# Nutrient loading from a separate storm sewer in Madison, Wisconsin

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CONCERN about the trophic state of many of the nation's lakes and streams has heightened interest in reducing waste discharges from point sources. Industries and municipalities have been required to increase their degree of treatment to provide greater removals of oxygen-consuming materials. In some regions, it has been necessary to provide additional waste treatment facilities for removal of nitrogen and phosphorus to control growth of nuisance algae and hydrophytes.

Diffuse sources of nutrients and organic wastes have received only limited attention in the past, mainly because of the difficulty and expense of monitoring and controlling them. One such nutrient source is urban runoff. Weibel[1] concluded that urban runoff was an important factor in the overall organic and nutrient loading from urban areas. Bryan[2] noted that urban runoff was a significant pollutant of nearby streams, mainly because of the intermittent high loadings that occurred after heavy rains. He stated that urban runoff could have a detrimental influence on a proposed impoundment downstream from the city of Durham, N. C.

A recent study of the character of urban runoff by AVCO Economic Systems Corporation[3] indicated that the increase in nutrients from urban runoff because of continued growth in the Tulsa Metropolitan area would be likely to offset any reductions in urban pollutional loadings of local streams brought about by improved wastewater treatment procedures in that locality.

Because of the potential importance of nutrient loading from separate storm sewers and general lack of information concerning amounts and variability of nutrients in urban runoff, this study was undertaken to determine:

1. The relationship between rainfall and runoff for a selected basin in Madison, Wis.;
2. Variability of nutrient concentrations throughout a storm and for different seasons of the year;
3. Nutrient loading on an annual basis;
4. Potential sources of nutrients in urban runoff;
5. Sampling requirements to quantify the nutrient loadings;
6. The significance of urban runoff relative to other known sources of nutrients influent to a small lake in Madison, Wis.

## METHODS

**Basin characterization.** The site selected for the urban runoff analysis was located in the southwest section of Madison, Wis. Figure 1 shows a portion of southwest Madison with the 5,200-acre (2,100-ha) Lake Wingra basin outlined by the solid line and the 123-acre (50-ha) Manitou Way storm sewer basin appearing as the shaded area. The University of Wisconsin arboretum (lined area) falls within the Lake Wingra basin, occupying about 2,000 acres (810 ha), a third of which drains directly to the lake. The remainder of the basin is occupied by urban Madison, primarily residential in nature. The triangles in Figure 1 indicate the location of continuous recording rain gauges; squares represent standard 8-in. daily composite rain gauges. Because the rain gauges were arranged in a nearly linear fashion, average rainfall amounts were computed arithmetically.

Figure 2 illustrates details of the Manitou Way storm sewer basin. The basin boundary was determined from



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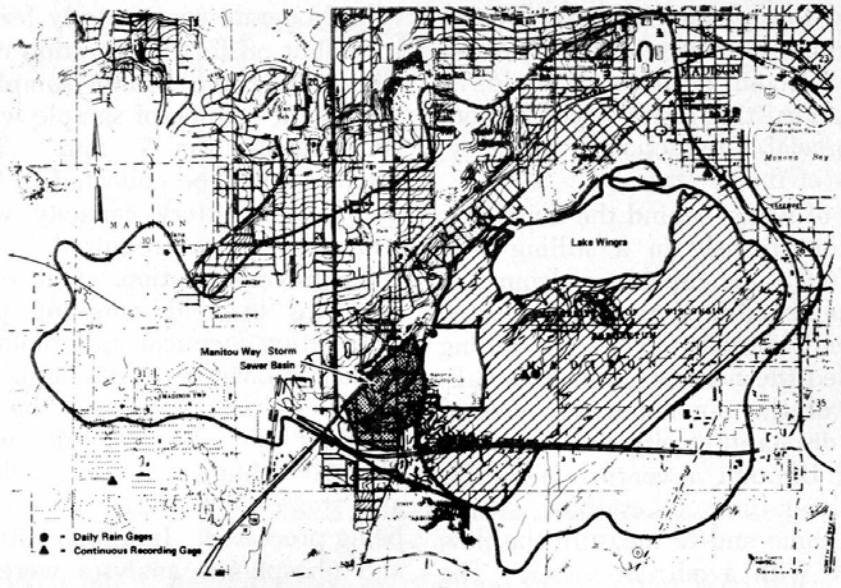


**FIGURE 1.—Lake Wingra drainage basin.**

topographic maps, City of Madison Engineering Division storm sewer platt maps, and physical inspection. The area enclosed by these boundaries comprises residential middle- and upper middle-class houses. The topographic divide along the eastern section of the basin passes through a part of the arboretum, which is composed primarily of hardwood trees. This section was not included in the calculation of the basin area that contributed to urban runoff because it was assumed that this forested area did not contribute significantly to urban runoff. (The justification for this assumption will be discussed later.)

A set of aerial photographs dated April 1968 was consulted to determine land usage within the Manitou Way basin and is summarized in Table I.

**TABLE I.—Land Usage for the Manitou Way Storm Sewer Basin**

| Land Use | Area | | Percent of Basin |
|---|---|---|---|
| | Sq ft | Sq m | |
| Streets | $0.83 \times 10^6$ | $0.77 \times 10^5$ | 15.4 |
| Houses | $0.40 \times 10^6$ | $0.38 \times 10^5$ | 7.5 |
| Driveways | $0.17 \times 10^6$ | $0.16 \times 10^5$ | 3.2 |
| Sidewalks | $0.08 \times 10^6$ | $0.07 \times 10^5$ | 1.6 |
| Total area | $5.35 \times 10^5$ | $4.95 \times 10^6$ | |

Approximately 27 percent of the basin was covered by impervious areas (streets, rooftops, driveways, and sidewalks). Drainage from the rooftops of most homes discharges onto the lawns.

The U. S. Geological Survey (USGS) installed a Palmer and Bowlus (P-B) flume in the storm sewer

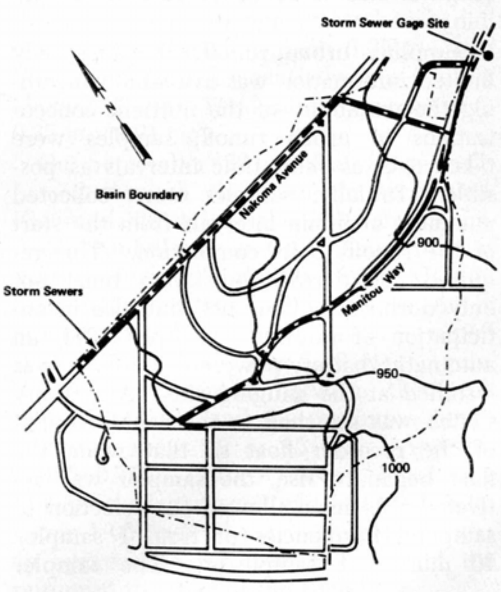


**FIGURE 2.—Manitou Way storm sewer basin.**

about 300 ft (100 m) upstream from the sewer outfall. A P-B flume was selected because it could be installed in an existing storm sewer without causing appreciable reduction in the carrying capacity of the sewer.

The head of water behind the flume was measured continuously in a stilling well about 15 ft (5 m) upstream from the flume. A punched-tape recorder, located above ground directly over the stilling well, recorded the head at 5-min intervals. Calibration of the P-B flume was accomplished by discharging city water from a fire hydrant through a venturi meter for sufficiently long times to establish steady flow at the flume and to measure the flow at the flume with a current meter. The flow was checked again downstream using a Parshall flume and a second current meter. Flows of 0.25, 0.51, 1.03, and 6.08 cfs (0.42, 0.87, 1.75, and 10.3 cu m/min) were monitored in this manner. Results of these calibration runs were used to modify the design equation for the P-B flume to obtain the operating curve. The USGS estimated flows could be measured to within 10 percent, at least over the range of 0.25 to 30 cfs ( 0.42 to 51 cu m/min).

**Sampling urban runoff.** Because only limited information was available concerning the variability of the nutrient concentrations in urban runoff, samples were taken over as short time intervals as possible. Initially, samples were collected manually at 5-min intervals from the start of the runoff to its completion. This required considerable on-station time, not only during runoff events, but also in anticipation of rainfall. In April 1971, an automatic, battery-powered sampler* was installed at the gauging site. A mercury switch was attached to the counterweight of the recorder float so that when the float began to rise, the sampler was activated. A timer allowed the selection of sampling frequencies of from 1 sample/10 min to 1 sample/hr. The sampler would operate continuously for 7 min and then shut off for the duration of the cycle. Thus, using the 10-min sampling period, a constant volume of sample was collected continuously for 7 min. Twenty-four samples could be collected in this manner before the battery capacity was drained and recharge was required.

**Sample preparation**. One of the major problems in field sampling programs is preventing chemical and biological transformations within the sample before the analytical procedures can he completed. To limit this effect, samples were usually filtered within 12 hr of sample collection and stored in the dark at 4ºC when not being processed. Inorganic nitrogen (I-N) and phosphorus analyses were completed within 24 to 48 hr of collection. Other analyses were completed within 1 wk.

**Chemical analyses.** Suspended and volatile solids (ss and vs) were determined in accordance with procedures outlined in "Standard Methods."[4] The persulfate digestion procedure was used on the unfiltered sample for total phosphorus (T-P) as described in "Standard Methods." After digestion, the total phosphorus sample was neutralized and the color was developed using the single-solution ascorbic acid procedure. The same ascorbic acid reagent was used for the determination of dissolved phosphorus (DRP) on the filtered sample. Automated procedures were used in the determination of nitrogen. The brucine method[5] was used for nitrate-nitrogen determinations while ammonia-N was determined by the alkalinephenol procedure.[6] Total Kjeldahl nitrogen was measured by the alkalinephenol procedure after manual digestion of the unfiltered sample in a micro-Kjedahl flask. The digestion reagent described in "Standard Methods," with a selenium catalyst substituted for mercury, was used to convert organic-N to ammonia-N. The concentration of selenium in each sample was about 0.01 g/sample, well below the limit suggested by Bradstreet.[7] Organic nitrogen (organic-N) was determined as the difference between total Kjeldahl nitrogen and ammonia-N.

* Model WM-2-24, Sigmamotor, Inc., Middleport, N. Y.

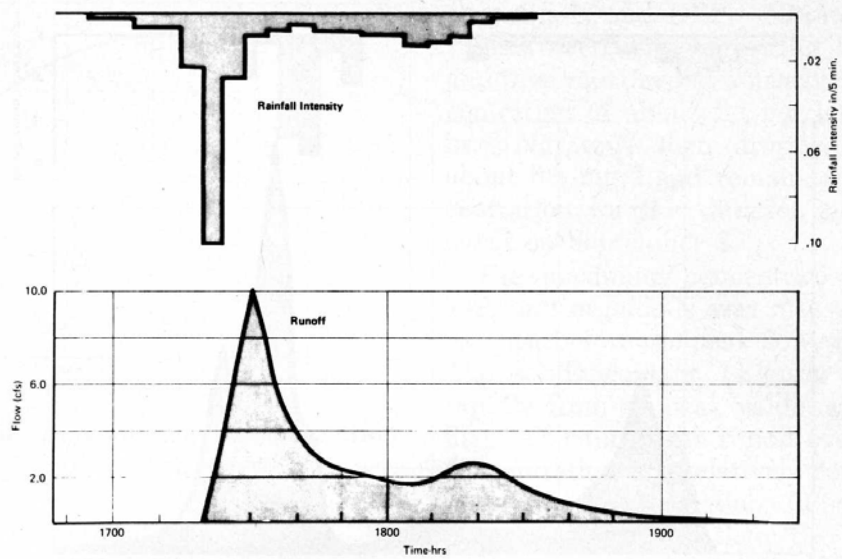


**FIGURE 3. Rainfall-runoff relationship for Manitou Way storm sewer, September 2, 1970.**

Sodium concentrations were monitored during the spring runoff period using the atomic absorption spectrophotometer.

## RESULTS

**Rainfall-runoff relationship.** The flume and rain gauges were installed in mid-August 1970. The first rainfall in the basin occurred on September 2, 1970, and between that time and the end of the study in July 1971, 34 storms were monitored for rainfall and runoff. These storms have been broadly categorized into those that involved only one storm cell (one burst of heavy shower activity) passing through the basin during a runoff event and those that involved two or more storm cells closely following one another so that the runoff from the previous cell was still significant when the second storm passed through.

Figure 3 illustrates the rainfall-runoff pattern for the single-celled storm of September 2, 1970. This rain occurred after about 2 wk of dry weather. Although the rain started at about 4:55 PM, there was no apparent runoff until almost 5:20 PM, indicating that puddle storage and evaporation were probably significant during this period. Rainfall intensity increased sharply to a maximum rate of 0.10 in./5 min (0.25 cm/5 min) at 5:20 PM. Flow in the storm sewer responded rapidly to this rainfall increase, peaking about 10 min after maximum rainfall intensity. The decrease in runoff lagged behind the precipitation, but followed a similar pattern. A slight increase in rainfall intensity again at about 6:05 PM caused the runoff rate to increase, this time about 15 min after the rainfall peak. Rain ceased at about 6:35 PM, and the runoff reached essentially zero flow by about 7:20 PM. Total rainfall amounted to 0.35 in. (0.91 cm).

On September 23, several storm cells passed through the basin in succession. Figure 4 illustrates the relationship between rainfall rate and runoff rate for this storm. Rainfall intensity on a 10-min basis indicated five periods of relatively intense rainfall, producing peaks in runoff at 2:20, 3:50, 5:15, and 5:40 PM. Again, the time differential between the peak rainfall intensity and the maximum runoff rate was about 10 or 15 min. Approximately 0.75 in. (1.9 cm) of rain fell during this particular storm, which lasted from about 1:00 to 5:50 PM. Again there was an appreciable lag from the start of the rain until the start of the runoff.

**Runoff yield.** The volume of runoff from each of the storms monitored in the Manitou Way basin was

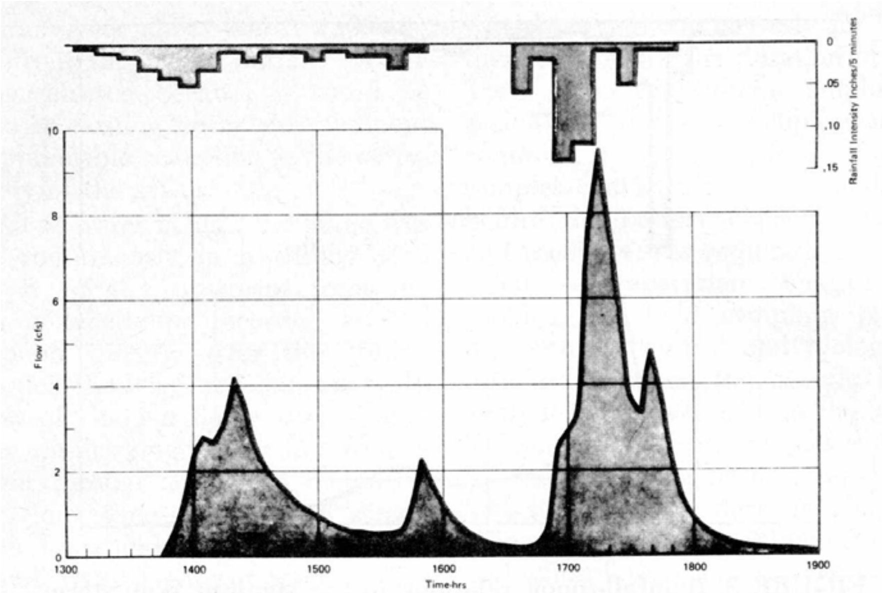


FIGURE 4.—Rainfall-runoff relationship.

computed by multiplying the 5-min flow by the time interval and then summing over the duration of the storm. The runoff volume was normalized by dividing by the amount of water that would result from 1 in (2.54 cm ) of rain on the 123.6-acre (50-ha) basin if the basin were completely impervious. These normalized runoff yields were plotted against average rainfall in Figure 5. Linear and parabolic regression analyses with rainfall as the independent variable indicated that rainfall and runoff were related in an essentially linear fashion (Figure 5). The line of best fit passed through the abscissa to the right of the origin, indicating that for rains of less than about 0.1 in. (0.75 cm) there was little or no runoff. No attempt was made to differentiate between low- and high-intensity showers or to account for antecedent rainfall conditions when plotting Figure 5. These factors undoubtedly account for some of the observed scatter.

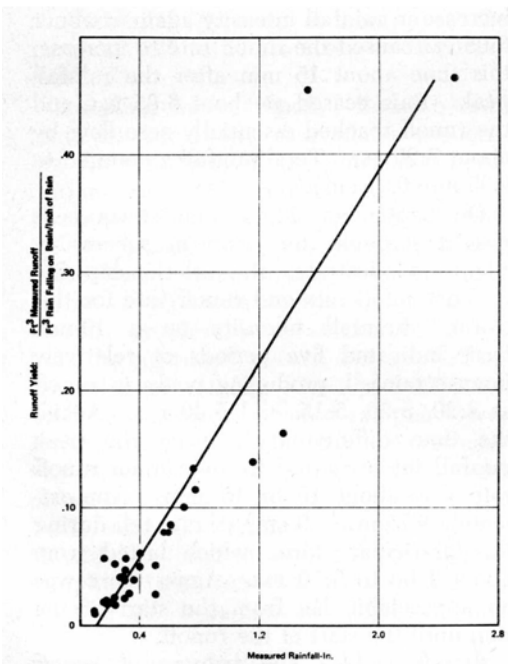


FIGURE 5.—Normalized runoff yield.

Because the regression line does not pass through the origin, the slope of the line is not directly comparable to the percent runoff. Figure 6 illustrates that the percent of the rain that runs off increases sharply until rainfall amounts of about 0.5 in. (1.3 cm) are reached. Rains in excess of this amount produce only moderate increases in runoff yield. Thus, for storms in excess of about 0.25 in. (0.65 cm) the runoff yielded varies between 12 and 19 percent of the average rainfall on the basin.

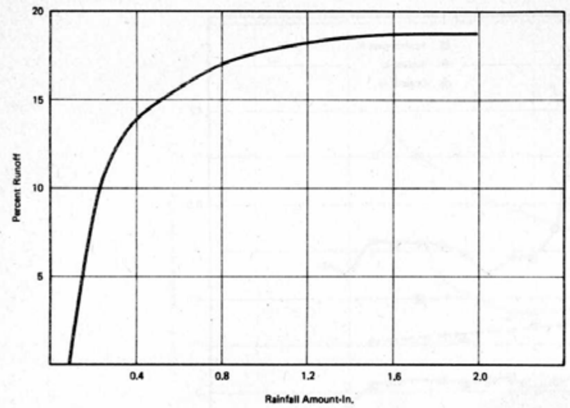


**FIGURE 6.—Percent runoff as a function of rainfall.**

**Variation of nutrient concentration**. The variation in nutrient concentrations was monitored at 5- or 10-min intervals during 17 runoff events over the study period. The first storms to be monitored occurred on September 2 and 3, 1970. Figure 7 indicates the change in concentration of organic-N and I-N during the runoff event, whereas Figure 8 shows how phosphorus and ss concentrations changed with time.

Figures 7 and 8 indicate that on September 2 the ammonia-N and DRP concentrations decreased moderately during the initial phase of the runoff cycle, remaining nearly constant after the first half hour. The declining concentrations of these inorganic species mirrored the increase in flow for the runoff, suggesting that the greater volume of runoff was diluting the ammonia-N and DRP. Nitrate-N (Figure 7) increased with increasing flow initially and then remained at a nearly uniform concentration of about 1.1 mg/L for almost 1 hr. Nitrate-N then dropped sharply to about 0.8 mg/L and remained at this concentration for the duration of the runoff event on September 2.

The maximum concentration of solids, T-P, and organic-N was measured at 5:25 PM, just before the peak flow was recorded. The solids content (Figure 8) dropped rapidly from its peak value, and after the first half hour of the runoff even the solids concentration was relatively constant. The organic-N concentration (Figure 7) declined less rapidly than the total solids (TS) and reached a relatively stable value at 5:55 PM, about 40 min after the runoff began. Total phosphorus declined even more slowly, stabilizing after about 1 hr of runoff (Figure 8).

Approximately 6 hr after the storm of September 2, a second shower passed through the Madison area at 1:00 AM on September 3. This storm delivered approximately 0.18 in. of rain to the basin. The data in Figures 9 and 10 indicate that the solids and organic-N were again highest at the start of the storm, corresponding to the time of highest flow. The peak of the solids concentration was only 0.14 g/L compared with a peak of nearly 0.9 g/L for the storm on September 2. Apparently most of the solids were washed from the impermeable surfaces by the earlier

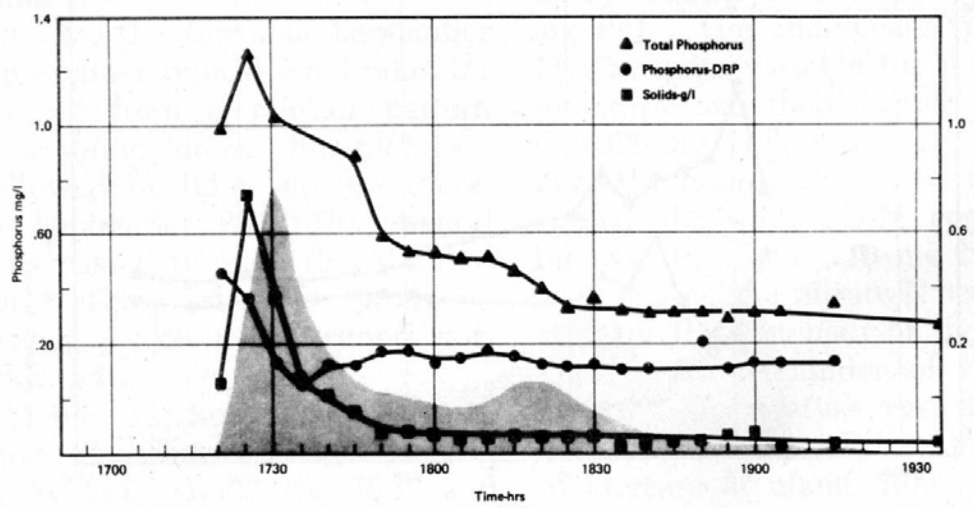


**FIGURE 7.—Concentration of nitrogen in urban runoff, September 2, 1970.**

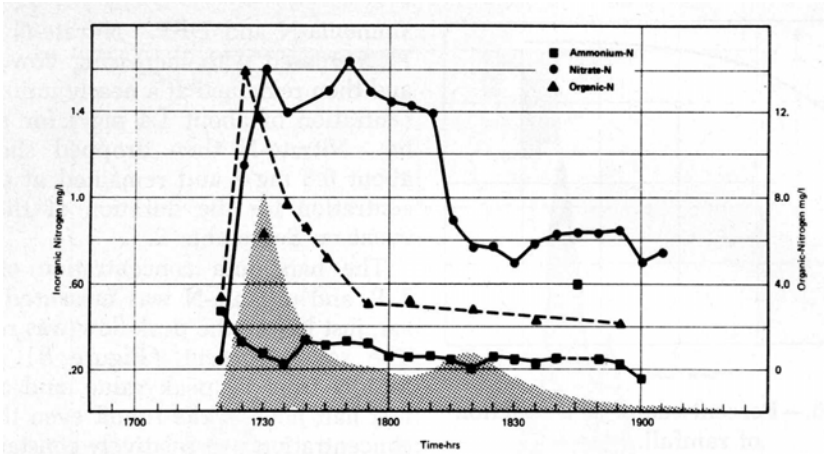


**FIGURE 8.—Concentration of phosphorus and suspended solids in urban runoff, September 2, 1970.**

storm. Similarly, the peak organic-N and T-P concentrations on September 3 were much lower than on September 2, and these peaks more closely corresponded to the final concentrations observed at 7:00 PM on September 2.

The ammonia-N and DRP concentrations in the runoff on September 3 were nearly identical to the concentrations found at the end of the runoff on September 2, 5 hr earlier. Both ammonia-N and DRP remained nearly constant throughout the storm of September 3. Nitrate-N initially was about 0.9 mg/L, almost identical to the concentration at the end of the storm of September 2, but after about 20 min of runoff, it decreased to a nearly steady concentration of 0.4 mg/L. The results discussed for these storms were somewhat typical of the results for most of the other storms sampled during this study. Parameters associated with the solids generally increased as flow increased, reaching a peak concentration sometimes

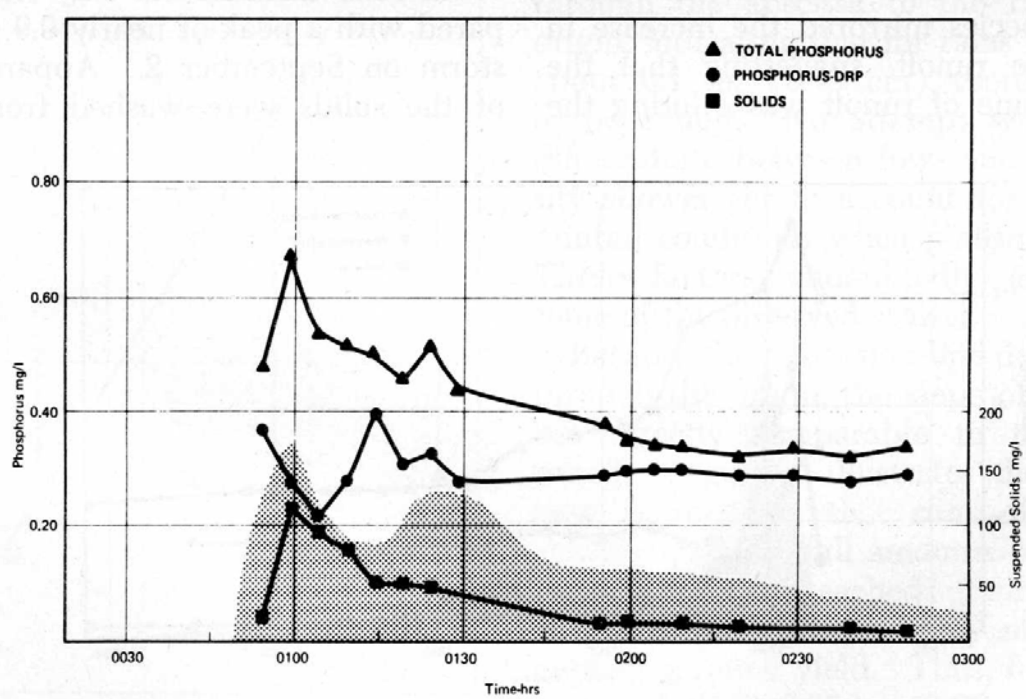


**FIGURE 9.—Concentration of phosphorus and suspended solids in runoff, September 3, 1970.**

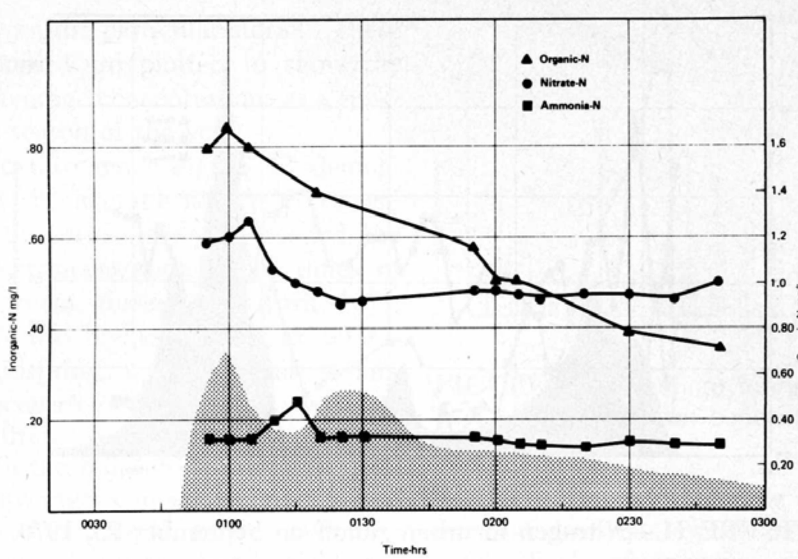


**FIGURE 10.—Concentration of nitrogen in runoff, September 3, 1970.**

before the flow reached its apex. Solids, organic-N, and T-P then decreased as the runoff progressed. If a second storm closely followed an earlier storm, the material associated with the ss usually corresponded closely to the conditions prevailing at the end of the earlier event. The dissolved nutrient concentrations were generally more constant during the second runoff event. In most cases the first few samples were somewhat higher in concentration and then decreased to nearly steady or slightly decreasing concentrations as the storm continued.

The results for the storm of September 2, 1970, represented typical conditions for runoff resulting from a rainfall pattern comprising a single intense burst of rain initially, followed by light showers thereafter. On September 23, 1970, several weather cells passed through the Manitou Way basin. These showers produced several distinct peaks in the runoff pattern, as indicated in Figure 4.

Figures 11 and 12 show the changes in nitrogen and phosphorus species during the runoff period. Both the T-P and organic-N increased sharply early in the storm as the flow rate increased and then decreased to a nearly steady value until about 3:40 PM, when the flow again increased. The maximum flow, which occurred at about 5:20 PM, again caused an increase in the T-P and organic-N concentrations, but not to the same extent as that observed when the storm began. Maximum concentrations in the T-P and organic-N again occurred on the rising leg of the flow peaks.

In Figure 12 the DRP increased to about 0.2 mg P/L just before the peak flow and remained near this concentration until about 5:00 PM, when the increase in flow apparently diluted the concentration of DRP, causing it to decrease to about 0.1 mg P/L. The ammonia-N plot in Figure 11 was quite variable for the first hour of the storm and then decreased at 3:30 PM to 0.05 mg N/L, remaining at this value until the intense shower at about 5:15 PM caused the ammonia-N concentration to increase to about 0.10 mg N/L. Like the ammonia-N, the nitrate-N varied considerably for the first hour of the runoff event. During the remainder of the event, the nitrate concentration varied between 0.4 and 0.6 mg N/L. When the flow began to increase at about 5:00 PM, the nitrate concentration decreased slowly to about 0.3 mg N/L, increasing later as the flow decreased.

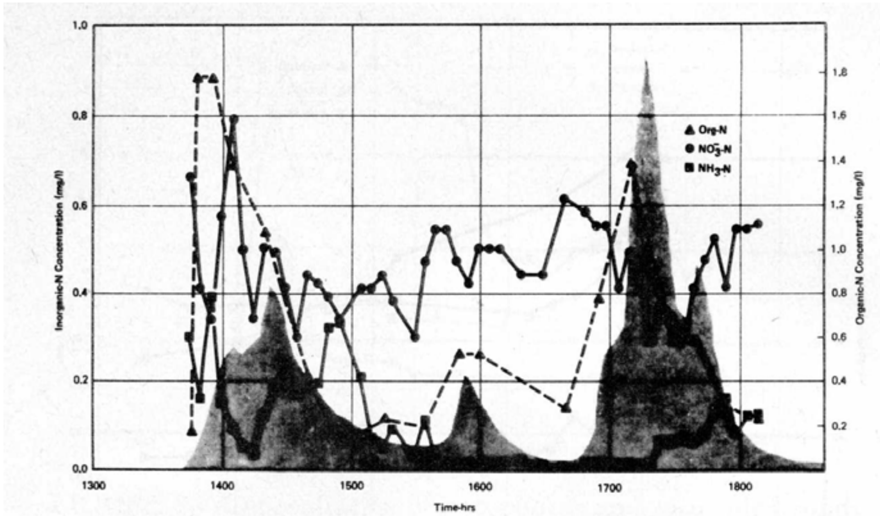


FIGURE 11.—Nitrogen in urban runoff on September 23, 1970.

The results shown for the September storms indicate that the materials associated with the ss in stormwater were greatest during the "first flush" of the basin, even if higher flows were encountered later in the runoff event. Organic-N and T-P reached their maxima on the rising leg of the runoff hydrograph, decreasing to a relatively steady concentration after about 30 min to 1 hr. If the flow increased again later in the runoff event, the solids, T-P, and organic-N concentrations also increased, but not to the same levels as were observed during the first flush.

Ammonia and DRP concentrations for the three storms discussed above showed very little change except during the initial runoff periods.

**Average nutrient concentrations.** The average concentrations of the nitrogen and phosphorus parameters for each storm were computed by determining the total weight of material passing through the storm sewer and dividing it by the volume of runoff

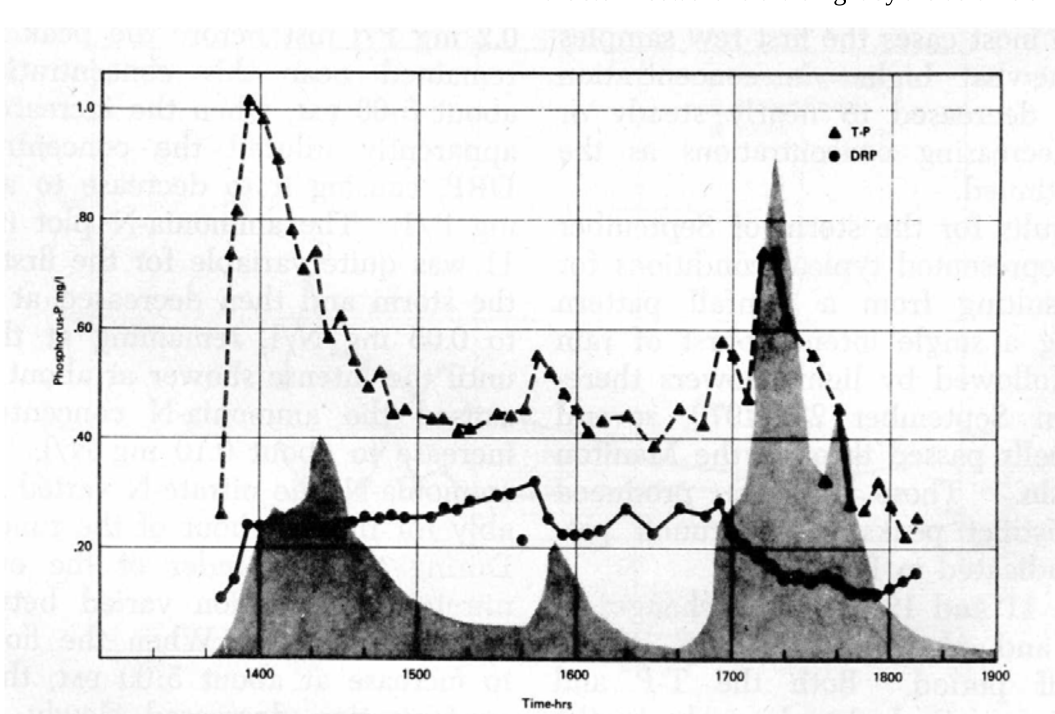


FIGURE 12.—Phosphorus concentrations in runoff, September 23, 1970.

from the particular storm. These concentrations were plotted to show the change in average concentrations as a function of the season of the year.

**Inorganic nitrogen.** Figure 13 demonstrates that the average nitrate-N concentration in the urban runoff exceeded the ammonia-N concentration at all times of the year except during mid-April 1971. Inorganic-N was highest in the late winter through midspring, with the peak in ammonia-N occurring on April 12, whereas the peak nitrate concentration occurred on May 18. In the fall, late spring, and summer, the average concentrations of ammonia-N and nitrate-N varied over the relatively narrow range of 0.2 to 0.6 mg N/L,compared with the early spring peak concentrations of 1.4 mg ammonia-N/L and 2.1 mg nitrate-N/L. Dry periods of 2.5 wk preceded the rains of September 2, 1970, and June 20, 1971, respectively. On September 2, the nitrate-N concentration was much higher than that found for the remaining sampling dates of 1970, but the ammonia-N on September 2 was only slightly greater than that found later in the year. In late August and early September, soluble nitrate had apparently accumulated on the impervious surface or in the atmosphere and was washed from the basin on September 2. Frequent rains later in September kept the nitrate-N from accumulating, so that on September 23 the average concentration of nitrate-N was only about 0.4 mg N/L. Apparently little ammonia-N had accumulated on the impervious surfaces or in the atmosphere during late August 1970.

The average concentration of I-N on June 20, 1971, was similar to that of late May and July, even though there had been no measurable rain for 19 days before the June 20 storm. It seemed that little leachable I-N had accumulated on the streets during the 19 dry days before the June 20 rain. The average nitrate-N concentration actually increased with each storm from June 20-24, while the ammonia-N remained relatively constant, indicating that it was unlikely that the major

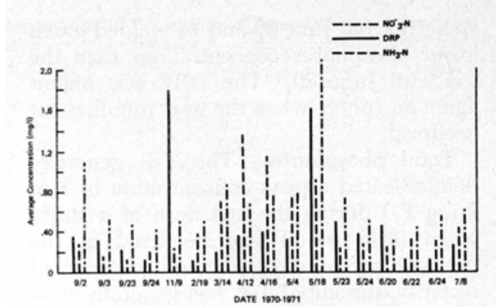


**FIGURE 13.—Average inorganic nitrogen and phosphorus concentrations.**

source of I-N at this time was leaching of litter accumulated on the impervious surfaces.

**Dissolved phosphorus.** The average DRP concentrations for the monitored storms were plotted as the solid bars in Figure 13. Throughout most of the year, the mean DRP concentration varied between 0.2 and 0.4 mg P/L. The notable exceptions were on November 9 and May 18 when the DRP concentrations were 1.8 and 1.6 mg P/L, respectively. Showers on October 27 and 28 and November 2 precluded the buildup of nutrients on the impervious surfaces resulting from dust fall alone. The rain of May 18 was preceded by about 2 wk of dry weather, so that atmospheric fallout (dust fall) could have accumulated on the streets before the May 18 storm. However, the runoff on September 2 and June 20 was also preceded by 2 wk of dry weather, and the DRP was only slightly higher than average on these dates. Apparently some source of phosphorus other than dust from the atmosphere was causing the unusually high phosphorus concentrations on November 9 and May 18. This possible source will be discussed in a later section.

Rainfall frequency seemed to have a greater influence on the DRP than on the I-N, at least for the late spring and early summer of 1971. After the peak DRP concentration on May 18, the concentration decreased on May 23 and 24. The average concentration was up slightly on June 20, possibly because of the nearly 3 wk of dry weather before this date, but the ensuing rains of June 22 and 24 yielded much lower phosphorus concentrations than the storm of June 20. The DRP was higher again on July 8, when the next runoff event occurred.

**Total phosphorus.** The T-P generally demonstrated a peak concentration of 1 to 2 mg/L during the first flush of a storm when little runoff had occurred in the previous several days. If rain had occurred recently, the initial T-P was generally near 1 mg/L. For instance, on June 20, 1971, the T-P varied between 2.0 and 2.5 mg P/L for the first hour of the runoff cycle. On June 22, the initial T-P was 1.2 mg P/L, which decreased to 0.5 mg P/L for the first hour of the runoff cycle. On June 22, the initial T-P was 1.2 mg P/L, which decreased to 0.5 mg P/L within 30 min. By the start of the storm on June 24, the T-P was only 0.76 mg P/L, whereas on July 8, after nearly 2 wk without rain, the T-P had initially been 1.75 mg P/L.

Figure 14 illustrates the average concentration of total phosphorus, organic nitrogen, and ss in the monitored storms. The maximum average concentration of T-P occurred during the runoff on November 11 and May 18. These dates corresponded to the peaks in DRP (Figure 13), indicating the likelihood that both forms of phosphorus were originating from a similar source. T-P concentrations in excess of 4 mg P/L were recorded in the early stages of the runoff on November 9, 1970, April 12 and May 18, 1971.

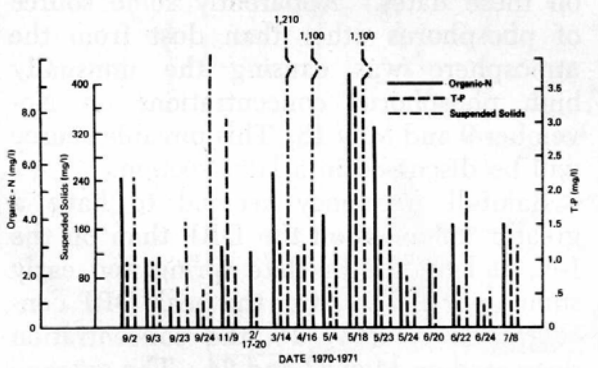


**FIGURE 14.—Average concentration of organic-N, total phosphorus, and suspended solids.**

**Organic nitrogen.** Unlike ammonia-N, organic-N reached a maximum concentration on May 18, 1971, (Figure 14) when it ranged between 20 and 40 mg N/L. Thus, the DRP, T-P, organic-N, and nitrate-N all reached their maximum concentrations on May 18. The organic-N was also quite high on April 12 and May 23 when the initial concentrations were near 20 mg N/L. As with the T-P, the organic-N concentrations decreased after the peak flow, reaching some relatively constant value in the latter stages of the runoff cycle.

**Suspended solids.** The ss content of the urban runoff was a maximum on March 14, 1971, when an intense, brief shower flushed the basin of the last remnants of winter snow. The high solids concentration at this time was probably caused by accumulated materials in the snowpack and erosion of soil from saturated lawns. The high average ss concentration on May 18, 1971, was observed to be caused by seeds from trees within the basin. At other times of the year, high solids concentrations in the early stages of runoff were offset by very low concentrations later in the event.

**Nutrient loading during spring thaw.** Samples were collected at 30-min intervals during the first thaw, which occurred February 16-19, 1971. As can be seen in Figures 13 and 14, there was little difference in the average concentrations for this period compared with those for runoff during the ice-free period. Generally, concentrations were greatest during the first day of the thaw, decreasing slowly and regularly with time.

The city of Madison, Wis., like many other cities faced with winter snow and ice, uses salt and salt mixed with sand to limit the hazards of ice on city streets. The sodium content of the runoff sampled during this period ranged from a high of 2.1 g/L during the first stages of runoff to a few tenths mg/L late in the thaw. Approximately 2,380 lb (1,080 kg) of sodium was flushed from the 123-acre (50-ha) Manitou Way basin February 16-19. This amounted to an average sodium

TABLE II.—Comparison of Average Chemical Concentrations in Urban Runoff from Different Locations

| | Runoff (%) | $NH_3$-N (mg/l) | $NO_3^-$-N (mg/l) | Organic-N (mg/l) | DRP (mg/l) | Total-P (mg/l) | Solids (mg/l) | Lead (mg/l) |
|---|---|---|---|---|---|---|---|---|
| Sawyer *et al.*[11] | — | 0.28 | — | — | 0.22 | 0.56 | 87 | — |
| Sylvester[9] | — | — | 0.53 | 2.0 | — | 0.15 | — | — |
| Weibel[1] | 37 | 0.60 | 0.40 | 1.7 | 0.26 | — | 227 | — |
| Bryan[2] | 60 | — | — | — | 0.14 | 0.19 | — | 0.32 |
| AVCO[3] | 16 | — | — | 0.8 | 0.22 | — | 84 | — |
| Kluesener[10] (this study) | 15 | 0.45 | 0.60 | 3.5 | 0.57 | 0.98 | 280 | — |

concentration of 212 mg/L in the runoff during the thaw, and a sodium chloride application rate of about 0.6 tons/mile of street (340 kg/km) within the basin.

## DISCUSSION

**Results of previous runoff yield studies.** The yield in runoff determined in several earlier studies indicated that this parameter was quite variable from site to site. In Durham, N. C., Bryan[2] found that the average yield of runoff was nearly 60 percent of the rain falling on a 1.7-sq mile (4.4-sq km) area. In contrast, the study in Tulsa, Okla.[3], indicated that although a residential neighborhood was 22 percent impervious (defined as paved areas plus one-half the area of roof tops and driveways) only 16 percent of the measured rain ran off. Weibel[1] reported that the yield in runoff for one storm in a residential light commercial area of Cincinnati, Ohio, 37 percent of which was covered by paved streets, parking lots, and roof tops, was 48 percent. The authors did not indicate whether the roof gutters were connected to the storm sewers. Feddes et al. [8] found that the runoff for an urban area in Bryan, Tex., varied from 20 percent to 52 percent for a basin having 23 percent impervious surfaces.

The runoff yield in this study closely paralleled that found in the Tulsa study. There seemed to be a general tendency for the percent runoff versus rainfall to increase rapidly for light rains and moderately for rains in excess of 0.5 in. (1.3 cm). This contrasts with the Tulsa study, where the yield was reported a constant 16 percent of the rain even for very light showers.

Initially, it was anticipated that the percent runoff would be less in the summer because of interception by vegetation. Unfortunately, there was insufficient rain during this period to indicate such a trend. In addition, the variability in rainfall amounts and intensities as well as the accuracy of the flow measurements were such that small differences of this type could not be accurately determined.

**Comparison of runoff quality.** The average concentrations shown in Figures 13 and 14 were used to compute the average monthly nutrient contribution from urban runoff by multiplying by the mean monthly rainfall amounts and assuming an average of 15 percent runoff for each storm. The weighted monthly concentrations were summed to determine an average annual concentration for the measured constituents of urban runoff. These concentrations are summarized in Table II together with some similar data from other studies.

The inorganic nitrogen concentrations shown in Table II are quite similar for all the studies. Organic-N, DRP, and T-P were about twice as high in the present study compared with the findings of the earlier investigations. The average TS concentration of 280 mg/L was about three times that found by Sylvester[9] and AVCO[3] but similar to the concentration reported by Weibel[1] in Cincinnati, Ohio.

The higher averaged concentrations of phosphorus and organic-N found in this study may have resulted from a more complete sampling of the first flush of runoff.

The range in concentrations reported in several of the studies would seem to substantiate this. The AVCO groups reported that the organic Kjeldahl nitrogen ranged from 0.10 to 1.6 mg N/L, whereas concentrations ranging from 0.2 to 40 mg N/L were recorded in this study. Similarly, they reported DRP concentrations generally between 0.09 and 0.47 mg/L, which was much less than the observed range of 0.1 to 1.8 mg P/L found for the Manitou Way basin.

**Nutrient sources.** Some of the possible sources of nutrients in urban runoff might include the following: precipitation, dust fall, leaching from living vegetation, street litter, lawn and garden fertilizers, dead vegetation, and gasoline combustion products.

**Precipitation.** The mass of nutrients present in the runoff was compared with that which would have come from the rain itself. This latter factor was determined by multiplying the measured concentration of the particular nutrient in the rain by the average depth of rain on the basin and by the basin area. This number was then multiplied by the factor relating runoff to rainfall for each storm. The data indicated that in many cases the amount of ammonia in the runoff was less than that supplied by the rain as computed in the above manner. Sequential sampling of rainfall for a few storms indicated that the ammonia concentration decreased with time for any particular storm. Because the first several hundredths of an inch of the precipitation were usually lost to evaporation and ponding, some of the more highly concentrated nutrients in the first fraction of the rain may have been lost from the runoff.

Nitrate-N in the fraction of the rain running off accounted for from about 20 percent (September 2, 1970) to as much as about 90 percent (April 1971) of the nitrate-N loading of urban runoff. Thus, most of the ammonia-N and about one-third of the nitrate-N in urban runoff seem to originate from rainfall itself. As would be expected, the organic-N and phosphorus in rainfall accounted for only a small fraction of organic-N and phosphorus in urban runoff, generally less than 10 percent.

**Leaching of vegetation.** Tamm[12] found that the average DRP concentration in throughfall beneath a spruce canopy (rain passing through the foliage) was 0.06 mg P/L compared with 0.03 mg P/L in rain collected in the open area. He attributed this increase in phosphorus to leaching from the trees. Thus, leaching from standing vegetation may add some nutrients, but the increase in concentration from this source would be offset somewhat by a reduction in the overall amount of rain reaching the ground. Tamm noted that throughfall amounted to only 60 to 70 percent of the volume of rain found in the open areas nearby.

**Fertilizers.** Increased nitrogen and phosphorus loading in the spring and fall could be attributed to the practice of fertilizing lawns during these periods. However, studies conducted by Kelling[13] using artificially generated precipitation indicated that runoff from established lawns in the Madison, Wis., area would occur only under unusually heavy rainfall conditions. This study indicated that the amount of runoff from the storm sewer basin could be accounted for by summing the area of streets in the basin (and in some cases the driveway areas also). Thus, unless the fertilizers were carelessly strewn on the impervious surfaces, it seems unlikely that the home gardener would be guilty of adding appreciable amounts of nitrogen or phosphorus to urban runoff with the types of soils found in Madison.

**Street litter.** On November 9, 1970, when the maximum DRP was observed, there were large bundles of leaves piled along the curbs in the Manitou Way basin. The inlets to the storm sewers in the Manitou Way basin are widely spaced so that the runoff must travel for some distance along the curbs in the basin. As the runoff passed through the piles of leaves, it apparently leached phosphorus from the leaves. The runoff water was markedly colored, varying between 200 and 300 color units. Although the phosphorus levels were quite high, I-N was near normal during this period (Figures 12 and 13). The organic-N varied between 2 and 5 mg N/L throughout the runoff event.

On May 18, 1971, the DRP, nitrate-N, organic-N, and T-P were again near their maximum concentrations. The color averaged about 100 color units at this time. The streets and gutters were cluttered with large amounts of seeds from the elm trees in the basin. Some of these seeds were scooped up and placed in a beaker in the laboratory where they were batch contacted with about 100 ml of glass distilled water for 10 min. and then analyzed with the runoff samples. The DRP of the extracted sample was 7 mg P/L while the organic-N and nitrate-N concentrations were 33 and 3 mg N/L, respectively. These two cases would seem to indicate that basins having large populations of trees may contribute appreciable amounts of nutrients to the stormwater, depending on the season of the year and the housekeeping practices within the basin.

Street litter, including branches from trees, trimming from lawns, and clippings from gardens, would probably act in a manner similar to leaves and seeds from trees. Litter from these sources not only acted as a source for nutrients and solids in the stormwaters but also tended to cover the entrance grates to the sewers, forcing the runoff to by-pass some sewer inlets.

**Combustion products.** Appreciable amounts of inorganic nitrogen were contributed to the runoff by precipitation and dry fallout, but these sources supplied relatively little phosphorus. Leaves and seeds from trees have been shown to be important potential sources of phosphorus in the fall and spring. One additional potential source of phosphorus would be emissions from automotive exhaust. Certain gasoline additives contain small amounts of phosphorus to control pre-ignition and spark plug fouling. This phosphorus combines with the lead in the gasoline, reducing the pre-ignition potential of the gasoline.[14] Because lead and phosphorus are being fed continuously into the ignition chamber, some of the additives must be exhausted from the engine. Lead halophosphate has been detected in automotive exhaust, and this may be an appreciable source of phosphorus on heavily traveled roads.

**Sampling urban runoff.** The chemical data plotted in Figures 7 to 12 indicated that the concentration of all parameters was highest during the first flush of the basin. Because flow was also high during this period, the mass of material passing through the storm sewer was also high at this time. Figures 15 and 16 indicate the mass emission rate for organic nitrogen and nitrate nitrogen during the storms of September 2 and 23, 1970. A common characteristic of these curves is a steeply sloping segment early in the runoff cycle with gradually changing slope, approaching zero at the end. of the runoff event. This parabolic behavior was similar for all of the chemical parameters measured. Three factors seem to cause the sharp rise early in the runoff cycle. First is the rain itself. The concentration of nutrients in rain decreased with sequential sampling in a particular storm.[10] Thus, the rain itself contributed more nutrient per unit of rainfall in the early stages of the rain. Second, the rainfall intensity was normally greatest early in the storm. Because samples were taken sequentially with time instead of as a function of runoff volume, the higher flow rates yielded greater loading per unit of time. Finally, the litter and pollutants accumulated on the impervious surfaces during dry weather were flushed from the basin early in the storm. The higher rainfall intensities swept more of the solids from the streets early in the runoff cycle, causing higher concentrations of ss and dissolved nutrients in the early stages of the runoff.

One method of sampling would be to use a composite sampler to take a volume of sample in proportion to the flow. While this would simplify the analytical requirements, it would be difficult to find a sampler that would sample runoff reliably over the range of flows experienced in storm channels. An alternative would

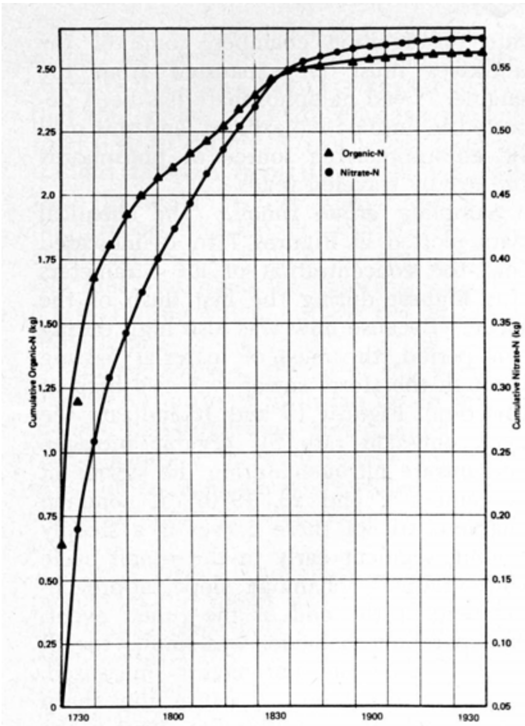


**FIGURE 15.—Cumulative nitrate-N in runoff on September 2, 1970.**

be to collect discrete samples with time and flow. Because it is not always possible to be on site for the start of all storms, the most convenient arrangement would be to install an automatic sampling device that would begin to collect discrete samples at the start of the storm. Samples should be collected at short time increments throughout the runoff event, if possible, and flow should be recorded throughout the cycle.

Once the pattern of the nutrient concentration is established, it should be possible to reduce the analytical requirements. Flow data and samples should continue to be collected over short time increments. However, inspection of the hydrograph before analyzing the samples and comparing it with previous data for fully characterized runoff events should permit selection of relevant samples for runoff characterization. For the storm of September 2, 1970, samples taken at 5:25, 5:40, 6:00, 6:15, and 7:00 PM would probably characterize that runoff event adequately.

Samples would be taken at 5:25 and 6:15 PM because it was observed that the peak in nutrient concentration generally occurred just before the peak in flow. The decline in nutrient concentration would then be approximated by the samples taken at 5:40 and 6:00 PM with the 7:00 PM sample providing the data on the probable minimum concentration.

Selecting samples for a storm such as that of September 23 would follow the same procedure; samples would be analyzed just before and after peaks in flow. Thus samples taken at 2:00, 2:15, 2:30, 3:00, 3:45, 4:40, 5:00, 5:10, 5:20, and 6:00 PM should give a good understanding of the variation in concentration and the mass loading rate for that storm without unduly overloading the analytical facility.

In summary, the recommended sampling procedure would be to characterize a few storms by collecting and analyzing all samples taken over some short time interval that is less than the response time of the basin

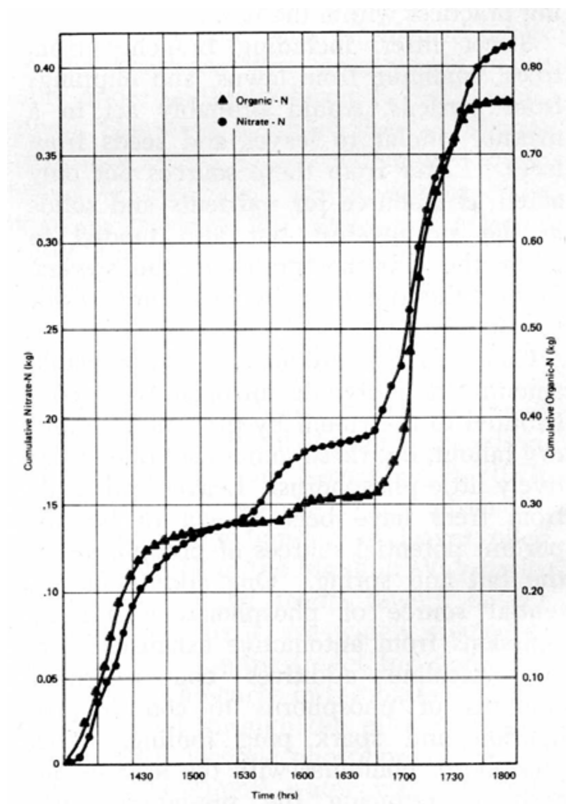


**FIGURE 16.—Cumulative nitrate-N in runoff on September 23, 1970.**

**TABLE III.—Summary of Measured Nutrient Sources for Lake Wingra (kg/yr)***

| Source | $NH_3$-N | $NO_3^-$-N | Org-N | DRP | T-P | Volume of Water (cu m) |
|---|---|---|---|---|---|---|
| Precipitation | 390 | 440 | 260 | 25 | 32 | $1 \times 10^6$ |
| (lb/acre/in. rain) | (0.09) | (0.10) | (0.06) | (0.006) | (0.007) | |
| Dry fallout | 560 | 480 | 1,100 | 21 | 110 | |
| Spring flow | 170 | 4140 | | 30 | 77 | $1.4 \times 10^6$ |
| Urban runoff | 450 | 600 | 3,500 | 507 | 980 | $1 \times 10^6$ |
| (lb/acre/basin/yr) | (0.45) | (160) | | (0.57) | (0.98) | |

* Lake Volume = $2.5 \times 10^6$ cu m.

(time lag between peak rainfall and peak runoff). Once the background data are available, flow and samples should continue to be collected over the short time interval, but selection of samples for analyses should be made on the basis of the observed hydrograph and past experience with the particular basin.

**Comparison of nutrient sources for Lake Wingra.** The major potential sources of nutrients to Lake Wingra were determined to be precipitation, atmospheric fallout, flow from springs, groundwater flow, urban runoff and surface runoff from the arboretum. The data developed by Kelling[13] for the Madison area indicated that little or no surface runoff occurred when rain intensities of 5 in./hr were applied to forested areas, prairies, or established lawns. This conclusion was reinforced by the very low runoff from urban Madison, which indicated that the percentage of the basin occupied by streets was contributing the majority of the surface runoff.

Because of a lack of information concerning the flow of groundwater into Lake Wingra, no estimates could be made of the significance of this potential nutrient source other than to assume that it would be similar to local spring water—high in nitrogen (1 to 3 mg $NO_3$ N/L) and low in the other nutrients. The nutrient loading from the remaining sources is summarized in Table III from data presented elsewhere.[10]

From Table III it is apparent that all sources of I-N are comparable except for spring flow, which contributes nearly 60 percent of the inorganic-N influent to the lake. Approximately 35 percent of the total-N budget results from urban runoff, with an equivalent amount arising from the springs. Precipitation and dry fallout account for 10 and 20 percent of nitrogen loading to the lake. Thus, nearly 65 percent of the nitrogen budget for Lake Wingra comes from natural sources. If groundwater contributes an appreciable amount of water to the lake, then the percentage of nitrogen coming from natural sources will be even larger than 65 percent.

More than 80 percent of the T-P and almost 90 percent of the DRP influent to Lake Wingra arises from the urban runoff. Spring flow, dry fallout, and precipitation contribute only a small amount (2 percent) to the T-P budget of the lake. Groundwater is not likely to contribute much phosphorus to the lake so urban runoff seems to be a very significant source of phosphorus in Lake Wingra, contributing almost 80 percent of the overall phosphorus influent to the lake. The weight ratio of nitrogen to phosphorus in urban runoff was 9.6 to 1 compared with about 20 to 1 in Lake Wingra.

## CONCLUSIONS

The following conclusions can be drawn from this study:

1. In general, approximately 15 percent of the rainfall on the Manitou Way basin appears as surface runoff from the basin. The percent runoff was approximately equivalent to the area of the basin covered by streets. For any particular storm, percent runoff varied as a function of rainfall amount.

2. Nutrient and ss concentrations were usually greatest during the early stages of the runoff event, decreasing with time. Phosphorus concentrations were greatest in spring and fall, whereas nitrogen concentrations were greatest in the spring.

3. Rainfall seemed to be the major source of inorganic-N in runoff from the urban area. Phosphorus generally resulted from accumulated litter and possibly automotive exhaust discharged to the streets.

4. Barring the availability of a suitable flow-proportioned sampler, the next most appropriate sampling procedure would be to characterize the particular basin by collecting flow and chemical data over fairly short time intervals for several storms. Samples should continue to be collected over the same short time intervals, but the flow data and historical relationship between flow and concentration should be used judiciously to select an appropriate number of samples for chemical analyses.

5. Urban runoff data from the Manitou Way basin as extrapolated to the entire Lake Wingra basin indicated that approximately 80 percent of the total phosphorus and about 35 to 40 percent of the total nitrogen influent to Lake Wingra arises from urban runoff.

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