{-K_2 t}$$

where:

D_t = DO deficit at time t

D_o = initial DO deficit

K_2 = reaeration rate (day^{-1})

t = time (days)

The reaeration rate (K_2) is considered a function of stream geometry.

$$K_2 = \frac{(C_1)\ (u)^{C_2}}{(H)^{C_3}}$$

where:

K_2 = reaeration rate

u = stream velocity

H = stream depth (ft)

C_1, C_2, C_3 = empirical constraints

While the decomposition is basically the biological process, reaeration can be termed a physical and chemical process.

Table A-11 lists general factors which affect the decomposition (K_1) and reaeration (K_2) rates and indicates the general impact of each parameter on these rates. Both temperature and turbulence effect decomposition and reaeration. Flow has a negative impact on reaeration and can increase or decrease the decomposition rate depending on whether the runoff concentration is higher or lower than the in-stream concentration. The table also indicates that the in-stream BOD concentration directly affects the decomposition rate.

The ultimate allowable BOD loading generally increases as flow increases or as temperature decreases. This is understandable since an increase in flow will generally improve a stream's assimilative capacity due to increased dilution while a decrease in temperature will lower the decomposition rate, and therefore, allow larger BOD loads without depleting additional DO. Figure A-10 graphically presents the relationship between the reaeration rate (K_2) and flow. A number of researchers have developed specific reaeration equations based on observations in various types of streams. These various equations have been plotted against flow to reflect the wide range of reaeration rates that have been observed in different types of streams for different flow periods. It should be noted that most of the reaeration rates are observed to decrease as flow increases.

TABLE A-11

EFFECT ON STREAM DECOMPOSITION AND REAERATION RATES OF INCREASING VARIOUS FACTORS

Factor Increased	Effect on Decomposition Rate	Effect on Reaeration Rate
Temperature	Increase	Decrease
Turbulence	Increase	Increase
Flow	Decrease*	Decrease
BOD Concentration	Increase	No direct effect
Dissolved Oxygen Concentration	Increase	Decrease

* Assuming dilution of in-stream BOD concentration

Source: Betz Environmental Engineers, Inc.

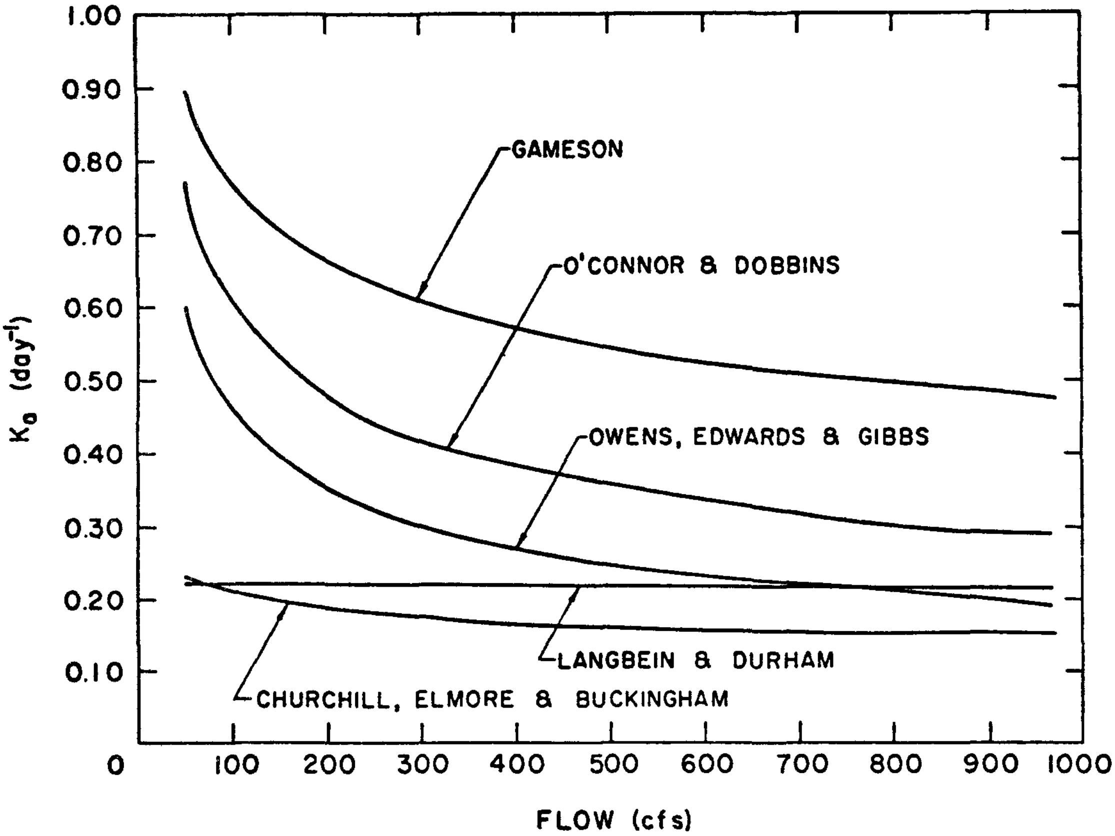

Figure A-10 KA vs. FLOW AS CALCULATED BY VARIOUS PREDICTION EQUATIONS

Source: Whipple, et al, 1974

Table A-12 presents various factors directly attributable to storms and their impact on decomposition rate, reaeration rate, and the likely overall impact on the DO concentration in slow and fast moving streams. The overall impact of a storm on the dissolved oxygen concentration will vary depending on the physical characteristics of the stream.

For streams exhibiting moderate to fast velocities, the DO profile during a storm would reflect an initial upward surge in the dissolved oxygen profile due to the highly oxygenated runoff entering the system. This initial pulse is generally followed by a gradual return to the pre-storm DO level. In moderate to fast moving streams, most of the additional BOD entering the stream is flushed from the system before it has a chance to exert an oxygen demand on the stream. In slower moving streams, the DO profile would be similar, except that the return-to-normal stage would also include a possible dissolved oxygen sag below the pre-storm level due to the exertion of material that had not been flushed from the system.

An illustration of this dissolved oxygen sag is provided in Figure A-11 which plots the dissolved oxygen concentration and the corresponding stream flow observed during three typical storms on the Passaic River at Little Falls, New Jersey. All three storms indicate an initial surge of dissolved oxygen followed by a gradual sag. The dissolved oxygen usually continues to decline below the level which prevailed at the beginning of the storm, reaching a minimum value 4-9 days after the hydrograph peak. The DO concentration then recovers while the hydrograph is still falling. This general path was observed for 80% of the recorded storms at Little Falls occurring between May and October 1971 to 1973. The Passaic River is a lethargic stream containing numerous benthic deposits. One explanation of the dissolved oxygen sag is that oxygen demanding material is scoured from these benthic deposits and resuspended during the course of the storm, and exerts a DO demand during the post-storm period as stream velocities return to normal.

Influence of Benthic Deposits on Water Quality: The above example indicates that benthic deposits can have significant impacts on a stream's dissolved oxygen levels. Benthic deposits can also be sources of nutrients, heavy metals and other deleterious parameters. In the above case, it was indicated that the DO depletion was from the resuspension of deposits by high flows following a storm. Benthic deposits may also cause oxygen depletion during low

TABLE A-12

EFFECTS OF STORM EVENT ON
DECOMPOSITION, REAERATION AND IN-STREAM DISSOLVED OXYGEN

Storm Factor	Effect on Decomposition (K_1) coeff.	Effect on Reaeration (K_2) coeff.	Overall Impact on DO Concentration: Slow Moving	Overall Impact on DO Concentration: Fast Moving
Flow Increase				
Runoff BOD lower than in-stream BOD concentration (dilution)	decrease	decrease	increase	increase
Runoff BOD higher than in-stream BOD	increase	decrease	decrease	increase
Turbulence	increase	increase	decrease	increase
Scouring	increase	no direct impact	possible decrease	no immediate impact
Runoff DO*	possible increase	possible decrease	temporary increase	
Runoff Bacteria	possible increase	no direct impact	possible decrease	no immediate impact
Storm related benthic deposits	local inc.	no direct impact	possible decrease	no immediate impact

*Generally, runoff DO is near saturation

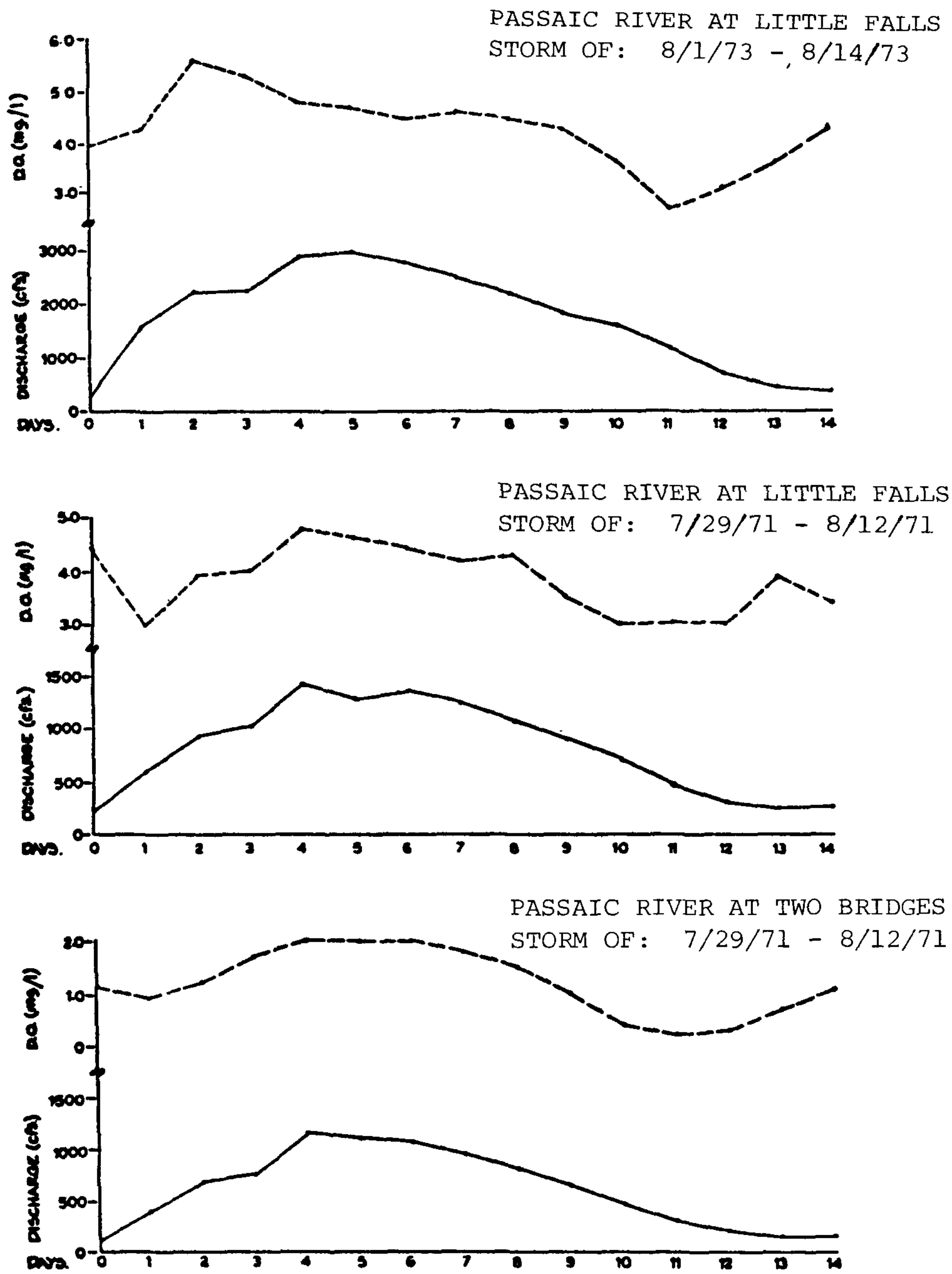

Figure A-11 DISSOLVED OXYGEN PROFILES OF PASSAIC RIVER FOLLOWING STORM

Source: Betz Environmental Engineers, Inc.

flow, steady-state conditions by releasing organic nitrogen and ammonia from the benthic layer, which then undergoes decomposition in the stream. Table A-13 presents typical oxygen uptake rates of sediment deposits.

Ogumrombi and Dobbins (1970), showed that two major processes exert oxygen demand on the water:

1. Addition of BOD from benthic deposits. The rate of this addition is designated as L_a (mg/l/day).

2. The removal of DO to satisfy the BOD of organic material within the top aerobic layer. The net rate of removal is designated as D_b (mg/l/day).

The authors presented data which indicated that both L_a and D_b decrease with time. This is depicted in Figure A-12, which shows BOD and the oxygenation rate of the supernatent effluent stream.

TABLE A-13

AVERAGE VALUES OF OXYGEN UPTAKE OF RIVER BOTTOMS

	Uptake (gms O_2/m^2 - day) @ 20°C	
Bottom Type and Location	Range	Approx. Average
Sphaerotilus - (10 gm dry wt/m^2)	-	7
Municipal sewage sludge-outfall vicinity	2-10.0	4
Municipal sewage sludge - "Aged" downstream of outfall	1-2	1.5
Cellulosic fiber sludge*	4-10	7
Estuarine mud	1-2	1.5
Sandy bottom	0.2-1.0	0.5
Mineral soils	0.05-0.1	0.7

* Calculated from reported uptake values of 2-5 and 3.5 gms/m^2/day at 11°C.

Source: Thomann, R. J., "Systems Analysis and Water Quality Management," McGraw-Hill, 1972.

Review of Ogumrombi and Dobbins data demonstrates that sludge depth has a significant impact on both parameters, whereas retention time does not. The effect of depth can be seen from Figure A-13, which shows a mass curve of total oxygen consumed. The total oxygen is the sum of the oxygen demand by the benthic deposits plus the oxygen consumed through decomposition of the BOD added to the supernatent water.

Let us use Figure A-13 in a hypothetical example to demonstrate the significant impacts of controlling the oxygen demand of benthic sources. Suppose that we have a stream in which benthic demand is a significant component of the total oxygen demand and control of benthic sources is being investigated. Let us further assume that the benthic problem is a long-term one and that the 36-day values presented in the figure are the parameters of interest. Our existing sludge depth is 7.62 centimeters and exerts the total oxygen demand of 27 milligrams per square centimeter. Computations indicate that we must reduce the oxygen demand of the benthic layer to 16 milligrams per square centimeter. The figure shows that in order to cut the oxygen demand by a factor of less than half, the sludge depth must be cut by a factor of 3 (down to 2.54 centimeters).

Other conclusions pertinent to the study of benthic demands are:

1. On the average, L_a appears to be about 28% of D_b in terms of mg/l/day.

2. The value of L_a and D_b for a fresh sludge deposit which is not continuously being replenished are gradually reduced with time.

3. Both L_a and D_b increase with increase in depth of sludge deposits; however, they do not vary in direct proportion to the depth of the deposit. The values of these parameters per unit depth decrease as the depth of the deposit increases.

4. When the environment in the supernatent water is aerobic, L_a and D_b are independent of the concentration of DO in the supernatent water; however, in an anaerobic environment, the value of D_b is

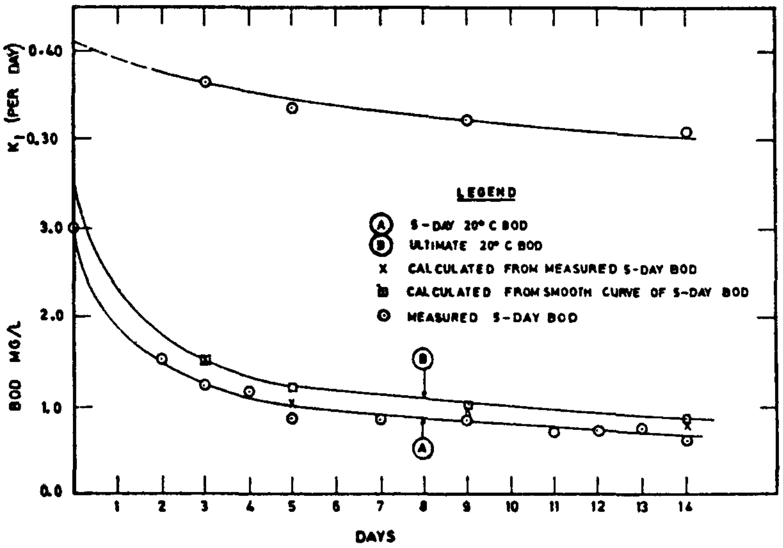

Figure A-12 BOD AND DEOXYGENATION RATE CONSTANT OF EFFLUENT STREAM FLOWING OVER SLUDGE AND BED (7.62 CM SLUDGE DEPTH)

Source: Ogurombi and Dobbins, 1970

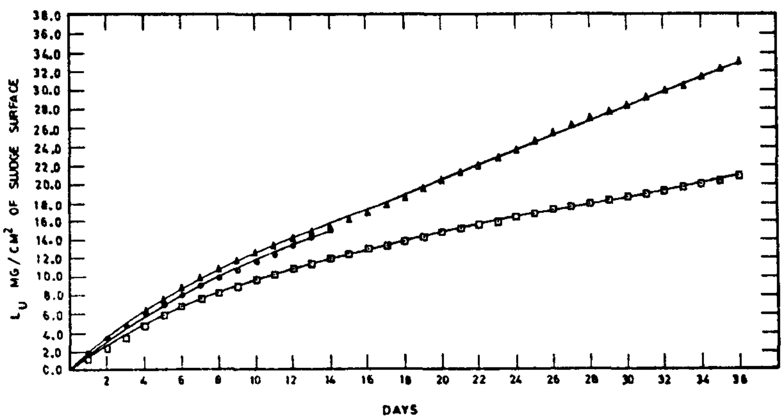

Figure A-13 MASS CURVES OF TOTAL OXYGEN CONSUMED, Oc, BY BENTHAL DEPOSITS

○ REACTOR I △ REACTOR II SLUDGE DEPTH 7.62 CM

□ REACTOR III ▽ REACTOR IV, SLUDGE DEPTH 2.54 CM

Source: Ogurombi and Dobbins, 1970

limited by the rate at which the DO is applied to the supernatent water, while the values of L_a are relatively unaffected.

A later article (Fillos and Molof, 1972) supported most of the findings of Ogumrombi and Dobbins. Some of their conclusions were:

1. A critical sludge depth of 3-4 inches exists; at depths greater than this, oxygen uptake rate is independent of depth.

2. BOD, PO_4 and NH_3 are released more rapidly as supernatent DO drops below 2-1.5 mg/l.*

3. The conclusion on BOD differs from the earlier study. The more recent study concluded that although D_b was generally dominant, L_a became a major factor affecting the oxygen economy of the stream when DO was greater than 1.5 mg/l.

Fillos and Swanson (1975) studied the release rate of nutrients from river and lake sediments. The authors indicate that release of nutrients, such as ammonia and phosphorus, may be sufficient to maintain the eutrophic state of waters long after external sources have been eliminated.

Benthal deposits were collected and analyzed from Muddy River and Lake Warner, both in Massachussetts. Phosphate and iron releases were found to be heavily dependent on the presence of a thin aerobic layer on the benthic blanket. Anaerobic conditions resulted in a sudden increase in phosphorus and iron releases. The orthophosphate release rate from Muddy River sediments averaged 9.6 mg/day/sq meter (as P) under aerobic conditions. Lake Warner demonstrated the following orthophosphate release rates:

Aerobic (avg) 1/2 mg/day/sq meter

Anaerobic (max) 26 mg/day/sq meter

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* This may be very important in nutrient analysis of impoundments where DO at bottom may be close to zero. Another ramification is that lower DO (below 2 mg/l) results in more release of BOD and NH_3, which further exacerbates the DO situation.

Ammonia levels were not found to vary with aerobic/anaerobic conditions.

The following release rates were reported for ammonia nitrogen (as N):

Muddy River	15 mg/hr/sq meter
Lake Warner	5 mg/hr/sq meter

It is clear from this study that short-duration intermittent anaerobic conditions in the immediate overlying water are capable of causing dramatic increases in the release rates of nutrients from sediments. Such anaerobic conditions may be localized and may result from the oxygen demand of the sediments themselves. Therefore, in any lake management procedure, the sediments must be treated as intermittent sources of nutrients and as a continuous sink for oxygen.

Types of Water Bodies and their Significance: Pollutant effects on water chemistry and aquatic ecology will vary significantly, depending on the type of water body the pollutant is discharged into. The three water bodies discussed below--streams, lakes, impoundments--each have hydraulic, ecological and physical differences which affect the fate of pollutants. The stream discussion which follows focuses on free-flowing streams rather than estuaries. Estuaries, being influenced by tidal action, may have pollutant transformation taking place which have characteristics similar to streams and impoundments and unique to estuaries.

This discussion will deal primarily with the mechanisms of pollutant transport and transformation of sediment and nutrients. Discussion of these pollutants will indicate the kinds of phenomena that occur when other types of pollutants are discharged to these waters.

1. Streams

The fate of the sediments entering cannot be determined *a priori* without knowing the characteristics of the basin. Slope, water velocity, particle type and size all play an important role in sediment transport. At best, a few generalities can be made.

a. As velocity increases, the distance of transport increases

b. Larger and more dense particles settle out first

c. Sedimentation occurs in pool areas

d. Turbulence will act to maintain particles in suspension*

The interaction between water velocity and sediment transport is a complex relationship. In general, as the velocity increases the rate of settling decreases; simultaneously, bank scour may also increase, causing an increase in the total solids being transported in the stream. According to Leopold (1968) a stream 2 ft. deep and 11 ft. wide carrying 55 cfs at bankfull stage would have to increase to 3 ft. by 20 ft. to accommodate a 2.7 times increase in maximum flow. An increase of this magnitude could occur as a result of development. These figures indicate that even if erosion were controlled during development, impervious surfaces could cause increases in flow that would result in higher sediment loadings, at least temporarily. Sedimentation problems could also occur as a result of shifting substrates and thereby cause a loss of certain aquatic species.

An example of the difficulty of relating suspended solids data to sedimentation is provided by Hoak (1959). At Braddock, PA. the mean suspended solids load in the Monongahela River is 1,924 tons/day; the volume about 345 acre-ft/mile. If the sediment load settled and stayed at this point the channel would be filled in in a little less than one year (Hoak, 1959). This example indicates that sedimentation occurs, but constant shifting of this material also occurs.

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* There is some evidence to suggest turbulence may in some cases increase agglutination of particules, increasing settling capacity. Turbulence can also result in suspended matter becoming dissolved. See Hoak, 1959.

A more general idea of where sedimentation problems will occur in a stream can probably be determined from information on soil types and by locating pool areas where water velocities decrease (the latter from on-site observation and topography maps).

Much of the transport of nutrients in streams is closely associated sediment transport. Phosphorus in particular is readily adsorbed onto soil particles. Nitrogen is also transported on soil particles but tends to be more soluble. The fate of these nutrients in the stream beds is dependent on several factors. Phosphorus and nitrogen in forms associated with particulate matter will disperse according to the mechanisms of particle dispersion. The dissolved fractions will either be immediately absorbed by aquatic vegetation or carried downstream. Factors affecting this process are:

water velocity and turbulence
microorganisms and vegetation
turbidity
temperature
particle size and type
channel characteristics
temperature

The dynamics of phosphorus in streams is discussed in greater detail by Ryden et al (1972).

Assuming no additional inputs of nutrients, concentrations decrease as materials proceed downstream. This is due to uptake by organisms and dilution by the entrance of cleaner water--assuming the other inputs are in fact cleaner.

The extent to which nutrients settling out affect the stream depends on the particular situation. During storm conditions with accompanying high flows, sediment material often becomes resuspended, which essentially acts as a new input into the stream.

2. Lakes

Determining the amount of sedimentation occurring in lakes is even more difficult than in stream systems. Although it may be assumed that lakes act as a settling basin for incoming streams, and therefore, essentially all entering suspended matter eventually settles on the bottom, this information does not solve the problem. Nonpoint sources are generally from diffuse sources of runoff that are difficult to measure. Even where inputs can be measured, current patterns and eddies which may not be constant make it difficult to determine where sedimentation will occur. Lake turnover may resuspend solids, creating further impacts. The initial point of entry is usually a major sedimentation point due to the abrupt decrease in velocity at this point. However, it may not be the only area affected.

The dynamics of nutrients in lakes and reservoirs is incompletely understood. In an essentially closed lake system, the nutrients entering *remain in the system;* they are either utilized by the vegetation, settle out, or remain in solution. Which path is taken depends on the water body characteristics and the nutrient form. Nitrates and phosphates in solution are readily available for plant growth. This is also true of ammonia which can be utilized as a nitrogen source by many types of aquatic vegetation. Ammonia may also be oxidized to nitrate before being incorporated into plant biomass.

Nutrients associated with particulate matter tend to settle out and become part of the sediments, but a number of factors may affect this process. Turbulence will tend to keep particles suspended and may also result in nutrients going into solution. Current patterns and eddies may cause suspended matter to settle out far from the point of input, making impacts difficult to determine.

To what extent nutrients tied up in the sediments are available to aquatic life is not definitely known. Phosphates in particular tend to form very stable complexes with elements such as iron and aluminum. Some evidence suggests that sediment runoff into reservoirs and lakes may actually reduce dissolved ortho-phosphate levels by forming complexes that precipitate due to the rapid equilibrium between water and sediments (Heinemann, in Ackermann et al, 1973). However, these sediments could later supply phosphorus to aquatic organisms when the sediments are stirred up during turnover, turbulence, or even by bottom feeding fish such as carp and catfish.

3. Impoundments

In impoundments, calculations of sedimentation can be as difficult to obtain as sedimentation estimates for lakes. Although the amount of sediment existing through the discharge stream may be measurable, problems similar to those found in lakes remain. Assuming that the entrance and exit of suspended solids can be determined, it is then necessary to consider retention time in the impoundment and whether the impoundment stratifies and undergoes turn-over, resuspending solids.

In spite of the complexities involved, a number of studies have been done on sedimentation in reservoirs. From these studies a few general trends have been observed:

a. There is an inverse relationship between size of reservoir and rate of filling in.

b. Particules tend to be deposited in a gradation of particle sizes along the longitudinal axis of the reservoir. Coarser and heavier particles are dropped in the headwater and finer sediments are deposited toward the dam. (Note: This is affected by: water level, temperature and dissolved minerals, mineral composition of the sediments, especially clay-sized fraction; volume relationship of reservoir storage capacity and influent water; configuration of basin; and amount of sediment previously deposited.)

The factors affecting sedimentation in reservoirs are discussed in greater detail by Glymph (in Ackerman _et al_, 1973). Data on reservoir sedimentation in the United States are provided by Dendy _et al_ (in Ackermann _et al_, 1973). These data support the generally held hypothesis that, as drainage area increases, sediment yields decrease. Therefore, the greatest sedimentation problems tend to occur in small upland reservoirs. A summary of sediment accumulation data for the reservoirs surveyed is presented in Table A-14.

There are some differences in nutrients between natural lakes and impoundments, although the basic principles apply. Impoundments are not a closed system and many nutrients may be removed due to greater concentrations near the bottom. There may also be a greater input of

TABLE A-14

SEDIMENT ACCUMULATION PER UNIT OF NET DRAINAGE AREA

Drainage Area		Number of Reservoirs	Average Annual Sediment Accumulation*		Median Annual Sediment Accumulation*	
mi^2	km^2		ac ft/mi^2	10^3 m^3/km^2	ac ft/mi^2	10^3 m^3/km^2
0 to 5	0 to 12.9	648	1.56	0.74	0.82	0.39
5 to 10	12.9 to 25.9	70	1.45	0.69	0.33	
0 to 10	0 to 25.9	718	1.55	0.74	0.80	0.38
10 to 10^2	25.9 to 259	189	0.71	0.34	0.44	0.21
10^2 to 10^3	259 to 2,590	103	0.53	0.25	0.27	0.13
10^3 to 10^4	2,590 to 25,900	70	0.38	0.18	0.26	0.12
10^4 to 10^5	25,900 to 259,000	25	0.36	0.17	0.39	0.19

*Annual sediment accumulation rates are based on the net drainage area (sediment-contributing area).

Source: Dendy et al, (Ackerman, et al, 1973) nutrients into a reservoir system because of the drainage pattern. Rivers characteristically carry higher concentrations of nutrients than lakes. By damming a river, these higher concentrations are retained in the system. The addition of nonpoint sources of nutrients to such a system could accentuate the buildup if flows are never high enough to flush the system.

Some Comments on Probable Controls: A recent paper by Barker (1974) offers several ideas on implementation constraints of nonpoint controls and how they might affect the study of nonpoint problems. They are presented here to give a perspective; adoption of Barker's convictions may have significant ramifications on the type of nonpoint analysis pursued.

Barker turns his focus beyond the investigation of nonpoint pollution sources to the implementation and enforcement of justifiable controls. In doing so, he argues that, because of implementation constraints, we can usually determine the control recommendations which will be coming from 208 programs after all the nonpoint study, assessment and analysis is completed. Barker's conclusions are indeed controversial and, by his own admission, "perhaps in excess." However, they are valuable in that they run counter to the conventional wisdom and may force rethinking of some preconceived notions.

The following points summarize some of Barker's conclusions:

1. Nonpoint controls for agriculture will consist of the same principles the Soil Conservation Service has espoused since the 1930s unless the economic structure of farming is drastically redefined.

2. The only practical controls for most urban runoff problems are related to sediment and erosion.

3. Mathematical modeling of nonpoint wastes is a very inexact science and may not be a cost-effective approach.

4. Legal defense of recommended control measures is extremely important because it is likely that controls will be challenged by an uncooperative developer or land owner. Thus, it is imperative that nonpoint recommendations be based upon accurate supportive data and an acceptable methodology.

Biological Effects of Nonpoint Source Pollutants

A clear understanding of the biological impacts of nonpoint source pollutants is necessary to adequately assess the severity of the nonpoint problem. Determining water quality criteria applicable to nonpoint phenomena and the nonpoint pollutant reduction goal also require a thorough knowledge of pollutant impact on water ecology.

Unfortunately, little information is available on the specific effects of nonpoint source pollution on the biological systems of water bodies. Although there are special circumstances associated with nonpoint source pollution, the source of an adverse input has no effect on the response of the organisms involved. Therefore, general responses of organisms to various pollution substances associated with nonpoint source will be discussed. In addition, the special aspects associated with nonpoint pollution will be considered in these discussions.

The following discussion will focus on the biological impact of six conditions/pollutants which are associated with nonpoint sources:

Low Oxygen Conditions

Flow Effects

Suspended Solids

Nutrients

Toxic Substances

Road Salts

Responses to Low Oxygen Conditions: A decrease in dissolved oxygen is one of the problems that frequently accompanies nonpoint source pollution. The effect of this decrease on aquatic biota depends on the amount of the decrease, the type of organism, the duration of the oxygen depression, and whether other adverse conditions accompany the oxygen drop.

The responses of fish to short term low oxygen conditions are not well defined. Doudoroff and Warren (1962) summarized previous studies and concluded that little mortality would be expected at concentrations near and above 3.0 mg/l, even for prolonged periods, provided other harmful agents were not present. A concentration of 2.0 mg/l may be critical for sensitive forms, but at low temperature, concentrations as low as 1.0 mg/l may be tolerated by acclimatized fish. The key factors affecting tolerances appear to be conditioning of the organism, temperature, and the presence or absence of other adverse factors. Fish have been found to grow little, or not at all, in the presence of abundant food at reduced oxygen concentration even though these levels could be tolerated for long periods of time (Doudoroff and Warren, 1962). Specific species were not named in the above summary.

In another study, carp and buffalo were reported in water carrying as little as 2.2 mg/l dissolved oxygen; however, a variety of fish species were found only where a minimum of 4.0 mg/l was present. The greatest variety of fish were present in waters carrying 9.0 mg/l dissolved oxygen (Ellis, 1957).

It is apparent from the available information that many factors affect the response of fish to a decrease in dissolved oxygen. Acclimatization was a factor in Doudoroff's findings (1962). This means fish gradually exposed to a gradient of low dissolved oxygen concentration will have a better chance of surviving than fish in an environment where the dissolved oxygen undergoes a sudden drop, which is frequently the case in nonpoint source pollution. Temperature is also a critical factor, with high temperatures accentuating the effects of oxygen stress. The presence of other factors, such as suspended matter and toxic substances, that frequently accompany low dissolved oxygen conditions, also reduce tolerances to oxygen stress.

Seasonal factors must also be considered. High temperature, low flow periods would be more critical than low temperature, high flow periods. Oxygen-demanding substances would also be more critical during spawning seasons because of the greater susceptibility of hatchlings and fry to oxygen stress.

The response of invertebrates to low oxygen conditions is affected by the same factors as those affecting fish response. Table A-15 lists the results of laboratory studies conducted in Montana and Utah. It is apparent that responses of different species, or even the same species from

TABLE A-15

MACROINVERTEBRATE RESPONSE
TO DISSOLVED OXYGEN CONCENTRATIONS

	96-hour TL_m				Long Term Effects						
Order	Mean DO mg/l	Range	No. Species Tested	Species Type	Species Locale	Mean DO mg/l	Range	Avg. Survival (days)	Range (days)	No. Species Tested	Avg. Percent Survival
Plecoptera (stoneflies)	3.04	1.6-3.9	8	Stream	Montana	4.9	4.4-5-8	62	69-111	4	42
					Utah	2.8	2.0-4.2	14	4- 41	5	30
Ephemeroptera (mayflies)	3.6	1.8-5.2	4	Stream	Montana	4.6	--	30	--	1	30
				Lake	Utah	3.3	3.3-3-8	10	3- 21	3	40
Trichoptera (caddisflies)	2.86	1.7-3-8	7	Lake	Montana	4.0	3.2-4.8	85	50-120	2	40
					Utah	3.1	1.4-5.2	48	16- 91	4	56
Diptera (flies)	3.2	--	1	--	Montana	2.4	--	40	--	1	90
					Utah	2.2		92		3	
Amphipoda	3.0 (80% survival)	--	1	--	Montana	2.8	--	20	--	1	50
Odonata (dragonflies)					Utah	2.2	1.1-3.0	39	21-100	2	32

Source: Gaufin, 1973

different localities, exposed to different laboratory conditions are highly variable.

Temperature can be extremely critical in determining tolerance. It has been estimated that aquatic organisms at an environmental temperature of 10°C can withstand a reduced oxygen concentration about 2.4 times as low as at a temperature of 15.6°C. Changes in flow are believed to have similar effects on survival at different oxygen concentrations. One study demonstrated that a gradual reduction in oxygen with a water flow of 0.06 ft/sec produced a 50 percent stonefly mortality, while similar conditions with a water flow of 0.25 ft/sec produced no mortality (Gaufin, 1973).

Flow Effects: The physical aspects of the increase in water volume and velocity are important considerations; however, these aspects are difficult to separate from the chemical considerations. Flow and suspended solids are particularly interrelated. An increase in flow can cause stream bank scouring that results in an increase in suspended solids concentrations without an external source of solids. The effects of bank scour on the biota of a stream is essentially the same as suspended solids entering from surface runoff.

The increase in velocity alone also affects the biota. Aquatic plants and animals are pulled off the substrate and washed downstream. The type of substrate also affects the degree of scouring. Small stones, gravel, or sand substrates are easily disrupted, while large rocks are less apt to be moved and may provide refuge for mobile aquatic organisms. The time for recovery or recolonization following a storm depends on the degree of scouring, the time of year and type of organisms. During the active growing season--spring--more rapid recovery would occur than in the fall. Although it is impossible to precisely predict how long it will take a stream to recover, an approximate recovery time may be from 2 to 4 weeks under normal circumstances.

Suspended Solids: Suspended solids (SS) can have a detrimental effect on aquatic communities. The turbidity caused by SS can inhibit light penetration that is necessary for photosynthesis, causing a decline in vegetation. The abrasiveness of the particles can damage plant bodies, and as the particles settle, attached vegetation is smothered.

Settleable solids blanket animals, plants and their habitats, either killing the organism or rendering the habitats unsuitable for occupation. Suspended solids also serve as a transport mechanism for pesticides, heavy metals, and other toxic substances which are readily sorbed onto soil particles.

Macroinvertebrate and fish species can be directly and indirectly affected by SS. Changes in habitat may occur because of destruction of vegetation that eliminate species, or food sources may be eliminated (Hynes, 1974). Suspended solids may directly affect species due to abrasion on delicate membranes and gill structures.

The specific biological effects depend on the nature of the suspended solids. If the solids have a high organic content, a high BOD may be associated with the SS. In addition, different particle types have different settling characteristics and these properties along with the flow will determine the zone of influence of the entering solids.

It has also been demonstrated that subtle changes in substrate type can affect aquatic organisms. Rocky substrates characteristically support the most diverse communities. One of the main reasons is apparently the availability of interstitial habitats that are utilized by many species (Brussen and Prather, 1974). Even a small degree of sedimentation can fill these spaces and eliminate or reduce species populations. The extent of the change is dependent primarily on the degree of sedimentation.

EPA has proposed a maximum limit of 80 mg/l SS in fresh water (EPA, 1973). There is no evidence that concentrations of suspended solids less than 25 mg/l have any harmful effects on fisheries (EPA, 1973). Waters containing 25 to 80 mg/l should be capable of supporting good to moderate fisheries, whereas concentrations greater than 80 mg/l are unlikely to do so.

<u>Nutrient Enrichment</u>: The main effect of nutrient enrichment is to increase aquatic vegetation. To what extent plant biomass will increase is difficult to determine because the question of what constitutes a limiting concentration of nitrogen or phosphorus has never been adequately answered. Sawyer (in Harms and Southerland, 1975) reported that concentrations of 0.01 mg/l of soluble phosphorus and 0.30 mg/l of inorganic nitrogen were sufficent to support

algal blooms in Wisconsin lakes when other environmental factors were optimum. Sylvester (in Harms and Southerland, 1975) reported limiting concentrations of 0.01 mg/l phosphorus and 0.2 mg/l nitrogen for Green Lake in Seattle, Washington.

For streams, Mackenthus (in Harms and Southerland, 1975) recommended that total phosphorus concentrations not exceed 0.1 mg/l (as P) in streams and should not exceed 0.05 mg/l P in streams entering a lake or reservoir. However, a study by the Federal Water Pollution Control Administration reported that total phosphorus concentrations exceeded 0.05 mg/l P in 48 percent of the U.S. rivers sampled. A Public Health Service study reported that an average of 77 percent of the stations sampled on U.S. rivers contained at least 0.1 mg/l PO_4 (0.03 mg/l as P) and 60 percent contained nitrate concentrations greater than 1.4 mg/l NO_3 (Harms and Southerland, 1975).

It should also be pointed out that the 0.01 mg/l of soluble phosphorus limiting concentration reported by Sawyer (in Harms and Southerland, 1975) and Sylvester is the detection limit for the Standard Methods colorimetric analysis customarily employed. There is little information on the effects of concentrations below this limit in water quality analyses. Perhaps the real answer lies in the following statement: "At this time, no procedure for evaluating nutrient supplies and detecting growth-limiting factors in lakes and streams seems to have been developed to the point of general reliability and usefulness" (Gerloff, 1969).

Established "threshold" concentrations are best used as a point of reference to indicate whether a given nutrient concentration may present potential or existing problems. A single parameter value is not sufficient to determine whether excessive aquatic growth will occur.

The form the nutrients take is important in determining effects on water quality. Ryden _et al_ (1972) discussed the effects of different forms of phosphorus. It was pointed out that much of the phosphorus that is exported from watersheds may be in biologically unavailable forms, such as apatite. The percentage of biologically unavailable forms is often related to soil type or the soil horizon exposed to erosion. Phosphorus in erosion from the lower soil horizon is to a great extent apatite. The difference between dissolved and particulate forms of phosphorus is also important. Measurements of total phosphorus concentration do not indicate how much phosphorus is readily available to aquatic vegetation. For this reason, dissolved phosphorus measurements are better indicators of immediately available phosphorus.

A large percentage of the nutrients associated with nonpoint source are associated with soil particles. An immediate algal response following runoff of this type would probably not occur. Whether these nutrients would become available at a later time depends on the chemical and biological characteristics of the water (see discussion of suspended solids). Nutrients entering in a dissolved state may be more immediately available, although a lag phase of two weeks was reported between the discharge of storm water into a lake and a large increase in phytoplankton biomass. However, an almost immediate increase in metabolic activity was noted (Knauer, 1975). This delay in biomass increase may be due to two factors: (1) the growth rate of the organisms, and (2) the time required for biotic recovery following high flow or storm conditions.

Toxic Substances: The toxicity of any substance is dependent on several factors:

Concentration of the metal

Type of organism

Type of metal compound

Synergistic and antagonistic effects

Physical and chemical characteristics of the water body

Because of the complexities involved, no single value can be used as an absolute to predict the effects of a toxic substance in a water system. The concentrations and quantities entering the system are frequently difficult to quantify, particularly where nonpoint sources are concerned. It is also difficult to determine the mixing characteristics and transport mechanics in the water body. Assuming these aspects can be dealt with, the toxicity of most substances to aquatic life is not clearly defined.

The majority of the information available on the effects of toxicity on aquatic organisms is based on bioassay tests which are carried out under controlled conditions that seldom occur in nature. This type of information is useful only as long as the limitations are considered. To use the results of bioassay tests as absolutes in determining whether a given concentration will be harmful in a natural environment is inappropriate. Typical bioassay tests do not measure behavioral modifications that may affect productivity or the possibility of lowering an organism's resistance to other adverse impacts, such as disease and/or parasites. Bioassay information is, however, useful for indicating potential problem areas.

Table A-11 gives an indication of the range of concentrations that have been reported as harmful or non-harmful to specific aquatic organisms. The problems involved in measuring toxicity are illustrated by the conflicting results that have been reported (Table A-16). The discrepancies do not necessarily reflect "right" or "wrong" answers, or even good or bad testing techniques, but rather the existence of unmeasured variables in testing procedures. In addition, threshold values recommended by EPA are given in the text. In most cases, these values are well below recorded acute lethal concentrations and are designed to prevent possible chronic effects and behavioral modifications.

Although most of the available toxicity information is for individual rather than combinations of substances, preliminary studies indicate acute toxicities for mixed solutions may be predictable if the TL_{50} (50% toxicity level) is known for the individual substances. In order to obtain a predictive three-day TL_{50} for mixed effluents the concentration of each toxic substance found in the effluent was expressed as the proportion of the expected three-day TL_{50} and these values were then summed to give a predicted Toxicity Index. Agreement was found to be good between predicted and measured results (Lloyd in Biological Problems in Water Pollution, 1962). However, synergistic or antagonistic effects could greatly affect the accuracy of this procedure. Table A-17 summarizes synergistic and antagonistic effects of selected toxicants.

1. Aluminum

There is little information on the abundance or toxicity of aluminum. Aluminum may have greater toxicity than has been assumed (EPA Water Quality Criteria, 1972, March 1973). Its presence in streams may be a result of industrial wastes, but a more likely source

TABLE A-16

REPORTED TOXIC AND NON-TOXIC CONCENTRATIONS OF SELECTED SUBSTANCES

Substance	Concentrations (mg/l)	Exposure	Organism	Water Type
Ammonia				
Toxic	0.3-0.4	-	trout fry	-
	0.3-1.0	-	fish	
	2.0-2.5	1-4 days	goldfish	
	3.4	96 hr TL_m -	bluegill sunfish rainbow trout	soft water $20^{o}C.$
Non-toxic	1.5	-	most varieties of fish	-
	4.3	1 hr	minnows	-
Aluminum				
Toxic	0.10	1 week	stickleback	-
	5.0	5 min.	trout	-
	5.0	48 hrs	fingerling rainbow trout	pH9
	0.05	-	fish	pH7
Non-toxic	1.0	5 min.	trout	-
Cadmium				
Toxic	0.01-10	7 days	rainbow trout	-
	0.01-10	2-6 days	fathead minnows	-
	0.01-10	96 hrs	bluegill sunfish	-
Chronically safe	0.03-0.06	-	fathead minnows bluegill sunfish	hard water (200 mg/l as $CaCo_3$)
Reduced reproduction	0.0005	3 weeks	crustaceans (daphnia)	
Chromium				
Toxic	17 to 118	96 hrs	fish	-
	0.05	-	invertebrates	
	0.032-6.4	-	algae	
Non-toxic	7.1	-	carp	
	35.3	-	goldfish	
Copper				
Toxic	0.015.3.0	-	fish, crustaceans, mollusks, insects, phytoplankton, and zooplankton	soft
Non-toxic	0.1-1.0	-	most fish	hardness (45 mg/l as $CaCo_3$)
	0.006		fish, crustaceans (Daphnia)	
Cyanide				
Toxic	2.5	120-136 hr	brook trout	-
	0.05-1.0	-	fish	-
Non-toxic	0.02	27 days	trout	-
	0.25	-	bluegills	-
	0.40	96 hr	bluegills	-

TABLE A-16
(continued)

REPORTED TOXIC AND NON-TOXIC CONCENTRATIONS
OF SELECTED SUBSTANCES

Substance	Concentrations (mg/l)	Exposure	Organism	Water Type
Lead				
Toxic	0.2	-	fish	soft
	0.34	48 hr TL_m	stickleback, Coho salmon	1000-3000 mg/l dissolved solids
	0.5-7.0 and 0.4-0.5	96 hrs LC50	fathead minnow, and brook trout	soft (20-45 mg/l $CaCo_3$)
	482 and 442	96 hrs LC50	fathead minnow, and brook trout	hard
Non-toxic	0.62	48 hr	trout	-
	0.7	3 weeks	minnows, sticklebacks	soft
Mercury				
Toxic	0.004-0.02	-	freshwater fish	-
	0.01	80-92 days	minnows	-
	0.05-0.1	6-12 days	fish	-
	1.0	96 hrs	fish	
	10-20	>10 days	fish	
Non-toxic	0.2	-	tench, carp, rainbow trout, char, fish, food organisms	-
Nickel				
Toxic	5	96 hr LC50	fathead minnows	soft (20 mg/l as $CaCo_3$)
	26-43	96 hr LC50	fathead minnows	hard (200-360 as $CaCo_3$)
Non-toxic	0.030	3 weeks	crustaceans, (daphnia)	soft (45 mg/l as $CaCo_3$)
Reduced reproduction	0.095	3 weeks	crustaceans, (daphnia)	soft (45 mg/l as $CaCo_3$)
Zinc				
Toxic	0.01-0.4	-	young rainbow trout	-
	0.5	3 days	fingerling rainbow trout	soft
	1.0	24 hr	sticklebacks	soft
	3.0	8 hr	fingerling rainbow trout	soft
	4.0	3 days	rainbow trout	hard
	0.87	96 hr LC50	fathead minnows	soft (20 mg/l as $CaCo_3$)
	33.0	96 hr LC50	fathead minnows	hard (360 mg/l as $CaCo_3$)
Non-toxic	0.13	20 days	brown trout fingerlings	hard
	3.0	10 days	fingerling rainbow trout	hard
reduced reproduction	0.10		crustaceans (daphnia)	soft (45 mg/l as $CaCo_3$)

Source: McKee and Wolfe, 1963; EPA, Water Quality Criteria, 1972, March 1973

TABLE A-17

DETERMINED SYNERGISTIC AND ANTAGONISTIC EFFECTS OF TOXIC SUBSTANCES

Constituent	Synergistic Effects	Antagonistic Effects
Ammonia	High pH, low DO, cyanide	CO_2
Cadmium	Zinc, cyanide	Hardness
Chromium	Low DO	---
Copper	Chromium, mercury, zinc, cadmium, low DO	Hardness (alkalinity), temperature, dissolved oxygen, turbidity, carbon dioxide, magnesium salts, phosphates, sodium
Cyanide	Low pH, high temperature, low DO, ammonia, zinc, cadmium	Copper, nickel, hardness
Lead	Low DO	Hardness
Mercury	Copper	---
Nickel	---	Hardness
Zinc	Copper, low DO, cyanide	Calcium

Source: McKee and Wolf, 1963; EPA Water Quality Criteria, 1972, March 1973 is wash water from water treatment plants. Many of the aluminum salts are insoluble and therefore likely to settle out rapidly (McKee & Wolf, 1963). The suspended precipitate of ionized aluminum is toxic and concentrations in this form greater than 0.1 mg/l would be deleterious to growth and survival of fish (EPA Water Quality Criteria, 1972, March 1973).

2. Cadmium

Although many forms of cadmium are highly soluble, the carbonate and hydroxide forms are insoluble. Therefore, at high pH, cadmium will tend to precipitate. High concentrations of cadmium has been found to occur in areas of high population density (Andelman, 1974 - in Singis, 1974). Available data indicate the lethal concentration varies from about 0.01 to 10 mg/l, depending on the test animal, type of water, temperature and time of exposure. Indications are that cadmium reacts synergistically with other substances, such as cyanide (McKee & Wolf, 1963). This metal is considered an extremely dangerous cumulative poison. EPA (Water Quality Criteria, 1972, March, 1973) recommends that aquatic life be protected where cadmium concentrations exceed 0.03 mg/l in water with a total hardness above 100 mg/l as $CaCo_3$ or 0.0004 mg/l in waters with a hardness of 100 mg/l or less.

3. Chromium

The toxicity of chromium is highly dependent on the organism, temperature, pH and synergistic or antagonistic effects. Although fish are relatively tolerant of chromium salt, many invertebrates are extremely sensitive. There is no conclusive evidence that the hexavalent form is more toxic to fish than the trivalent form (McKee & Wolf, 1963). However, the evidence tends to be conflicting and it may depend to a great extent on the organism and the compound. The apparent "safe" level for fish (less than 17 mg/l) is moderately high, and the recommended EPA (Water Quality Criteria, 1972, March, 1973) upper limit of 0.05 mg/l was selected in order to protect mixed aquatic populations.

4. Copper

Copper salts occur in surface water only in trace amounts and their presence in concentration above 0.05 mg/l is generally considered a result of pollution (McKee & Wolf, 1963). Although the chloride, nitrate and sulfate of the cuprous ion are soluble in water, the carbonate, hydroxide, oxide and sulfide are not. Therefore, at a pH of 7 or above, the cupric ions will rapidly precipitate (McKee & Wolf, 1963).

In hard water, copper toxicity is reduced by the precipitation of copper carbonate or other insoluble compounds. Synergistic reactions are believed to occur between copper and chlorine, zinc, cadmium and mercury. In contrast, evidence suggests copper decreases the toxicity of cyanide (McKee & Wolf, 1963).

The factors influencing the lethal toxicity of copper to fish include hardness, dissolved oxygen, temperature, turbidity, carbon dioxide, magnesium salts and phosphates (EPA Water Quality Criteria, 1972, March 1973). The implications that copper is particularly toxic to algae and mollusks should be considered for any given body of water; however, the criteria (safe-to-lethal ratios 0.1 to 0.2) that apply to fish will protect these organisms as well. The safe-to-lethal ratio of 0.1 should be multiplied by the 96-hour LC_{50} of the most sensitive important species in the locality to determine a recommended safe concentration of copper to protect aquatic life (EPA Water Quality Criteria, 1972, March 1973).

5. Cyanide

The toxicity of cyanide is highly dependent on pH. As the pH decreases, toxicity increases; however, it has been reported that in the pH range of 6.0 to 8.5, there is little effect on toxicity. In natural water, cyanides deteriorate or are decomposed by bacterial action. Degradation is unaffected by temperatures in the range from 10^{o} to $35^{o}C$ but is greatly reduced at lower or higher temperatures (McKee & Wolf, 1963).

The toxicity of cyanide is increased by elevated temperatures (a $10^{o}C$ increase produces two- to three-fold increases in toxicity), low dissolved oxygen, zinc and cadmium. The toxicity of cyanide is lower for invertebrates than for fish (McKee & Wolf, 1963).

6. Iron

Iron is less toxic than most other heavy metals. Extremely high concentrations in unbuffered water can lower the pH to toxic levels, but the deposition of iron hydroxide precipitate is more likely to harm fish by coating gills or smothering fish eggs. Ninety-five percent of U.S. water supporting good fish life have iron concentrations of 0.7 mg/l or less (McKee & Wolf, 1963).

7. Lead

The carbonate, hydroxide and sulfate salts are relatively insoluble; therefore, lead generally settles out fairly rapidly except in soft waters. Lead toxicity increases with a reduction in dissolved oxygen. EPA (Water Quality Criteria, 1972, March, 1973) recommends that the concentration of lead should not exceed 0.03 mg/l at any time or place in order to protect aquatic life.

8. Mercury

Although elemental mercury is insoluble in water, many of the salts are quite soluble. Mercuric ions are considered highly toxic to aquatic life (Table A-16). The toxicity of mercuric salts is increased by the presence of trace amounts of copper (McKee & Wolf, 1963).

There is not sufficient data available to determine the levels of mercury that are safe for aquatic organisms under chronic exposure. Since experiments on sublethal effects are lacking, the next most useful information available is on the lethal effects following moderately long exposures of weeks or months. As exposure time increases, lower concentrations of mercury become lethal. Data are not available on the residue levels that are safe for aquatic organisms (EPA Water Quality Criteria, 1972, March 1973). According to the Food and Drug Administration, mercury residues should not exceed 0.5 micrograms per gram of total mercury in edible portions of fresh water fish. EPA (Water Quality Criteria, 1972, March, 1973) suggests that this level be the guideline to protect predators in aquatic food chains.

9. Nickel

Although nickel as a pure metal is insoluble in water, many nickel salts are highly soluble. Nickel is one of the least toxic metals. Although 0.8 mg/l has been reported as lethal to sticklebacks, fish have been found living in water with concentrations of 13-18 mg/l of nickel (McKee & Wolf, 1963). The safe-to-lethal ratio for nickel is 0.01 for the protection of fish. This application factor should be applied to the 96-hour LC_{50} of the most sensitive important species in the locality to determine the recommended concentration of nickel safe to aquatic life (EPA Water Quality Criteria, 1972, March 1973).

10. Zinc

Zinc salts such as zinc chloride and zinc sulfate are highly soluble in water; however, salts such as zinc carbonate, zinc oxide and zinc sulfide are insoluble in water. Therefore, the compound present is important in determining whether zinc will settle out or remain in solution.

Zinc is toxic to aquatic organisms. The acute lethal toxicity of zinc is greatly affected by water hardness. The sensitivity of fish to zinc varies with species, age and condition of the fish, as well as with the physical and chemical characteristics of the water. Acclimatization to zinc has been reported for some fish. Calcium is especially antagonistic to zinc toxicity. In soft water, zinc and copper react synergistically, but this does not hold in hard water. Toxicity is also thought to increase in the presence of cyanide and as dissolved oxygen concentrations decrease. The safe-to-lethal ratio for zinc (0.005), if multipled by the 96-hour LC_{50} of the most sensitive important species in the locality, will determine the recommended concentration of zinc safe to aquatic life (EPA Water Quality Criteria, 1972, March 1973).

Sublethal Effects: In addition to direct toxicity, sublethal effects must also be considered. If a substance causes avoidance, interference with sensory mechanisms, or prohibits reproduction, aquatic organisms gradually will be eliminated, even though dramatic die-offs do not occur.

Young Atlantic salmon are reported to avoid copper and zinc at concentrations one-fiftieth the incipient lethal level. Low levels of copper have also been reported to interfere with odor cues necessary for salmon to return to home streams for spawning (Sutterlin, 1974).

Avoidance behavior may be beneficial if a substance is temporary and localized and can prevent sudden die-offs of mobile organisms. However, where chemical senses are interfered with, organisms may be restricted in feeding and reproductive processes which may cause gradual reduction or total elimination of species.

Road Salts: The biological effects of road salts on aquatic organisms have received little attention. One study reported direct and indirect effects on lake benthic organisms. The increase in salinity directly eliminated dipteran larvae, and the decrease in oxygen concentration that occurred because of the density changes eliminated several oligochaete species (Judd, n.d.).

The effects of adding salts to freshwater can be predicted to a great extent on the basis of reactions of freshwater organisms to marine and estuarine environments. Freshwater organisms cannot survive in salt water environments because of the change in osmotic pressure that affects fluid balance. Although specialized species that can tolerate wide ranges of salinity exist, adaptation to the intermittent input of salt associated with nonpoint source runoff would be unlikely. Chloride concentrations in freshwater supporting good fish life are below 9 mg/l in 50 percent, and below 170 mg/l in 95 percent, of the waters (McKee & Wolf, 1963). Concentrations reported as harmful to fish are presented in Table A-18.

TABLE A-18

CONCENTRATIONS OF CHLORIDE HARMFUL TO FISH

Cl Concentrations (mg/l)	Type of Fish
400	Trout
2000	Some fish
4000	Bass, Pike, Perch
4500-6000	Carp eggs
8100-10,500	Small Bluegills

Source: McKee & Wolf, 1963

Analysis of Water Quality Data to Determine Nonpoint Problems

In many areas, the extent and severity of nonpoint problems is often unknown. This is usually due to past concentration on point sources and inadequate water quality data. This obviously makes it extremely difficult to set priorities and develop a coherent strategy for analyzing nonpoint problems and establishing controls.

It is often possible to use existing water quality data to help focus on specific pollutants and certain watersheds and stream segments where nonpoint problems appear most severe. The remainder of the 208 nonpoint program can then concentrate on the major problems that have been identified. Undoubtedly, additional data collection will also be required to better define existing nonpoint problems. This section covers these two crucial areas of nonpoint analysis; analysis of existing data and collection of additional data. The presentation is organized by the following topics:

Analysis of Existing Data: An Example

Use of Steady-State Models in Nonpoint Source Analysis

Analysis of Biological Data for Nonpoint Analysis

Development of a Nonpoint Source Sampling Program

Analysis of Existing Data: An Example: In areas where a good water quality network has been in existence for several years, a surprisingly large amount of information on the location and severity of nonpoint problems can be obtained by proper analysis of the data. The objective of this subsection is not to detail the techniques for nonpoint analysis but merely to indicate the types of analyses which may be used to shed light on major nonpoint problems. A recent study on the Passaic River in New Jersey (Berger/Betz, 1975) is used as an example of what innovative evaluation of existing data might yield.

1. The Setting

The example used was taken from a recent water quality management study of the Northeast New Jersey metropolitan area (Berger/Betz, 1975). The major stream in the study area is the Passaic River, a slow moving stream which is heavily used for water supply and waste assimilation throughout its length. The analysis which follows was for the free flowing portion of the stream; the estuary portion was not included in the analysis because of the magnitude of combined sewer overflows into the estuary, insufficient data, and the complications of data interpretation caused by tidal fluctuations.

The Freshwater Passaic covers a drainage area of 806 square miles and is the third largest drainage area in the State of New Jersey. Average annual rainfall over the area is about 47 inches. The majority of the Freshwater Passaic is geographically located in the New England Upland Province. Topography is generally flat. Population in the basin is over 600,000 (population density over 700 people per sq mi). Land uses in the basin are:

1970 Land Use	% of Total Area
Single Family Residential	23.5
Multi Family Residential	1
Industrial	3.5
Commercial	1.5
Public and Quasi Public	5
Conservation, Recreation and Vacant	65.5

The analysis was structured to gain information on three broad types of nonpoint sources. The following quotation (Berger/Betz, 1975) defines the three categories:

> "An important distinction of nonpoint sources exists among storm-activated sources, continuous sources and erratic sources. Storm-activated sources involve contaminant loads derived from the land surface and delivered to the stream system by surface runoff. These pollutant loadings can result in transient water quality problems during storm periods, and also can contribute to long-term problems due to the settling out of material in benthic deposits. Annual nonpoint source pollutant yields tend to be dominated by loadings derived during storm periods--although these loadings are not necessarily most important in terms of problems created.
>
> "Continuous nonpoint sources generally involve contamination of the groundwater reservoir which feeds the stream system more or less continuously over time and space. Continuous sources tend to have relatively less impact on water quality during storms than during nonstorm periods, due to the much greater dilution of effluents during storms; thus, continuous nonpoint sources are analyzed primarily as a low-flow problem.
>
> "Erratic sources, such as unauthorized dumping and accidental spills, are difficult to evaluate without direct monitoring of individual source area. Their impact is usually established only on an average long-term basis, usually in combination with other types of sources."

2. The Analysis

BOD, dissolved oxygen and sediment data were deemed adequate for analysis; heavy metal and nutrient data were extremely sparse and not appropriate for rigorous analysis. Monthly parameter values were available on several stations located along the freshwater Passaic and its tributaries. A continuous recording station existed at the most downstream station, yielding daily data on DO, temperature, pH and conductivity.* Data from a summer survey conducted to calibrate a low flow model were also available.

The analysis consisted of mass balance techniques, annual load computations and plotting of data. The analysis was divided into four separate techniques, each used for defining different portions of the non-point source problem:

Low Flow Mass Balance

Annual BOD Loads

DO Response to Storm Loadings

Annual Sediment Loads

The purpose of each technique, parameters analyzed, etc., are summarized in Table A-19.

3. The Results

Details of the analysis techniques can be found in the original report (Berger/Betz, 1975). The results of the analysis yielded the following conclusions:

a. Based on the low flow mass balance, nonpoint problems occurring during low flow conditions (benthic deposits, polluted groundwater inflow, unreported point sources) were prioritized. Various sections of the river and its tributaries were identified as having especially severe problems. The results were used to better define a nonpoint source sampling program.

b. The annual BOD load calculations, which tend to be dominated by storm period loads, were used to locate areas having significant storm-activated

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* Hourly data was not utilized in the analysis, but it was available through USGS.

TABLE A-19

EXAMPLE TECHNIQUES FOR ANALYZING EXISTING DATA FOR NONPOINT SOURCE PROBLEMS

Technique	Condition	Data Analyzed	Purpose
Low Flow Mass Balance	Low Flow	CBOD & NBOD* values from summer survey data collected for low flow model calibration	To identify areas with significant steady-state or continuous non-point source problems.
Annual BOD Loads	All flow conditions used to calculate annual load	CBOD values published for several stations in USGS' annual "Water Quality Records"	To identify areas with abnormally high nonpoint BOD loads. This is strongly related to storm runoff loads as opposed to steady-state nonpoint sources.
Dissolved Oxygen Response to Storm Loadings	Storm Conditions	Daily DO values published for the most downstream station in the network	To determine transient impact of non-point sources on DO and make preliminary determination of what causes DO depression after storm.
Annual Sediment Loads	All flow conditions used to calculate annual loads	Sediment values for several stations in USGS' annual "Water Quality Records"	To test hypothesis of significant benthic deposition.

* CBOD B carbonaceous BOD; NBOD B nitrogeneous BOD

Source: Berger/Betz, 1975

sources. Two stream segments were identified with extremely high nonpoint loads, it was suspected that discrete sources, such as spills, material storage yards, bypasses from sanitary sewers, pump stations and treatment plants, may be the cause of some of the high readings. A sampling program was designed to collect additional data on the significant problem segments. It is hoped that future sampling will identify discrete sources, which are usually easier to control than distributed runoff sources.

c. Analysis of daily dissolved oxygen values at the last downstream station revealed that DO levels increased shortly after the start of a storm but declined over a period of several days to below the level which prevailed at the beginning of the storm (plots of this phenomena have already been presented in Figure A-10). The DO response appeared to be explained by assuming that the DO was depressed by organic material which was washed into the stream by runoff and by the scouring of benthic deposits. Because of the characteristics of the Passaic (extremely slow velocities) it is unlikely that benthic deposits can be sufficiently controlled by runoff control measures to significantly alleviate the post-storm DO depression.

d. The sediment mass balances were computed to gain perspective on the benthic deposit accumulations. Analysis indicated that nearly half of the annual sediment input to the main river segment settles out rather than leaves the basin.

Use of Steady-State Models in Nonpoint Source Analysis: Steady-state water quality models cannot adequately handle transient events associated with some nonpoint sources. However, use of steady-state models can aid in the assessment of several nonpoint sources. As indicated in the previous section, the actual data collected for model calibration can be used for mass balances (in the example given in the previous section, this technique located areas of significant steady-state loads).

Nonpoint sources which may be handled by steady-state modeling include:

Source	Typical Parameters
Landfill leachate	BOD/DO, nutrients, heavy metals
Marshes	BOD/DO, nutrients
Pervious lagoons	BOD/DO, nutrients
Salt water intrusion	Chlorides
Areas of septic tank malfunctioning	BOD/CO, nutrients
Acid mine drainage	Heavy metals

These pollutant sources can be handled in steady-state modeling by adjusting certain modeling parameters to reflect loads from nonpoint sources. Benthic loads are generally handled specifically in the benthic demand components of the model. Distributed sources, such as septic tank areas, marshes, etc., can be handled by adjusting the incremental runoff loads in the model. Sources such as lagoons and landfills may be addressed either as a point source or a distributed source, depending on the characteristics of the groundwater flow system and the length of the model reaches.

Considerable skill and experience is needed in adapting and calibrating steady-state models to accurately reflect actual conditions. It is possible to miscalibrate a model and develop water quality predictions which are grossly in error. The only safeguard to prevent this from happening is to collect adequate calibration data and perform model calibration with experienced modelers.

Analysis of Biological Data: The assessment of biological data offers a tool for the investigation of nonpoint sources which is often neglected or under-utilized. Reliance on only chemical and physical data does not yield a complete picture of water quality. Because of the general lack of sufficient chemical data and the complexity of interpreting physical and chemical data as they relate to the health or quality of a stream, it may be cost effective to place greater emphasis on biological parameters.

Aquatic organisms and communities can be used as natural pollution monitors. When an aquatic community undergoes a stress, such as pollution, the community structure can be affected. This change can be monitored and the long-term effects can be measured and analyzed. Because aquatic organisms respond to their total environment and reflect long-term conditions, they can often provide a better assessment of stream quality and environmental damage than can other monitoring methods. Some organisms tend to accumulate or magnify toxic substances, pesticides, radionuclides and a variety of other pollutants. Organisms also can reflect the synergistic and antagonistic interactions of point and nonpoint source pollutants occurring within a specific receiving water system.

Chemical analyses can only indicate the water quality at the time the sample is collected, and unless extensive sampling is done, variation in different areas of the water will not be determined. Even if adequate chemical data were available, the problem would still remain: interpret its significance to aquatic ecology. For example, suppose a stream which demonstrates a sharp DO decline to 3 mg/l after storm periods (rainfall greater than 0.5 inches). This level is generally maintained for 6 hours; DO then recovers to 5.5 mg/l. Apparently, storm runoff is causing the DO drop, but is this drop causing a problem? If a biological survey indicates that the fish and other aquatic species desired for the stream are relatively unaffected then the answer may be negative.* At least the problem could not be termed critical and the remaining nonpoint program could be modified accordingly.

In evaluating the condition of an aquatic system, many factors must be considered. The available information must be evaluated on the basis of habitats surveyed, season, and flow regime. The guidelines discussed in the following paragraphs must be used with the above point in mind.

Biological sampling programs for the detection of nonpoint problems are presented in a later section of this appendix. The following discussion assumes that the data has already been collected and must be evaluated.

The concept of indicator, or sensitive organisms is frequently employed in evaluating water quality. While this concept, in conjunction with community structure, is the

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* The storm runoff could be causing deleterious loads of nutrients or heavy metals which cause problems downstream. This is neglected in the above example.

basis for biological surveys, a number of limitations must be acknowledged when evaluating water quality on the basis of the presence or absence of certain organisms.

First, many factors besides water quality affect the distribution of organisms. In streams, velocity and substrate are two important factors. Although the presence of certain organisms usually indicates good water quality, their absence may be due to factors other than poor water quality (Hawkes, 1974). An English study, Report of the River Pollution Survey, found that 98% of the length of a fast-moving stream was classified as first class quality, biologically and chemically. Only 6% of the length of a slow-moving stream was first class biologically and chemically, while 65% was ranked as third class biologically but first class chemically (Hawkes, 1974). The difference in biological condition was due to unsuitable habitats, not chemical or physical water quality.

A second limitation of indicator systems is that they have been developed on the basis of organic pollution, which may not always be the main consideration for nonpoint source analysis. Organisms differ in their respective tolerances to different forms of pollution. For example, stoneflies which are considered the most intolerant of organic pollution were found to be among the most tolerant organisms in heavy metal-polluted Welsh rivers (Hawkes, 1974). However, suspended solids and BOD, two parameters associated with organic pollution, are also concerns in nonpoint source pollution. Therefore, existing information on organisms tolerant of organic pollution can be applicable to nonpoint source pollution.

As long as the limitations of the information are realized, the concept of indicator organisms can be very useful in assessing the effects of nonpoint source pollution. Although the presence or absence of a single species does not define water quality, the presence of large numbers of certain species, or absence of whole groups of organisms, can be indicative of water quality conditions.

Palmer (1969) lists 80 algae species tolerant of organic pollution. The list was part of a compilation based on 269 reports from 165 authors. Rankings were determined by assigning a score of 1 or 2 for each species reported as tolerant to organic pollution. A 2 was assigned if the species was reported to tolerate large amounts of organic pollution. Hart and Fuller (1974) listed invertebrate species found at pH values less than 4.5 and greater than 8.5 and adverse oxygen and BOD conditions (DO less than 4 mg/l and BOD greater than 5.9 mg/l). Use of the species lists contained in the cited publications can aid in assessing water quality conditions.

In addition to the concept of indicator organisms, community structure is also considered in evaluating aquatic systems. Characteristically, aquatic systems with good water quality have a greater number of species than systems with poorer quality water. There are some exceptions to this pattern, but it generally holds true. Species distribution is also important. Polluted waters are usually dominated by a few species with numerous individuals while other species present have very few individuals. Good quality waters usually have a more equal distribution of individuals per species.

Numerous methods have been devised for analyzing biological data. The following is a classification for streams that provides a means for general and specific evaluation. The classification is based upon combining aspects of community structure with the indicator organism concept. Although there are exceptions to this pattern, it provides a general overview of expected conditions.

The biological organisms are divided into the following seven categories:

Category	Description
1	Blue-green algae and the green algae genera *Stigeoclonium*, and *Tribonema*; the bdelloid rotifers plus *Cephalodella megalocephala* and *Proales decipiens*
2	Oligochaetes, leeches and pulmonate snails
3	Protozoa
4	Diatoms, red algae, and most of the green algae
5	All rotifers not included in column one, plus clams, prosobranch snails, and tricladid worms

6 All insects and crustacea

7 All fish

After the data have been categorized, the sampling stations thought to be affected by nonpoint source pollution are compared to an unaffected station or the control; or compared to a standard that has been set up for a geographical region.

The number of species in each category for the control station or standard is set as equal to 100%. The percentage of species for each of the categories is then computed for the affected stations. For example, if the control station had 10 species in Category 1 and the impact station had 5 species in Category 1, the value for the impact station would be 50%. The resulting patterns are defined as follows:

Healthy: The algae are mostly diatoms and green algae, such as *Cladophora crespata* and *glomerata*, and the insects and fish are represented by a great variety of species. There are numerous protozoa, but they do not fall into a set pattern.

Categories 1 and 2 tend to vary greatly, depending on ecological conditions in the area. Categories 4, 6 and 7 are all above the 50% level.

Semi-healthy: The pattern is irregular, indicating the balance found in a healthy station has been disrupted but not destroyed. Often a single species will be represented by a disproportionately large number of individuals. This condition may be defined as follows:

1. Either or both categories 6 or 7 below 50%, and categories 1 or 2 under 100%.

2. Either category 6 or 7 below 50%, and categories 1, 2 and 4 100% or over: or categories 1 and 2 100% or over and category 4 having large numbers of some species.

Polluted: The overall balance of the community is upset. However, conditions are favorable for some species in categories 1 and 2. This conditions is defined as follows:

1. Either or both of categories 6 and 7 are absent, and categories 1 and 2 are 50% or better.

2. Categories 6 and 7 are both present, but below 50%; then categories 1 and 2 must be 100% or more.

Very Polluted: Conditions are definitely toxic to plant and animal life, with many groups absent. This condition is defined as follows:

1. Categories 6 and 7 are absent, and category 4 is below 50%.

2. Category 6 or 7 is present, then 1 or 2 is less than 50%.

Although this level of information is not available in many cases, this classification provides an overall picture of the types of organisms and general community structure characteristic of different ecological conditions (Patrick 1949).

Development of a Nonpoint Source Sampling Program: Additional data will be required in almost all 208 areas to further define nonpoint source problems. The data may be used for problem assessment, model calibration, etc., and thus is critical to adequate nonpoint source evaluation. Since the time span of initial 208 work is relatively short, it is unlikely that all, or even most, of the questions concerning nonpoint pollution can be answered by additional data; a long-term sampling program based upon "best guess" priorities is probably the best strategy for sampling.

The following paragraphs do not present the methodology for developing a nonpoint sampling program. Rather, important considerations are reviewed and an overview is presented which may help in establishing study area specific programs.

1. The Nonpoint Source Sampling Framework

   A partial listing of major nonpoint sources is presented in Table A-20. This list includes storm-activated sources and sources which operate more or less independently of hydrologic conditions. The analysis of these sources involved two elements:

TABLE A-20

MAJOR NONPOINT POLLUTANT SOURCES

Surface Runoff (including intermittent point sources)

Combined sewer overflows
Other urban runoff (including storm sewers and sanitary sewer bypasses)
Suburban runoff (including storm sewers and sanitary sewer bypasses)
Runoff from other developed land--e.g., highways
Agricultural runoff: cropland
Pastureland, feedlots, other ag. land
Runoff from construction sites
Silviculture and surface mining operations

Sources Involving Groundwater Contamination

On-site waste disposal systems
Leachate from landfills and other residual waste disposal activities
Agriculture, including agricultural specialities
Acid mine drainage
Lagoons (municipal and industrial)
Spray irrigation

Factors Affecting Water Quantity

Salt water intrusion
Hydrographic modifications:
- Impoundments
- Channelization
- Impervious surface

Miscellaneous Sources

Unauthorized discharges, dumping
Accidental spills, overflows, leakages (e.g., lagoons, pipelines)
Port operations
Recreational water use

a. Pollutant generation

b. Receiving water response

Generally, neither the nature nor extent of water quality problems resulting from storm-period pollutant loadings is well defined. The sampling program must therefore carefully balance the needs of pollutant generation and receiving water response.

Pollutant generation refers to the quantity of pollutants yielded to the surface water system, including the timing of pollutant loads and their relationship to hydrologic conditions. Receiving water response refers to the actual problems created by nonpoint source loadings in surface waters. Analysis of receiving water response must consider:

a. Pollutant routing under various flow conditions

b. In-stream processes such as:

   decomposition
   photosynthetic activity
   reaeration
   precipitation of materials into the benthos

c. Characteristics of all water bodies being affected by a given nonpoint source.

It appears that a cost-effective approach to nonpoint source impacts focus upon the <u>limiting conditions</u> for design of control measures. That is, although a given pollutant source in a given basin may contribute to several different types of problems, detailed quantitative analysis need be provided only for those sources causing the problems. These sources will require the most stringent control measures. An extremely important goal of the sampling program and initial analysis will be to identify these conditions, and thus to narrow the focus of subsequent activities.

2. The Type Problem Approach to Nonpoint Source Questions

The "Type Problem Approach" is suggested as an orderly and logical method of investigating nonpoint source effects. The major nonpoint pollutant sources in Table A-20 can be conveniently organized into four major classes of problems:

a. General non-storm quality factors

b. Site-specific nonpoint sources

c. Transient storm problems

d. Long-term storm effects

The four separate types of problems can be attached by four supplementary measurement programs which, taken together, provide a unified overview of the major possible categories of problems.

a. General Non-storm Quality; General non-storm quality factors include geochemically-related natural background changes and changes attributable to man's activities. Quality problems may be related to dissolved oxygen, nutrients or toxic materials. A low flow sampling program for steady-state model calibration (a usual component in many 208 studies) will provide the basic input to the definition of regionalized incremental runoff quality factors. Major deviations in quality not attributable to point sources will serve to flag that area as a nonpoint source special interest area.

   The role of benthic demands on water quality is generally not well established. The low flow sampling should include a general characterization of the nature and depth of sediments at each location. The objective is to produce a benthic map. Benthic demands appearing in the modeling analysis will be of special concern. Such areas should be subsequently investigated in detail through field surveys to verify their existence, extent, depth, uptake rate and other characteristics.

b. Site-Specific Sources: Site specific nonpoint sources are those which have clearly defined source areas such as:

Landfills
Spray irrigation fields
Lagoons of various types
On-site disposal areas, i.e., septic tank concentrations

To a significant degree such locations are amenable to a regulatory action. Their actual impact on the receiving water quality is often not well known, especially for sites installed before the current complex environmental monitoring requirements were adopted. A major requirement of the nonpoint work element is the establishment of nonpoint source priority lists. The case of landfills is illustrative of the priority dilemma.

Landfills are generally too numerous in the study area to be considered individually in any data effort. There is usually little information as to whether specific landfills have a significant impact on surface water quality. The magnitude of the problem should be determined, as suggested below, along with its hydrogeologic and seasonal variations. The same types of questions apply to other site-specific sources.

Assuming that monitoring all site-specific sources is not possible, it is proposed that a sampling approach involving the monitoring of the seasonal performance of a number of representative and critical site-specific sources be adopted. Questions concerning the seasonal variation of loads as they directly affect surface water quality can be answered by sampling from high water spring conditions through dry summer conditions.

This approach would provide assistance in developing pollutant generation relationships and in identifying current and potential surface and groundwater quality problem areas. It would also be an important aid in establishing priorities for the extent of the particular problem and the allocation of the 208 project resources to be devoted to their solution.

c. Transient Storm Problems: Transient storm problems may be investigated in terms of three broad effects:

dissolved oxygen variations
nutrient, toxics and heavy metals washoff
the integrated effects on the major downstream water bodies (e.g., estuaries)

Dissolved oxygen levels are of concern because they exert an intermediate effect on a stream's fishery resources. During a storm, two oxygen forces are activated. The first is the effect of cloud cover in reducing photosynthesis. This may be especially important when clouds persist for several days with slow moving storm systems. A high initial biomass to flow ratio would aid in the oxygen depression. The second effect is the elevation of dissolved oxygen levels due to increased reaeration from raindrop impact and increased turbulence due to higher flows.

The relative magnitude of these two forces determines whether the net effect is an elevation or depression of dissolved oxygen levels. The relationship of these effects to critical levels is not well documented for most streams. It is proposed that a sampling program involving a reconnaissance level study of dissolved oxygen levels during storm events on area tributaries be adopted. This is an important part of problem assessment because, generally, it is not even known whether there is indeed a problem that must be addressed by 208 planning.

The establishment of pollutant-generation relationships is generally a central aspect of the 208 approach. Washoff rates for nutrients, toxics and heavy metals must generally be established for various land uses. The storm sampling should include sampling for important parameters; this will permit a limited verification of the SWMM/STORM pollutant-generation methodology.

The assessment of tributary storm effects on estuaries or other major downstream water bodies is an extremely complicated task because it must bridge the gap between the process of pollutant generation and the actual amount of pollutants being delivered by the tributaries into their receiving waters.

Two approaches to this problem may be appropriate. Within the framework of the reconnaissance sampling network, stations should be chosen to represent segments upstream and downstream from relatively flat uniform reaches having no tributary inputs. The net difference in the stream load across the reach would represent the effect of possible sediment resuspension, sediment deposition, or bank and channel scouring. The second approach would involve an analysis of the differences between the SWMM/STORM-generated pollutant loads and those that were actually measured in the course of the sampling program.

A major potential problem in the verification of the modeling results is that the inherent errors in the pollutant generation algorithms have the potential of being of the same or greater magnitude than the effect that the modeling process is trying to detect. This means that interpretation of the modeling results will have to be made judiciously. A major accomplishment would be the development of reliable relationships between pollutant generation and pollutant delivery. This would permit modifications of SWMM/STORM outputs to reflect more accurate water impacts.

d. Long-Term Storm Effects - Dissolved Oxygen: Long-term residual effects of storms may have a significant effect on steady-state water quality conditions through the mechanism of benthic demand. The exact role of benthic demand in controlling water quality is not well defined on most of the study area streams.

Benthic deposits may be particularly troublesome behind river impoundments or slow, flat portions of the river. If benthic problems are suspected, the sampling program should investigate in detail the oxygen relationships in impoundments. This involves systematic measurement of dissolved oxygen and the use of light and dark respirometers to measure the benthic oxygen uptake rate. Measurements should be made before and after storms. This will help determine long-term stream responses to nonpoint pollutants washed in from tributary streams. Data should also be collected during relatively stable streamflow sequences to determine possible changes in benthic demand due to steady-state accumulations. This program should help resolve questions concerning the relative effects of storm washoff, bottom resuspension and steady-state accumulation.

Another sampling program may be necessary to determine the relative importance of diurnal dissolved oxygen variations. Many times, steady-state modeling without accounting for diurnal effects may be a gross misstatement of the ongoing stream processes. If diurnal problems are suspected, there is a need to establish the relative importance of the periphyta, rooted aquatics, in controlling the phyotosynthesis/respiration balance in local streams.

3. Biological Monitoring

Biological monitoring provides an effective means by which to evaluate water quality because biological data are generally the best indicators of the overall conditions of a water body. This type of monitoring seems especially appropriate when one considers that water quality standards are partially designed to protect biological organisms.

For purposes of biological monitoring, a station will normally encompass areas, rather than points, within a reach of river or area of lake, reservoir or estuary that adequately represent a variety of habitats typically present in the body of water being monitored. Unless there is a specific need to evaluate the effects of a physical structure, it will normally be advisable to avoid areas which have been altered by a bridge or weir, are located within a discharge plume, etc. Thus, biological sampling stations may not always coincide with chemical or sediment stations.

Several types of biological monitoring programs can be used, depending on the suspected problem and the needed information. Three examples that might be used are listed below.

a. Short-term Survey: Site examinations made once or only a few times to determine quickly the biological quality of the area and the possible causes for the condition.

b. Long-term monitoring: Sampling is conducted at regular intervals over a period of time. This method offers the opportunity to measure seasonal variations and fluctuations caused by random events.

c. Specific Parameter Monitoring: Selected organisms or groups (such as plankton, fish or invertebrates) are monitored for changes in numbers, size, condition, etc., and extrapolations are made about water quality.

If transient pollution problems following a storm are suspected, the following biological sampling may yield valuable information on the extent and severity of the problem:

> Conduct three surveys, one during a dry period, a second directly after a period of heavy rainfall, and the third approximately a month after a heavy rainfall. The first set of samples provide baseline information on the quality of the stream or lake. The second set will indicate the immediate effects of scouring and runoff materials. The third set will provide information on the extent of recovery following storm conditions and whether the effects are long-term. For each survey, a comparable area relatively unaffected by runoff would also have to be sampled to provide a control.

Ideally, permanent biological collections are made and identification to species level are established where possible. Constraints of time and money often make this level of study impossible. Although modifications of this program are possible, it must be emphasized that the information obtained will also be reduced accordingly.

More superficial surveys can be conducted that provide an overview of the condition of the system. A general idea of biological quality can be gained by an experienced biologist making on-site field observations. The latter, in spite of limitations, would probably provide sufficient information for determining whether there was an existing nonpoint source pollution problem. A major disadvantage of a superficial survey is the lack of a permanent or quantitative record for future comparison.

Comparable lakes or streams unaffected by point or nonpoint sources should be studied for purposes of comparison. In actuality, these conditions are difficult to find. Frequently, reaches of the stream or parts of the lake under study can be found which are not influenced by pollution; they can be used as comparative controls. It must be emphasized that similarity between habitats is essential in making any comparisons between different areas.

ADDENDUM 1

The regression analyses relating chemical concentrations to precipitation variables utilized the following functional form:

$$Y = b_o X_1^{b_1} X_2^{b_2} \cdot \cdot \cdot X_n^{b_n} - 1$$

or, $\ln(Y + 1) = \ln b_o + b_1(\ln X_1) + . . . + b_n(\ln X_n)$

where: Y is a chemical concentration;

$X_1, . . ., X_n$ are precipitation variables; and

$b_o, b_1, . . ., b_n$ are coefficients to be estimated.

The objective was to control for effects of basin characteristics on Y by allowing the "constant term" ($\ln b_o$) to assume different values for different basins. This was done by inserting dummy variables into the logarithmic form of the regression. Each was simply a variable with a value of unity for all observations pertaining to a given basin, and zero for all other observations. There was thus one dummy variable corresponding to each basin. These could be entered into the regression as ordinary independent variables; the regression coefficient obtained for each would be, in effect, an estimate of ($\ln b_o$) for the given basin.

A minor complication was that the full set of dummy variables could not be entered along with a conventional constant term since these would be redundant (resulting in singularity of the covariance matrix). For convenience, the ordinary constant term was retained, and the first dummy variable was deleted. The regression equation was therefore the following:

$$\ln(Y + 1) = \ln b_o + a_2 D_2 + \ldots a_m D_m$$

$$+ b_1(\ln X_1) + \ldots + b_n(\ln X_n)$$

where: $D_2, \ldots, D_m$ are dummy variables; and

$a_2, \ldots, a_m$ are additional parameters

to be estimated.

The appropriate constant term for a given basin could then be obtained as the sum of ln b_o, as estimated in the regression, and the regression coefficient for the dummy variable pertaining to that basin. The predictive equation for basin "i" was thus the following:

$$Y = -1 + (b_o \exp(a_i))\, X_1^{b_1} \cdots X_n^{b_n}$$

In all regressions cited here, the set of dummy variables as a whole made a statistically significant contribution (at the 1% level) to the explanation of the dependent variable. The regression coefficients and significance tests for individual dummy variables are not of major interest and therefore are not reproduced here.

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