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URBANIZATION AND STREAM QUALITY IMPAIRMENT[1]

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ABSTRACT: A study was conducted in the Piedmont province of Maryland to determine if a relationship exists between stream quality and the extent of watershed urbanization. During the first phase of the study 27 small watersheds, having similar characteristics but varied according to land use, were investigated. Using these controlled conditions, eliminating as many interferences as possible, this first phase was intended to determine if a definite relationship did exist between the two factors. Finding that the first phase was successful the second was initiated which consisted of a comparison of biological sampling data, from other studies, with degree of watershed urbanization. The purpose of this second phase was to ascertain if the relationship between degrees of urbanization and decline in stream quality was linear as watershed area increased and in streams spread throughout the Maryland Piedmont. The principal finding of this study was that stream quality impairment is first evidenced when watershed imperviousness reaches 12%, but does not become severe until imperviousness reaches 30%.
(KEY TERMS: urbanization; impervious surfacings; benthos; fish; toxic substances; stream quality impairment; sediment; migration barriers; baseflow; storm water; temperature.)

INTRODUCTION

The biological community structure of urban streams is generally quite different from that of streams draining rural or natural watersheds. Specifically, the typical urban stream exhibits a paucity of life with the inhabiting organisms being those normally associated with stressed environments.

The study described herein, was undertaken to determine if a direct relationship exists between the degree of stream quality impairment and the extent of watershed urbanization. If such relationships were found then it should be possible to develop a series of recommendations for the amount of urbanization that can occur without impairing stream quality.

The factors which affect urban stream quality, when point source discharges and sewerline overflows are absent, include:

> Increased storm water runoff which in turn causes an increase in the frequency and severity of flooding, accelerated channel erosion, and alteration of the stream bed composition.

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Reduced base flow.

Alteration of the natural stream temperature regimen.

Alteration of the character and volume of energy inputs to the stream.

Increased entry of toxic substances such as heavy metals, pesticides, oil, road salt, detergents, etc.

Elevated nutrient inputs to the stream.

For the purposes of this study, percent impervious area was selected as the characteristic common to urban watersheds to be used in relating degrees of impairment to the extent of urbanization. The study was divided into two phases:

1. The examination of several stream quality parameters in a series of small watersheds having similar characteristics but varied according to land use. The specific parameters examined in each were baseflow, the benthic community structure, and fish populations.
2. A review of literature relevant to the effects of urbanization upon stream quality and a comparison of biological sampling results, from other studies, with the degree of watershed urbanization.

It was assumed that the effects of urbanization upon stream quality would vary between physiographic provinces. Therefore the sampling data presented here are restricted to the Piedmont province.

METHODS

The sampling program conducted during this study was designed to compare several stream quality parameters under carefully controlled conditions, eliminating as many variables as possible. This sampling effort was intended to determine if streams draining watersheds of similar size, geology, shape and geographical location, but varied according to land use, would exhibit decreasing quality as the degree of urbanization increased using percent impervious area as the unit of measure.

Percent impervious area was determined by first determining the watershed land use from the 1973 county land use maps prepared by the Earth Satellite Corporation for the Maryland Department of State Planning. Percent impervious area was then computed using the figures given in *Urban Hydrology for Small Watersheds* (SCS, 1975) and Graham, *et al.* (1974).

Twenty-three small watersheds, ranging from 2.4 km^2 – 7.3 km^2 in size, were selected to determine the degree of baseflow reduction. Two precautions were taken to reduce the possibility of error resulting from highly localized storm events – first, the discharge of each stream was measured on three separate dates; and secondly, the measurement dates were selected to allow the passage of at least one week since the last significant rainfall.

The first of the three measurements were made with the Marsh-McBirney Model 201 electromagnetic current meter. The second and third measurements were made with a Price pygmy current meter. All measurements were made in accordance with the procedures recommended by Buchanan and Somers (1973). The results of each series of flow measurements were averaged, then divided by the planimetered drainage area of each watershed, yielding a discharge value expressed in cubic meters per second per square kilometer (cms/km^2).

Benthic organisms were collected with a Surber square foot sampler. At each of the 15 streams sampled, care was taken to avoid the influence of nearby road crossings or other physical alterations of the channel. A total of three 0.09 m^2 bottom samples were

collected from a single riffle at each study stream. The sampler contents were placed in a U. S. No. 30 sieve bucket and then transferred to a plastic container in which the contents were preserved in 70% ethanol. The Surber sampling was carried out in accordance with *Biological Field and Laboratory Methods* (Weber, 1973).

Due to the small size of the study streams (most less than 2 meters wide) fish collections were made with fine mesh rectangular dip nets. On each of the 11 streams sampled two collectors waded a 100-meter section, in an upstream direction, sampling every microhabitat encountered. At the end of this first section the specimens collected were examined to determine the species. Then an additional 50-meter section was sampled and at the end another species census was made. If any new species were collected then additional 50-meter sections were sampled until no new species were obtained.

RESULTS

A definite relationship was found between baseflow and watershed imperviousness as illustrated in Figure 1. Baisman Run, the watershed of which 70 percent is woodland, consistently had the highest discharge per square kilometer of drainage area. Redhouse Run, which drains the eastern perimeter of Baltimore City and is covered by impervious materials over 38 percent of its 4.4 km^2 watershed, was dry on the dates investigated. Generally, as watershed imperviousness increases, baseflow diminishes.

Of the 15 benthic samples collected, the three from the control (wooded watersheds) streams had the greatest diversity. The index used to assess diversity was that developed by Shannon and Weaver and recommended by Weber (1973). The Species Diversity Index ($\bar{d}$), expresses diversity as a number ranging from 0.00 to 4.00, with high values indicating a diverse community. The $\bar{d}$ values have been verbally expressed as: 0.00 – 1.00 = poor conditions; 1.00 – 2.00 = fair conditions; 2.00 – 3.00 = good conditions; and 3.00 – 4.00 = excellent conditions.

Applying the Species Diversity Index to the benthic collections leads to questionable results due to the small sample size of most urban stream samples. Weber (1973) suggests that $\bar{d}$ values for samples containing less than 100 organisms should be evaluated with caution, if at all. Results of the Surber samples are summarized in Table 1.

Of the 11 streams in which fish collections were made, Buffalo Creek, draining an agricultural watershed, had the greatest number of species present. Five of the 9 urban streams sampled were completely devoid of fish life. The largest aquatic organism inhabiting the streams draining intensely developed areas appeared to be the crayfish, *Orconectes virilis*.

Due to the sampling techniques used, fish collections can be considered valid only from a qualitative viewpoint. It is interesting to note that in 3 of the 4 urban streams where fish were collected the dominant species was the Blacknose Dace, *Rhinichthys atralatus*. Dietemann and Giraldi (1973) stated that, " . . . this fish can tolerate a wide range of environmental conditions. It can be found where no other fish can live." Therefore the dominance of the Blacknose Dace may be assumed to be another indicator of the low quality of the urban stream environment.

DISCUSSION

The degraded character of urban streams does not result from any single factor, but rather from the interaction of a variety of detrimental effects. Although none of the

streams investigated in this first phase received point source discharges or sewerline overflows, they none the less exhibited increased quality impairment as watershed imperviousness increased. Following is an overview of data gathered in this study and by other workers. This discussion is provided so that the reader can fully appreciate the complexity of the stress factors present in urban streams.

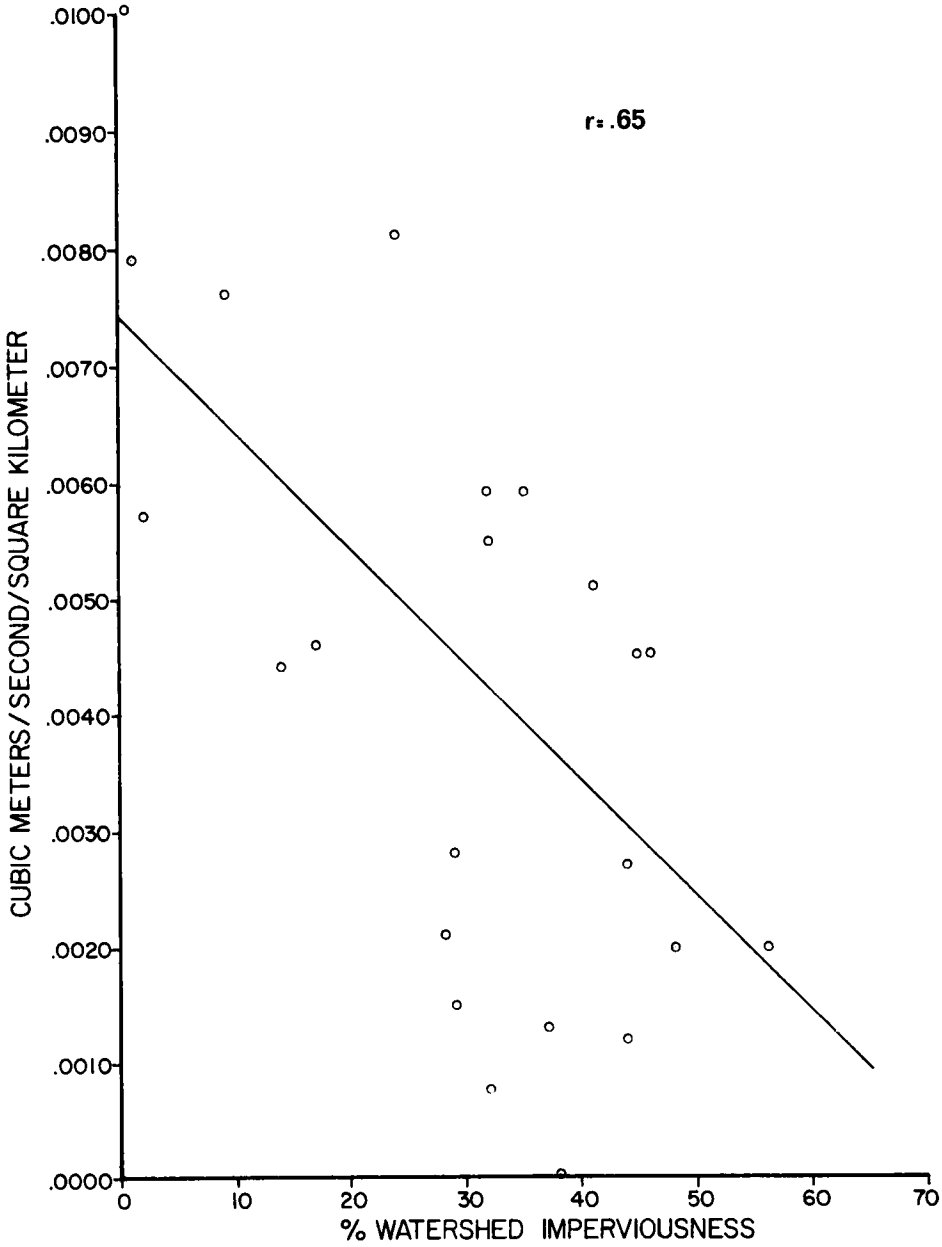

Figure 1. Base Flow Versus Watershed Imperviousness.

TABLE 1. Results of Surber Sampling and Fish Collections Made in Baltimore County, Maryland.

			Surber Sampling Results			Fish Collections		
Stream	Dominant Land Use	Impervious Area	$\bar{d}$	Organisms* Collected	Taxa Collected	Organisms Collected	Species Collected	Dominant Species
Unnamed Tributary to Gunpowder Falls	Forest	0%	3.33	181	19	Not Sampled		
Panther Branch	Forest	1%	2.85	89	16	Not Sampled		
Baisman Run	Forest	0%	2.48	122	12	19	2	Rosyside Dace (*Clinostomus funduloides*)
Buffalo Creek	Agric.	0%	1.92	315	18	61	6	Creek Chub (*Semotilus atromaculatus*)
Long Quarter Branch	Resid.	44%	1.78	203	4	0	0	
Spring Branch	Resid.	32%	1.45	230	8	0	0	
Unnamed Tributary to Beaverdam Run	Resid.	41%	1.45	97	6	0	0	
Keysers Run	Agric.	0%	0.96	519	9	Not Sampled		
Slaughterhouse Branch	Resid.	17%	0.94	167	7	32	2	Blacknose Dace (*Rhinichthus atralatus*)
Bens Run	Resid.	23%		20	7	2	1	Blacknose Dace (*Rhinichthus atralatus*)
Unnamed Tributary to Gwynns Falls	Resid.	48%		6	4	3	1	Creek Chub (*Semotilus atromaculatus*)
Perring Run	Resid.	48%		18	4	0	0	
North Branch-Whitemarsh Run	Resid.	28%		8	2	0	0	
Whitemarsh Run	Resid.	56%		10	3	0	0	
Jennifer Run	Resid.	28%		12	2	54	2	Blacknose Dace (*Rhinichthus atralatus*)

*All macroinvertebrates collected were identified to genera except the Chironomids which, with the exception of one sample, were represented by only a few individuals appearing to be of the same genera.

Construction Phase

The first environmental insult resulting from urbanization occurs during the construction phase when denuded earth is exposed to the full force of erosion. Wolman (1964), discussing very small watersheds stated, "Because construction denudes the natural cover and exposes the soil beneath, the tonnage of sediment derived by erosion from an acre of ground under construction in developments and highways may exceed 20,000 to 40,000 times the amount eroded from farms and woodlands in an equivalent period of time." In her study of the Patuxent River basin, Fox (1974) found urbanizing watersheds were generating 9 times as much sediment as rural or natural drainage areas. Fox also found that with a steady sediment source sand covered the natural stream bed in 2 to 3 months. Sand, when it is of the shifting, unstable variety, provides one of the poorest substrates for benthic life. Fox determined that the total volume of sand in an urbanizing stream could be 15 times that found in nearby rural watercourses. Her estimates indicated that 10 to 50 years were required for a stream to recover from the construction phase of urbanization and in some cases hundreds of years might be needed for full recovery. Fox also concluded that an average of 4.8 to 5.6 kilometers of stream below a sediment source were affected by the eroded soil particles.

Runoff Quantity

When the construction phase is completed and the soil stabilized the land surface is left in an altered hydrologic condition, the net effect of which is increased storm water runoff and decreased infiltration. Leopold (1968), stated that a direct relationship exists between the number of bankfull flows that occur annually and the extent of urbanization. When the watershed is in a rural or natural condition bankfull flows usually recur once annually. When watershed imperviousness reaches 40 percent bankfull flows occur 3 times yearly. When the drainage area is completely developed the stream fills from bed to banktop with runoff an average of 5.6 times each year. Hoopes (1975), in his study of the effects of Hurricane Agnes on a central Pennsylvania stream, found that the flood had reduced the young-of-the-year trout population by 96 percent. In another study Elwood and Waters (1969) found that two-year classes of Brook Trout, *Salmo fontinalis* Mitchill, were nearly eliminated by 4 severe floods which occurred over a two-year period. They also found that invertebrate populations were severely damaged by the floods. Under natural conditions such catastrophic events are usually spread out over a long period of time and therefore have a minimal effect upon the overall health of the stream. Some workers have even stated that such floods are essential to stream health through their scouring and cleansing effect. But as floods become more frequent the resiliency of the stream community is strained, making it difficult to rebuild stable populations. As Leopold pointed out the volume of storm water runoff and subsequent flooding increases as urbanization intensifies. For instance, estimates made by the author using the Peak Discharge Method (WRA, 1975) indicates that a stream, typical of that found in the Maryland Piedmont, with a watershed of 2.6 square kilometers in area, would carry 4.25 cms at the flood peak during a 100-year storm when the watershed is completely forest covered. This same stream would be subjected to a flood peak of equal volume (4.25 cms) once every 5 years when watershed imperviousness reaches 25%. At a watershed imperviousness degree of 38 percent this same peak volume would recur once every 2.5 years. And when 65 percent of the watershed is covered by impervious surfacings the former 100-year peak discharge of 4.25 cms would recur once annually.

Channel Morphology. The increased runoff delivered to urban streams causes several changes in channel morphology. Robinson (1976), in his study of 8 small watersheds located in the Piedmont province of Maryland, found that streams draining developed watersheds averaged twice the channel width of rural streams. Hammer (1972), reporting on 78 small watersheds near Philadelphia found much the same effect upon urban stream morphology although some of the streams he investigated had channel widths 3.8 times that of nearby rural streams. Fox (1964), in her study of 64 points in the Patuxent River basin, found much the same degree of channel widening in urban streams. Channel enlargement, resulting primarily from erosion of the banks, introduces a rather high quantity of sediment into the stream. Robinson (1976) estimated that the total quantity of sediment resulting from erosion occurring during the enlargement period averages 2,300 m^3/km^2 of drainage area. Robinson also estimated that some 15 years are required for the enlargement process to end. He also found that the substrate of urban streams tends to be composed of coarser particles, with a paucity of the sand and silt fractions, than that found in rural watercourses. The ever-changing character of urban streams during the enlargement process, coupled with the sediment inputs, would in itself make it difficult for aquatic life to build stable populations much less those resembling preurbanization communities. Once the enlargement process ends, aquatic life may still be faced with high velocity floodwaters and the coarser bed materials. These larger bed particles could increase the potential for washout or predation for those organisms which lay their eggs or dwell within the stream bed.

Migration Barriers. Many of the Piedmont streams flowing to tidewater support spawning migrations of anadromous fish species, particularly in their lower reaches (O'Dell, *et al.*, 1975). Debris dams – accumulations of logs, brush, litter, etc. – are one of several obstacles limiting the extent of a stream available to the spawning fish. Fox (1974) found that in the Patuxent River system debris dams occur at an average of once every 335 meters in streams draining natural watersheds, while urban streams average a debris dam every 73 meters. Therefore, migrating fishes would either find upstream movement more difficult or halted at a closer distance to the mouth in urban as compared to natural streams. This problem would not solely affect anadromous species since most stream dwelling fishes also make annual migrations.

Baseflow. Tennant (1975) found that the suitability of a stream for fish declines as baseflows diminish. The adverse affects attributed to reduced flow include loss of cover, reduced velocities, alteration of the temperature regimen, and impairment of the ease with which riffles could be negotiated. Tennant states that severe degradation of the suitability of a stream for fish occurs when the baseflow drops to 10 percent or less of the average discharge. Analysis of the U.S. Geological Survey data on 14 gauged streams, by this writer, in Baltimore and Carroll Counties, Maryland, indicates that discharges in this region average 0.092 cms/km^2. The author found that baseflow is reduced to 10 percent of the regional average when 65 percent of the watershed is covered by impervious materials (see Figure 1). Tennant also stated that "fair to degrading" conditions are maintained when April to September baseflows drop to 30 percent of the average. The author also determined that flows reach this level when 45 percent of the watershed is covered by impervious materials. It is important to remember that the discharge measurements made in this study were not taken at the time of year, autumn, when streams

usually reach their annual low flow point. Therefore, the 10 percent and 30 percent flow values may occur in watersheds with lesser degrees of urbanization than given above.

Leopold (1968) states that, "Reduced volume also effects low flows because in any series of storms the larger the percentage of direct runoff, the smaller the amount of water available for soil moisture replenishment and for ground-water storage. An increase in total runoff from a given series of storms as a result of imperviousness results in decreased ground-water recharge and decreased low flows. Thus increased imperviousness has the effect of increasing flood peaks during storm periods and decreasing low flows between storms." Hammer (1973) also concluded that increased imperviousness reduces infiltration and therefore baseflows. In his study of Philadelphia streams Hammer found a steady decline in baseflow per square kilometer of drainage area until watershed imperviousness reached 40 percent to 50 percent. In these intensely developed watersheds he theorized that municipal water imported to the drainage area was offsetting, somewhat, the effects of reduced infiltration. Hollis (1976) in summarizing the results of other studies found that decreased baseflow, as a result of urbanization, is less likely to occur than baseflow increases. It appears that the direction baseflow changes take is dependent upon the particular physiographic province a stream is located within. In the coastal plain of Maryland, where bank soil tends to be relatively permeable, it is possible that increased flooding, resulting from urbanization, could also increase the volume of water stored in bank soils then released during post-flood periods and therefore baseflow might increase. But in the Piedmont, with its silty soils, perhaps bank storage is insufficient to offset the effects of reduced upland infiltration in urbanized watersheds. Additionally, one other possible explanation exists for the relationship between urbanization and baseflow documented in this study. As stated earlier Robinson (1976) found that urban stream beds tend to consist of coarser particles. It is possible that a portion of the flow may be traveling beneath the bed surface through the coarser particles. Whatever the reason, it appears certain that baseflow does diminish as imperviousness increases in the Maryland Piedmont.

Temperature. Several of the changes wrought by urbanization can affect the natural stream temperature regimen. The effect of reduced shade upon maximum stream temperatures has been well documented (Brown, 1969; Brown and Krygier, 1970; O'Dell, 1971; Ringler and Hall, 1975; and Hartley, 1975). The author (Klein, 1977) documented an 11°C difference between a wooded section along a Harford County, Maryland, stream and a poorly shaded pasture section of the same stream located 1.2 km below the woodland measurement point. Reductions in the amount of shading afforded urban streams results from bank alterations during sewerline installations, channel realignment projects and other construction activities. The two-to-four-fold widening of the channel due to increased runoff and enlargement not only reduces the amount of the stream shaded, but also results in shallower water depths which further adds to the degree of heat loss and gain. Under conditions of reduced shade diurnal temperature fluctuations are also greater. During July 1977 I found that the differences between daily minimum and maximum temperatures along a Harford County, Maryland, stream were 1.9^{o}C in a wooded section, 4.3^{o}C in a shrub lined section, and 8.3^{o}C in a pasture reach. Pluhowski (1970) found when investigating 5 streams on Long Island, New York, that urban streams reach lower winter temperatures, 1.5^{o} – 3°C, than relatively undisturbed streams.

The temperature of headwater streams is influenced greatly by ground water inflow. Data collected on Jones Falls in Baltimore County, Maryland, determined that ground

water, as it surfaces, has a temperature of 10° – $11^{o}C$ (J. A. Gracie, 1977 personal communication). As a result the temperature of streams near the sources of ground water inflow, such as upper Jones Falls, rarely falls below $7.8^{o}C$ in the winter and infrequently rises above $20^{o}C$ in the summer. Therefore, reducing ground water inflow can further the degree of departure from the natural stream temperature regimen, allowing streams which were normally ice free through winter to freeze or to reach critically high summer temperatures.

Runoff Quality

The quality of urban runoff has been likened to that of raw sewage and in several respects can be 2 to 10 times as polluted. Though the quantity of specific pollutants contributed by urban runoff is high it is important to remember that the dilution rate is equally large, yet the net effect of the contaminants exported from urban areas remains uncertain due to a paucity of basic data. For instance, though urban runoff contributes a large volume of oxygen demanding material it seems relatively rare for the oxygen content of urban streams to be depleted appreciably. Davis and Hammer (1976) attributed this to the short residence time of the material in the stream.

Nutrients. Nutrient loadings are also quite high from urbanized watersheds. Omernik (1977), in his graphical description of loading rates from various land uses, illustrated that mean total nitrogen exports from urban areas was second only to intensively farmed watersheds. Mean total phosphorus exports were second only to cleared, unproductive land. While the effect of high nutrient loads upon streams seems unclear, Cole (1973) found that macroinvertebrate diversity declined from a high of 3.51 above a nutrient input source to 1.31 downstream of the source. The principal effect of nutrients upon a stream would be the stimulation of algae and other aquatic plant growth. When plant growth becomes intense night time dissolved oxygen levels can become critically low. Also the community structure could be altered in favor of those organisms capable of exploiting the increased plant growth. Under natural conditions algae growth constitutes a mere 1 percent of the energy budget of headwater streams (Cummins, 1974) where shading bank vegetation appears to be the primary factor holding plant growth in check. When the watershed is urbanized a portion of the shading vegetation is usually removed. With the combination of increased sunlight and nutrient inputs, conditions would seem right for a considerable increase in algae populations. It appears, however, that such algae blooms seldom occur in urban streams. The author has rarely witnessed intense or even moderate algae growth in streams draining highly developed watersheds. Perhaps these aquatic plants are just as susceptible to the adverse effects of urbanization as are other stream dwelling organisms.

Toxic Substances. Heavy metal inputs from urban areas can be high also. Laxen and Harrison (1977) reported that lead concentrations in highway runoff were 10^3 to 10^4 times that of background levels. The Northern Virginia Planning District Commission (1977), in its interim report on the Occoquan/Four Mile Run Nonpoint Source Correlation Study, does provide a comparison between lead and zinc loadings from various land uses. As illustrated in Figure 2, the loading rates of these two metals rises as watershed imperviousness increases. In a Massachusetts study Berger (1976) found that, " . . . urban runoff appeared to exert a significant negative impact on the benthic biota. Analysis of sediment, detritus and benthic macroinvertebrates revealed unexpectedly high and

normally acute toxic concentrations of several metals." Yet Berger concluded with the caution that the specific source of these metals remains to be determined.

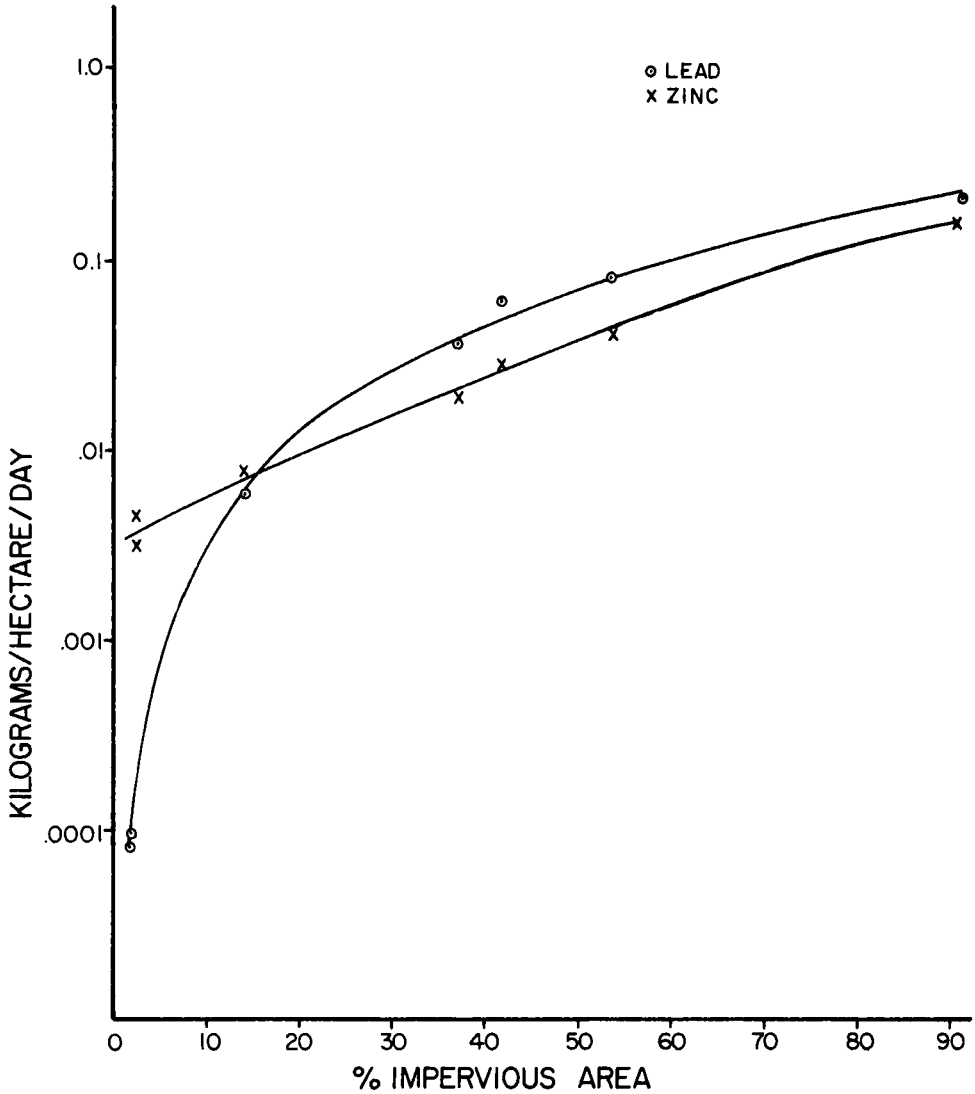

Figure 2. Total Extractable Metals Loadings Versus Watershed Imperviousness.

Bryan (1972), in summarizing pesticide loadings found in his study and that of others, stated that rural runoff contained a mean value of 0.43 ug/l while the mean of urban runoff ranged from 1.16 to 1.70 ug/l.

In 1973 70 million liters of automotive lubricants were sold in Maryland. Of this quantity the final disposition of only 45 million liters could be accounted for with the whereabouts of the remainder uncertain. A 1973 estimate indicated that "do-it-yourself" mechanics drain 19 million liters of used oil from Maryland cars annually. A door-to-door

survey (Klein, 1976) conducted by the Baltimore County Save Our Streams program indicated that 9 percent of the do-it-yourselfers dispose of used oil by pouring it into strom drains or gutters. In the early 1970's it was estimated that 9.5 million liters of oil entered Baltimore Harbor annually and originated from runoff and small diffuse sources. Whipple, *et al.* (1975), estimated that runoff from Philadelphia carried 3,600 kilograms of oil on an average daily basis. Therefore, it appears certain that a considerable quantity of oil does reach urban streams, adding its share to the impairment of these waters.

McKee and Wolf (1963) reported that chloride concentrations of 400 mg/l were harmful to trout with other species tolerating levels up to 9,000 mg/l. In urban watersheds where sewerlines are present, and not overflowing, street salting appears to be the principal source of chloride entry into streams. Hawkins and Judd (1972) reported that road salt washoff resulted in a chloride concentration of 11,000 mg/l in a small New York state stream. A Chicago study (APWA, 1969) documented chloride concentrations in receiving waters draining a salt treated highway of 25,100 mg/l. Critikos and Klein (1978), while collecting daily samples from a small urban stream, found that chloride concentrations over a 23-day period averaged 219 mg/l and ranged from 113 to 410 mg/l. The tolerance levels given above are based upon test periods ranging up to 96 hours. It is possible that exposure to concentrations of chloride of 200 mg/l over a 23-day period could well be at or above the long-term tolerance level of sensitive organisms.

Summary

As indicated earlier the degraded character of urban streams is not the result of any single detrimental factor, but the synergistic interaction of all the detrimental factors discussed above. Analysis of the baseflow data from the present study indicates that "severe degradation" as defined by Tennant, occurs when 30 percent to 70 percent of the watershed is covered by impervious surfacings. All the urban streams whose watersheds fell within this range of imperviousness evidenced severely degraded conditions for aquatic life in the form of either reduced benthic communities or the absence of fish life.

When watershed imperviousness ranged from 30 percent to 45 percent baseflows were reduced to Tennant's "fair to degrading" level. Slaughterhouse Branch, which was the only urban stream supporting both an abundant benthic community and a fish population, was biologically in the best condition of any of the urban watercourses investigated. It is interesting to note that its benthic Species Diversity Index, verbally expressed, is on the borderline between "poor to fair," agreeing with the verbal description of its baseflow.

To determine if the relationship between degree of urbanization and stream quality remains constant as watershed size increases and throughout the Piedmont province, 78 fish collections from Montgomery and Prince Georges County streams were examined (Dietemann, 1975; Dietemann and Giraldi, 1973). The Species Diversity Index ($\bar{d}$) was calculated for each collection then plotted against watershed percent imperviousness using the same procedures outlined earlier, the results of which are illustrated in Figure 3. Though a fair amount of scatter can be seen in the graph, a generally direct relationship does exist between the degree of urbanization and the diversity of fish populations.

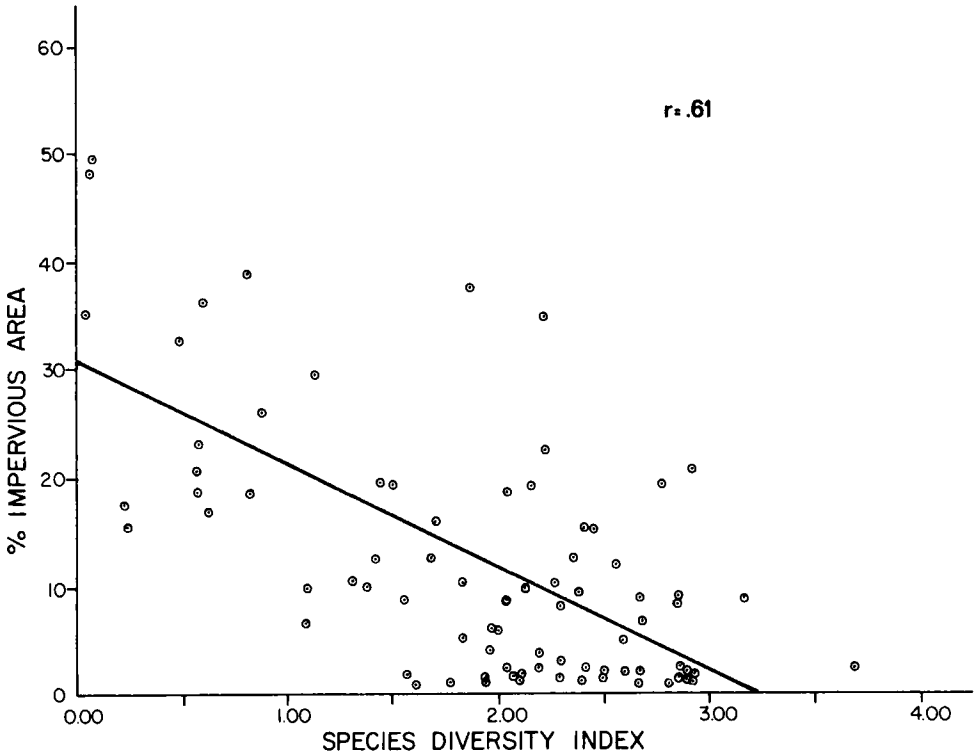

Figure 3. Montgomery/Prince Georges County Fish Collections Versus Watershed Imperviousness.

CONCLUSIONS

It is the author's opinion that impairment begins when stream quality drops from good to fair. Using these guidelines, data from the first phase of the study indicates that stream quality impairment is initially evidenced when watershed imperviousness reaches 15 percent. From Figure 3, which is based on fish collections made in streams draining watersheds 5 to 130 km^2, note that the line of regression crosses the Species Diversity Index of 2.00, which separates the good to fair range at the 12 percent imperviousness point. From these data two recommendations can be made:

1. Generally, stream quality impairment can be prevented if watershed imperviousness does not exceed 15 percent.
2. For the more sensitive stream ecosystems, such as those supporting self-sustaining trout populations, watershed imperviousness should not exceed 10 percent.

If a jurisdiction were to decide to limit urbanization in undeveloped areas to the recommendations given above, the degree of development allowed should not exceed that given in Table 2. Should a jurisdiction decide to adopt these recommendations it should consider duplicating the study described herein once every 5 to 10 years, or whenever a new control strategy is applied to the detriments resulting from urbanization. This precaution would prevent a landowner/developer from being penalized by an outdated

restriction and would also serve as a stimulus for designing developments to be as environmentally compatible as practical.

TABLE 2. Allowable Watershed Development Rates Based Upon This Study.

Land Use Category	Imperviousness	Maximum Amount of Watershed that can be Developed Based Upon an Imperviousness of 10%	15%
Individual Homes			
0.40 Hectare (1.00 acre) Lot	20%	50%	75%
0.20 Hectare (0.50 acre) Lot	25%	40%	60%
0.13 Hectare (0.33 acre) Lot	30%	33%	50%
0.10 Hectare (0.25 acre) Lot	38%	26%	29%
0.05 Hectare (0.12 acre) Lot	65%	15%	23%
Townhouse/Garden Apartments	44%	22%	33%
High-Rise Residential	56%	18%	27%
Industrial Districts	75%	13%	20%
Commercial/Business Area	85%	12%	18%
Shopping Centers	95%	11%	16%

Some controls are currently being applied or planned to reduce the effects or urbanization upon stream quality. In the Maryland jurisdictions located in the Piedmont, where storm water management is required for most new developments, Detention/Retention structures dominate. These devices, consisting mostly of open ponds or underground storage areas, are intended to temporarily detain a portion of the runoff. As a result the "peak discharge" volume is lessened along with downstream erosion and scouring. While this approach does reduce some of the physical effects of urbanization it has a minimal impact upon the runoff quality. Currently, infiltration systems make up only a small portion of the control strategies outlined in Storm Water Management Plans. This fact is said to be due to the difficulty involved in designing these systems. Yet if infiltration systems were to dominate, not only would erosion and scouring be reduced, but baseflows would also be improved through the added recharge of the ground water system. Additionally, percolation through the soil would provide removal of the quality constituents of urban runoff. But this raises another question. Neither the filtration, adsorption, nor ion exchange capacity of a soil is infinite. In 50 years after their installation would we find that a healthier stream has been purchased at a price of a contaminated aquifer? And once the neutralization capacity of the soil is exhausted would the pollutants eventually reach the stream anyway? Unfortunately once an infiltration system failed it would not be as easy to correct as a failing septic system, in which case a new system is simply installed. Infiltration systems designed as storm water management devices require a rather extensive amount of land to handle the volume of runoff delivered to the device. Even if money were available to install the device, how frequently would sufficient land for the new structure be available in an existing development?

The third option available for controlling urban runoff is treatment. This option is a rather expensive one with the cost of providing secondary treatment for all of Maryland's urban runoff placed at $6 billion. If only primary treatment were used, the cost would run about $500 million.

In summary, four options are available to reduce the adverse affects or urbanization upon stream quality. Detention/Retention systems will reduce the velocity-scour problem resulting from urbanization with minimal impact on the other detrimental effects. Infiltration systems offer a means of temporarily lowering the impact of land development but improved stream quality may be exchanged for a polluted aquifer. Treatment of storm water would also mitigate many of the adverse affects of urbanization and provide a more lasting improvement than infiltration systems alone. Yet treatment appears justifiable, due to its high cost, in only the severest of situations.

The last alternative is that proposed by this study. Limiting watershed development to the rates recommended in Table 2 would preserve stream quality with the only costs involved being that incurred by the landowner due to building restrictions. It is not unlikely that the long-term reliability of existing control strategies such as infiltration systems will be found acceptable. Nor is it unlikely that new control strategies will be developed to resolve the adverse affects of urbanization upon stream quality. Therefore, the landowner/developer will probably be faced with only a temporary restriction upon the use of his property should this fourth approach be adopted by a jurisdiction.

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