CHAPTER 1

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1.00 WATER QUANTITY AND QUALITY

1.10 HOW URBANIZATION AFFECTS WATER QUANTITY

URBANIZATION CHANGES HYDRAULICS

In Minnesota, precipitation varies from event to event and geographically from the northwest to the southeast. We use statistics to help understand the significance of these patterns and variability. Over time, these events can be averaged to develop what is called the "normal annual precipitation pattern" (see Figure 1.10-1).

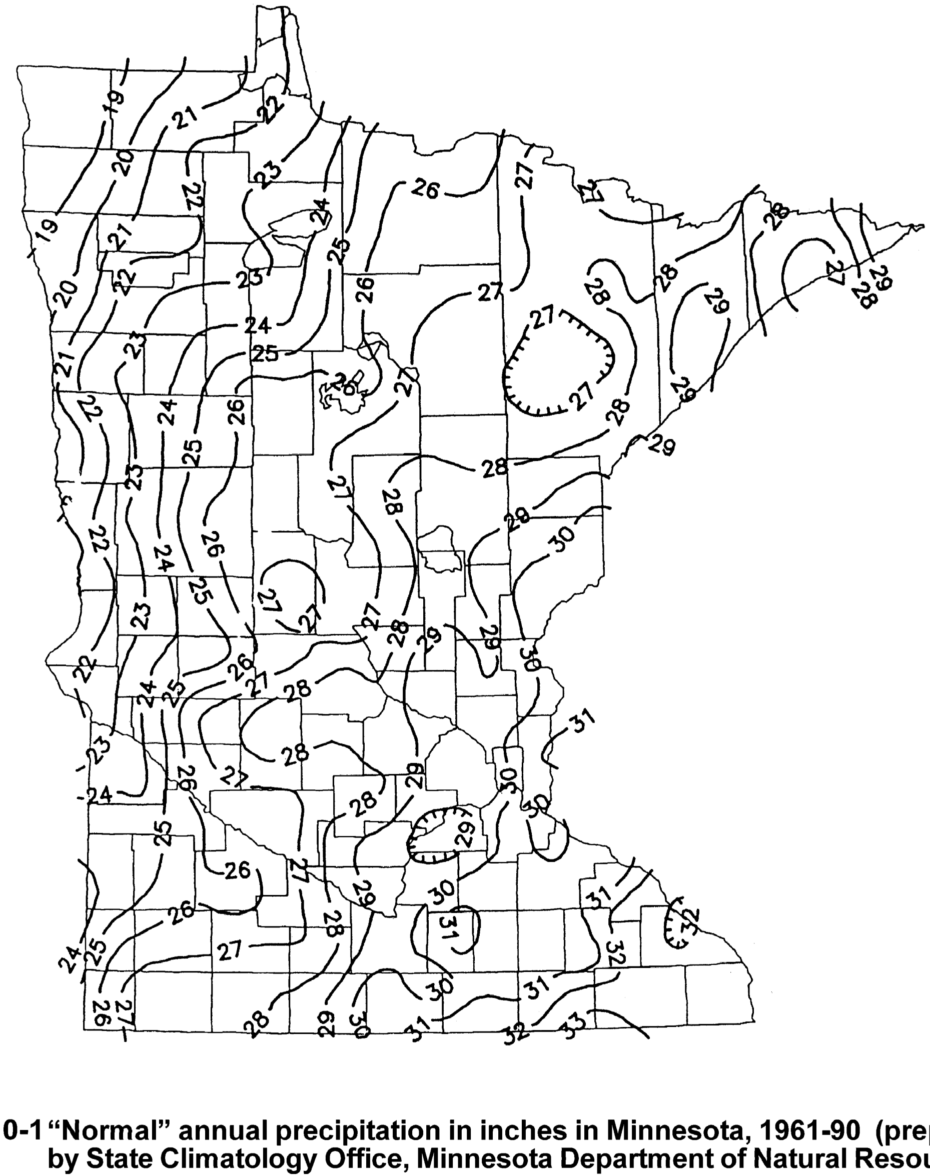


Figure 1.10-1 **"Normal" annual precipitation in inches in Minnesota, 1961-90 (prepared by State Climatology Office, Minnesota Department of Natural Resources, Division of Waters)**

While rainfall patterns may or may not have been affected by human activity, it is clear that runoff has changed significantly with human development. In the presettlement Midwest, entire watersheds were in vegetative cover (*e.g.,* prairie, oak savanna), with maximum infiltration and minimum runoff. With the massive conversion of the landscape to agricultural and urban uses came substantial changes in runoff of precipitation to wetlands, lakes and streams.

Table 1.10-1 Urban areas: average percent impervious surface by type of land use

Land Use Type	Percent
Commercial and business districts	85
Industrial areas	72
Residential districts by average lot size	
1/8 acre or less (townhouses)	65
1/4 acre	38
1/3 acre	30
1/2 acre	25
2 acres	12
From: USDA, Soil Conservation Service, June 1986	

Removal of perennial vegetation led to a decrease in infiltration and an increase in the volume of runoff. Exposing soils to wind and water erosion increased sediment loads carried by runoff. Impervious surfaces and artificial drainage systems increased the volume of runoff and accelerated the rate at which water was removed from the landscape. Impervious surfaces in urban areas also transported runoff more rapidly and in greater volumes than before development (see Table 1.10-1). Fertilizers, pesticides, automobile exhaust residues, animal waste and other sources greatly increase nutrient loading and contaminants carried by runoff. All of these factors have prominent roles in altering and degrading wetlands, lakes and streams.

QUANTITY OF RUNOFF

When an urban area is developed, natural drainage patterns are modified as runoff is channeled into road gutters, storm sewers and paved channels. The amount of rainfall that can infiltrate into the soil is reduced, which increases the volume of runoff from the watershed (see Figure 1.10-2). Drainage modifications also increase the velocity of runoff, which decreases the time required to convey it to the outlet of the watershed.

Figure 1.10-2 shows the relationship of runoff, infiltration and evaporation for watersheds with varying degrees of impervious cover. Typical impervious cover percentages are shown in Table 1.10-1.

Increased volume and increased velocity of runoff results in higher peak discharges and shorter times to reach peak discharge. This causes higher flows, flooding, erosion and adverse effects on habitat in natural streams.

Figure 1.10-3 shows typical predevelopment and postdevelopment hydrographs for a watershed that is being developed for urban land uses. The areas below the hydrographs represent the volume of runoff. The increased volume of runoff after development is important because of the increased pollutant loading it can deliver as well as potential flooding and channel-erosion problems.

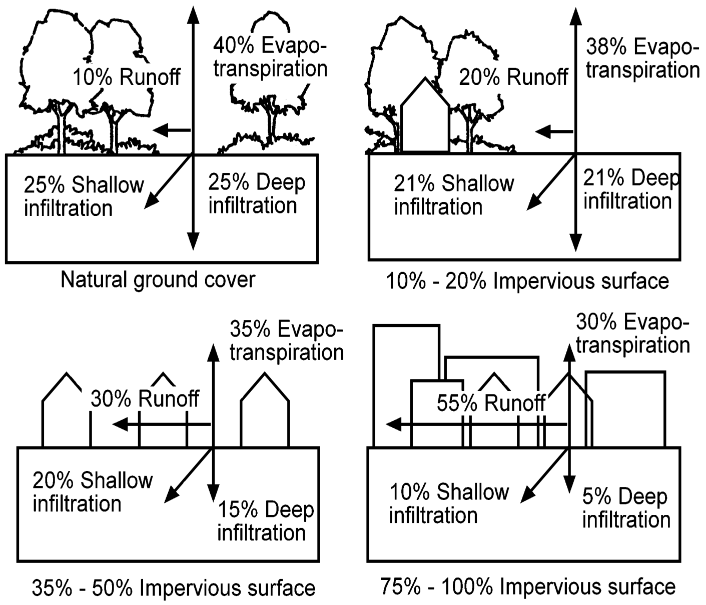


Figure 1.10-2 Changes in runoff due to urbanization

Under natural conditions and at bank-full capacity, studies have shown that streams can handle a flow approximately equal to the one-and-one-half- to two-year frequency peak discharge within their banks (Rosgen, 1994; Leopold *et al.*, 1964). After urbanization, increased flows can cause bank-full flow to be exceeded several times each year. In addition to regular flood damage, this condition causes previously stable channels to erode and widen. Much of the eroded material becomes bed load and can smother bottom-dwelling organisms. Sediment from streambank erosion eventually settles in streams, rivers and lakes, reducing their capacity and water quality. Base flow in streams is also affected by changes in hydrology from urbanization because a large part of base flow comes from shallow infiltration. Impervious cover reduces base flow, reducing the volume of water available for base flow in streams. These changes in hydrology, combined with increased pollutant loadings, can have a dramatic effect on the ecosystem of urban streams. Studies of streams affected by urbanization have shown that fish populations either disappear or are dominated by “rough” species that can tolerate a lower level of water quality (Klein, 1979).

HYDROLOGIC CHANGES IN WETLANDS AND WATERWAYS

Water is the driving force in wetlands. A naturally fluctuating hydrologic cycle over hundreds or thousands of years has helped shape the plant and animal communities present in wetlands. Many of the organisms, including plants, have become adapted to fluctuating water levels, saturated soils and anaerobic conditions. Wetlands have adapted to natural cycles of wetness and drought. These are important factors in natural wetland hydrology that maintain the functions and values that wetlands provide.

Water that drains from a project area into an off-site drainage basin impacts trees and other vegetation. In such cases, water itself is the damaging agent even if it is clean. The increase in water level, both surface and subsurface, can result in the death of roots. In Minnesota, few tree species can tolerate extended periods of flooding. Roots require oxygen from the air, and saturated soils create an anaerobic condition that will eventually kill the roots. A case in point is a tamarack swamp that receives water from several developments. The water travels very slowly through the swamp, and the increased flow results in the death of many of the tamarack trees.

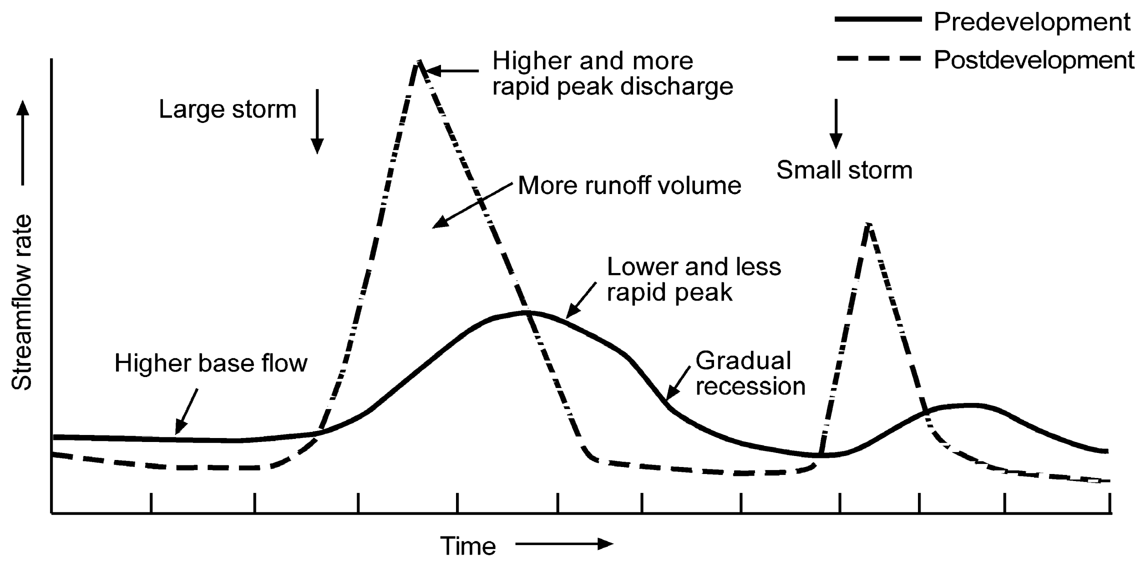


Figure 1.10-3 Changes in stream hydrology as a result of urbanization (Schueler, 1992)

HYDROLOGIC MODELING CONCEPTS

Urban hydrology models often depend on information gained from studies of flood and drainage conditions in rural areas. However, assumptions that are appropriate for large storms may create problems when used for small storms. The runoff values for storms often do not approach conventional runoff predictions until several inches of rain have fallen.

More infiltration occurs through street pavement than is generally anticipated, and the infiltration rates through disturbed urban soils are highly irregular. Under some conditions, these disturbed areas can have much less infiltration than pavement. For example, turf playing fields and unpaved parking lots can have less infiltration than a paved area, such as a roadway. However, large paved areas, including freeways, have less infiltration because of longer drainage paths and sealing overcoats (Pitt, 1987).

Figure 1.10-4 (Pitt, April 29-30, 1998) shows measured rain and runoff distributions for Milwaukee during 1983. Rains between 0.05 and 5.0 inches were monitored, and two very large events (greater than 3.0 inches) occurred, which greatly bias these curves, compared to typical-rain years. It was found that the median rainfall was about 0.3 inch, and that 66% of all Milwaukee rains were less than 0.5 inch. In addition, 50% of the runoff was associated with rains of less than 0.75 inch for medium-density residential areas.

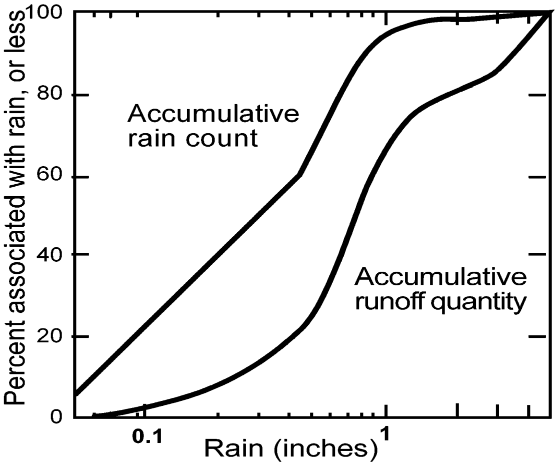


Figure 1.10-4 **Milwaukee rain and runoff distributions**

In contrast, a 100-year, 24-hour rain of 5.6 inches for Milwaukee could produce about 15% of the average annual runoff volume, but only contribute about 0.15% of the average annual runoff volume when amortized over 100 years. Similarly, typical 25-year drainage design storms (about 4.7 inches in Minneapolis) produce about 12.5% of the annual runoff volume when they occur in a typical year, but only about 0.5% of the average runoff volume over a given 100-year period.

Figure 1.10-5 (Pitt, April 29-30, 1998) shows actual measured Milwaukee pollutant discharges associated with different rain depths for a medium-density residential area. Monitored discharges of suspended solids, chemical oxygen demand, lead, and phosphates (PO_4) closely follow the runoff distribution shown in Figure 1.10-4. These figures substantiate typical statistical analysis results that show that concentrations of most runoff pollutants do not significantly vary for runoff events associated with different rainfall amounts.

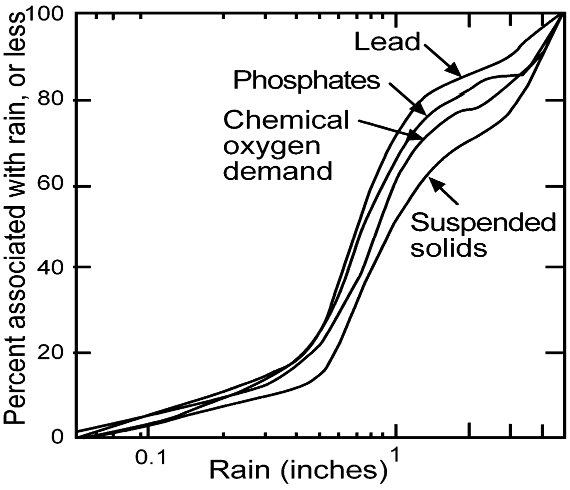


Figure 1.10-5 **Milwaukee pollutant discharge distributions**

Therefore, being able to accurately predict runoff volume is very important in order to reasonably predict runoff pollutant discharges. The best way to verify how well a model and the included assumptions perform is to compare the results with data independent from those used for calibration. Data can be collected on site or from other sites considered adequately representative of the study site. This verification of model results is often overlooked. Encouraging or requiring verification is the only way to have confidence in the results.

Figures 1.10-4 and 1.10-6 show three distinct rainfall categories:

1. Common rains less than approximately 0.5 inch have relatively low pollutant discharges (less than 25% of the annual pollutant mass discharges from residential areas), but occur very often (on about 95 days a year in Minneapolis-St. Paul). These are key rains when evaluating runoff-associated water-quality violations, especially for bacteria and heavy metals. These pollutants in the storm water exceed water-quality standards for almost all rains.
2. Rains between 0.5 and 1.5 inches are responsible for about 75% of the annual runoff-pollutant mass discharges from residential areas, and are the key rains that need to be addressed when concerned with mass discharges of pollutants.
3. Rains greater than 1.5 inches occur rarely (on only about two days a year in Minneapolis-St. Paul) and are needed for designing and evaluating storm drainage systems. However, these rains are only responsible for relatively small portions of the annual pollutant mass discharges. In

Minnesota, more than 90% of the precipitation events are less than 1.0 inch (Figure 1.10-6). These rainfall events also account for the majority (about 65%) of the cumulative runoff quantity and proportionately large amounts of the pollutant loading associated with these rainfall events (Pitt, April 29-30, 1998). The pollutant loading is more closely associated with total runoff volume than with peak runoff rates.

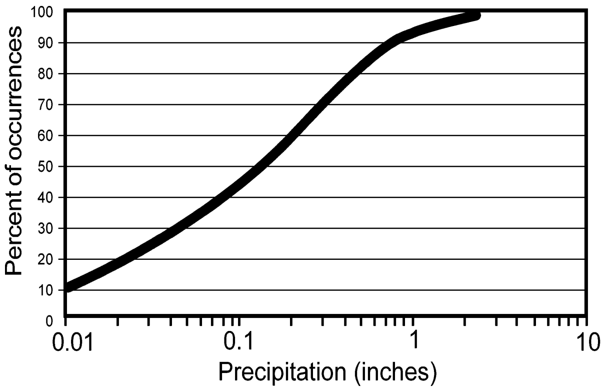


Figure 1.10-6 Daily precipitation — cumulative frequency distribution, Minneapolis-St. Paul (April-October 1891-1998)

SMALL-STORM HYDROLOGY

Urbanization will increase the runoff volume from each storm event, thereby overloading the natural drainage systems. Existing stream characteristics are a reflection of past conditions in the watershed.

The frequency of bank-full events increases with urbanization, causing the stream to enlarge its channel to reach a new equilibrium with the increased flows. Increased flow volumes increase the erosive force of the flows in the channel and can significantly upset the sediment load equilibrium that was established over many years.

While the significance of large flood events should not be underestimated, the smaller flows with an approximately nine-month to two-year return period frequency can be very erosive. Often, these smaller flows have not been given sufficient consideration. Several states have developed policies regarding volume controls (Schueler, Thomas R., *et al.*, 1998) and erosive flow controls (Washington State Department of Ecology, 1992a). Hydrologic studies need to look at flood, peak flow and total flow conditions, while keeping in mind that small-storm hydrology is a critical component for protection of property, water quality and habitat.

WATERSHED ANALYSIS

Predicting the magnitude of adverse impacts when natural watersheds are converted to urban development is a complex task. One must assume that any change in the landscape changes the runoff from what had occurred previously due to any given rainfall event. A water body can be affected when urban development surrounds it, but does not actually encroach upon it. If the supply of water is increased or reduced beyond the limits that a water body’s sensitivity allows, or if it carries excess pollutants, the important functions and values of that water body may be destroyed.

CONCLUSION

Maintaining the pre-existing hydrologic conditions is recommended in all cases, but especially for water bodies that are highly or moderately susceptible to stormwater impacts. The relationship between any storm event, no matter how small or how large, and runoff volumes must be thoroughly understood. Best management practices (BMPs) that address the full range of hydrologic conditions should be employed to minimize impacts.

1.20 HOW URBANIZATION AFFECTS WATER QUALITY

The Nationwide Urban Runoff Program (NURP) sampled and studied urban runoff on a large scale throughout the United States. The final report of this study presented the results and a statistical analysis of those data (USEPA, December 1983).

Urban surfaces are subject to the deposit of contaminants, which are then subject to wash-off by rainfall or snow melt. Typical contributors to pollutants in runoff include vehicular traffic, industry, power production, lawn care, pets, eroded sediments and vegetative litter.

The major urban nonpoint-source pollutants include sediment, nutrients, oxygen-demanding substances, toxic chemicals, chloride, bacteria and viruses, and temperature changes. Each of these pollutants is discussed below.

SEDIMENT

Sediment is made up of tiny soil particles that are washed or blown into lakes and streams. Sediment is considered one of the more damaging pollutants in Minnesota, and it is the major pollutant by volume in the state’s surface waters.

The suspended particulates and bed-load solids are inorganic (sediment, sand) and organic debris (vegetative and animal waste) that enter the water through bed and bank erosion as well as by wind and water. De-icing grit, dirt, soil disturbed by construction activities, litter, vegetative debris and lawn clippings are some of the many sources.

Among the problems these pollutants cause in receiving waters are turbidity (cloudiness), destruction of the aquatic habitat (burying, alteration of bottom material), transport of adsorbed contaminants, clogging of drainage systems, and direct impact on aquatic organisms (altered respiration, reduced light penetration).

Sediment fills in road ditches, streams, lakes, rivers and wetlands and can affect aquatic life by smothering fish eggs and larvae. Suspended soil particles cause water to become turbid. Excessive turbidity reduces light penetration in water, impairs sight-feeding fish, clogs fish gills, and increases the cost of treating drinking water. Fine sediment also acts as a vehicle to transport other pollutants, including nutrients, trace metals and hydrocarbons, to nearby surface waters.

Runoff from construction sites is a major source of sediment in urban areas under development. Average sediment-loading rates from construction sites vary from 36.5 to 1,100 tons per acre per year. Rates for construction sites are five to 500 times greater than those from undeveloped land (USEPA, 1977). Another major source of sediment is streambank erosion, which is accelerated by increases in peak rates and volumes of runoff due to urbanization. In fully developed urban areas, sand applied to icy roads can also create a significant sediment load (Oberts, G.L., 1986).

Control of solids can be achieved by avoiding or minimizing impacts from activities such as clearing, grading and filling. BMPs, such as detention ponds, or prevention measures, such as housekeeping and street sweeping, can be used to reduce impacts. The use of reduced impervious surface and enhanced infiltration can be encouraged to reduce total surface water movement.

NUTRIENTS

Phosphorus and Nitrogen

Many naturally occurring materials are essential for life, and are therefore termed “nutrients.” However, an excess of some nutrients can lead to explosive growth of noxious life, such as algae, or can be toxic to some forms of aquatic life (as is the case with ammonia). Most of the complaints received by the Minnesota Pollution Control Agency (MPCA) about lake water quality concern problems that are caused by excessive nutrient levels (Munson, W., 1988).

Of particular concern for receiving waters are nutrients that are increased in urban runoff from such sources as lawn-care products, vegetative and animal debris, or automotive additives. Atmospheric deposition (wind erosion, industrial activity) is a concern in urban areas because it can easily be picked up by runoff from impervious surfaces. Nitrate nitrogen, most commonly from fertilizer overuse, can also adversely impact ground water when concentrated to high-enough levels.

Control of nutrients before discharge can be achieved by such measures as source control (fertilizer application limits), housekeeping (pet control ordinances, street sweeping), detention and enhanced infiltration.

In Minnesota, the effects of nutrients are a major concern for surface water quality. Nutrients — especially phosphorus and nitrogen — can cause algal blooms and excessive aquatic plant growth. Of the two, phosphorus is usually the limiting nutrient that controls the growth of algae in lakes. As phosphorus loadings rise, the potential for algal blooms and accelerated lake eutrophication also increases.

Un-ionized ammonia (NH_3) is highly toxic to aquatic organisms. The ammonium (NH_2) form of nitrogen can also have severe effects on surface water quality. The ammonium is converted to nitrate and nitrite in a process called “nitrification.” This process consumes large amounts of oxygen and can kill fish by lowering dissolved oxygen levels of the water. These conditions can impair many important uses of these waters, including recreation, fish habitat and water supply.

The nitrate form of nitrogen is very soluble, and it is present naturally in water at low levels. When nitrogen fertilizer is applied to lawns or other areas in excess of plant needs, nitrates can leach below the root zone, eventually reaching ground water. Water contaminated with high levels of nitrates presents a health hazard to young infants who consume formula prepared with it. Adults can tolerate higher levels of nitrates in drinking water; however, studies suggest that long-term consumption of drinking water with elevated nitrate levels may cause some forms of cancer (Freshwater Foundation, 1988).

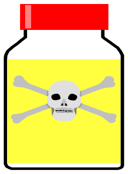
Major sources of nutrients in urban areas are organic matter, such as lawn clippings and leaves, and fertilizers applied improperly or in excessive amounts. In areas with heavy automobile traffic, orthophosphate from auto emissions also contributes phosphorus (Shelly and Gaboury, 1986).

Phosphorus in urban runoff has also been associated with the application of sand and salt to roads (Oberts, 1986).

OXYGEN-DEMANDING SUBSTANCES

While land animals extract oxygen from the air, aquatic life depends on oxygen dissolved in water. When aquatic microorganisms consume organic matter, dissolved oxygen is depleted. Following a rainfall, urban runoff can deposit large quantities of oxygen-demanding substances in lakes or streams. The biochemical oxygen demand (BOD) of typical urban runoff is about as large as that of effluent from an efficiently run secondary wastewater treatment plant (USEPA, December 1983). A "pulse" of high oxygen demand can be created during storm runoff that can totally deplete oxygen supplies in shallow, slow-moving or poorly flushed waters. Oxygen depletion is a common cause of fish kills. In urban areas, pet wastes, street litter and organic matter are common sources of oxygen-demanding substances.

Much of the material washed off urban surfaces exerts a demand for oxygen as it degrades in the water. Organic debris, oxidizable metals and nutrients all require some oxygen in their material degradation. If the levels of these materials are high enough, oxygen otherwise available for aquatic life is depleted, resulting in stress or death for these organisms. Oxygen depletion can cause water-quality problems in any kind of receiving water body. Oxygen-demanding substances can be limited through such BMPs as erosion control, leaf and litter management, and storm water detention.



TOXIC CHEMICALS

Many of the everyday activities in urban areas also contribute substantial amounts of toxic material to receiving waters. Essentially, anything that is applied to the land or emitted from fertilizer or pesticide applications, a smokestack or a vehicle's tailpipe can be deposited on, and washed off, impervious urban surfaces.

Trace metals

The toxic effects that trace metals can have on aquatic life are a major water-quality concern. The most common trace metals found in urban runoff are lead, zinc and copper (USEPA, December 1983). These metals were found in more than 90% of the samples taken as part of the Nationwide Urban Runoff Program (NURP) (USEPA, December 1983). Chromium, cadmium and nickel were also detected frequently in the NURP sampling. These metals originate from galvanizing, chrome plating and other industrial operations in urban areas. Automobile emissions used to be a major source of lead in urban areas. Lead and zinc in urban runoff have also been associated with the application of sand and salt on roads (Richards *et al.*, 1973; Oberts, G. L., June 1986).

As metals corrode, dissolve or settle out of the air, small amounts are carried away by wind or water and concentrate in urban runoff. The toxicity of trace metals in runoff varies with the hardness of the receiving water. As total hardness of the water increases, the threshold concentration levels for adverse biological effect increases. Many of these metals become attached to fine sediment and are carried with it until the sediment settles out. When these metals settle out, they can accumulate over a period of time to levels that are harmful to aquatic life. Studies have shown that trace metals bioaccumulate in plants and aquatic life in areas where they are contained in sediment (Meiorin, December 1986; USFWS, 1988).

Hydrocarbons

As part of the NURP study, residential runoff was sampled to determine the presence of more than 100 organic compounds. NURP's analyses generally indicated that organic compounds are not normally found in residential runoff.

When these chemicals were detected, their concentrations were generally low. The most commonly detected compound was a plasticizer used in plastic products. However, there were two instances in which the concentrations reached toxic levels. In those cases, one compound was a wood preservative and the other was a pesticide (USEPA, 1983). This indicates that these materials can result in significant water quality problems if they are not properly handled and applied.

Hydrocarbons and organic chemicals permeate commercial, industrial and highway runoff, and can be toxic to aquatic life if they are at high enough levels. These materials also move easily, exist for extended periods in a toxic state, and concentrate in sediments, from which they can be re-suspended later. The petroleum (gas and oil) that leaks from cars or comes out tailpipes, or the pesticides applied to urban lawns, can wash into gutters and eventually into a water body.

Petroleum-derived hydrocarbons commonly found in urban runoff initially float on the surface of the water and create the familiar rainbow-colored film, or sheen. Hydrocarbons have a strong affinity for sediment and quickly become adsorbed to it. They are then transported with the sediment and settle out with it. Hydrocarbons are a concern because they are known to be toxic to aquatic organisms at relatively low concentrations (Stenstrom *et. al*, 1984). Common sources of hydrocarbons are spillage at oil-storage and fueling facilities, leakage from crankcases and improper disposal of drained oil (MacKenzie and Hunter, 1979).

CHLORIDE

In Minnesota, a tremendous amount of salt is used each year to melt ice from roads, parking lots and sidewalks. Although the Minnesota Department of Transportation has reduced the amount of sodium chloride applied to highways in the Twin Cities metropolitan area in the last 10 to 15 years by about 50%, much salt is still being applied. Because it is extremely soluble, almost all salt applied ends up in surface or ground water (Pitt *et al.,* 1994a). If the concentration of chloride becomes too high, it can be toxic to many freshwater organisms.

Normal application of de-icing salt to roads is unlikely to create toxic conditions due to elevated chloride levels. However, there have been many documented cases of surface and ground water contamination caused by runoff from inadequately protected stockpiles of salt and sand-salt mixtures.

BACTERIA AND VIRUSES

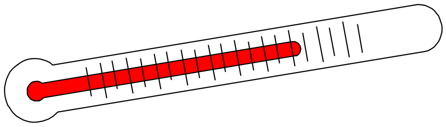
High concentrations of many bacteria and viruses are found in urban runoff.

The NURP study found that total coliform counts exceeded U.S. Environmental Protection Agency (EPA) water-quality criteria at almost every site and almost every time it rained (USEPA, 1983). Apparently, soil can act as a source of bacteria even when it is very unlikely that the high levels are of human origin or that they indicate significant human health risk (Barrett *et al.*, 1996). The coliform bacteria that are detected may not be a health risk in themselves, but are often associated with pathogens that are.

The sources of pathogens can include sanitary sewer leaks, pets, vermin and discarded infected material. The result of contact with these pathogens can be disease.

Pathogens can often be controlled by good urban housekeeping, disconnection of illegal sanitary sewer connections, and pet control.

TEMPERATURE CHANGES



While temperature is usually not considered a critical factor for discharges to most wetlands, temperature differences can significantly impact streams (especially trout streams).

Various types of temperature criteria can affect the success and mortality of organisms in waterways. Temperature changes that occur over a short period can have a shock effect, resulting in their death. There can also be long-term temperature effects, which cause changes in the growth, reproduction or mortality of organisms. These mean and maximum temperature effect levels vary from organism to organism and can be different for even the same organism in a different waterway.

In Minnesota, the water-quality standards reflect daily maximum average temperatures for most waterways, or changes above the ambient which are limited to a few degrees on a monthly average basis (Minn. R. ch. 7050).

The Washington Council of Governments (Galli, December 1990) concluded that several factors affect extreme temperatures. The primary determinants of extreme temperature are watershed imperviousness and riparian canopy. In addition, Galli studied four BMP types: (1) infiltration dry pond, (2) extended-detention artificial wetland, (3) extended-detention dry pond and (4) wet pond. The researcher concluded that all four caused temperature increases, and each monitored BMP violated applicable water-temperature standards at least once.

POLLUTANT DELIVERY

Both the short- and long-term impacts of pollutant delivery must be understood and addressed to meet water-quality goals.

Many people tend to be concerned about pollutants only if they cause fish kills or toxic problems. The short-term effects on water quality may need to be considered. These effects are important when evaluating pollutants, such as toxic trace metals and oxygen-demanding substances, which can kill aquatic life. A more thorough understanding of the characteristics of urban runoff is needed to select BMPs to meet a long-term water-quality goal. For many situations in Minnesota, estimates of annual pollutant loadings or concentrations in runoff can be used to evaluate these characteristics. These estimates provide an indication of long-term effects on water quality, such as nutrient loading to lakes and trace metal buildup in sediments. A different methodology is used to evaluate these effects.

VARIATION DUE TO LAND USE

One component of the NURP study involved an evaluation of the data based upon geographic location. The study did not find any distinct patterns in the data that could be attributed to geographic location. NURP concluded that individual site differences are far more significant than geographic differences for urban pollutant concentrations. This is important to remember when determining how transferable data are from one location to another.

NURP also evaluated the impact of different land uses on urban runoff characteristics. The mean concentrations from the NURP study are included in Table 1.20-1. Because of the variability of the data, the researchers concluded that, except for open/nonurban land use, differences in pollutant concentrations were not statistically significant. In addition, the NURP data showed that urban pollutant concentrations for most sites could not be correlated statistically with either storm runoff volume or storm intensity.

When estimating pollutant concentrations, using water-quality-monitoring data for a local watershed is preferable to using data from remote study areas or using summary data (such as the NURP data) from areas with similar land uses. However, if local data are not available, values from NURP (Table 1.20-1) or Bannerman (Table 1.20-5) can be used for an estimate of pollutant export from similar urban land-use areas.

Table 1.20-1 Mean pollutant concentrations (mg/L)

Pollutant	Land Use			
	Residential	**Mixed**	**Commercial**	**Open/nonurban**
Chemical oxygen demand	83	75	61	51
Total suspended solids	140	101	90	216
Lead	0.18	0.19	0.13	0.054
Zinc	0.18	0.19	0.33	0.23
Total Kjeldahl nitrogen	2.35	1.44	1.40	1.36
Nitrate nitrogen	0.96	0.67	0.63	0.73
Total phosphorus	0.46	0.33	0.24	0.23
Soluble phosphorus	0.16	0.07	0.098	0.06

Some local data are available from a study that was based on a smaller data set than NURP. During this study, the U.S. Geological Survey and the Metropolitan Council collected water quality data from 19 monitoring sites in the Twin Cities area (USGS, 1982). These data show considerable difference in pollutant loadings, which vary according to watershed land-use characteristics. To provide a basis for judgment about local loadings, mean pollutant concentrations from four of these sites are included in Table 1.20-2. These watersheds’ characteristics are described in Table 1.20-3.

In Table 1.20-2, the ranges of the data are presented in addition to mean values to show the extreme variability that occurs in urban runoff water-quality monitoring. It is important to keep this variability in mind when using mean values. Mean values should always be used with caution and qualified to avoid the impression that they are absolute values. These data are provided to help a planner decide the range in values that may be appropriate for a given situation.

Table 1.20-2 Flow-weighted mean pollutant concentrations (mg/L) and ranges

Pollutant	Monitoring Site				
	Yates	**Iverson**	**Sandburg**	**Elm**	
Chemical oxygen demand	90 24-879	38 1-597	138 10-850	65 4.5-157	mean range
Total suspended solids	133 2-758	740 17-26,610	337 7-4,388	10 2-374	mean range
Lead	0.23 0.015-1.8	0.02 0.008-0.31	0.19 0.003-1.5	0.005 0.001-0.012	mean range
Zinc	0.198 0.02-2.2	0.235 0.028-0.53	0.185 0.02-0.81	0.012 0.005-0.019	mean range
Total Kjeldahl nitrogen	3.6 0.6-28.6	1.2 1.0-29.2	2.5 0.4-16.0	2.1 1.2-5.4	mean range
Nitrate nitrogen	0.79 0.05-4.5	0.07 0.05-2.45	0.42 0.05-2.4	0.27 0.05-1.35	mean range
Total phosphorus	0.63 0.10-3.85	0.62 0.2-13.1	0.63 0.07-4.3	0.35 0.11-2.23	mean range
Source: U.S. Geological Survey, 1982					

In Table 1.20-3, Elm Creek data show typical values for a watershed with a minimal amount of development. The Iverson and Yates data are included to provide a comparison of residential runoff for a stabilized watershed (Yates), and a watershed under development (Iverson). Note the elevated total suspended solids (TSS) levels in the developing watershed. The Sandburg site provides data from an area with a commercial/industrial land use.

Table 1.20-3 Watershed characteristics for monitoring sites in Table 1.20-2

Name	Monitoring Site			
	Elm Creek	**Iverson**	**Sandberg**	**Yates**
Major Land Use	Relatively open, less than 25% farmed	Residential area under construction	Light industrial	Medium to high density
Drainage Area (square miles)	14.3	0.15	0.12	0.35
Drainage	Low-gradient stream	Curb and gutter with some in-stream wetlands	Curb and gutter	Curb and gutter
Typical Soils	Loamy, well-drained soils	Gently sloping, loamy soils	Moderately loamy soils	Flat, sandy soils

When comparing pollutant levels for present and future land uses, it is extremely important to understand the difference between pollutant loadings and concentrations. Tables 1.20-1, 1.20-2 and 1.20-4 show mean concentrations of pollutants in runoff. In many cases, the differences in concentrations for various land uses may not be significant. However, pollutant loadings are a function of both concentration and runoff volume. As an area develops and the percentage of impervious area increases, the volume of runoff can increase drastically. If the pollutant concentration remains constant while the volume of runoff triples, the annual pollutant loading will also triple.

Table 1.20-4 Median stormwater pollutant concentrations for all site by land use, nationwide Urban Runoff Program

Pollutant	**Residential**		**Mixed Land Use**		**Commercial**		**Open/Nonurban**	
	Median	**COV**[1]	**Median**	**COV**	**Median**	**COV**	**Median**	**COV**
BOD_5, mg/L	10.0	0.41	7.8	0.52	9.3	0.31	--	--
COD, mg/L	73	0.55	65	0.58	57	0.39	40	0.78
Total soluble solids, mg/L	101	0.96	67	1.14	69	0.85	70	2.92
TKN, µg/L	1900	0.73	1288	0.50	1179	0.43	965	1.00
$NO_2 - N + NO_3 - N_1$ µg/L	736	0.83	558	0.67	572	0.48	543	0.91
Total phosphorus, µg/L	383	0.69	263	0.75	201	0.67	121	1.66
Soluble phosphorus, µg/L	143	0.46	56	0.75	80	0.71	26	2.11
Total lead, µg/L	144	0.75	114	1.35	104	0.68	30	1.52
Total copper, µg/L	33	0.99	27	1.32	29	0.81	--	--
Total Zinc, µg/L	135	0.84	154	0.78	226	1.07	195	0.66

[1] COV: coefficient of variation = standard deviation / mean
BOD = biological oxygen demand
COD = chemical oxygen demand
TKN = total Kjeldahl nitrogen
Source: U.S. Environmental Protection Agency, 1983

SOURCES OF POLLUTANTS

Bannerman and others have studied the runoff of pollutants, trying to determine their source and the relationship between concentration and loading from various urban land uses. The findings of the studies are presented in Table 1.20-5. The studies (Bannerman *et al.*, 1992) show that one or two source areas in each land use usually contribute most of the pollutants. Data from Minneapolis compare reasonably well with the Bannerman data.

To determine pollutant loading, the study areas must be accurately characterized for both pollutant concentration and the volume of runoff. It is important to understand the pollutants of concern to the system, their sources (especially by land-use type), the source-area concentrations in runoff, and the source-area loading (see Table 1.20-4). This requires a knowledge of the hydrology of the source areas, especially the small-storm hydrology and the differences between small-storm and floodwater routing models.

Table 1.20-5 Means and coefficient of variation for the source area and storm sewer outfall considerations (Bannerman *et al.*, 1992)

	POLLUTANT											
	Total Solids (mg/L)	Susp. Solids (mg/L)	Total Phos. (mg/L)	Diss. Phos. (mg/L)	Diss. Cd (μ/L)	Diss. Cu (μ/L)	Total Cd (μ/L)	Total Cr (μ/L)	Total Cu (μ/L)	Total Pb (μ/L)	Total Zinc (μ/L)	Total Hard. (mg/L)
	Geometric Mean											
S_IndustRoof	78	41	0.11	0.02	0.2	2	0.3	-	6	8	1155	-
S-ArterialST	879	690	0.94	0.20	0.6	14	2.5	23	74	60	575	38
S_FeederST	958	763	1.50	0.53	0.4	18	3.3	15	76	86	480	43
S_ParkingLot	531	312	0.39	0.05	0.3	15	1.0	12	41	38	304	42
S_Outfall	146	0.34	0.14	0.2	10	1.0	6	28	25	265	31	
M_ResiDriveway	173	1.16	0.49	0.5	9	0.5	2	17	17	107	33	
M_FlatRoof	113	15	0.20	0.08	0.5	6	0.3	-	9	9	331	34
M_CollectorST	494	326	1.07	0.31	0.3	24	1.4	12	56	55	339	30
M_ArterialST	374	233	0.47	.010	0.9	18	1.8	16	46	50	508	35
M_ParkingLot	127	58	0.19	0.05	0.4	9	0.6	5	15	22	178	22
M_ResiLawn	600	397	2.67	1.45	-	6	-	-	13	-	59	39
M_ResiRoof	91	27	0.15	0.06	0.2	3	0.1	-	5	8	149	20
M_FeederST	796	662	1.31	0.37	0.5	9	0.8	5	24	33	220	9
M_Outfall	369	262	0.66	0.27	0.3	5	0.4	5	16	32	204	26
	Arithmetic Mean											
S_IndustRoof	83	54	0.13	0.02	0.3	2	0.3	-	7	8	1348	--
S-ArterialST	993	875	1.01	0.25	1.0	17	2.8	26	85	85	629	41
S_FeederST	1134	969	1.57	0.62	0.6	22	3.7	17	97	107	574	47
S_ParkingLot	603	474	0.48	0.07	0.5	18	1.2	16	47	62	361	48
S_Outfall	293	174	0.38	0.16	0.2	12	1.1	7	31	26	295	32
M_ResiDriveway	328	193	1.50	0.87	1.3	11	0.5	2	20	20	113	34
M_FlatRoof	126	19	0.24	0.11	0.8	8	0.4	-	10	10	363	44
M_CollectorST	544	386	1.22	0.36	0.8	30	1.7	13	61	62	357	32
M_ArterialST	389	241	0.53	0.14	2.0	22	2.6	18	50	55	554	37
M_ParkingLot	165	91	0.26	0.07	0.7	14	0.8	7	21	30	249	24
M_ResiLawn	656	457	3.47	2.40	-	7	-		13	-	60	51
M_ResiRoof	105	36	0.19	0.08	0.2	3	0.2	-	5	10	153	22
M_FeederST	1152	1085	1.77	0.55	1.3	11	0.8	7	25	38	245	30
M_Outfall	462	374	0.86	0.34	0.7	7	0.6	5	20	40	254	27
	Coefficient of Variation											
S_IndustRoof	0.40	0.71	0.72	0.54	0.75	0.81	0.47	-	0.44	0.30	0.46	-
S-ArterialST	0.52	0.64	0.38	0.90	1.25	0.68	0.49	0.53	0.47	0.85	0.40	0.39
S_FeederST	0.60	0.66	0.29	0.60	0.62	0.63	0.49	0.57	0.77	0.60	0.56	0.39
S_ParkingLot	0.44	.061	0.50	0.65	1.04	0.70	0.51	0.64	0.44	0.65	0.50	0.63
S_Outfall	0.60	0.50	0.59	0.70	0.79	0.44	0.42	0.50	0.42	0.45	0.39	
M_ResiDriveway	0.43	0.51	0.84	1.08	1.60	.067	0.42	0.46	0.62	0.53	0.37	0.32
M_FlatRoof	0.48	0.68	0.54	0.75	1.19	0.59	0.87	-	0.52	0.42	0.44	0.72
M_CollectorST	0.42	0.58	0.54	0.58	1.95	0.64	0.75	0.43	0.32	0.49	0.33	0.38
M_ArterialST	0.30	0.26	0.53	0.86	1.78	0.62	1.18	1.47	0.43	0.48	0.44	0.43
M_ParkingLot	0.74	0.91	0.95	0.96	1.22	1.07	0.86	0.84	0.86	0.82	0.90	0.57
M_ResiLawn	0.48	0.58	0.68	0.90	-	0.58	-	-	0.21	-	0.24	0.79
M_ResiRoof	0.60	0.68	0.59	0.82	0.73	0.47	0.57	-	0.25	0.58	0.24	0.36
M_FeederST	1.02	1.19	0.90	1.02	1.48	0.53	0.41	0.91	0.38	0.50	0.44	0.29
M_Outfall	0.64	0.75-	0.70	0.67	1.97	0.63	0.81	0.54	0.67	0.66	0.66	0.25

1) Dash indicates insufficient sample size.
M = Monroe study area
S = Syene study area

Delivery Process

Understanding the pollutant delivery process is fundamental to controlling nonpoint source pollution. There are three steps in the delivery process: availability, detachment and transport. Most substances must go through this entire chain before they become pollutants. Breaking this chain at any step will prevent a substance from being delivered to receiving waters. Some pollutants are more readily controlled at a particular step in the delivery process. A basic understanding of this process and the characteristics of the pollutants in question helps to target BMPs so they prevent delivery most effectively.

Availability

A substance must be available before it can become a potential pollutant. The quantity of a substance in the environment and its characteristics determine its degree of availability. The quantity of certain pollutants is a function of the intensity of the land use. For instance, a high density of automobile traffic makes a number of potential pollutants, such as hydrocarbons, more available. Control methods, such as street sweeping, which would reduce the availability of these pollutants, have been studied as part of the NURP. These studies concluded that street sweeping was ineffective in controlling very fine pollutants such as those associated with automobile traffic (USEPA, December 1983). From a water quality BMP standpoint, these materials are best controlled later in the delivery process (Schaefer and Hey, 1983).

The availability of a material such as fertilizer is a function of the quantity and the manner in which it is applied. Applying fertilizer in quantities that exceed plant needs and soil absorption capacity leaves the excess nutrients available for loss to surface or ground water. Reduced use and proper application are the best ways to control nonpoint-source pollution from fertilizers.

Detachment

Detachment is the process in which materials are dislodged from their original location and become mobile. The detachment process can be physical or chemical. Most physical detachment is the result of raindrop impact or overland flow.

Chemical detachment involves dissolving soluble materials or ion-exchange processes. Control of pollutant delivery in the detachment phase is most practical for materials such as sediment when erosion-control practices are used to prevent the detachment of soil particles. Once soil particles are detached, coarser particles can be trapped effectively by sediment-control practices. However, fine soil particles are not readily trapped except by detention practices with very long detention times.

Transport

Transport is the final phase of the delivery process. Transport involves moving a material from its point of detachment to a receiving water. In urban areas, a large part of the runoff is transported to receiving waters over impermeable surfaces, such as streets or in storm sewers. This results in very efficient transport of pollutants to receiving waters once they are detached.

MITIGATION

Detention or infiltration practices can be effective for interrupting transport of many pollutants. But for many urban nonpoint-source pollutants, especially those associated with sediment, preventing transport by retaining vegetative cover or by providing soil stabilizers such as mulch, is the most practical way to control their delivery to receiving waters.

It is important to note that BMPs cannot completely mitigate the impacts caused by urbanization. A combination of practices, including land-use controls, riparian or stream buffer requirements, and employment of temperature-sensitive BMPs will be required to maintain water quality, especially in cold-water streams. The significance of thermal impacts and their mitigation through appropriate BMP implementation needs further research and careful site-specific evaluation for critical areas.

ESTIMATING ANNUAL POLLUTANT LOADINGS

The procedure presented here gives a planner the flexibility needed to develop a site-specific estimate of pollutant loadings for various conditions. The procedure is relatively simple, but one should be aware of its limitations. First, the results are very dependent upon the mean pollutant concentrations used. As mentioned previously, local monitoring is the best source of data for present conditions as long as sufficient data are available. Lacking local monitoring data, estimates can be made from Tables 1.20-1 or 1.20-2 or from an other appropriate reference. For future conditions, an estimate must always be made based upon mean concentrations from other, similar locations.

The procedure in this chapter uses the product of the estimated annual runoff volume and mean concentrations to estimate annual loading. This procedure, expressed in equation 1.20-1, is only intended to provide a rough indication of loadings for an average year.

Mean pollutant concentrations can be converted to annual pollutant loadings with the following simple relationship:

Equation 1.20-1:

$L = (C)(V),$

where L = annual pollutant loading,
C = mean pollutant concentration and
V = annual volume of runoff.

The only factors needed to compute the estimated annual loadings are the watershed size, annual rainfall, watershed runoff coefficient, mean pollutant concentration and a conversion factor.

Normally, the watershed area is determined in the very early stages of any planning activity for stormwater-management considerations. Watershed size can be determined from local data, topographic maps or field inspection. In urban areas, storm sewer drainage areas must also be checked.

The average annual precipitation for an area can be determined from local rainfall records. Table 1.10-1 shows average annual rainfall values for Minnesota.

The runoff coefficient (R) is the ratio of average runoff to average rainfall when both are expressed in watershed inches. Studies (USEPA, 1983) of runoff coefficients from NURP data found them to be related to watershed imperviousness. An analysis of those data resulted in the following relationship:

Equation 1.20-2:

$$R = 0.05 + 0.009(I),$$

where R = runoff coefficient (unitless) and I = impervious area in watershed (percent).

Rainfall events that do not produce runoff should not be considered in this equation. To be compatible with the rainfall values in Figure 1.10-1, an adjustment must be made to account for non-runoff events. Schueler (1987) evaluated rainfall events in the Washington, D.C., area and suggested that 10% of the events resulted in no appreciable runoff. To account for the 10% of events that produced no runoff, R should be reduced by 10%, and can be represented by:

Equation 1.20-3:

$$R = 0.9\,[0.05 + 0.009(I)]$$

This equation only applies to surface runoff and does not consider base flow. If the site under consideration is large enough so that base flow is involved, that loading should be considered separately using site-specific data for base flow volume and pollutant concentrations.

The mean pollutant concentration is best determined from local monitoring data. Lacking those data, estimates of mean concentrations from the NURP studies or the U.S. Geologic Survey Twin Cities data can be used. It is important to realize the general nature of these data when they are used in place of site-specific information.

An average annual pollutant loading (L) can be computed with this information using the following formula:

Equation 1.20-4:

$$L = (A)(P)(R)(C)(0.226),$$

where L = annual pollutant loading (pounds),
A = watershed area (acres),
P = annual precipitation (inches),
R = runoff coefficient (unitless),
C = mean pollutant concentration (mg/L) and
0.226 = the conversion factor.

This average annual pollutant loading can be useful for estimating changes in pollutant loadings and long-term impacts of urban pollutants on receiving waters, such as lakes. It is also a useful tool for comparing the pollutant loadings for pre- and postdevelopment land uses in order to have a basis for BMP selection. Table 1.20-4 lists some typical annual loadings that are estimated for various land uses.

The Metropolitan Council has developed another short-cut procedure for estimating pollutant loadings from urban watersheds. This information is presented in *Surface Water Management, Simplified Modeling for Watersheds* (Oberts, December 1983).

Hydrology Methods

Runoff quantities and pollutant runoff are estimated using such factors as land use, rainfall volume and soil type. Several computer models are described in chapter 8. The runoff curve number was developed by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service, or SCS) for storm events with rainfall amounts over 1.5 inches. When the concern is smaller storm events, methods appropriate for events of this size need to be used. For example, Pitt (1998) has developed methods to compute the volumetric runoff coefficients for smaller storm events based on the characteristics of the land use in the drainage area.

Careful analysis of hydrologic conditions, and planning which minimizes the potential impacts of runoff water provide the best long-term solution.

SHORT-TERM EFFECTS ON WATER QUALITY

If a planner wishes to assess the short-term effects of urban runoff on streams or rivers, a different method is more appropriate. An analysis that determines the probability of exceeding certain threshold levels of pollutants will provide a more meaningful representation of in-stream effects. To evaluate water quality in this manner, NURP developed a stochastic procedure for analysis of data. This method relates the median pollutant concentration and the coefficient of variation for the data to arrive at an expected concentration for any frequency of occurrence. This relationship is expressed by Equation 1.20-5.

Equation 1.20-5:

$$x = C_m^{[\,(Z\,\sqrt{\ln(1+(CV}\,)\,]}$$

where x = expected pollutant concentration for specified chance of occurrence,
Z = standard normal probability,
C_m = median pollutant concentration, and
CV = coefficient of variation.

Equation 1.20-5 can be used to estimate frequency of occurrence from data with a sufficiently large population set. This formula was used to determine expected concentrations of several pollutants based upon NURP median concentrations. Expected values for a 25%, 10% and 1% chance of occurrence were computed. These values are summarized in Table 1.20-6.

Table 1.20-6 Pollutant concentrations (mg/L) in urban runoff for various chances of occurrence

Pollutant	Residential Chance of Occurrence			Mixed Chance of Occurrence			Commercial Chance of Occurrence		
	25%	10%	1%	25%	10%	1%	25%	10%	1%
COD	103	141	241	93	130	223	63	97	199
Lead	0.23	0.34	0.68	0.23	0.42	1.22	0.16	0.23	0.44
Zinc	0.22	0.34	0.47	0.25	0.37	0.77	0.41	0.69	1.7

COD = chemical oxygen demand
Computed from median values in USEPA, 1983, Table 6-12.

To put the trace metal concentrations in perspective, MPCA water-quality standards are reported in Table 1.20-7. This table lists water-quality standards the MPCA has developed for Class 2B, warm-water fishery. Other standards may be applicable (*e.g.,* 2Bd, warm-water fishery used for drinking water). The effect that urban runoff trace metal concentrations will have upon a stream or river depends upon factors such as dilution and total hardness of the water. For information on Minnesota water quality standards, contact the MPCA.

Threshold levels for toxicity usually increase as the total hardness of the water increases. These toxicity data are based on laboratory studies with the trace metals in the ionic form. Trace metal concentrations reported for urban runoff may contain a portion that is not in a toxic form.

The effects of oxygen-demanding substances on a stream or river depend upon several factors. Some of the more important are the oxygen requirements of organisms that inhabit the water body and the ability of the system to reoxygenate itself. In a slow, sluggish or poorly flushed system, oxygen demand from urban runoff can totally deplete the dissolved oxygen supply.

Table 1.20-7 Mississippi River, below St. Anthony Dam and above the Minnesota River

Substance or Characteristic	**Units**	**2B,2C Chronic Standard**	**2B,2C Maximum Standard**	**2B,2C Acute Standard**	**Other Standard**
Ammonia, un-ionized as N	µg/L	40			
Bicarbonates (HCO3)	meq/L				5 (4A)
Chloride (3A)	mg/L	230	860	1720	100 (3B)
Chlorine, total residual	µg/L	6	19	38	
Cyanide, free	µg/L	5.2	22	45	
Dissolved oxygen	mg/L				5 (2B,2C)
Fecal coliform	#/100 ml				200 (2B,2C)
Hardness, total as CaCO3 (3A)	mg/L				250 (3B)
Hydrogen sulfide	mg/L				0.02 (5)
Oil (freon extractable)	µg/L	500	5000	10000	
pH	Low				6.5 (2B)
	High				8.5 (4A)
Salinity, total	mg/L				1000 (4B)
Sodium	mg/L				60% cations (4A)
Specific conductance	µmhos/cm				1000 (4A)
Temperature	F				max 86(2B)
Total dissolved salts	mg/L				700 (4A)
Turbidity	NTUs				25 (2B,2C)
METALS AND ELEMENTS					
Aluminum	µg/L	125	1072	2145	
Antimony	µg/L	31	90	180	
Arsenic	µg/L	53	360	720	
Boron	µg/L				500 (4A)
Cadmium*	µg/L	1.64	56.8	113.6	
Chromium, +3*	µg/L	304	2552	5098	
Chromium, +6	µg/L	11	16	32	
Cobalt	µg/L	5	436	872	
Copper*	µg/L	13.2	27.6	55.2	
Lead*	µg/L	5.8	148.5	298	
Mercury**	µg/L	0.0069	2.4	4.9	
Nickel*	µg/L	235	2111	4221	
Selenium	µg/L	5	20	40	
Silver*	µg/L	1	4.5	9.1	
Thallium	µg/L	0.56	64	128	
Zinc*	µg/L	158	174	349	
ORGANICS					
Acenapthene	µg/L	12	41	81	
Acrylonitrile (C)**	µg/L	0.89	1140	2281	
Alachlor (C)**	µg/L	59	800	1600	

Anthracene	µg/L	0.029	0.78	1.6	
Atrazine (C)	µg/L	10	323	645	
Benzene (C)**	µg/L	114	4487	8974	
Bromoform	µg/L	466	2900	5800	
Carbon tetrachloride (C)**	µg/L	5.9	1750	3500	
Chlordane (C)**	µg/L	0.00029	1.2	2.4	
Chlorobenzene	µg/L	10	423	846	
Chloroform (C)	µg/L	224	2235	4471	
Chlorpyrifos	µg/L	0.041	0.083	0.17	
DDT (C)**	µg/L	0.0017	0.55	1.1	
1,2-Dichloroethane (C)**	µg/L	190	45050	90100	
Dieldrin (C)**	µg/L	0.000026	1.25	2.5	
Di-2-ethylhexyl phthalate (C)	µg/L	2.1			
Di-n-Octyl phthalate	µg/L	30	825	1650	
Endosulfan	µg/L	0.031	0.28	0.56	
Endrin	µg/L	0.016	0.09	0.18	
Ethylbenzene (C)	µg/L	68	1859	3717	
Fluoranthene	µg/L	20	199	398	
Heptachlor (C)**	µg/L	0.00039	0.26	0.52	
Heptachlor epoxide (C)**	µg/L	0.00048	0.27	0.53	
Hexachlorobenzene (C)	µg/L	0.00024			
Lindane (C)**	µg/L	0.036	4.4	8.8	
Methylene chloride (C)**	µg/L	1561	9600	19200	
Naphthalene	µg/L	81	409	818	
Parathion	µg/L	0.013	0.07	0.13	
Pentachlorophenol***	µg/L	5.5	24.8	50	
Phenanthrene	µg/L	2.1	29	58	
Phenol	µg/L	123	2214	4428	
Polychlorinated biphenyls (C)**	µg/L	0.000029	1	2	
1,1,2,2-Tetrachloroethane (C)**	µg/L	13	1127	2253	
Tetrachloroethylene (C)**	µg/L	8.9	428	857	
Toluene	µg/L	253	1352	2703	
Toxaphene (C)**	µg/L	0.0013	0.73	1.5	
1,1,1-Trichloroethane	µg/L	263	2628	5256	
1,1,2-Trichloroethylene (C)**	µg/L	120	6988	13976	
2,4,6-Trichlorophenol	µg/L	2	102	203	
Vinyl chloride (C)	µg/L	9.2			
Xylenes, total	µg/L	166	1407	2814	

* Based on a background pH of 8.0.
** Use FAV or 200 x chronic for the end-of-pipe acute standard, whichever is lower.
*** Based on a background hardness of 160 and an effluent hardness of 160.
(C) indicates the chemical is a carcinogen. (3A) indicates the chloride standard is 50 mg/L for 3A waters.
(AL) indicates these values are special action limits.

Example 1.20-1: Estimating pollutant loadings

A planner wishes to compare the predevelopment and postdevelopment pollutant loadings for a proposed commercial development. A detention pond that meets the criteria in this handbook is planned to reduce pollutant loadings as well as to reduce peak discharges from the site. The following procedure is used to evaluate the pollutant loadings:

1. Compile site data:
   Average annual rainfall: 30 inches (from Figure 1.10-1)
   Predevelopment impervious area: 5%
   Postdevelopment impervious area: 80%

2. Compute runoff coefficient (R) using Equation 1.20-3:
   Predevelopment R = 0.0855
   Postdevelopment R = 0.69

   1. Estimate predevelopment mean concentrations and compute annual loadings. In this case, monitoring data were not available, so values from Table 1.20-1 and Table 1.20-2 were used. Equation 1.20-4 was used to compute annual loadings. Values for C were obtained from Table 1.20-2, Elm site.

Pollutant	Mean Concentration (mg/L)	Annual Loading (lb)
Chemical oxygen demand	65.0	6,029.0
Lead	0.005	0.46
Zinc	0.012	1.1
Total phosphorus	0.35	32.0
TKN	2.1	190.0

3. Estimate postdevelopment mean concentrations and pollutant loading, using the same procedure as above. Values for C were obtained from Table 1.20-2, Sandburg site.

Pollutant	Mean Concentration (mg/L)	Annual Loading (lb)
Chemical oxygen demand	138.0	103,000
Lead	0.19	140
Zinc	0.185	140
Total phosphorus	0.63	470
TKN	2.5	1,900

4. Estimate postdevelopment loadings after installation of the detention pond.

   Long-term removal efficiencies are based upon the performance data presented in the detention pond section of this handbook.

Pollutant	Long-term Pollutant Removal (%)	Annual Loading with Pond (lb)
Chemical oxygen demand	95	5,200
Lead	97	4.3
Zinc	80	28
Total Phosphorus	70	140
TKN	40	1,100